



Zbigniew Bromberek

ECO-RESORTS

PLANNING AND DESIGN FOR THE TROPICS

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About this book

At the time of writing this book society faces a looming problem of global warming, seen by many as the consequence of ignoring warning signs over many years of industrialisation. It appears that emissions of carbon dioxide and other civilisation by-products into the atmosphere have added to other factors with disastrous effect for the entire world. In truth, the signs of global warming have come upon us more quickly than even the pessimists could have predicted. Yet, we do not actually know what causes global warming – we can at best take an educated guess. The fact remains, though, that global warming is a reality.

In our field of architecture, we could be contributing to the environmental problems facing the planet more than others. We have known for many years that we should be paying greater heed to the way we design and construct, so that the resultant impact on the environment is minimal. Building is an irreversible activity, leaving – directly and indirectly – a permanent mark on the Earth. Yet we choose simplistic solutions to complex problems and we let economic imperatives override any pricking of the conscience that our current design practices might be generating. With the new awareness of the world that we are gaining through intensive scientific studies, we have a duty to understand the ramifications of what we are doing.

We are part of the world – an important part, yes, but only a part. Most of our present-day efforts to achieve ‘sustainability’, as I see them, are anthropocentric and inherently flawed. They are a highly tangible manifestation of our interference with systems we know very little about. At the moment, we apply our limited knowledge to preserve what we believe is worth having – according to our own priorities, presumed importance or perceived needs. There is something fundamentally wrong with even a mere suggestion that we improve the world.

Indeed, the very notion of ‘improving’ the world seems bizarre: improving it for whom or for what? Unless, that is, we are prepared to openly admit that we are not doing it for the world in its entirety, but for ourselves and ourselves only – in our selfish and egocentric pursuit of our current convictions. Nothing more and nothing less...

This book is about planning and design in one of the most fragile environments on Earth: the tropics. It does not offer, least prescribe, solutions that would deliver a sustainable outcome. Nevertheless, it does invite using caution to protect what remains unchanged and to build in a way that makes as little impact as possible. It asks you to make good use of existing local resources before reaching for more of them, further away from the places of their use. It also argues that we should take only what we really need from this environment, leaving the rest untouched. Inherent in eco-tourism is the paradox of drawing on pristine environments and thus causing the inevitable loss of their principal quality: their unspoilt purity.

I would like to see all eco-resort developers in the tropics tread lightly, eco-resort operators and users to scale down their demands and adapt to the conditions, and eco-resort planners and designers to utilise the acquired knowledge in drafting their responses to the tropical setting. I would advocate a broad use of the precautionary principle: a process in which we weigh up the long-term consequences of our actions, refraining from, or at least limiting, activities that may cause irreversible change. We must proceed cautiously because, even with the best intentions, it is possible that actions we take now, well-informed as they may now seem to be, may in future turn out to be deleterious to the environment. Together, using this respectful and considerate approach, we can save the beauty and diversity of the tropics for ourselves and for the generations to come.

Zbigniew Bromberek

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Figure 4.8.7	The change of character from a former cattle ranch to a tourist resort is most visible in the landscaping design; view from the restaurant deck towards one of the accommodation buildings
Figure 4.8.8	The Hacienda has undertaken a massive effort of re-vegetating degraded parts of the property with indigenous plants, giving employment to the local villagers in the process
Figure 4.8.9	The property has its own historic attractions including a small church built by the Spaniards in the seventeenth century
Figure 4.8.10	The extent of the resort's potential environmental impacts. (Note: The extent of resort's impacts [ranging from positive through neutral to negative] should be read in conjunction with the information in Figure 4.1)

Part One

Eco-tourism and the Tropics

The world's tropical zone extends to approximately 4000 km north and 3500 km south of the equator and covers one third of the Earth's land surface: in total it takes in over 50 million square kilometres. Globally, the tropical lands have a coastline of over 60 000 kilometres attracting millions of tourists every year with these numbers rising dramatically in recent times. Consequently, more tourist and recreational infrastructure in the tropics is increasingly needed and tourist resorts have started moving also into previously undeveloped areas.

Meanwhile, up until the 1980s, the emphasis of any tourist development in the tropics was on primary resources, such as the beach and the sea; the contribution which accommodation can make to successful holidays was neglected. This situation has obviously changed. Facilities built for tourists have to be designed to cope with the climatic stress of the tropics yet must provide a lifestyle compatible with tourists' requirements, and do it in the most economical way. Furthermore, although a vast majority of the travellers come from developed countries, most tourist-attracting tropical areas are in developing countries of the third world.

This dichotomy causes or contributes to many undesirable phenomena that follow tourism developments in such regions. And yet, many of them seem easily avoidable by correct interpretation of, and response to, the visitors' expectations. Ever increasing portions amongst them are tourists who want to get closer to the nature and culture of the region whilst at the same time being conscious of the need to preserve what is left of it. This desire gave rise to the eco-tourism movement more than 30 years ago. Today eco-tourism is coming of age, being the fastest growing segment of the tourist industry. Our environmental concerns are more and more often reflected in choices that we make about the way we spend our holidays. Eco-tourism is an expression of this trend.

The events surrounding the last of a three-decade long series of nuclear tests in French Polynesia clearly demonstrated a heightened environmental awareness in the region and in the world. In Australia, an attempt to develop a resort in an environmentally sensitive area of the Whitsunday Passage met with a similar reaction of concern from the public. These stories are repeated around the tropical world, from Yucatan to Borneo and from the Bahamas to the Am-

azon basin. Nevertheless, it seems unlikely that developments, and tourist developments in particular, in all sensitive environments will be stopped or prevented. In some of them, and eventually in most of them, tourist infrastructure will be developed. This will, most certainly, be followed by unavoidable impacts, which these establishments will make, on the environment. It is up to resort planners, designers and operators to make such impacts the least possible or, at the very minimum, the least damaging.

It is said that architecture reflects needs, desires, customs, attitudes and aspirations present in society. There are then a number of reasons for which eco-tourist resorts should display an environment-friendly attitude. An efficient passive climate control, providing indoor environmental comfort in the resort, could effectively propagate solutions based broadly on non-powered passive techniques. Many tourists, and certainly the vast majority of eco-tourists, would be happy to try to adjust to the given climate conditions at the holiday destination they have chosen. It is not true that the tropical climate is unbearable. It is equally not true that passive architecture cannot cope with the conditions found in the tropics. Passive climate control will not secure constant low temperature as powered air-conditioning can do. However, the need for constant temperature is at least questionable. Adaptation is apparently much healthier than desperate efforts to insulate the building and its occupants from climatic impacts. It is also much healthier and more sustainable. Much more can also be done to integrate tourist developments with the cultural heritage of their hosting regions, their customs and social fabric.

New trends in global tourism require that tourism developers in the tropics take an environmentally conscious stance if they do not want to undermine the base on which they operate. Developers of tropical resorts have to meet the demand to accommodate growing flows of people who arrive there with quite specific expectations. An important, if not rather obvious, observation to be made is that tourists go to a resort for leisure. They try to break away from their everyday work, everyday life and everyday environment. Tourists tend to contrast everything left behind with the time spent in the resort. Part of the holiday excitement is derived from experiencing the tropics indeed, the tropics as they really are, hot,

often humid, and sometimes rainy as well. The provided accommodation should make that experience possible at a somewhat comfortable level – home levels of comfort are seldom required. Another obvious but often-overlooked fact is that visitors are very

different from the local residents. Their expectations are driving their perceptions and have the ability of modifying them to a large extent. This fact could and should be utilised in the resort plan and design to work with the environment rather than against it.

1.0

A question of sustainability

Tourist facilities in the tropics, and eco-tourist facilities in particular, target very valuable and usually highly sensitive environments. For example, the greatest demand for tourist development opportunities in Australia can be seen on its eastern coast, from the central coast of New South Wales to Marlin coast (the coastal area near Cooktown) in the far north of Queensland. Concentrations of this demand build up pressure for extensive development in several locations, including the entire coastal strip in the tropics up to Daintree, Cooktown and Cape Melville National Park. While in the south of Australia the natural environment has been subjected to urbanisation for many years, in the tropics this type of modification has been introduced fairly late, in the last several years. In other words, the targeted tropical section of the coast in Australia remains its only unspoilt part, the only refuge for many endangered animals and the only remaining habitat for many endangered plants. This trend was also noted, and a response to it called for, by the Alliance of Small Island Developing States in its 1994 Barbados Programme for Action (WMO 1995). The same can be said about other parts of the world. The focus of tourist developments is nowadays firmly trained on previously untouched or undeveloped areas. [Figure 1.1](#).

Apparently, there is an answer to this environmental dilemma and it is the 'ecologically sustainable (tourist) development'. Many definitions of ecologically sustainable development or ESD have been offered, some general and some more precise. The following definition, promoted by the United Nations, is also known as the 'Brundtland definition':

[ESD] is development, which meets the needs of the present without compromising the ability of future generations to meet their own needs.

The concept of 'sustainability' is relatively new. The Bank of English, the database on which the first edition of Collins-COBUILD Dictionary of English was based in 1987, contained around 20 million words of written and spoken English of the 1980s. There was no mention of 'sustainable' let alone 'sustainability' among them. Both appear as low-frequency words in the 1995 edition of the Bank, based on a collection of 200 million words of the 1990s. Even the most recent (2006) edition of the dictionary

does not define 'sustainability'. As a concept, is it still too early or too difficult to grasp, perhaps?

'Sustainability' is a term that represents a social and cultural shift in the world order. It has become a symbol describing this inevitable, ongoing transformation. As such, the term has little to do with the literal description or dictionary definition of the word, but is the name for a new attitude and new way of looking at the world. 'Sustainability' is also a concept increasingly used as a measure of worth – when it comes to evaluating the contemporary built environment. It appears that a lot of effort has been put into integrating various assessment techniques related to environment-friendly, energy-efficient buildings and developments as well as other activities involving management of natural resources under a banner of 'sustainability'.

More prudent approaches to the environment gain recognition and importance. Development methods and approaches have been changing worldwide to adopt the concept of sustainability into the planning and design of the built environment. To build, by definition, means to make a lasting impact on the environment. The challenge is to find a balance between the aesthetic and environmental needs of a project, as well as between tangible and intangible threats and opportunities, to secure increasingly scarce resources for future generations. Architecture these days more often than ever is judged as 'good architecture' as long as it provides a high quality environment that is cost-optimal and consistent with energy-efficiency at all stages of construction and use.

Users, owners, designers, constructors, and maintainers from all sectors are actively seeking techniques to create a built environment, which will efficiently use all resources and minimise waste, conserve the natural environment and create a healthy and durable built environment. Numerous sources offer principles of 'sustainable architecture' to guide and help architects.

Within the field of 'sustainable architecture', sustainability represents a transition to a 'more humane and natural' built environment. However, architecture, by its very nature, uses energy, alters the existing fabric and imposes its structural forms upon others. It will always have some detrimental impact on the environment. No active human-created system can

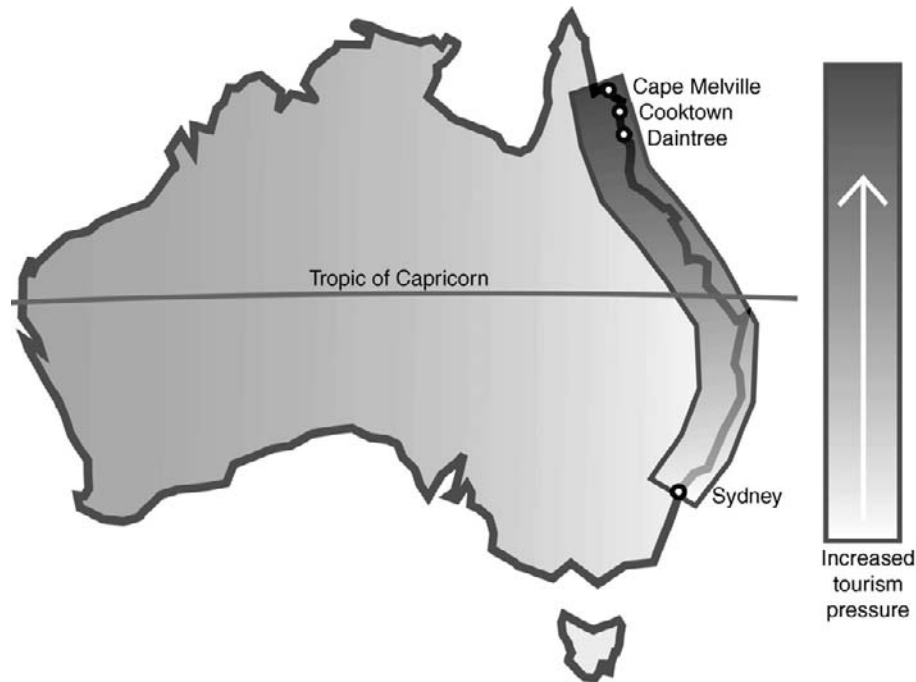


Figure 1.1 Environmental pressures from tourist developments in Australia.

survive without contributions from the larger natural environment or ecological systems. In this context, the sustainable response is an approach which limits that detrimental impact – not so much in terms of the design itself as of any worthy objectives. We can, nevertheless, conserve our resources and lessen the physical, social and cultural impacts on the environment through appropriate building design. Sustainable architecture hence requires consideration of issues that have the scope considerably broadened from those involved in, say, ‘solar architecture’.

‘Sustainable architecture’ has also been defined as the creating and responsible management of a healthy built environment based on ecological and resource-efficient principles. Sustainable buildings aim to limit their impact on the environment through energy and resource efficiency. Sustainable architecture is expected to bring together at least five key elements:

- environmental sustainability
- technological sustainability
- financial sustainability
- organisational sustainability, and
- social sustainability.

In practice, an ESD project is always the result of a compromise and trade-off between these characteristics since usually one may only be achieved at a slight detriment to the others. One has to doubt whether such a ‘partial sustainability’ can be sustainable at all.

Nevertheless, it appears to be the only approach acceptable to the majority of developers and politicians.

A sustainable architecture approach is essentially context specific, and relates to the resources that are locally available, to a specific environmental setting, to local customs and identifiable needs. One cannot classify any particular building technology as being the ‘sustainable technology’, nor can one assume that any system that works well in one place will work equally well in another. Extrapolation of results from one location is useful only to estimate the potential to make a valid contribution towards sustainability of the built environment somewhere else. It should be stressed that, despite its global connotations, sustainability is all about a very localised interplay of various influences. If sustainable development is to become relevant, it has to evolve from local conditions, principles, traditions, factors, indicators and actions.

It works both ways. Decisions about a facility’s design, made by tourist developers and their designers alike, have a direct impact on local ecosystems. The design should achieve its aims adequately and efficiently without wasting or damaging local resources or polluting the environment globally, but locally in particular. Both creative (aesthetic) qualities and indoor environment conditions should therefore derive from relevant practical knowledge based on relevant and up-to-date scientific theory. On the part of the designer, the principal requirement

is that of a greater understanding of the total nature of the built environment. Particularly important is an understanding of the role which the building envelope, i.e. the system of walls, roofs, floors and windows, manipulated by the architect, plays in response to local conditions in creating the internal environment. Clearly, the design of the physical indoor environment is very much an architectural problem and needs to be considered at the earliest stages of the design process.

Examples of architecture seen in the tropics around the world seem to demonstrate that architects are seldom aware of the fundamental relationships at play at the 'building – (external) environment' interface. Even more evident is the designers' lack of knowledge and experience concerning the diverse and complex problems of human responses to temporary changes of climate – much the same, as is the case with tourists. Habits, established preferences, reasons for travelling to the tropics, and related expectations and perceptions all influence requirements to which the design should respond.

Sustainability objectives, relevant to the built environment, can be both tangible and measurable. Apart from others, which are not less important, in the technological area they are:

- conservative management of the natural environment;
- minimising non-renewable resource consumption;
- reducing embodied energy and total resource usage;
- reducing energy in use;
- minimising external pollution and environmental damage;
- eliminating or minimising the use of toxins; and
- minimising internal pollution and damage to health.

All these objectives put together can be expressed as the ultimate (technological) goal of sustainable architecture to restrict the impact that the buildings make on their surroundings to an unavoidable minimum. This is why 'sustainable architecture' can be referred to as 'low-impact architecture'.

Low-impact design elements, brought to the buildings in the form of, for instance, energy-saving features, can be quite appropriate and functionally adequate in performing a specified task. Furthermore, the effect can be both creative and sustainable – also in the ideological sense of the latter term. All the resources that go into a building, whether materials, fuels or the contribution by the users – including unintentional impacts such as those caused by acci-

dents – need to be considered if sustainable architecture is to be produced. This entails passively and actively harnessing renewable energy and using materials which, in their manufacture, application and disposal, do the least possible damage to the so-called 'free' resources: water, ground, and air. Low-impact architecture is about integrating the environment, building fabric and building technology in one package. This package should correspond to the precautionary principle calling for actions causing least possible damage and not resulting in other effects, which we may not fully appreciate at this point in time. Developing low-impact or sustainable buildings involves resolving many conflicting issues and requirements as each design decision has environmental implications. [Figure 1.2.](#)

Within the scope of a task and work responsibility, each planner/designer should understand the goals of, and issues related to, sustainability. The individual and cumulative social, environmental and economic implications must be taken into account. The short- and long-term as well as direct and indirect consequences must be carefully considered, and all reasonable alternative concepts, designs and/or methodologies thoroughly assessed. Finally, appropriate expertise, in areas where the designer's knowledge is inadequate, should be sought and employed.

Sustainable architecture implies an approach, which in a development context goes well beyond the project phase. A focus is required on the building's operation as well as on the building itself. All possible measures are to be taken to achieve a functional, efficient, long-lasting and elegant relationship of various functions and circulation, building form, mechanical systems and construction technology. Symbolic relationships with appropriate traditions and principles have to be searched for and expressed. Finished buildings should be well-built, easy to use and maintain, durable and beautiful.

Against a background of this straightforward and down-to-earth set of requirements, the question of sustainability appears as a rather vague and somewhat fuzzy concept.

Do we need the concept of sustainability in architecture at all? The answer to this question is: yes and no. Yes, because the concept of sustainability encompasses issues of tremendous importance not only to architecture, but also to the entire world and the human race's ability to survive. No, because we have already had for centuries a concept that describes virtually the same notion, and it is also more precise and generally better understood than sustainability. This concept is known as 'best practice'. In other words, designers should be talking about

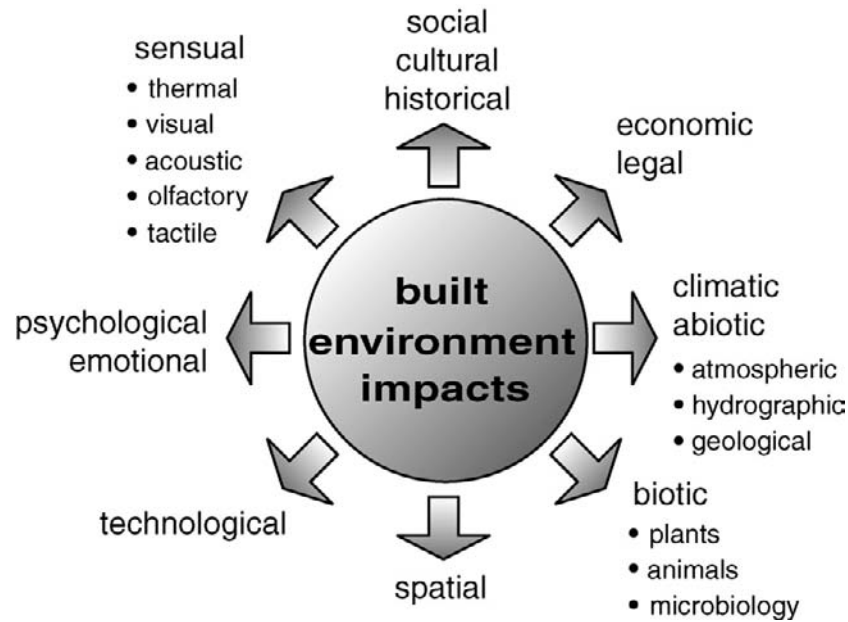


Figure 1.2 Various environments impacted on by the built environment.

sustainability issues but, at the same time, use a different vehicle to do it.

In the context of 'sustainability', 'sustain' does not mean that nothing ever changes. Nor does it mean that nothing bad ever happens. 'Sustainability' is not about maintaining the status quo or reaching perfection. 'Sustainable architecture', then, is a response to an awareness to pursue certain ideas and not a prescriptive formula for survival. In its literal meaning, it is a misnomer. Moreover, the integrity of the concept would be eroded if it were to have to rely on too many or overly prescriptive measures. 'Best practice' avoids this trap by relating to a constantly evolving set of solutions.

In architecture, 'best practice', for all practical purposes, is synonymous with 'sustainable' but easier

to grasp and more beneficial in the long term, and should replace it as an environmental education vehicle. Nevertheless, architects should be made aware that in this profession these two terms are interchangeable and clients demanding 'sustainable design' in fact require that best practice objectives be followed and best practice solutions adopted.

New knowledge being generated in the area of sustainability will be forcing reviews of existing practices as long as we consider sustainability important. It is going to pose a challenge to resort designers and planners as well as architectural educators for many years to come. Instead of aiming at some abstract perpetual objective, the professionals we trust our future with need to promise to do the best they can – today and every day.

1.1

Tropical tourism and tropical eco-tourism: scale and trends

Leisure, as a tip of the triangle of life activities (dwelling–work–leisure), has been fast gaining in importance in recent years. Tourism and travel (T&T) is the world's fastest growing industry. Its contribution is soon expected to approach US\$5 trillion or one-eighth of the world Gross Domestic Product (GDP). According to turn of the century forecasts from the World Tourism Organization, the number of international tourist arrivals is expected to reach 937 million by the year 2010 and 1600 million by 2020. Tropical regions will record the biggest growth. In a group of countries enjoying warm (subtropical and tropical) types of climate, tourism industries become increasingly important sectors of their economies. For quite a few of these countries, development of tourism and recreation services is a vital part of their survival strategies during cyclical periods of economic downturn. Tourism already generates 95 per cent of GDP in the Maldives and 75 per cent of export earnings in the Bahamas. Such growth in tourism is matched with a growing need for infrastructure and facilities, and this is where the problems start appearing. While tourism, no doubt, represents a huge stimulus to the global (and local) economy, it will also have a lasting impact on the global (and local) environment. [Figure 1.3.](#)

In search of variety and new sensations, tourists have started exploring even the most remote and inaccessible corners of the Earth. Increasing numbers of travellers seek natural and cultural locations which remain pristine. Numbers of visitors to national parks and protected areas, and to remote rural communities, continue to rise. Some of these regions are extremely important habitats, as they constitute the last refuges for endangered species. The importance of other locations is derived from their place in regional and/or global ecosystems. In the case of coastal tropics, the problem of protecting these habitats is exacerbated by their natural vulnerability. Any uncontrolled disturbance in such an environment has potentially disastrous consequences. Sports and leisure activities by their nature depend heavily on a healthy environment with high quality of air and water as a minimum prerequisite.

While nature based eco-tourism is generally considered to have a lower impact than typical mass tourism, requiring less infrastructure and development, even small-scale use can damage the natural resources, which attract tourists in the first place. There are also other effects, extending tourism's influence beyond the ecological impact. The best example is its socio-economic impact. Tourism, especially in rural and undeveloped areas, tends to create a dependence on foreign income among the local population. It displaces traditional customs and social interactions, and makes those communities vulnerable to foreign economic conditions. Degradation of the corals of the Great Barrier Reef, deforestation in the foothills of the Himalayas, disruption of feeding and breeding patterns of wildlife in Kenya's national parks, and the gradual dismantling of the Kalahari and Amazonian indigenous communities all serve as warnings to the potential dangers of uncontrolled tourism. Eco-tourism, with its focus on local nature and culture, should be a kind of 'import' that promises to explore those environments without destroying them. [Figure 1.4.](#)

Eco-tourism appears to be a value- (or philosophy-) laden approach to tourism, aiming at environmental sustainability. One has to ask, however, what is sustained (natural environment, culture, the activity itself) and how is it sustained (at what costs and benefits, and who is to benefit). The World Tourism Organization's Environment Committee established a task force to investigate the development of international sustainability indicators of tourism. The indicators, explained and described in the Indicators for the Sustainable Management of Tourism (1995), are designed to address links between the tourism industry and the environment, the impact of the industry on the environment, and the effects of social and natural environmental factors on the prosperity of the industry.

The participants at the World Conference on Sustainable Tourism, meeting in Spain in 1995, adopted the Charter for Sustainable Tourism (www.geocities.com). It recognised that tourism is ambivalent, since it can contribute positively to socio-economic and

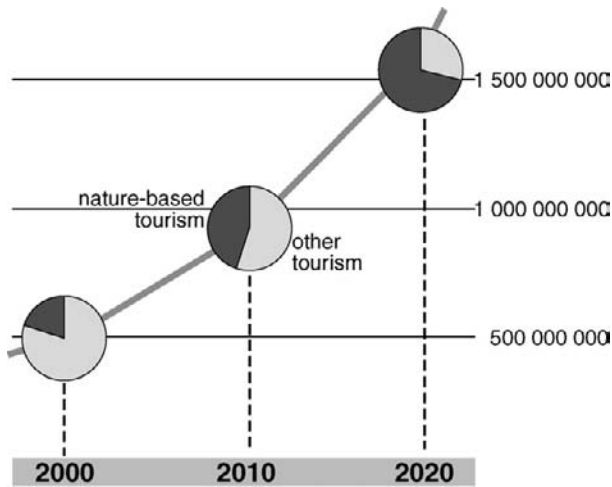


Figure 1.3 Tourist numbers globally and nature-based tourism market share.

cultural achievement, while at the same time it can also contribute to the degradation of the environment and the loss of local identity. It should be approached with a global methodology taking into account a simple truth that the resources, on which tourism is based, are fragile and that there is a growing demand for improved environmental quality. To be sustainable, tourism needs to meet economic expectations and environmental requirements, and respect not only the social and physical structure of destinations, but also the local population. In particular, the use of energy, tourism-related transport, the 'Triple R' (Reduce–Reuse–Recycle) and impact minimisation strategies in resorts should receive a great deal of attention.

As is the case with sustainability, there is no commonly agreed definition of 'eco-tourism'. This is because the general concept of eco-tourism (such as

nature-based tourism or 'sustainable' tourism) itself is still a much-disputed topic. Eco-tourism can be defined as visiting relatively undisturbed places for enjoying biotic (fauna and flora) and abiotic components of the local environment. However, different experts tend to stress different aspects of eco-tourism: economic, social, cultural or others. Eco-tourism is supposed to have three main components: it is to be nature-based, sustainable (which also includes consideration of economic and socio-cultural impacts), and have educational/interpretative qualities. A scrutiny of these three components reveals that almost invariably financial costs of eco-tourism business endeavours, which operate in a way of making no more than negligible impacts on the environment and educating at the same time, tend to be higher than the generated income. This raises the chief concern about eco-tourism, which has a potential to develop into smaller forms of mass tourism. Examples of facilities practising environmental audits or monitoring schemes, where impacts can be identified, controlled and eventually minimised, are very rare indeed.

Nowadays, eco-tourism seems to be a very fashionable trend, which emphasises direct contact with nature, and protection and conservation of the natural environment. It is one of the two relatively new major trends that can be identified in the development of coastal resorts, the other being 'business tourism' (defined as the tourism related to professional/occupational activities of the traveller). The National Ecotourism Strategy, tabled by the Australian Commonwealth Department of Tourism defines eco-tourism as nature-based tourism that involves education and interpretation of the natural environment and is managed to be ecologically sustainable.

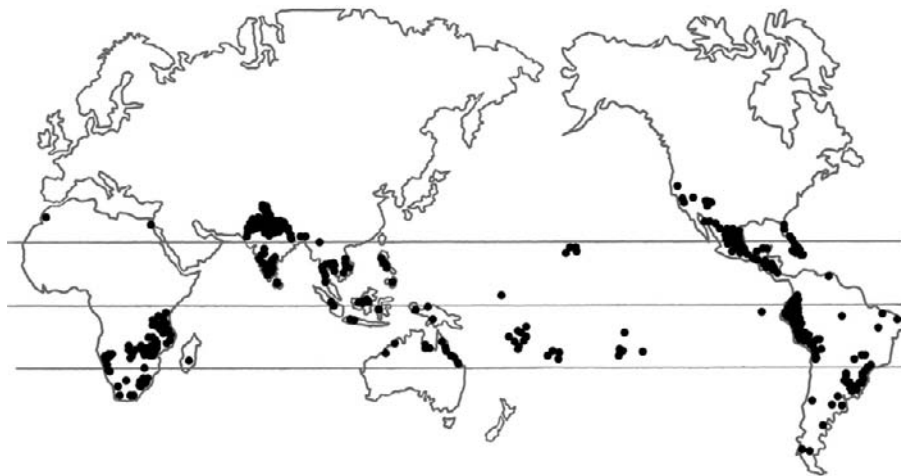


Figure 1.4 Locations of eco-tourist resorts around the world.

This 'nature-based' virtue seems to be a powerful keyword when it comes to developing a resort in a tropical location. Nevertheless, the term 'eco-tourism' all too often appears to be a misnomer and more an idea than an actual practice. As it is popularly understood, eco-tourism is more about watching nature than about staying in tune with it. One advertisement of an 'eco-resort' in northern Australia suggested contact with the environment of a tropical rainforest from luxuriously fitted and obviously extravagant accommodation, with air-conditioning and satellite TV sets in all rooms, imported marble floors in common areas and other such 'enhancements'. This is an absolutely unsustainable approach to eco-tourism, which should be deprecated as unacceptable in this setting.

For the reasons previously indicated, tourism in tropical areas – perhaps more than anywhere else – should contribute to sustainable development and be integrated with the natural, cultural and human environment. It must respect the fragile balances that characterise many tropical destinations, particularly small islands and environmentally sensitive areas

such as the coast. Eco-tourism, when mindfully developed, is capable of ensuring an acceptable evolution as regards its influence on natural resources, biodiversity and the capacity for assimilation of any impacts, generated waste, emissions and residues.

From a resort designer/planner's point of view, one of the more significant aspects of eco-tourism is that eco-tourists are encouraged to get involved in primarily, if not exclusively, outdoor activities such as wilderness exploration, water sports, scenic trips or even so-called 'soft' pastimes such as photographic expeditions. This particular focus of eco-tourism determines the character of the visit in the tropics as 'outdoor-oriented'. Thus, tourist facilities and resorts are frequently perceived as merely overnight shelters and a base for these daytime activities. This applies not only to tourists staying in a resort on holiday. Even business meetings and conferences, when organised in a tropical resort, tend to shift the focus of the meeting from plenary sessions to discussions in small 'problem groups' – often moved outdoors. We should expect that this purpose will be reflected in the character of the resort architecture.

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1.2

Delineation of the tropics

Definition of what constitutes the tropics can pose a considerable problem. The trouble usually starts with a popular meaning of the term, which often and rather inappropriately refers to only a part of the tropics, namely the 'wet tropics'. For instance, according to a broad classification of climates for building purposes given by Szokolay and Sale (1979), which is a variation of many similar proposals, the tropics are a zone within a group of hot humid climates. Geographical system-based classifications (e.g. Köppen-Geiger-Pohl scheme) are also popular and widely used, and include both humid and arid tropics in the group of tropical climates.

The zone's name originates from the Greek word for 'turning' – the farthestmost latitudes where the sun can be observed in the zenith and a point where it 'turns back' in its annual march through the sky. These can vary slightly due to irregularities in the Earth's rotation. In the northern hemisphere the extreme latitude of 23.5 °N is called the Tropic of Cancer, while in the southern hemisphere it is the Tropic of Capricorn at 23.5 °S. Taking the Tropics (the latitudes) as boundaries of the zone, however, would exclude from the 'tropics' (the climatic zone) large areas such as the South California Peninsula and North Mexico or South Africa. The climates of those areas show profiles similar to the regions, which are within the boundaries determined by the latitudes of both tropics.

There are suggestions of dividing the Earth's surface into 'tropical' and 'extra-tropical' halves setting northern and southern boundaries between them at 30° with much the same result. Geographers prefer to define the tropics as that part of the world where atmospheric processes differ decidedly and sufficiently from those in higher latitudes, with seasonally fluctuating lines between easterly and westerly winds in the middle troposphere serving as the boundaries, which is not very helpful from our point of view.

One climate classification suggested calling the 'tropics' all areas where the mean temperature of the coldest month of the year is higher than 18°C (or 65°F), irrespective of their geographical location. This definition, however, excludes areas such as most of Central Australia and a large part of Indochina – located between the Tropics and, in principle, climatically similar to other areas covered by this definition.

Another definition of the tropics includes in the zone such regions where the daily temperature range exceeds the yearly range of daily means. This approach would result in an exclusion of areas such as most of the Arab and Indian peninsulas, and Indochina again.

It seems that using instead a simple criterion of the mean annual temperature, one that is above 20°C, is more practical. Application of this criterion would extend the tropics beyond the 'tropical latitudes' to approx. 35–40°N and 30–35°S, and include almost the entire African continent, southern Asia, large parts of South America and Australia, and the southern USA. This definition could be further refined following a suggestion that areas within the zone where the mean daily temperature on a warm design-day (a day representative of the prevalent conditions taken as the basis for the design) in the warmest month of a year drops below 27°C should be excluded. This generally applies to high altitude regions – more than 1500 metres above sea level. Many of these areas could, perhaps more appropriately, be called 'subtropical'.

In a group of definitions based on human response rather than purely climatic factors, Atkinson (1953) suggested a classification of tropical climates which has been widely accepted and proven useful. The classification is based on only two factors: air temperature and humidity as, seemingly, these two factors dominate human perception of comfort/discomfort in the tropics. Although still not ideal, this classification is generally the most popular and widely accepted one. Based on the effects of variation in the extreme values of temperature and humidity, the tropical regions can be divided into the following three major groups and their three subgroups:

1. Warm-humid equatorial climate.
 - 1a. Warm-humid island/trade wind climate.
2. Hot-dry desert/semi-desert climate.
 - 2a. Hot-dry maritime desert climate.
3. Composite/monsoon climate – a combination of climates 1 and 2.
 - 3a. Tropical upland climate.

It is worth noting that the sea influence has been acknowledged to the extent of arranging 'maritime' climates into separate subgroups, namely 1a and 2a. These 'maritime' or 'coastal' tropics are the focus of

this book. They are representative of regions and areas most popular among 'inter-climatic' travellers. These regions and areas are also primary targets for tourist developments.

It is rather obvious that, for use in the built environment, a definition of the tropics based on broad 'geographical' terms of reference is unsatisfactory. The required data inputs are different from variations in temperature and precipitation affecting vegetation. We build to filter and modify various geographical impacts, and the climatic ones in particular. Thus, the definition should refer to the required response by the building to achieve the comfort of its occupants. Following a similar suggestion made by Koenigsberger *et al.* in 1973, the definition of the tropics, adopted also for this publication, is:

Tropical climates are those where heat is the dominant problem, where for the greater part of the year buildings serve to keep the occupants cool, rather than warm, and where the annual mean temperature is not less than 20°C.

Designers and planners working in tropical locations have to respond to heat, which is a dominant problem throughout extended periods of time, and address a few other climatic factors applicable to a tourist facility's design. Tropical climates are challenging but also offer opportunities. It can be demonstrated that knowledgeable and skilful utilisation of the climate greatly enhances the 'tropical experience' – probably the most sought-after commodity in tropical eco-tourism (Figure 1.5).

1.2.1 Tropical climates and the building

The tropical climate influence is a little different for people and for the buildings they occupy. The elements of climate influencing our comfort are solar radiation, temperature and humidity, as well as availability of wind and breezes to alleviate combined effects of the former three. Buildings in the tropics are also affected by temperature and humidity, but their integrity requires considering wind pressure and precipitation in the first instance.

Tropical climates are those where persistent excessive heat is a dominant problem. Our ability to respond to the heat depends largely on the moisture content in the air. This in turn, because of evaporation, is directly related to precipitation. If a region receives more than 500 mm (or 20 inches) of precipitation annually, there is too much evaporating water to be absorbed by the air and relative humidity increases as a result. Most climates of this type are found within a band 15° north and south of the equator. The American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE) has described hot-humid climate as areas characterised by a 67°F (approximately 19.4°C) or higher wet bulb temperature for 3000 or more hours (equivalent of 125 days) during the warmest six consecutive months of the year, or a 73°F (22.8°C) or higher wet bulb temperature for 1500 or more hours during the warmest six consecutive months of the year. Typically, air temperatures in this equatorial band would range between 27 and 32°C (around 80–90°F) during the day

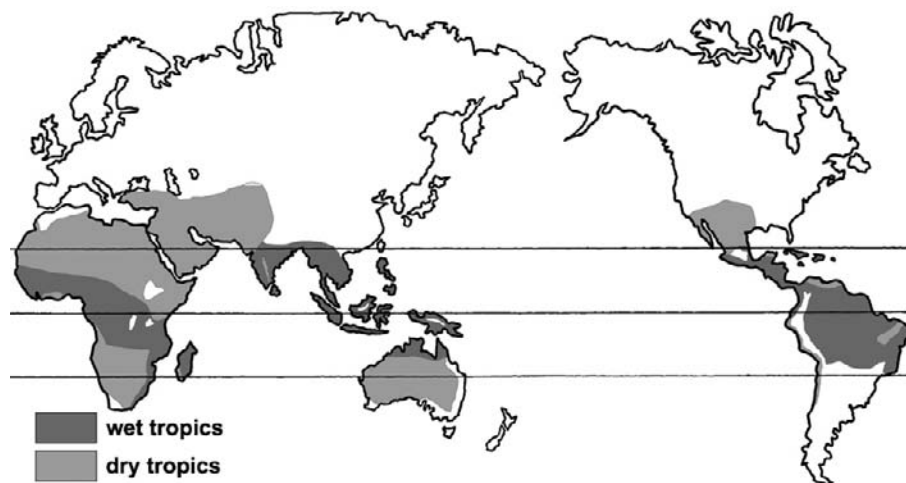


Figure 1.5 Distribution of tropical climate types.

and 21–27°C (around 70–80°F) at night with very little variation throughout the year. Precipitation and relative humidity (RH) are high with RH exceeding 75 per cent for most of the time.

Figure 1.6 illustrates the meteorological data collected at tropical locations around the world and illustrates the type of conditions to be found within the tropics. Annual average of mean daily maximum temperatures in these sample locations ranges from around 24°C in several island locations (Honolulu, Noumea, Fitzroy Island, Tamatave and Port Louis) to 35°C in Bangkok; annual average daily minimum from around 14°C in Broome to nearly 27°C at Minnicoy and in Bombay. Annual rainfall totals display a much larger variety ranging from 71.3 mm in the arid climate of Sao Tomé to 4172 mm in monsoonal Padang, Indonesia. Despite differences, all the listed locations have many shared characteristics and are representative of a great many more locations in the tropics. The following discussion concentrates on extremes rather than on average conditions. Figure 1.7.

One must remember that even within the wet tropics as described above, areas close to the coast

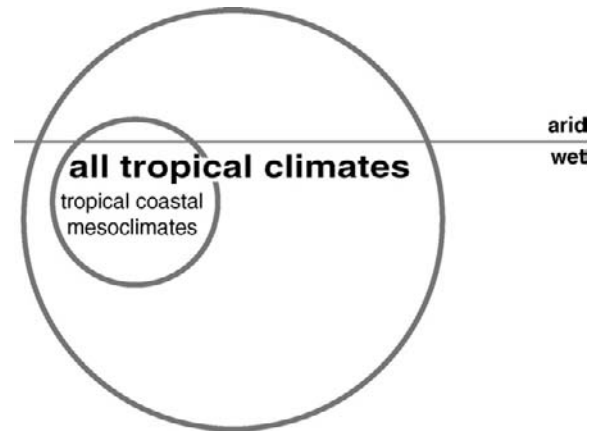


Figure 1.7 Position of the coastal tropics among all tropical climates.

display a few significant differences. The general characteristics of the tropics can be largely modified by a distinctive addition of localised influence of a large body of water. Although the influence of the sea can be felt even several kilometres inland, in many places its impact is limited to only 1–2 km from the shore because of hills or mountain ranges running

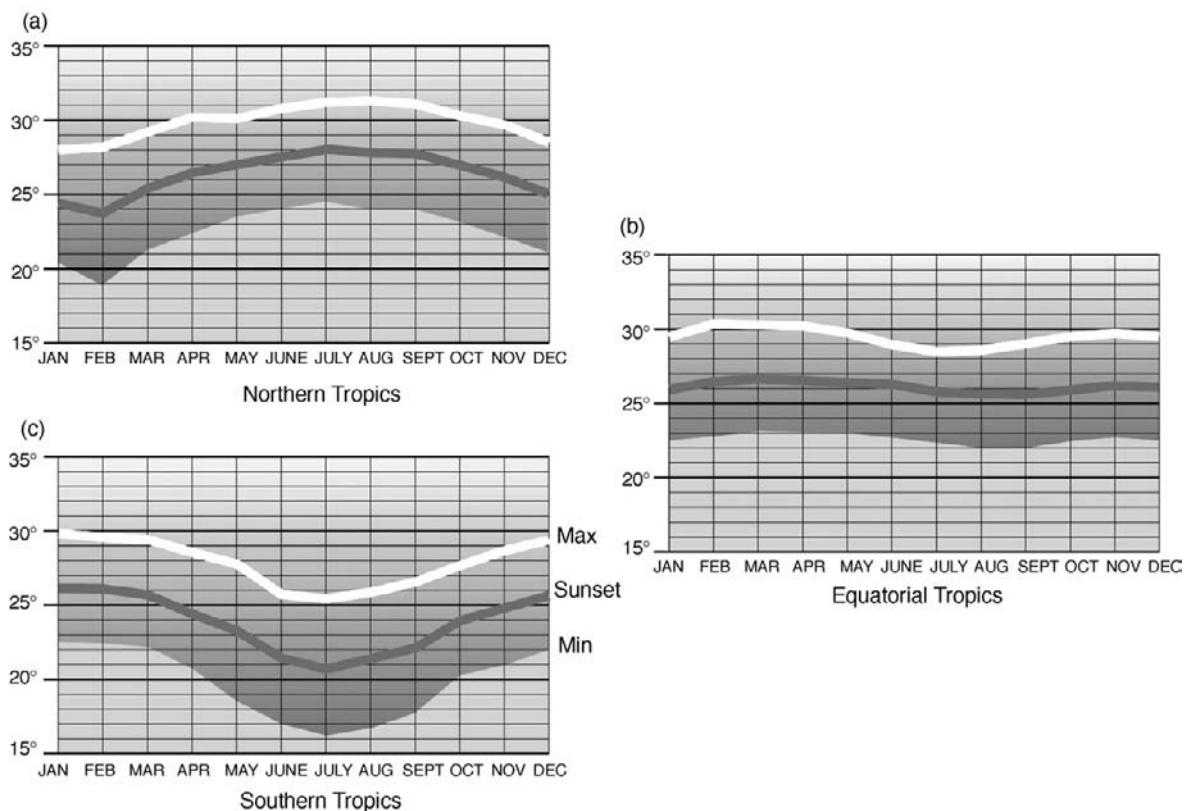


Figure 1.6 Maximum and minimum temperature, humidity and rainfall averages for northern, equatorial and southern tropical locations.

along the coast. However contained, tropical coastal regions are not ideally uniform in terms of their climatic characteristics. This is because site-specific factors form small-scale patterns of microclimates in any given climatic context. Locations within even quite a small area show noticeable topo-climatic differences. The coastal zones demonstrate otherwise relatively few and quite small macro-scale climatic differences in terms of temperature, rainfall, radiation or humidity variation (Figure 1.8).

The climate of a particular site (or microclimate) is a condition linked to, but not strictly derived from, the site location. At least, not to the extent that general inclination to perceive the climate would suggest. At ground level a multitude of minute climates may exist side by side, varying sharply with an elevation difference of only a few metres and within very small horizontal distances. For example, the wind speed, cloudiness, precipitation and humidity conditions are often very different on the windward and on the leeward slopes. These deviations should be analysed and utilised for making the correct siting decisions and microclimate improvements (Figure 1.9).

One has to be careful of comparisons because meteorological data are usually collected by meteo-

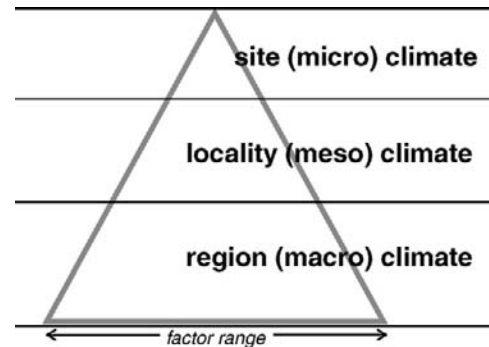


Figure 1.9 Range of climatic conditions found in macro-, meso- and microclimates.

rological stations at airports or airfields and can be distorted – by large masses of concrete runways and/or above-normal exposure to direct solar radiation, which follows deliberate clearing of all taller vegetation. It was Victor Olgyay who noted as early as 1963 that the climate of a particular area or mesoclimate can differ considerably from the regional climate (macroclimate) due to, for example, site topography, continent–sea influences and forestation ratio. Hence, most often, a general climate description is inadequate for building design purposes. Moreover,

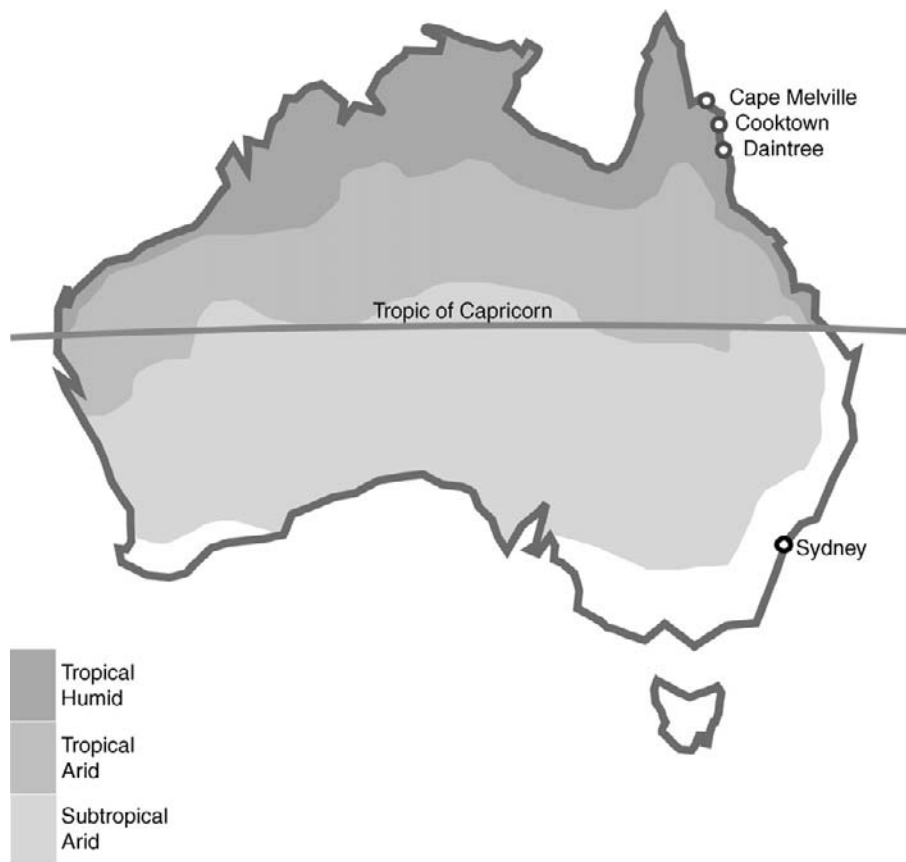


Figure 1.8 Distribution of tropical climatic zones in Australia.

it is necessary, in theory, to collect data for at least 10 years (usually about 30 years) to achieve recordings that have statistical significance. One could even argue that, with weather as variable as that, for instance, in Australia, rainfall records for 150 years and temperature records for 50 years or more may be considered necessary to adequately determine and describe the climate. As this is usually either impracticable or impractical, particularly at times of more rapid climate changes, some care in interpretation of results, when obtained through statistical manipulation of available data, is recommended.

It gets even more complicated and difficult when we move down to an individual building level. A great deal of effort, technical skill and judgement, gained from experience, is usually required to bridge the gap between the raw climatic data and appreciation of its effects on the internal environment created by a particular building design. In many situations, the data one would like to have are not available, while in other cases one is unsure of an appropriate technique to use in evaluating the effects of available data. Climatic influences are particularly evident in so-called 'free-running' or 'passive' buildings, which do not employ air-conditioning devices.

Every eco-resort should aspire to have its indoor environment controlled without support from mechanical means and respond to the climate by virtue of its design only. The aim of such climate-responsive architecture is to provide protection from the negative climatic factors and take advantage of the positive ones in order to meet the comfort requirements of the occupants. It should do this by consuming the minimum amount of energy or no energy at all. Ideally, information on local climate and reliable local experience should be considered jointly to fully appreciate 'positive' and 'negative' climatic influences. Then these influencing factors can be utilised (with or without modification) to assess the microclimate of the site around the building. Changes introduced by a design at this level can provide significant benefits, as opposed to attempts at macroclimate and mesoclimate levels, the latter being generally beyond the designer's influence. This approach, in addition to improving the amenity and extending the utility of outdoor spaces, can help to minimise or even avoid what are often more complex and expensive measures in the design of the building itself.

Furthermore, it is very rare that climatic data for a particular site are readily available. For instance, no detailed information about winds/breezes is collected on a regular basis at more than four or five locations in the whole of Far North Queensland, Australia – an area that takes in more than 2500 kilometres of the

coast. Yet, the wind is the most important localised climatic factor in the tropics. From the few places where such data are collected, we know that, generally, one may expect very few calm days in the maritime tropics. Prevailing winds are usually of moderate speeds 1.5–3.0 m/s. During relatively brief cyclone seasons, January to March in the southern hemisphere and July to September in the northern one, very strong winds (with speeds occasionally exceeding 60 m/s) can cause severe damage to buildings and vegetation, and disrupt normal tourist traffic in the area. Along the coast and up to between 2–8 km inland (depending on the topography of the terrain), the prevailing wind patterns are modified by sea-land breezes during the day and, to a lesser extent, by land-sea breezes in the evenings.

It is more than 20 years to date since a fundamental work by Szokolay, *Climatic data and its use in design* (1982), was first published. It offered a method of analysing climatic data for building purposes, which is sophisticated enough to be useful in most instances and simple enough to be performed manually. Nevertheless, with an environmental crisis looming and calls for less reliance on mechanical services to provide comfort in buildings, it is possible to improve a method employed in designing building response to climate. Such attempts have already been made. They suggest taking into account a number of factors not previously considered to improve the method and localise the design input data.

Climatic differences between the coast and its immediate hinterland, within the same zone as identified by geographers, are far greater than variations along the coast and merit distinguishing the 'coastal tropics' as a separate sub-zone for building purposes. It seems quite appropriate to narrow a definition of the tropical coast even further to include only a several-hundred-metres-wide belt adjacent to the seashore. The belt combines features of a tropical climate with a geographical definition of the coast. This approach is justified by early observations, which indicate the rapidity of change in conditions causing thermal stress relative to the distance from the shore in similar areas. Such sharp differences in climatic conditions over very short distances can often be found in areas where mountains are parallel to the coast – even if their height is modest they produce a most profound influence on annual rainfall patterns.

It is suggested that, in order to achieve better accuracy, the mesoclimate or locality climate characteristics, which is the data set usually accessed for design purposes, be modified by two factors applied to every building site: the 'hill factor' and the 'sea factor'

(though 'vegetation factor' can also be considered). The 'hill factor' allocates modifying values to the building's site in relation to an idealised hill and valley. The distance from a large body of water becomes the 'sea factor' to represent a modifying sea influence. Similarly, various types of ground cover could be seen as 'ground surface factor' modifiers. Regional climate averages, which are found in a given zone and affected by the method's factors are: diurnal temperature ranges, humidity and irradiation values, rainfall and wind. The exact extent of all those modifications would have to be established by empirical research. In this place, we can only suggest that topography and sea influence are entered into climatic data analyses in the way shown in the diagrams. The numbers indicated in both diagrams are the suggested temperature differentials, which should be added to or taken off the monthly average ambient temperatures for the locality (Figures 1.10 and 1.11).

Brown and DeKay (2001) proposed an interesting method of microclimatic site analysis based on topography (translated to site shading) and wind direction. It can be used to further enhance the proposal of modifying climate data with the sea and hill factors.

Design problems, which the tropical coasts pose, are different from those found away from the sea. Among the more prominent climatic features of the coast, there are local sea to land (in the morning) and land to sea (in the evening) breezes. Sea to land breezes, which build up at mid-morning, might be in the order of up to 4–8 metres per second, while land to sea breezes usually reach a speed of 1–2 metres

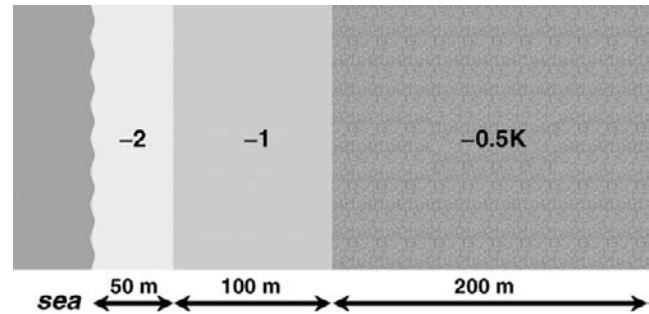


Figure 1.11 Calculation of the 'sea factor'.

per second. That makes them eminently suitable for cooling purposes. Breeze/wind speeds usually follow a distinct diurnal pattern: after calm nights they slowly pick up shortly after dawn, reaching a peak in the mid-afternoon, with moderate but weakening breezes continuing into the evening. Breezes, which are present within only a few hundred metres of the shoreline, tend to moderate thermal conditions and alleviate thermal stress in humans. Moreover, due to the sea influence, the diurnal temperature swing is smaller at locations close to the shore by about 3 degrees: while mean maximum temperatures are similar, mean minimum temperatures are markedly higher on the coast than inland. Furthermore, relative humidity values in the afternoon are, generally, lower when moving away from the coast.

Precipitation, on the other hand, is substantially higher in this zone than in adjacent areas. For example, inland locations such as Mareeba in Queensland, Australia, only 37 km away from coast-side Cairns, or

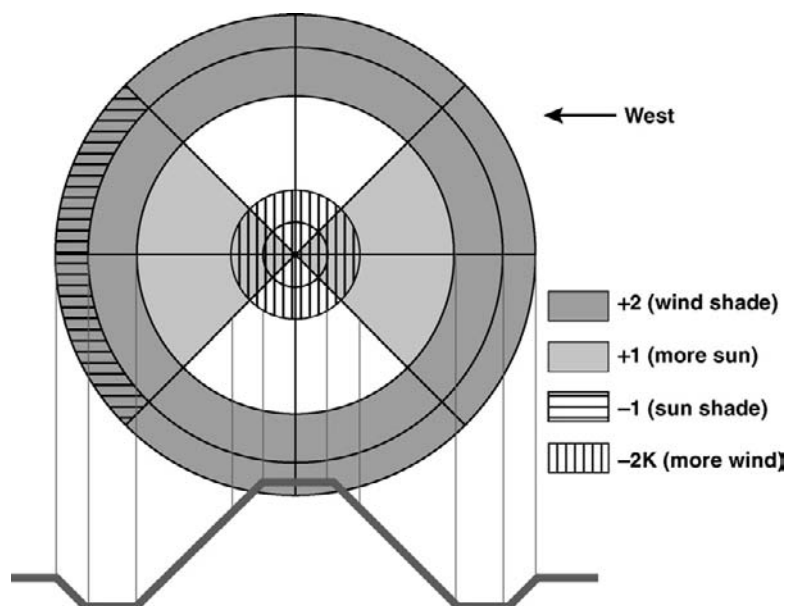


Figure 1.10 Calculation of the 'hill factor' (modified 'tropical' version of the Sealey's [1979] proposal).

Herberton, 70 km inland from Innisfail, receive 900–1200 mm of rainfall annually while all coastal stations in the region register more than 1800 mm annually. The seaside area around Mt Bartle Frere, including Innisfail, records rainfall in excess of 3500 mm. Another example comes from the small island of St Helena, where the 600–800 m high mountain range raises island-averaged precipitation by a factor of four. There are also quite a few more subtle differences, such as the strength and direction of incident winds and the amount of solar irradiation received due to differences in cloud cover.

All three factors, ‘hill’, ‘sea’ and ‘ground cover’, have been already identified as contributing to microclimate. Their inclusion in the Szokolay method, by the way of modifying input figures (increasing them or decreasing), should result in a climatic data set representing local conditions of the site more accurately. We do not need to worry about the complexity of such a method any more: computers are nowadays omnipresent and powerful tools, and would easily deal with the task of modifying the input. The ‘hill factor’ data, for instance, can be obtained through computer analyses of maps generated from satellite images using a 10 m by 10 m grid.

To be effective, modification of climatic data should be supported by adjustments derived from usage (this is discussed in more detail in Part Two). The Australian Greenhouse Office in its ‘Scoping Study’ (1999) suggested for energy rating purposes that energy used in buildings was tied to and influenced by the building category based on use patterns. It is rather obvious that required energy levels are different in dwellings, in a range of work environments, or at leisure facilities, for example resorts. This demand, however, can be reduced. Particular qualities, for instance greater availability of breezes, should be utilised by allocating areas displaying such qualities and incorporating them into the design of buildings serving particular functions, for instance those related to activities at higher metabolic rates.

Climatic differences between various points on a coast and the site of the nearest data collecting station can be quite significant. The two most important localised climatic factors at any point on a tropical coast are the wind and the sea, which work as a heat sink. The coastal zone, as defined in this text, distinctively differs from the rest of the tropics. Its temperature ranges, both diurnal and seasonal, are smaller, winds and breezes more frequent and more consistent, and humidity higher than inland. Such microclimatic data, most useful in design, are usually not available at micro-scale. This means the zone’s description covers too large a range of conditions and turns the whole

idea of climatic zoning, as far as building is concerned, into a very broad and inexact exercise, which produces results that must be greatly improved and refined to guide our environmental responses.

Differences between the coast and inland part of the tropics are not limited to the climate. There are several other basic physical aspects of the coastal environment that need to be evaluated while considering any building endeavour. Information on these aspects can be obtained from various secondary sources like hydrographical charts, topographic maps, aerial photographs and other published data on ground cover, soils, geology, etc. However, for designing or planning purposes, particularly in relation to a site adjacent to a shore, it may also be necessary to obtain data which are not commonly available. For instance, information on aspects like beach gradient, the extent of beach changes, the limit of high and low tides, the limit of storm surges or grain size of ground material must be collected on site. The difference between high and low tides, i.e. tidal range, is one of the more important factors to be taken into account when considering a development on the coast. In particular, steep beaches are more vulnerable as high gradient is usually associated with their exposure to high energy storm waves which, combined with human-use induced beach erosion, can cause severe damages.

Baud-Bovy and Lawson (1998) suggest drawing several sub-zones of the coastal environment for the purpose of tourism and recreational development. In their beach surveys, they use the terms sea, strand/beach, back-beach, coastal stretch and the hinterland. The zones differentiate sea and atmospheric conditions directly influencing the beach and the areas beyond as well as conditions found at the foreshore, i.e. part of the shore within the tidal range, the shore beyond the tidal range, and the hinterland directly adjacent to the shore. Every such zone requires a different approach and imposes different restrictions on a tourist development (Figure 1.12).

In summary, it can be pointed out that, although climatic data have (or should have) tremendous importance for the tropical resort design, there are many reasons to approach the issue of climate with extreme caution. Completeness and reliability of the available data defining the climate in the tropics is nearly always a serious problem. Furthermore, despite seemingly similar climatic characteristics shared by many locations, they differ significantly ‘at the ground level’. Differences can be caused by proximity to water, proximity and height of nearby hills and mountain ranges, aspect and slope angle of the land, vegetation type, soils or other local factors. For the climatic data

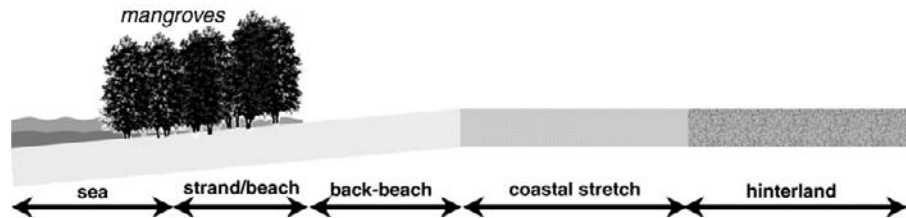


Figure 1.12 Coastal zones for analysis of local conditions.

to be of any relevance and practical value, they need to be adjusted, modified and enriched with local observations and experiences. Drawing on the local building tradition also might be helpful. Whenever possible, the method of one prominent Australian architect can be used. David Oppenheim in one of his public presentations recommended camping on a prospective building site for some time to ‘get a feel of the place’.

1.2.2 Ecology of the tropics

Market reality delivered two sets of requirements specific to developing and operating a resort in the tropics: one concerning comfort as such, and another related to the manner and costs of providing energy to drive necessary comfort devices. The latter issue, while being a matter of concern for tourist operators, is most important when consequences for the natural environment and long-term viability of the industry are at stake. The uniqueness of this environment calls for preserving the tropical coast, by somehow combining the heritage values of tropical ecosystems with tourist developments and long-established patterns of land use with newly introduced functions.

Most tourist resorts in the tropics can be considered remotely located. A remote location is any location that makes both access for tourists and delivery of goods, and energy required for operating a tourist facility, expensive and/or difficult. The importance of this observation is reinforced by the virtual interchangeability of the terms ‘remote location’ and ‘protection-requiring area’ in most of the tropical regions targeted by eco-tourism. Pressure of recent trends more and more often opens for tourism development areas that are separated from established settlements (and from the electricity grid) either by distance or location characteristics, for example tropical islands. Most vulnerable are semi-protected areas, which are threatened enough to be put on a list of areas under threat but deprived of the high-protection status of a national park. The rate at which tourist developments will be taking over the tropical coast is difficult to predict in an ever-changing economic

and political situation – one generally lacking direction and stability. There is also strong opposition to further tourist development from conservation movements.

Protection of the environment is a consideration of tremendous importance to building activities in the entire tropics. Some areas, such as most of north-eastern Queensland in Australia, have been given World Heritage status while others, such as large parts of Hawaii and Sian Ka’an in Quintana Roo, Mexico, are protected as national parks or nature reserves. Still others are clearly areas of high natural value even if not listed. The recognised need for protecting these vulnerable assets further compounds the difficulty of making an adequate response to the environment. Conservation of the natural environment has become an important political issue around the world.

All the factors mentioned earlier – climatic and others – influence our ability to protect the environment and affect one of the most prominent types of building-based land uses in the tropical coastal areas, namely tourism and recreation. The coastal tropics are also different from their respective regional hinterlands when ecological terms of reference are applied. They are, in fact, too different to be considered jointly. Their ecosystems are based on interlaced effects of sea and land influences, and support flora and fauna species which cannot live anywhere else. Furthermore, recreational uses often include an adjacent maritime environment, which can be as fragile and as precious as its shore-side counterpart.

The need for passive and low energy design in tourist resorts in sensitive ecosystems of the tropics should be taken as an imperative from the environment protection point of view. However, replacing mechanical air-conditioning with good climate-responsive design is also an ethical issue for architectural professionals. The brothers Victor and Aladar Olgyay stated as early as 1957 that it is architects’ moral obligation ‘[to] build the shelter in such a way as to bring out the best of the natural possibilities’ (Olgyay and Olgyay, 1957). This obligation should always stay at the forefront of the tropical

resort design criteria list, and in the coastal tropics perhaps even more than anywhere else. Resort planners and designers should be proactive in seeking available information and help necessary to cope with the complexity of the built environment in this exceptional setting.

The physical isolation of tourist facilities operating in a very sensitive natural environment has been maintained – and quite probably will be maintained for some time – as a mandatory condition of its ecological sustainability and the resort's attractiveness. Such isolated locations, although ecologically desirable and attractive to visitors, pose considerable challenges. Above all, they usually make operating a tourist facility both difficult and expensive. It is a problem of reconciling the quality of services being provided to users of a tourist facility with low operating costs and low environmental impact. In particular, costs related to the demand for energy can prove to be enormous.

Low energy building design for such locations is a principal requirement of their feasibility. Lowering the total demand for energy can be understood as a search for the best match between quantity of energy that is to be supplied and the demand for its purposeful use. These are not mutually exclusive notions. Whenever the provision of indoor conditions falling within the (individually) tolerable limits for the relevant kind of activity has been achieved at a lower cost, any surplus money can be spent on perhaps improving service delivery. This action would eventually result in higher consumer satisfaction. It is better still if tourists are made aware that meeting their requirements this way makes a lower impact on the natural environment than would otherwise be the case.

The principal ecological quality of most tropical environments is their fragility. This characteristic is caused by a number of factors. Most importantly, the remnant pristine environments targeted by eco-tourism are nowadays disjointed and physically isolated. This situation is further compounded when they lack 'eco-corridors' between them, allowing the movement of species from one liveable pocket to another. This is required to expand the habitat for availability of food, to avoid inbreeding or to escape when threatened. The need for such connections should be taken into account when planning any green-field development. Native vegetation should be allowed to weave through the built-up area, grouped and enlarged whenever possible. Such vegetation can be employed to create shelter belts used for redirecting wind and breezes, visual screens or acoustic barriers.

Tropical systems are extremely fragile and sensitive to any disturbance. The coral reef is the most

extreme example and thus deserves special attention since protecting its beauty and vitality is essential to the operation of most tropical coastal resorts. Although the reef can suffer from many factors, the impact of nutrients and sediments are among the most devastating. The natural ecology of the coral reef is low in nutrients. Increased levels of nutrients stimulate growth of algae, which can overgrow the coral, increase plankton population, reduce light availability to corals and upset their physiology.

An important contribution to the overall fragility of these ecosystems is brought about by their uniqueness. An important consideration is the origin of tropical biodiversity: some experts believe that an uninterrupted and stable 40 million years of evolution has been the reason behind a much higher density of different species co-existing in the tropical biomes, while others tend to put it down to Pleistocene refuges (shelters) surviving independently within the present-day rainforests. Both arguments add to validity of conservation efforts. Many tropical areas support the rather complex interdependent relationships which some plants and animals have with each other. Such interdependencies have developed these species into highly specialised endemic varieties: when their habitat is damaged beyond an acceptable limit, such species have nowhere to go and perish. Because these ecosystems have often evolved in isolation, they are susceptible to all kinds of impacts associated with resort construction and operation.

Apart from just a few larger ones, an average tropical ecosystem is relatively small in size. This causes any introduced activity to have a significant impact on its flora and fauna. Tropical ecosystems also have weak soil composition and are prone to quick degradation and erosion once the original ground cover has been removed. Research has shown that once weathering and leaching processes have started, there is no practicable means of halting rapid soil erosion or replacing lost organic matter. A design implication is that any required circulation on the site should be planned with extreme caution and care. Other requirements can be presented as follows:

- Any unnecessary changes to the environment should be avoided;
- Landscaping should become an extension of the existing ecosystem, mimicking it and preventing further fragmentation;
- Plan resort development in border zones between, rather than deep within, ecosystem units;
- Avoid encroaching by resort developments, and their intensive use parts in particular, on unique land features, such as the only hill in the vicinity,

the only lake or one of just a handful of freshwater streams as it is more likely than not that these areas host endemic flora and/or fauna species;

- Do not introduce imported live organisms, plants or animals, to the area; landscaping and population of decorative pools should be done with native species;
- Traffic should be planned using the shortest available routes; whenever possible, it should be taken

above ground or led in a way which will not contribute to erosion, for instance avoiding steep gradients;

- Avoid using pesticides and herbicides. Pest and weed control, when really necessary, can be carried out using permaculture methods and manual removal; however, adaptation and passive methods such as screen and barriers are much more environment-friendly.

1.3

Operational issues in eco-friendly resort design

The approach to tropical resort design presented in this book is an environment-friendly one. It draws a picture of an eco-resort in the tropics which offers a 'tropical experience' to visitors. Such a resort makes only a minimal impact on the environment without compromising guests' comfort and safety. It can also be an economically viable alternative to typical air-conditioned structures. The eco-resort has to draw on and blend with the local natural and cultural environments by employing principles of Environmentally Sustainable Design (ESD). It must minimise use of energy through passive solar design and, where additional energy inputs are required, it should utilise the renewable resources of sun, water and wind. It also has to make minimal impact on the environment by limiting waste, emissions, pollution and other undesirable effects of its operation.

In very broad terms, the impact that the resort will make on the environment can be derived from solutions adopted for:

- energy and water supply
- discharge of waste and emissions
- construction technology and materials used in buildings and infrastructure, and
- direct human impacts through daily activities on the site

While environmental impacts are related to both design and operation of the resort, this publication deals only with the former. Nevertheless, the reader should keep it in mind that operational impacts will always follow on design decisions and are reflected at later stages of the facility's life cycle in maintenance, waste generation, various types of pollution and socio-economic impacts. Consideration of all benefits and all costs, not only at the construction stage but also throughout the entire life of the facility, should be put in a broad context. In the following sections, we will consider various factors affecting environmental sustainability.

Eco-resort design should begin with its indoor environment. Creating the tropical resort so that it performs exceptionally well is, in this usually extremely fragile environmental setting, far more

important than its looks. Achieving an exceptional aesthetic quality (on top of the exceptional functional and structural qualities) in the unforgiving environment of the tropics should be taken only as a welcome bonus after performance requirements have been satisfied (Figure 1.13).

While no single design or planning issue can be considered in isolation, it is the response to the climate that is the most obvious design problem in the tropics. The overall objective of climate-responsive architecture is the provision of high standards of thermal, acoustic and visual comfort, while working with the climate rather than against it. It follows that the building should respond to the environment in which it is built by taking full advantage of any useful climatic conditions at the site and eliminating or minimising the influence and effects of undesirable phenomena. Furthermore, it should closely match the needs and expectations of its occupants, which in many respects are different from those of occupants in a residential or office building. These objectives can be achieved without high energy input – nowadays widespread and on the increase in typical tropical buildings.

Service system integration is a means to achieve the eco-resort design goals: close fit, accurate response, and highest possible efficiency. There is a range of services that need to be looked at:

- water supply, including demand for potable and non-potable water, and drainage management
- lighting
- energy supply management
- ventilation/air-conditioning
- water heating
- sewerage and waste management
- pest management
- telecommunication and information services
- fire safety and security services
- transportation.

The integration occurs at two levels, as internal and external integration. The internal integration requires that the most economical solution for a given service be adopted in response to the identified

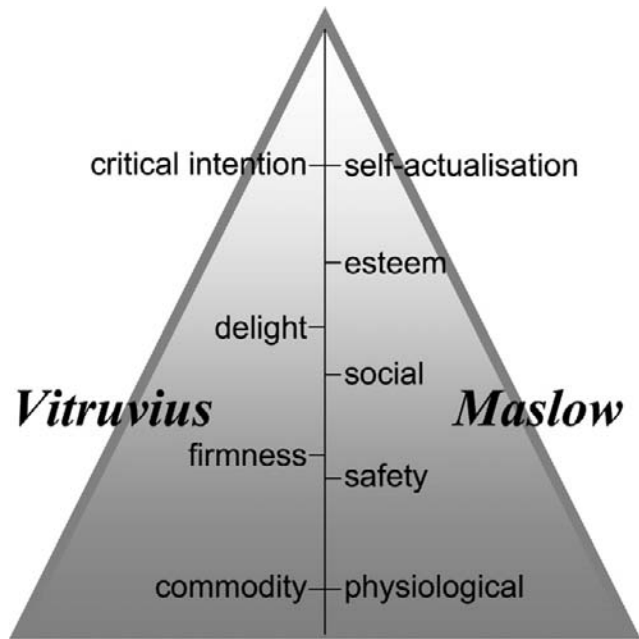


Figure 1.13 Hierarchy of human needs according to Vitruvius and Maslow.

and quantified need. The selected system should be robust and necessitate minimum redundancy. Its modular structure should allow for easy coordination with other parts of the system, speedy construction and, later on, least maintenance. Practically all operational issues are influenced by decisions taken much earlier, at planning or design stages. Smaller is better – this old truth definitely holds when applied to tropical eco-resort design. ‘Reducing the demand’ is the paramount principle in systems designed for use in a typical eco-resort setting.

External integration is about coordination of one system with all others as well as with indoor and outdoor environments. What this means is that, if unnecessary waste is to be avoided, systems need to respond to environmental conditions in the most efficient way. Furthermore, parts of the system should be able to perform multiple functions. For instance, a decorative pool can double up as an evaporative cooler, fire-fighting reservoir and a security barrier, even if we forget its role in supporting the native wildlife.

Landscaping can be done with edible plants and deliver required visual and acoustic barriers, roof ponds can be used in controlling indoor environment and store water for other needs, and photovoltaic arrays can form a part of a roof cover. Such landscaping impacts on the indoor and outdoor environments and is limited to the functions and services required of them. For instance, structural elements can be size-

coordinated with building functions and complement the envelope, provide room for electrical wiring and hydraulic pipes while contributing to the visual environment in a way expected of the architecture built in places where nature is more important than the human contraptions. Outdoor lighting can be incorporated in the structure of walkways in response to safety and security needs but not spilling light into the surrounding wildlife habitats. In addition, location of power-generating equipment can be chosen to minimise transfer losses but not intrude with unwanted sound or visual impacts.

There are a number of preventive measures that can be taken to minimise operational impacts. They include assessment of and follow-on actions appropriate to what was found in the areas of:

- impact of the resort and its operations on visual landscape
- impact of use of energy, in particular lighting devices, on site
- potential effects of use of fuels and (maintenance) chemicals
- sourcing and retention of water as well as possible water conservation measures, including reuse of grey water
- impact of storm water, including drainage techniques, wastewater and effluent on site
- impacts of noise at the site
- use of transport for various tasks
- use of natural surroundings of the resort
- potential interaction between resort staff and guests and the environment
- impact of the resort and its operations on biodiversity
- ways in which the resort can support conservation within and beyond its site.

Reduce–Reuse–Recycle (–Replace)

In response to diverse environmental pressures, the 4Rs (sometimes referred to as the 3Rs, omitting the replacement considerations) have emerged in recent years as a major social phenomenon. Reduce, reuse, and recycling strategies can minimise environmental impacts by lowering environmental pressures from preparing the site, construction, operation and maintenance of the resort. The strategies based on the 4Rs principles should be implemented at all stages of the facility life cycle. Most people are familiar with some recycling programmes, but it is worthwhile to review what reduce, reuse, recycle mean in the context of the tropical eco-resort (Figure 1.14).

The following sections look at planning and design issues related to some aspects of resort

REDUCE !!! → REUSE !! → RECYCLE ! → REPLACE ?

Figure 1.14 Hierarchy of operational objectives in energy and waste management.

operations. Interested readers may find discussion of energy generation, water supply and waste disposal in specialist literature, some of which is given in the Bibliography. In these pages, we focus on planning and design implications of particular selections as well as on choice of building materials, construction technologies and opening the site to the tourist presence.

1.3.1 Energy management

Key recommendations in brief:

- Select carefully the services to be powered – many can work with no additional energy input;
- Use local context as the main criterion of energy source selection;
- Match demand to supply in order to avoid over-sizing the power generation system;
- Investigate planning/design implications of selecting a particular source of energy.

Eco-tourist resort operations hugely depend on energy needs, waste and pollution minimisation. While most of the respective aims are achieved through adopted practices and considerate behaviour of staff and guests, some aspects of minimisation programmes have to be supported with adequate planning and design.

Resorts use significant amounts of energy required for their daily operations and recreational activities. In most remote facilities, energy expenditure is the largest part of operational costs. This high demand for energy is often due to the use of energy-intensive technologies to provide home comforts and conveniences, such as air-conditioning, to resort guests – whether they want it or not. The vast majority of resorts meet their energy needs by generating or purchasing energy produced through burning of fuels from sources such as coal, oil and natural gas, which contributes to air pollution locally and to climate change globally. Passive design with efficient use of renewable energy can decrease dependency on unnecessary energy input. Environmentally-friendly practices can enhance resort reputation among its guests and others who are concerned about impacts from growing energy consumption.

Decisions regarding energy generation and supply are among the most significant environmental initiatives that may be taken in a resort. Perhaps,

the global warming, acid rains and other broad environmental impacts are not something that we are usually concerned about when it comes to using relatively small amounts of energy in remote areas. Nevertheless, the utilised energy systems certainly belong to the most visible aspects of running any establishment aiming at the eco-friendly status. This is because the environmental problems, which have very local impacts, for instance fuel spills, disposal of used engine oil, discarded batteries and worn-out engines, fumes, noise and fire hazard, are even more serious than the global impacts.

The extent of such impacts depends on the system or combination of systems selected to meet resorts' energy needs. There are also direct planning and design implications of selecting some energy sources – because of the associated noise, vibrations, visual impacts, operational requirements or safety reasons. Such implications, when neglected, can have a very significant impact on the efficiency of the utilised systems and operational costs of the resort, and a potentially detrimental effect on the eco-friendly image being at the core of any environment-focussed development.

The key to reducing impacts from the energy systems is to minimise the need for using the energy in the first place, and then to increase efficiency of energy use: in its generation, then supply and, finally, possibly recovery. It is necessary to identify tasks for which the energy will be needed in the resort, identify the most efficient way of performing these tasks, quantify the energy required to meet the needs and, finally, to generate and supply the quantified amounts of energy in a most efficient way and with the least environmental impact. Environmental and other location or site-specific constraints, for example availability of spare parts and expert repair services, should be factored in before selecting a power generation system (Figure 1.15).

The starting point is at the assessment of the forecast energy use to determine where the highest energy consumption takes place within the resort and the most likely places for efficiency improvements based on existing similar resorts. The design should enable guests to follow energy-saving practices, such as going without lights and air-conditioning when they are not really needed, closing window shades before leaving their rooms during the day and opening windows at night. When feasible, renewable energy sources, such as biogas, wind or solar power, should

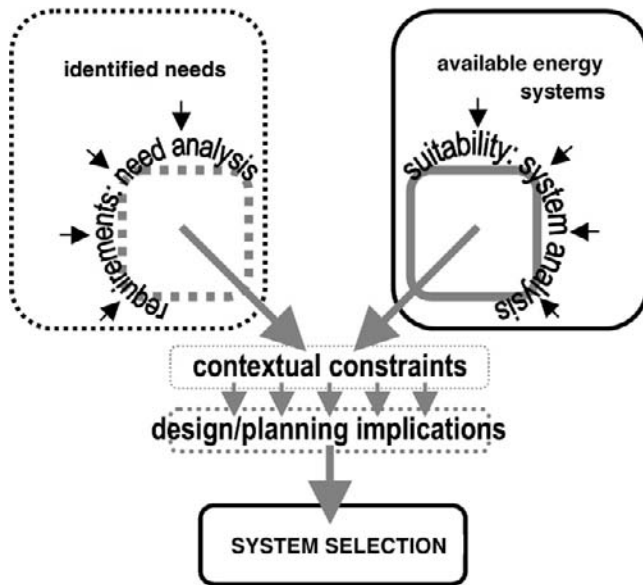


Figure 1.15 Energy system selection process.

be used. Decisions taken at the design stage will have a long-lasting effect in terms of impact on the environment, operational costs and, ultimately, customer satisfaction. The ultimate goal should always be to maintain, or prevent deterioration to, the natural condition of the site.

From the energy management point of view, the important issues to be resolved include the identification of needs and services requiring additional energy inputs in terms of the input's timing, place, quantity and quality. Energy can be used in a tropical resort for water pumping, space cooling, ventilation, lighting, water heating, food refrigeration and preparation, site transportation, powering small appliances, office needs, communication and information services, and a range of others. These energy decisions must prevent air, water and soil pollution as well as minimise any visual and acoustic impacts from a power source. Depending on the type of the source, other considerations include impacts from maintenance materials and activities. The possibility of pollution caused by regular deliveries of the required type of fuel, and with this the risk of accidents (fires, spills, etc.), also must be considered.

There are resorts in the tropics using energy for only limited lighting and cooking, and there are others where power is being used to aerate decorative fishponds. The bases for making decisions – about which services are or are not offered – are beyond the scope of this book. Here, I will present only a few considerations that can help in reducing energy amounts needed for most of these services. Passive design, supported by adequate site planning, is well

suited to addressing issues of cooling, ventilation and lighting. It is, most certainly, capable of meeting needs in these areas to a large extent – without resorting to powered machinery and equipment. We will move on now to the remaining aspects of power generation, supply and recovery.

Once the needs have been identified and a decision about using energy-based devices to meet them has been taken, a power supply system must be considered. Generally, two options are available: a grid connection, involving electricity generated elsewhere and transmission lines, and power generation on site. The grid connection is a viable option for resorts located fairly close to the local powerlines network: distances of several kilometres make the connection prohibitively expensive in both capital and maintenance costs. In a few places around the world an attractive hybrid solution is possible, whereby a resort is connected to the grid and generates its own electricity on site with any surplus energy flowing back to the grid in buy-back schemes. This option is most desirable where a resort's own electricity is generated by photovoltaic (PV) panels and thus has its peak output mismatched with its peak energy demand. Opportunities for recovering heat in a process of energy generation should also be explored as a means to curb demand.

A number of energy sources are available for use in stand-alone systems used in generating electricity on site (Fraenkel, 1979; Hulscher and Fraenkel, 1994). There are a large variety of options that can be broadly categorised as conventional and non-conventional generators with the boundary between them increasingly blurred. A different classification divides energy generation into groups of renewable and non-renewable sources. These classifications are not mutually exclusive as shown in Figure 1.16. It should be noted that not all non-conventional sources could be used in a remote tropical location, while others might not be suitable in small applications. On the other hand, use of some renewable fuels, such as biodiesel or

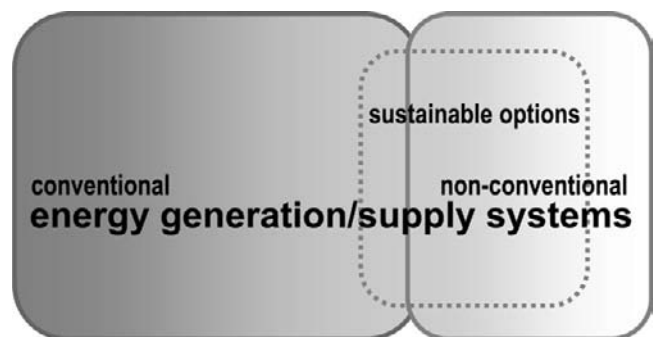


Figure 1.16 Energy source classification.

charcoal, can have potentially disastrous impacts on the environment, bringing with them deforestation, monoculture crops, soil erosion and a plethora of other problems. Other renewables can cause environmental problems in the regions where the components are sourced from or manufactured.

The main reason for favouring renewable technologies in tropical eco-resorts is usually because of difficulties and costs related to acquiring conventional fuel supplies on a regular basis, transmission losses over large distances and reliability of powerlines, or problematic maintenance of conventional generators. In this particular setting, also the non-tangible effects of using conventional diesel or petrol engine-driven systems, such as noise, vibrations and smells, can be crucial to a resort's operations. Such environmental factors can expand human-felt presence, scaring off wildlife or making adjacent areas uninhabitable for the local fauna.

A definite advantage of using conventional power sources lies in the relative easiness of storing energy (or rather fuel for its generation) and using it in line with the current demand levels. Non-conventional systems are not reliable in all-weather conditions and require back-up to secure vital services, although in some areas the opposite might be true. Non-grid energy supply options include renewable energy sources such as photovoltaic cells, wind and micro-hydroelectricity, and non-renewable diesel or petrol generators. The quietness and environmental benefits of most renewable energy sources make them preferable to fossil fuel-fired generators.

Generator capacity should be carefully matched to the expected electrical load. For small variable loads, and in parallel with electricity generation to meet peak demands, batteries can be charged by a generator, which does not have to run when loads are very low. This solution, however, adds to the cost and complexity of the system and has its own design/planning implications concerning required outbuildings, supply roads and distances from other parts of the resort.

Where possible, low-power direct current (DC) equipment can be used to minimise the need for the use of inverters. While this will involve using a distribution system with heavier duty wiring than would be required for an AC distribution system, and may require the duplication of distribution systems to some areas, the reduced cost of installing and maintaining inverters will be considered a reason good enough for this choice in most situations.

Eco-resorts require energy for lighting and cooking. Secondary demands include power for air-conditioning, water heating, powering communication equipment, and transportation needs among others. As mentioned earlier, selecting the energy source has almost always certain implications for the planning/design of a resort. A list of affected issues is quite extensive: from zoning with the aim of reducing acoustic and visual impacts, through distances impacting on system efficiencies, particularly DC power transmission and direct solar heating, to safety, security and risk management. Closely related are the fuel and energy storage problems.

1.3.1.1 Internal combustion (IC) engine generators

Fossil fuels, or rather fuels from fossil sources, are the most common type of fuel used to generate power. Due to the rate of replenishment, they must be considered a non-renewable resource. Nearly all uses of fossil fuels also belong to the 'principal greenhouse gas polluter' category. The major advantages and disadvantages of generators using this type of fuel are listed in the [Table 1.1](#).

Biofuels, as both liquid and gaseous fuels such as biodiesel or ethanol, are emerging as a viable alternative to fuels from fossil sources as an energy source in IC generators. The requirements for their use are virtually identical to fossil fuels but they are effectively carbon emission neutral and renewable. Another similar source is biomass. Biomass energy is

Table 1.1 Major planning/design advantages and disadvantages of using IC engine generators

Advantages	Disadvantages
Availability	Non-renewable fuel that requires (usually hazardous) replenishment procedures
Popularly known installation and maintenance procedures	Require isolation and/or insulation for noise and vibrations
Relatively small size	Level of pollution produced (noxious exhaust fumes contain CO ₂ , nitrates, particulates, etc.) is high locally
Constant source of reliable power	Uneconomical at intermittent power demand below 0.5 kW
Flexibility in terms of installation location	Biofuels are destructive to the natural environment as their sources are large monoculture crop fields/plantations (land use competition)
	Biomass requires a fairly large organic waste base

a general term for energy sourced from organic materials. It can be used directly (by combustion) or can be converted into a biofuel. Biofuel is a more efficient and convenient form to store and use. The process of converting biomass into biofuel uses either biological (by fermentation) or thermochemical (by pyrolysis, gasification and trans-esterification) processes.

1.3.1.2 Solar generators

Solar energy can be used in power generation systems of two types. Generators of the first type convert light into electricity using solar photovoltaic arrays. Most common systems are currently available with power outputs ranging from a few watts to the megawatt level. Single solar modules are available in a variety of power ratings up to 200W. In generators of the second type, solar energy is concentrated using mirrors or lenses to produce high temperatures. The heat is then used to generate steam, which in turn is used to drive either a generator or alternator to produce the electricity. Solar systems, which currently are being installed, have efficiencies around 30% – similar to petrol-driven generators. Major advantages and disadvantages of using solar generators as power source are listed in Table 1.2.

1.3.1.3 Wind energy

Wind power involves utilising the kinetic energy of the wind and converting it into mechanical energy, which is then used to generate electricity. Several turbine types are available on the market. Typically, a turbine needs to be raised high above the ground to capture more wind energy. Wind availability and speeds increase with height and, as the power increase is proportional to the wind speed increase cubed, significant gains can be achieved with increases in height. Horizontal axis systems usually also have the generator raised. Vertical axis systems can have the generator either at ground level or raised. Horizontal axis turbines are efficient at lower wind speeds and are self-starting but they need to be oriented to the wind, which adds complexity to the system (Table 1.3).

1.3.1.4 Hydraulic generators

The use of water as an energy source is a well-established technology. There are three major methods to generate energy using water. The most popular of these technologies converts the potential and kinetic energies of water flowing down a gradient to power a turbine. Other technologies utilise wave and tidal

Table 1.2 Major planning/design advantages and disadvantages of using solar PV generators

Advantages	Disadvantages
No pollution associated with operation	Only work at full efficiency for part of the day, and at reduced efficiency at other times – mismatched with resort demands
No fuel supply required	Require significant energy storage capacity
Require little ongoing maintenance	May require back-up power source
Require low skill level to operate/repair	Fairly large area required (1 m ² per 200 W at the best commercially available technologies)
Easily installed	Susceptible to mechanical damage – particularly crystalline arrays that have a glass cover
Can be integrated into the roof design	Require full exposure to sunlight – efficiency is dramatically decreased even when fractionally shaded
Provides extra shading for the roof	
Robust and resilient – no moving parts	
Long life (10+years guarantee)	

Table 1.3 Major planning/design advantages and disadvantages of using wind generators

Advantages	Disadvantages
Little pollution associated with operation	Only work at full efficiency at certain wind speeds and at reduced efficiency at other times – not always matching resort operations
No fuel supply required	Require significant energy storage capacity
Require little ongoing maintenance	May require back-up power source
Require low skill level to operate/repair	Significant visual impacts
Easily installed	Significant sound pollution
	Significant source of ultrasounds, having potential health impacts
	Susceptible to mechanical damage
	Can pose a serious threat to wildlife, i.e. birds and bats

Table 1.4 Major planning/design advantages and disadvantages of using hydroelectric generators

Advantages	Disadvantages
Little pollution associated with operation	Great affect both to downstream and upstream river environments (scouring of river beds, loss of riverbanks and erosion of sand bars disturbing aquatic life, silting, etc.)
No fuel supply required	Might produce methane (green house gas) as the newly flooded area is being inundated with water and decaying organic matter in an anaerobic environment – having local impact on wildlife and resort operations
Require little ongoing maintenance	Site-specific and quite restrictive technologies requiring high head (altitude differential) or fast flowing permanent stream
Require low skill level to operate/repair	Subject to seasonal shortages often mismatched with resort operations
Continuous supply – no need for power storage	
The dam can be multi-usage. Provides excellent space for leisure facilities such as water sports; can be used for irrigation and flood control	
Long life span	

powers of the ocean as energy sources and are, usually, beyond reach of small-scale customers.

Hydroelectric schemes usually require a dam to provide a substantial drop and to maintain adequate flow rates. One litre of water per second falling about 100 metres can generate about one kilowatt. Small-scale hydro systems with outputs as small as 200 W can be installed to provide electricity for a small resort. These systems need only constant water supply and a drop of as little as one metre. In-stream turbines, typically installed floating on pontoons, have even less of an impact. Some advantages and disadvantages of using hydroelectric schemes are shown in [Table 1.4](#).

1.3.1.5 Geothermal energy

Geothermal energy is extracted from the earth in the form of heat. Practically it is not a limitless source (as was plainly demonstrated in Rotorua, New Zealand, where the source was easily depleted); technically it is renewable and sustainable when used responsibly. Temperature increases with depth: well depths of a few kilometres are required for viable systems and are thus impractical for small customers. Geothermal energy can also be used in conjunction with heat pumps. Pipes buried only a few metres underground can heat a liquid medium passing through them to a practically constant temperature. The heat is carried to the building where temperature can be further raised in a heat exchanger. Coupling heat pumps to the ground heat produces a very reliable and cheap source of thermal energy. It is not suitable for conversion into electricity but, since supply of hot water places a large demand on the power system in a resort, the overall demand for electricity can be substantially reduced.

1.3.1.6 Energy storage

A problem closely related to energy generation is that of energy storage. Here too, there are a large variety of solutions, some intrusive and environmentally damaging, others more neutral. A number of energy storage options are available depending on what form of energy is being used to generate heat and/or electricity.

Batteries are the most generally useful and the most readily available form of energy storage. They are also a form of storage that does not require an alternate generation system to convert the stored energy back to electricity. They can also be used to store energy irrespective of the energy source being used. The use of kinetic energy storage in the form of fly-wheels is somewhat problematic when used on a large scale. The use of water as a potential energy store is a practical system and has been shown to be effective in large-scale systems where water is pumped to a higher level using excess power and then used in a hydro system when the primary power source is not available. The use of compressed liquefied gas as an energy storage system to drive a turbine is also a practical system. The conversion of water to hydrogen by electrolysis is a generally useful system, but other chemical storage systems like the conversion of ammonia to hydrogen and nitrogen, and methane to longer chain hydrocarbons, are only useful when the high temperatures generated by concentrating solar energy are the energy source. Major advantages and disadvantages of these systems are listed in [Table 1.5](#).

Many of the energy storage systems described here require a conversion system to change the stored energy back into electricity. The required conversion is usually different to the original energy capture system. This re-conversion requirement adds

Table 1.5 Major planning/design advantages and disadvantages of energy storage systems

Storage system	Advantages	Disadvantages
Batteries	Easily available Available in a wide range of capacities Relatively efficient Can be used with all major energy sources	Weight and size of the system Pollution on disposal Short life span
Kinetic energy storage	Inexpensive operation Maintenance-free	Expensive to install Apparently unproven technology at useful scales
Potential energy (water)	Expected long operational life Pollution-free Fairly closed system Pollution-free Potential for multiple uses	Large storage area required Requires significant height difference Potential environmental impacts caused by the changed water table level and its interrupted flow
Potential energy (compressed/liquefied gas)	Can use air so an open system is possible	Danger from high pressures requires isolation Requirement for large quantity storage Relatively high maintenance requirements
Chemical energy (hydrogen from water)	Established process Non-polluting	Relatively inefficient Requires storage of explosive gas May require large amount of storage
Chemical energy (methane and ammonia)	Can be a closed process	Both are pollutants Requires specialised processing Relatively high maintenance Only useful where high temperatures are available

complexity and cost to the system. Most of them also represent technologies that are not environmentally neutral. The environmental impact of batteries' disposal is thus also of significant concern.

Power generators for remote areas are a very small segment of the market. As a result, they are expensive in initial outlay requirements, expensive to run when fuel transportation is involved, and require highly skilled labour to provide maintenance. Small scale of operation (output is usually under 100 kW) results in using machinery that is less efficient and less durable.

The utilised energy systems certainly belong to the most visible aspects of running any establishment aiming at the eco-friendly status. Energy costs are also the largest part of operational costs in most resorts that are remotely located, which the majority of eco-resorts are. This high cost, tied to high demand for energy, is often due to the use of energy-intensive technologies to provide home comforts and conveniences, such as air-conditioning, to resort guests. Passive design, typical of eco-resorts, with its limited use of energy, can only decrease dependency on total energy input. The biggest opportunities to save energy usually occur during the design, construction, refurbishment and replacement stages. The decisions taken at these stages can lock in long-term energy

efficiency or inefficiency and influence the environmental impact of energy use for many years.

The internal combustion (IC) petrol and diesel engines are the cheapest ones from the required capital point of view. They are also the most expensive in terms of running costs and the most problematic from environmental impact standpoints in all aspects of their exploitation. Wind and water turbines, photovoltaic cells and solar hot water heaters, although neutral in operation and less invasive to the environment they are operated in, often have high embodied energy and, even more often, represent high capital cost and/or require expert and costly maintenance. The economics of these devices indicate that power generators utilising renewable resources quickly become competitive and their payback periods have substantially shortened over the recent years.

To maximise the effectiveness of power generation, it is important to assess energy end-uses carefully. Some power needs are constant, for example refrigeration, and require reliable supply while others, for example pumping water to storage tanks, are time-independent and can be supplied from less predictable or intermittent sources such as wind or sun. Variation of demand and variability of load are important considerations as generators are generally more efficient at full load. That makes a number of

smaller generators a better option than one large generator even if the larger one is more efficient, but only while running at its full capacity.

In assessing the cost of alternatives the following should be taken into consideration:

- cost of purchasing and replacing, which has to include cost of the loan or interest lost had the money been invested elsewhere;
- cost of fuel, if the generator requires any, including cost of transporting the fuel to the site. The amount of fuel required for the expected life of operation (or for the expected amortisation period) should be calculated and, together with delivery charges, added to the cost of purchase;
- cost of maintenance and repairs;
- risk of possible environmental pollution assessed against possible power failure of less reliable but safer option;
- noise and vibrations;
- visual pollution;
- risk of failure to the facility and its operation.

For example, low voltage DC operated systems are usually preferable over systems using 120/240 V AC wiring: they are safer, equally efficient, and can be run directly (without still largely inefficient and quite expensive inverters) from the renewable power system. In particular, low wattage compact fluorescent fixtures, while more expensive to buy than conventional incandescent lamps, last longer, consume less energy and usually prove much cheaper in the long run. For electricity generation in a self-contained development, a combination of PV and wind generator can often offer the best solution because it diversifies the (renewable) sources. Water heating is a large user of energy and a solar water heater is a simple and economically competitive solution. [Figure 1.17](#) summarises some of the characteristics of the existing and emerging technologies.

Sound generated in the resort can come from many sources. Most power generators, including wind turbines, can develop substantial noise levels; vehicles and most vessels (except for sailing boats) used in and around the resort produce sounds peaking, which is most irritating, at the potent low-frequency end of the spectrum. Transportation of supplies should use carefully plotted routes and vehicles/vessels should use electric rather than internal combustion engines. Where the latter seem unavoidable, they should be placed in soundproofed enclosures.

The selection of energy supply and storage systems will have implications also from the designer/planner point of view. For instance it translates into a need for separation of the source from parts of the

resort occupied by guests. This kind of action is required in the cases of vibrations, ultrasound generation or unwanted sounds and smells. Some systems, however, demand total integration with the building; prominent examples of this are solar water heaters or PV panels. In some instances safety zones need to be established around fuel stores and/or electricity generation equipment and, sometimes, even separate buildings to house generators must be provided. Planning and design should include supply and maintenance roads and buffer zones. Environmental impacts of the selected system should be carefully considered, as the condition of the environment is the very basis on which operation of an eco-resort depends.

The architectural expression is only the last of the four steps in the process of building a climate-responsive tropical resort. It must be preceded by the study of the variables in climate, biology and technology. Different energy efficiencies of tourist facilities, which are the main economic effect to be accomplished in this process, can be achieved through reduction of demand, use of energy efficient appliances and use of renewable sources. A comprehensive effort in all the three areas is the only solution acceptable to the majority users in the eco-tourism market segment. While higher efficiencies and lesser impacts are achievable through retrofitting of existing structures, a real reduction of demand, put on the energy system in use, requires changes (over a 'conventional' resort) introduced at the planning and design stages of development and includes adjustment to the selected power supply system.

The eco-resort is a mark of human presence in an otherwise largely undisturbed environment. Among many other impacts, the resort is a source of light, sound, air, water and soil pollution related to its operation. All of these will increase with the scale of operations, including power generation and supply. Hence, first of all, the design and plan of the resort should help to reduce the demand for energy. With the selection of energy source the most important factor for deliberation is the local context, which should determine the type and size of the system. This consideration must be in step with the resort's plan and design to ensure that the least amount of energy is being wasted either in transmission, or conversion, or as operational losses.

Selection of the source of energy required in resort operations should not be based on its capital cost alone. It must be preceded by consideration of many different factors that are likely to manifest their importance at any stage of the eco-resort's entire life cycle. They range from difficulties in maintaining

	Typical application scale	Contraption size	Purchase cost	Maintenance frequency	Comparative maintenance cost	Maintenance impacts	Reliability	Continuous power availability	Energy storage requirements	Fuel cost locally	Source renewable locally	Acoustic impact	Ultrasound	Vibrations	Visual impact	Air, water and/or soil pollution	Breakdown environmental risks	Impact on resort plan/design	Overall suitability for eco-resort
Remote powered electricity grid	⊕	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■	⊕	■	⊕	■
Nuclear fission micro-system	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	⊕	■	■	⊕
Nuclear fusion micro-system	■	■	■	■	⊕	■	■	■	⊕	■	⊕	⊕	⊕	⊕	■	⊕	■	■	⊕
Solar-electric (photovoltaics)	⊕	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■	■
Solar engine	⊕	⊕	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■	■
Solar water heater	⊕	⊕	⊕	⊕	⊕	■	■	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■	■
Wind-electric system	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■	■
Wind-water-pumping system	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■	■
Micro-hydroelectric system	⊕	■	⊕	⊕	■	■	■	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■
Open fire (Franklin) stove	⊕	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕
Open fire water heater	⊕	⊕	⊕	■	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕
Heat reclaimer	⊕	⊕	⊕	⊕	■	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■	■
Heat pump	⊕	⊕	⊕	⊕	■	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■
Methane digester	■	⊕	■	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
Steam-raising plant	■	■	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
Biomass gasification plant	⊕	■	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
Diesel IC engine	⊕	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■
Spark ignition IC engine	⊕	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■
Gas turbine	⊕	⊕	⊕	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■
Steam engine	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■
Stirling engine	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■
Thermo-electric converter	⊕	⊕	■	⊕	⊕	■	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	■

■ Large/high ⊕ Medium/average ⊕ Small/low

Figure 1.17 Various energy sources, their costs and environmental impacts.

energy delivery and its reliability, through risks involved in operating the generator and running its supplies, to any anticipated environmental impacts. The selection must also be coordinated with the planning and design process. It should inform and be informed by decisions regarding siting, building materials, roof forms and their orientation, and even by the direction of prevailing winds, to avoid noise, light, vibration or smell affecting more sensitive areas at the resort or around it. Separating the source from resort plan and design will inevitably lead to inefficiencies in energy management resulting in increased demand and expanding, otherwise avoidable, impacts on the surroundings.

It must be noted that many of the so-called 'alternative' sources can successfully compete with 'traditionally' used IC generators both on price and operational costs. It appears that interest in alternative energy has already grown into a whole industry.

Alternative energy sources are increasingly attractive to the public. Depletion of natural resources and subsequent energy price increases, combined with the economy of scale, can soon result in a significant improvement of economic indicators for those solutions, which already are quite competitive. Economic feasibility lays down a solid foundation on which arguments for implementation of such solutions can be based. What is even more important is that economic benefits of alternative systems do not have to be achieved at the expense of the environment, which is particularly important for eco-resorts.

1.3.2 Water management

Key recommendations in brief:

- Carefully select services that require water: opt for waterless solutions when available;

- Retain on the site as much water as you can;
- Find resort uses for water you harvested, including grey water;
- Only water for direct consumption should be subject to purification and treatment.

In many areas of the world, demand for water exceeds supply and is seriously straining available water resources. Some of the most water-stressed areas in the world, such as the Pacific islands, became very popular tourism destinations. Impact is quite perceivable as guest demand for water usually exceeds that of local residents. In addition to the water required for each resort room and general activities such as kitchens and laundry, features such as swimming pools and water-hungry landscaping can add significantly to total usage. Excessive water use can degrade or destroy local water resources, threatening the availability of water for local and/or future needs.

Problems may be made worse in areas where high tourist season corresponds with periods of low rainfall, which usually is the case in the tropics. Decreasing overall water use can lead to cost savings, especially during periods of drought, use restrictions or increasingly strict government regulations on water use. Reducing water use can conserve and protect local water resources upon which a resort and the local community depend. Preserving the quality of local water resources can eliminate the need for costly drinking water treatment processes. Water conservation can enhance resort reputation among its guests concerned about water consumption levels and protecting local resources.

Resorts can produce significant quantities of wastewater, both grey water, which mainly comes from washing machines, sinks, showers, baths and roof run-off, and black water, which comes from kitchen dishwashing and toilets. In a number of destinations, little or none of this waste is treated, and pollutants such as faecal coliform bacteria and chemicals are discharged directly into the environment. Poor sewage treatment can lead to pollution of ground- and surface water, and degradation of marine resources, such as coral reefs. In the most severe cases, beaches have to be closed to the public because of high levels of chemical and organic pollution. At the same time, practically no wastewater is reused and very little of it is recycled. Avoiding the discharge of untreated wastewater or sewage can protect tourism resources by conserving marine habitats and reducing coastal pollution.

Water is an essential part of comfortable living and, for both practical and supply reasons, it is not reasonable to rely completely on natural fresh water

resources. This must be recognised and measures have to be taken to reduce water demand increasing beyond its natural replacement rate. The scale and impacts of certain water conservation and reuse strategies vary, but even on a small scale of a single resort we can look at different methods of saving water whilst also being cost-effective. For instance, advantage can be taken of rainwater, which is often abundant but wasted in many tropical climates.

There are several steps in a good working water-management solution:

- capturing water from freshwater and other sources
- storing water
- reducing water consumption
- redistributing water, and
- preventing wastage.

They all have their planning and design implications. They also involve educating water users, staff and guests, and making them a part of the solution.

There are two main sources of water other than wells (not always sustainable) or freshwater streams (usually not safe): rainwater and grey water. Resorts extending over large areas can utilise the expanse of their land for rainwater catchment. Such areas must be protected (shaded) against rapid evaporation but building a dam is not required and the decision whether to build it or not will ultimately depend on the geological structure of the area. Much easier is using resort roofs. Instead of allowing all water landing on the unit roof to run into storm water drains, it should be captured, stored and prepared for future use. Designing the roofs and angling them properly can result in a maximum intake of rainwater. Naturally, this water would be stored in tanks and used in units they are attached to. For other buildings, tank systems provided could act as reserves for guest units or for other needs of the resort. The distribution of this water would be fairly simple if room for the tank was provided under the building or right next to it. Harvesting the grey water requires installation of separate grey water systems. It is an additional expense but payback periods are typically quite short.

The reusable water from the kitchen, laundry and bathroom is referred to as 'grey water'. Due to the recently reported worldwide shortages of groundwater, grey water has become a more explored avenue in water usage. There are definitely many benefits of reusing this water. They include:

- lower fresh water use
- less strain on septic tank or sewage treatment plant
- highly effective purification

Source	Available volume	Grey water quality
Shower	■■■■■	★★★★★★
Tub	■■■	★★★★★★
Washing machine	■■■	★★★★
Reverse-osmosis purifier (wastewater)	■■	★★★★★★
Wash basin	■	★★★★
Automatic dishwasher	■	★
Water softener backwash (softened water)	■	★
Kitchen sink*	■■	(★★★★)
Toilet* (water)	■■	(★★★★★)

*Technically, a source of black water, although usable grey water can be obtained under certain conditions

Figure 1.18 Main sources of grey water.

- less energy and chemical use
- groundwater recharge
- plant growth
- reclamation of nutrients
- increased awareness of and sensitivity to natural cycles
- sites not suitable for septic systems, and
- economics.

The main source of grey water is anything that is not connected to the toilet (there are systems that make reclamation of toilet water possible). Main sources of recyclable grey water are shown in Figure 1.18.

Issues involved with water conservation strategies in the tropics and in an eco-tourism setting are largely based on decreasing the amount of water used in an eco-resort. This water can easily be saved (stored water can last much longer) and also used in other parts of the property, such as for watering plants. As water in a remote tropical area can become very valuable, simple methods can be used to minimise wastage. The easiest way of minimising the volume of wastewater being discharged is by reducing water usage in general. All technologies that reduce water use through recycling – instead of discharging it immediately – should also be investigated.

To reduce water consumption, we have to look at the main areas where water is used. The bathroom and laundry are the main points of use, whilst the kitchen and landscaping also require water. Simple water-saving methods can be used, so that reserves in the tanking system are used before resorting to the external supply. Efficient shower and tap heads are an effective way to start. Low-flow fixtures in showers can reduce the flow of water by 50 per cent without affecting the comfort level of the user. Not only does this reduce water consumption but also less water must be heated and thus less energy input is

required. Alternatives to the common toilet can also be used. Low-flush toilets or even composting toilets are an effective way to reduce water consumption. The latter requires provision of ample space under the building directly underneath the bathroom to accommodate bulky toilet units.

As for linen washing, this can be done either in an efficient washing machine or outsourced to subcontractors operating in conditions that are more suitable. Landscaping is another big-spender when it comes to water usage. Savings can be achieved by planting drought-resistant native plants rather than imported species and by using drip (if any) irrigation systems. Many plants and associated bacteria can be employed to purify water, rather than use chemicals, either in closed or open systems, such as reed beds.

So, which of these can be applied to the tropical environment? Certainly grey water can be used to serve the surrounding landscape rather than using drinking water. It also adds to the total volume of water generated from within this semi-sustainable environment. The technology, energy needed or difficulty of filtration required to purify the water into something that is potable, however, could make the entire process costing close to the amount needed to receive water from external sources. These sometimes complicated and expensive measures should be reserved only for amounts destined for direct human consumption.

1.3.3 Waste and pollution management

Key recommendations in brief:

- Try to limit waste to what you are able to process on site by adjustments to your resource lines;

- Select materials, construction and demolition technologies to limit amount of waste, emissions, pollution and site contamination at all stages of development and operations;
- Be mindful of waste and pollution caused by construction and maintenance materials' extraction and manufacturing processes in places where they come from;
- Contain pollution at its source rather than deal with its broader effects.

Waste is a material which has, or is believed to have, no further use. While much effort is now directed at using materials more efficiently and at recovering materials from what were previously regarded as waste streams, the waste minimisation and materials recovery industry will still take some time before it matches the scale and sophistication of the energy minimisation industry.

Resorts produce large quantities of waste – solid and liquid – from packaging to food scraps to cleaning and maintenance materials, some of which is toxic. In many cases, this waste is collected in badly designed waste dumps, discarded directly into oceans or rivers, or simply dumped in areas out of sight of guests. In addition to visually degrading a destination, improper waste disposal can lead to water and soil pollution through leaching of contaminants from waste piles. Poorly designed waste dumps can result in fires, odours, flies and ineffective containment of wastes. Uncontrolled disposal of toxic items such as paint cans and batteries can severely contaminate water, air and soil resources, threatening the environment and human health. Even where waste is disposed of legally, landfills have limited capacity, which is a particular problem on small islands.

There are many dangers related to waste and pollution generated in the daily operations of a resort. Excessive or improper use, storage and disposal of various wastes can result in contamination of local environmental resources. Use of pesticides, fertilizers and herbicides for gardening and to control insects can lead to toxic run-off into streams, coastal waters and groundwater. Chemicals used for cleaning guest rooms or in recreational facilities such as swimming pools can contaminate local soil and water supplies, and may pose a potential hazard to human health.

Combustion of conventional fuels is the most significant single cause of environmental pollution. Energy use in resort buildings – for air-conditioning, water heating, artificial lighting and a range of appliances – has the largest share of fuel consumption and resulting environmental pollution. As every kWh of electricity used produces 1 kg of CO₂ emission at the

power plant, eliminating the need for air-conditioning, e.g. in just 50 guest units, would be equal to the reduction of the annual CO₂ emission by around 500 tonnes.

An effective waste management programme can reduce waste removal problems and costs. Reuse and recycling of products can also cut operational costs. Effective waste management can enhance a resort's image by limiting visual degradation of the area. The visible effects of waste disposal are the most likely concern mentioned by guests regarding their holiday destinations. Waste can also decrease the quality of tourism resources by affecting marine life or even making the water unsuitable for recreational activities.

Waste deposited around the resort, as well as water and airborne pollution, would ultimately cause irreparable damage to the ecosystems while at the same time diminishing the value of the resource that attracted the resort's guests. The resort's design should therefore provide for safe disposal of waste generated at various phases of its operation. This includes solid and liquid waste coming as:

- construction waste, such as excavation material, building materials and equipment/transportation-related waste;
- waste resulting from the chosen power generation method (e.g. water used for cooling of diesel generators, accidental fuel spills, stored or transported fuel and oil discharges);
- waste related to the chosen transportation mode (e.g. oil and fuel spillage into water or on the ground, and fumes from combustion engines);
- organic waste and wastewater generated in food preparation and dishwashing processes;
- wastewater from the laundry;
- wastewater from bathrooms and toilets;
- other room or consumer waste;
- discarded packaging;
- excess rainwater collected from roofs and paved surfaces (and storm water run-off) around the resort.

Some of the liquid waste (so called 'grey water') and some solid waste (food scraps and other organic matter) can be treated on site. All other waste has to be disposed of by taking it away to approved places where disposal of such waste is relatively safe. The waste management plan developed for the resort should ensure that there is no adverse environmental or amenity effect on the resort site and its surroundings or in the discharge area. It must be remembered that both liquid and solid wastes are capable of contaminating surface and groundwater resources. Therefore, waste disposal and even its processing

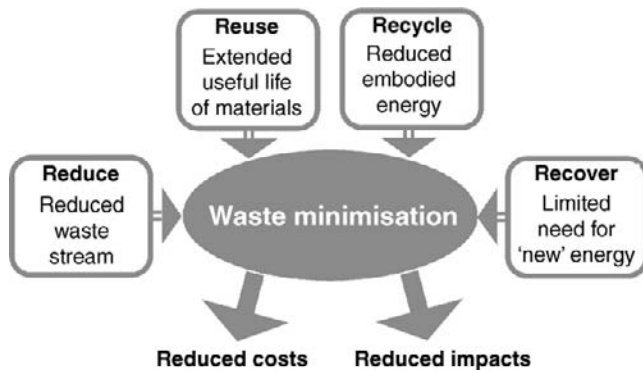


Figure 1.19 Benefits of a waste minimisation programme.

must be carried out in a considerate and responsible manner.

In very much the same way as with energy issues, the principal problem is not how to dispose of waste effectively and efficiently, but how to minimise the amount of waste to be disposed of. Recycling and reusing are among the methods best understood by operators and guests alike and, provided that adequate facilities are available, can lead to significant reductions in waste (Figure 1.19).

1.3.3.1 Reduce–Reuse–Recycle–Replace of waste and pollution management

Waste and pollution management should begin by reviewing the types and quantities of waste produced, and current disposal methods and costs at all stages of the resort's life: from construction, through operation, to demolition. The developed management programme should revolve around the three R's: Reduce, Reuse and Recycle. Only then, the fourth R (Replace) can be added.

Reduce (waste prevention) – means consuming and throwing away less; for example, purchasing durable and long-lasting goods, purchasing products and packaging which are free of toxins, and redesigning products that can be used again after the original use.

Reuse – by repairing items which still can be used; donating the items to staff and local community rather than dumping them; finding new (alternative) uses for the products that have been already used – whenever possible.

Recycle – turn the waste materials into a valuable resource by becoming new products, new materials and fodder for livestock or fertilisers supporting growth in plants.

Waste and pollution are generated at all stages of construction, operation and, eventually, demolition of a resort. At all these stages, effective management

requires that the four-step strategy (Reduce–Reuse–Recycle–Replace) be implemented. Planning and design decisions, which should demonstrate this commitment, are aiming at matching the need with a carefully considered accurate response.

Reducing both energy and materials consumption can be achieved by increasing efficiency (doing more with less) or by doing less. In some circumstances, doing less will be an important part of the experience being sought by clients. Reuse and recycling of materials are well-accepted and useful waste minimisation strategies, which often bring financial benefits.

Waste and pollution management starts at the planning and design stages by reducing the size of a building: optimum use of interior space through careful design will ensure that the overall building size, and resources used in constructing and operating it, are kept to a minimum. Considerate selection of the construction technology will minimise construction-site waste and protect trees and topsoil during works on site. This can be done by, for instance, limiting site works to the assembling of prefabricated elements. Otherwise, all cutting operations to reduce waste and simplify sorting can be centralised, and bins for different types of usable waste set up. Building material use should be optimised: waste is minimised by avoiding structural over-design (using sizes larger than required in given conditions and circumstances) and designing for standard sizes. Careful planning also helps to protect vegetation from unnecessary damage during construction and avoid major changes to the geomorphology of the site. The following strategies can be suggested:

- Designing for future reuse makes the structure last longer as well as adaptable to other uses, and materials and components reusable or recyclable. Because manufacturing is very energy-intensive, a product that lasts longer or requires less maintenance usually saves energy. Durable products also contribute less to our solid waste problems. Incorporate waste recycling into the design.
- Use salvaged building materials and products made from recycled materials when possible and choose building materials with low embodied energy, locally produced if available. Building products made from recycled materials reduce solid waste problems, cut energy consumption in manufacturing and save on natural resource use. A few examples of materials with recycled content are steel, cellulose insulation, reconstituted timber in various forms and recycled plastic. Transportation is costly in both energy use and

pollution generation. Look for locally produced materials (local softwoods or hardwoods, for example) to replace products imported to your area.

- Use detailing that will prevent soil contact and rot. Where possible, use alternatives such as reconstituted timber, engineered timber products and recycled plastic. Take measures to protect workers when cutting and handling pressure-treated wood and never burn scraps because of the toxins contained in them. Look into less toxic termite treatments and keep exposed parts of walls free from obstructions to discourage vermin and insects. Avoid timber products produced from old-growth timber when acceptable alternatives exist. Laminated timbers can be substituted for old-growth solid wood. Minimise use of pressure-treated and old-growth timber, and avoid use of pesticides and other chemicals that may leach into the groundwater, as well as materials that will generate noxious, usually airborne, pollutants.
- Follow recommended practices to minimise potential health hazards. Plan electrical wiring and placement of electrical equipment to minimise electromagnetic field exposure. Design insect-resistant detailing that will require minimal use of pesticides.
- Biodegradable waste is an easier problem to solve. Composting solutions are most appropriate for the eco-resort, bringing additional benefits to the surrounding landscape. Sewage-treatment solids, material retained on sewage-treatment screens, settled solids and biomass sludge can be composted or processed on site. Composting organic wastes such as food scraps, leaves and tree cuttings is a great way to prevent waste. Compost or other organic material can be then used instead of chemical fertilisers. However, composting as well as earthworm farms, leach fields (artificial wetlands) and all other similar technologies requires considering them at planning stages. The space must be set aside and, possibly, cordoned off for sanitary reasons. On the other hand, it is often possible to use fish, geckos, iguanas or other animals to control insects, in place of dangerous pesticides and other chemicals, which does not involve any extra expense. Also, when making landscaping decisions, native plants that require less water, pesticides, fertilisers and herbicides should be chosen over imported species.
- Design room for waste bins in key areas, particularly by the beach and along nature trails. When using services of a disposal contractor, plan for a safe sanitary holding place until waste is picked up.

- For inert waste the processes are quite different. There is potential to reuse some of the construction and demolition waste created by these events. Dirt and cleared trees can be relocated for use in other projects at the resort or elsewhere (some possible uses include flood levies, berms protecting against storm surge waves and roads). In demolition, if done properly, the dismantling of the structure can lead to its reuse in other buildings.

All of the above help to prevent waste build-up on site or in landfill. Recyclable materials do not benefit the immediate environment in the resort, but if initiatives like recycling are implemented it would help to promote the resort's 'green' image.

1.3.4 Impact of building materials and construction technology

Key recommendations in brief:

- Select materials in small modular sizes that do not require heavy machinery to handle;
- Select technologies, either vernacular or prefabricated, with low water requirements;
- Select reusable and recyclable materials with low energy content;
- Select materials that are durable and require minimum maintenance.

Materials used in tropical eco-resort buildings have potentially a number of direct and indirect impacts on the environment, both indoors and outdoors. The direct impacts are the ones where materials interact with the environment, for instance by off-gassing or supporting vermin. The indirect impacts manifest themselves through a variety of actions required for the use of particular materials in applicable construction technologies or in their maintenance. Issues that must be considered are:

- available sizes, required components, required finishes, preventing corrosion, etc.;
- prefabrication versus on-site construction (traditional and modern methods);
- waste and pollution (water, air, noise) associated with some technologies;
- health impacts.

Considerations regarding building materials and technologies should include assessment of the following:

- impacts of construction methods on landscape and wildlife;

- source and origin of construction materials;
- available construction technologies appropriate for the selected building materials;
- impacts of resort on visual landscape;
- amount of water required by the selected technology and water conservation methods;
- impacts of construction noise on wildlife;
- amount and type of fuels and chemicals required in construction;
- emissions from equipment;
- drainage techniques used for discharge of construction wastewater;
- use of energy-saving renewable energy equipment and techniques;
- use of transport for various tasks specific to and associated with the given material.

The resort designer should aim at reduction of quantities of materials required before any of the considerations listed above would be contemplated. Then, one may expect that the selected materials will not adversely affect human health, will contribute to operating energy efficiency, will require minimal manufacturing and processing as well as have low embodied energy. They should be durable, require little or no additional finishes and minimal maintenance, and preferably be obtained from renewable resources and harvested in a sustainable manner. Materials that are locally manufactured or reusable, which have been salvaged from demolished structures or have recycled content, and recyclable, should be regarded as better for the environment – in a very broad sense of the word. Possible environmental effects also require that non-recyclable materials can be disposed of safely.

1.3.4.1 Design context

Selection of construction materials is a process that occurs within a larger design context. The design process deals with a broader range and scale of issues, and often offers greater opportunities for reducing environmental impacts than are offered at the level of material selection. Basic schematic design decisions related to building size and form can have major impacts on issues such as energy performance. Deciding which way to orientate a building, and how much glazing will be used, may have a greater effect, over the life of the building, than a decision to use a particular type of insulation material. In applying the recommendations listed above, the particular circumstances of the project in question should be considered. Overall, building impacts will be a function not just of the environmental profile of individual materials, but also of the amount of the material in

question. Efforts should be directed towards changes and materials substitutions that will achieve the greatest net improvement.

Equally important as the selection of materials is how those materials are used. It is possible to use the green materials inappropriately and achieve no significant environmental benefit. Over the life of a building, it is likely that savings in operating energy and maintenance will more than compensate for negative impacts associated with the extraction and manufacture of the high embodied energy material.

1.3.4.2 Health effects of building materials

Avoiding negative impacts on the health, safety, and comfort of building users should always be the primary concern in selecting building materials. The majority of them are inert and have few health concerns or are used in locations where they are encapsulated with little direct exposure to building occupants. The principal categories of materials that can potentially affect building users are interior finishes, joinery and furniture. It is important to also consider emissions from, for instance, cleaning agents and other supplies used in maintenance and repairs of resort buildings. The health effects associated with various chemicals can be obtained from a number of web-based resources, including the US Environmental Protection Agency's Office of Pollution Prevention and Toxics.

It is important to evaluate both the quality and overall quantity of materials to be used, and how the use of one material over another can influence indoor air quality. Attention should be directed to the materials with the greatest surface area as well as the materials with the largest concentration of volatile compounds. Material installed in the building in wet form will generally evaporate its excess moisture in the short-term – over several hours or a few days. Dry product emissions are usually much more prolonged, occurring over a period of many months or even years. Certain surfaces can also act as sinks and absorb some of these emissions to be subsequently released over time.

1.3.4.3 Operating energy

The energy consumed to provide heating, cooling, lighting, etc. in buildings is referred to as 'operating energy'. At present, operating energy is by far the most significant component of total building energy. Because of the relatively poor thermal performance standards of most buildings, operating energy offers

the greatest potential for achieving reductions in overall energy use. Lifecycle operating energy over a 50-year service life is likely to be more than double the initial embodied energy. Operating energy efficiency is a function of the thermal performance of the building envelope and of the performance characteristics of the heating, cooling and lighting systems. The selection of those systems and of materials, such as insulation, air barriers, and glazing assemblies, is therefore a key component in improving performance and reducing operating energy use. Because of the importance of operating energy, identification of materials and products that contribute to energy efficiency should be one of the primary selection criteria.

Where particular materials or products will significantly improve energy performance, the environmental benefits of reduced energy consumption will, most probably, compensate for the negative impacts associated with the material in question. This is not to suggest that other criteria are of lesser importance. Ideally, materials should both contribute to operating efficiency and also satisfy other green material selection criteria.

1.3.4.4 Embodied energy

In addition to operational energy, a considerable amount of energy in industrial activities is devoted to processing materials and manufacturing products for the construction of buildings. Energy used in these processes, the energy spent on transporting building materials, and energy required during construction, is referred to as the 'embodied energy'. Although operating efficiency is currently the key energy issue in buildings, embodied energy is still important, particularly as materials are replaced and renewed over the full service life of the building. In addition, as operating energy efficiency improves over time, embodied energy will come to represent a more significant portion of total building energy. In highly energy-efficient buildings, embodied energy may ultimately offer greater opportunities for reducing overall energy use.

Embodied energy is the total energy requirement of all activities necessary to produce a material, product, or service, from raw material extraction to delivery of the product to the consumer. The term 'embodied energy' does not imply that the energy is physically present in the material – rather that the energy has been consumed in the various processes involved in its complete life cycle. This 'invisible' energy content can be found in every separate activity or stage of the life cycle in its two forms: as direct and

indirect energy input. The latter can be related to the tools and equipment used in production, transportation, construction or maintenance; other materials used in a given manufacturing process, for example solvents; energy required in assembling building parts on site, for example welding or trimming; and many other elements.

Calculating the embodied energy of building materials is a complex and time-consuming process. Arriving at precise energy intensity figures is difficult. Energy intensity will vary, not only from material to material, but also within particular material categories. Differences in manufacturing plant efficiency, distance to markets, and ease of extraction of raw materials, can result in regional differences in the embodied energy of the same material. For example, steel with a large recycled component made in energy-efficient mini-mills requires less than half of the energy required to produce steel from iron ores in conventional plants. Energy intensity – the energy required to produce a unit quantity of material – is dependent on the level of processing and manufacturing required to produce the finished material. Natural materials such as wood and stone require minimal processing and energy inputs when compared with more highly processed materials such as petrochemical products.

In addition to comparing the embodied energy of alternative materials, it is also important to assess the end use of each material and the quantities of the material used in typical applications. For example, manufacturing aluminium is an energy-intensive process when compared with producing concrete. This may suggest that from an environmental perspective concrete is somehow a better material. However the two materials are not equivalent in terms of their use and the volumes used in a typical building will vary significantly. Embodied energy impacts, like other environmental impacts, should be assessed in the context of the use of the material or product in question.

1.3.4.5 Durability

Selecting durable materials is a key strategy in attempting to reduce overall impacts associated with buildings. If construction materials quickly become obsolete, or require such high levels of maintenance that replacement is the only viable option, environmental impacts are multiplied. Even if the material in question is a relatively small component of the initial building, repeated replacement can quickly multiply the overall impacts.

Several studies have been carried out to determine the lifespan of a typical building and its

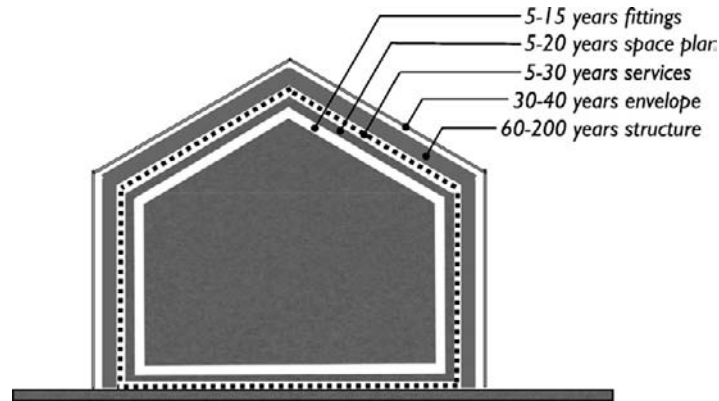


Figure 1.20 Lifespan of various building elements.

components to establish their embodied energy. Because of the way materials and various building parts are combined to create construction assemblies, replacement of one material or component often requires that other materials are also removed and replaced. Insulation, for example, is often damaged when roof membranes are replaced. Durability is also an important criterion in the case of materials that have little or no environmental merit. There are categories of materials, for example roofing membranes, where there are no viable green alternatives and architects must choose between products with few environmental merits. Specifying long-life materials may extend the replacement date to a time in the future when green alternatives will be available.

How long should a sustainable building last? The recommended design service life for resort buildings is between 50 and 100 years. The longer periods are preferable as they reduce embodied energy content per unit of time by spreading it over a larger number of years. When such an approach is not feasible, at least building components should be reused or recycled (Figure 1.20).

1.3.4.6 Reduce–Reuse–Recycle–Replace of building materials and technology selection

Building materials are another area where the 4Rs strategy is particularly applicable. As with the other areas, such as waste management or operational energy, the best way of minimising the impacts from the materials and applicable construction methods required by certain material choices is by reducing the amounts being used. Smaller buildings generally require less timber, steel, glass, stone or concrete. Although the relationship between environmental

impacts and building size is not directly linear, in principle a smaller building will have fewer impacts than a larger one.

The idea of reducing environmental impacts by limiting the size of buildings may at first seem to be fundamentally opposed to some principles of standard architectural practice. As a norm, fees are tied directly to construction costs, which are in turn often determined on a cost per area basis. However, work on smaller buildings does not necessarily mean less work or reduced fees for architects. Designing smaller buildings and spaces offers an opportunity to spend more time on design and, if construction budgets are maintained, allows better quality and more durable materials and assemblies to be used. Savings for the client will come through durability, low maintenance and low energy costs.

Another way of demand reduction is by careful selection leading to exclusion of certain choices. In the detailed analysis required to decide on material A over material B, a third option is often overlooked. Can the material be omitted entirely? Particularly in the case of finishing materials, it is worth considering whether the selected finish is necessary at all. Can the floor/wall/ceiling material be exposed or finished in another way? For example, the design of roof assemblies, where insulation is located on the outside of sheathing rather than in the framing space, offers an opportunity to leave the roof structure exposed and omit interior plaster board. In general, reduction of building material quantities leads to reduced impacts at all stages of the material life cycle by diminished consumption of raw material resources, reducing the environmental impacts from product manufacturing and by limiting the quantities ultimately entering the waste stream.

‘Reuse’ refers to the application of previously used building materials such as those removed from

an existing building and incorporated into new construction in essentially their original form. Heavy timbers are commonly removed from buildings before demolition, recut and refinished, and sold as salvaged material for use in new construction. The concept of reuse can also be applied to entire buildings. Where a decision is made to renovate an existing building as an alternative to demolition and new construction, the existing building is essentially being reused. Although some material may be removed and new material added, the majority of the structure is usually retained. One of the case studies presented in Part Four is an example of such an approach. When materials or buildings are reused, the environmental impacts associated with the extraction and manufacture of new materials are avoided. In addition, material that would otherwise become waste is diverted from landfill disposal.

In addition to using salvaged components of the building fabric, architects should consider designing building assemblies to facilitate future reuse of such materials. Building elements should be installed in a manner that allows for their future removal with little or no damage. Bolted connections are preferable to welding structural steel, mechanical fasteners can be used rather than adhesives, and homogeneous materials rather than the composite ones.

'Recycled' typically refers to a building material that is manufactured using recycled content. For example, during the manufacturing process of steel it is common to substitute recycled scrap steel for virgin material coming directly from iron ore. Many construction materials include recycled content. The US Environmental Protection Agency has established guidelines for recommended recycled content for a number of construction materials. A distinction should be made between post-industrial and post-consumer recycled content. It is common in many manufacturing processes to recycle off-cuts and other scrap material. This type of recycling is known as post-industrial recycling and is part of normal efficient manufacturing practices. Greater environmental benefits are achieved, however, through post-consumer recycling, when unwanted items are taken back, after they have ended their useful life, and turned into new materials.

Another consideration in recycling could include efforts to ensure that the substance is recycled into a comparable new product. On one hand, when steel is recycled, scrap steel is used to make new material with essentially the same characteristics as the original one. This form of recycling can occur many times – without changing the original material's quality. Recycling can also result in the production of

resources that differ from the original ones. Although this kind of resource recovery can only occur once, such recycled contents represent a lower level of new material use and, in some cases, this can provide justification for the use of products that would otherwise have little tangible environmental benefit.

It is worth noting that, although it is technically feasible to recycle many materials, not all of those that can be recycled undergo any reprocessing procedure. It depends on a number of factors, including ease of separation from the waste stream as well as the existence and location of a recycling facility and, most importantly, the economics of collection and transportation. Reprocessing is most feasible where materials are manufactured locally and where transportation costs are low, or where the materials are sufficiently valuable to make transportation over longer distance a viable option.

1.3.5 Impacts from tourist presence in the area

Key recommendations in brief:

- Concentrate and channel tourist movements through the site;
- Create physical barriers to prevent uncontrollable penetration of the area;
- Develop zones corresponding with environmental responses to various types and extent of impacts;
- Contain impacts at their source with visual, acoustic and other pollution buffers.

Tourism developments can have significant environmental impacts, including the socio-economic ones, on the surrounding inland and coastal areas. The previous sections of this book have addressed some of the actions that designers and developers can take to minimise and/or prevent negative effects from those impacts. Beyond simply reducing the local impacts, resorts can also seek opportunities that benefit biodiversity and nature conservation by improving the state of the environment at a regional or national level. Such actions can be particularly important in countries where capacity and resources for environmental conservation are limited. Conservation of the environment locally can help to preserve tourism resources in a broader perspective.

In many places, and in the tropics probably more so than elsewhere, the natural environment is the principal basis of a holiday. Correct course of action can minimise the risks of future environmental

problems and contribute to the destination's quality. This, in turn, can enhance reputation among guests and others who are concerned about global and local biodiversity loss and environmental damage. Supporting conservation efforts can generate positive publicity and earn reputation, as well as positively influence relationships with local people and organisations. Winning environmental awards for successful conservation programmes can become a powerful marketing tool. Promoting responsible ways to enjoy the environmental resources in a destination also improves the guest experience.

The concept of sustainable development involves recognition of the strong interdependence of social, economic and ecological issues. It applies to eco-resorts in particular because in these developments the environmental damage can gradually undermine the capacity of the land to support the developer's chosen activities, resulting in reduced overall economic benefit. It seems that tourist operators in increasing numbers are becoming aware of the broad context in which their establishments exist and of factors influencing the demand for their services. The following are among environmental issues which should be important to operators running eco-tourism establishments:

- conservation and protection of the natural environment on local and regional levels;
- preservation of the cultural heritage of the region;
- conservation of buildings representing traditional architectural styles and aesthetic qualities;
- control over building and construction in the area;
- avoiding overcrowding of the development area and its immediate neighbourhood.

Appraisal of the impact a resort is likely to make on its biophysical environment is possible through a number of procedures known collectively as Environmental Impact Assessment (EIA). The EIA is a process to predict the consequences of decisions and to prescribe strategies and/or measures minimising their adverse effects or to maximise their benefits. The process follows four stages of environmental prediction:

1. Identifying potential impacts the development of the resort could have on the natural, social and economic environments.
2. Describing resources and receptors which are vulnerable to adverse changes.
3. Examining the chain of events or 'paths' linking cause with effect in each case of the identified impact.

4. Predicting the probable nature, extent and magnitude of the anticipated changes or effects.

Next, criteria-based measures of significance or importance need to be attached to impact predictions. Criteria used in such determination usually include:

- extent and magnitude of the impacts;
- short-term and long-term effects;
- reversibility (or irreversibility);
- performance versus environmental quality standards;
- sensitivity of the site; and
- compatibility with the locally adopted environmental policies.

Environmental trade-offs in planning projects can be assessed using various procedures. Probably the most popular is a multiple-criteria decision-making method used in a form of impact assessment matrix. Some form of quantitative information is needed to make an objective assessment of building proposals. The information entered into the matrix should be objective and rational on at least the most important environmental consequences of proposed solutions. For many aspects, however, qualitative information is the best that can be obtained. This important shortcoming of EIA practices, identified since it was first introduced in the USA (National Environmental Policy Act 1969), has not been overcome yet. Moreover, the EIA process seems to exclude consideration of options based on withholding – it evaluates intended actions and not the intended restraints. The EIA continues to be treated as an evaluative tool and its ability to generate solutions is limited. The latter remark would apply, probably, to most EIA policies around the world (Figure 1.21).

The overall assumption underpinning ideas presented in this publication is that the eco-resort designers and developers should follow the Precautionary Principle in their actions and inactions: in this fragile environment it is much better to leave things as they are than to introduce a change of unknown or difficult to predict consequences. It is important to realise that building in the wilderness will almost never be 'environment-neutral'. Tourists can impact on the environment in many ways: directly and indirectly. They interact, knowingly and unknowingly, with the environment by their sound and smell, by introducing light, tramping vegetation underfoot, leaving rubbish behind, polluting and contaminating, spreading alien bacteria and fungi, removing plants and animals, etc. They also introduce permanent, or at least long-lasting, changes to

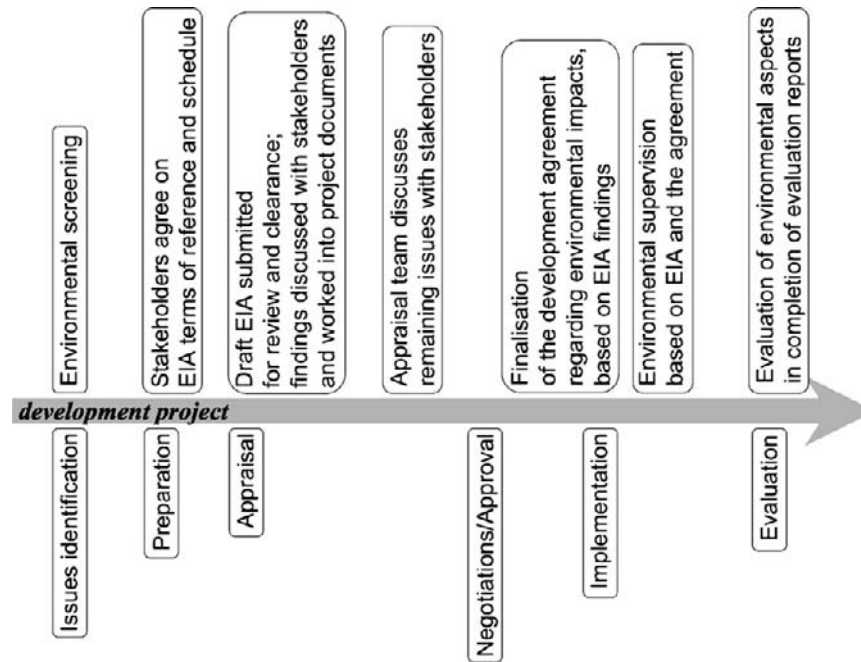


Figure 1.21 The EIA process and corresponding development project stages.

the environment by using its resources, compacting the soil, interfering with migration routes, disturbing water balance, or introducing pests and supporting vermin.

The role and main concern of designers and developers should be to find the solution that, considering the resort and context for its construction and future operation, is the best that can be devised. A number of specific measures can be suggested to limit visitor impacts on the environment and constrain their effects. Among many others, using areas of dense vegetation or primary forest should be avoided to prevent unnecessary interaction that could disturb the existing ecosystems. Instead, wild-life viewing could be provided from points that are

not too invasive or disturbing. In landscaping, endemic plant species should be used whenever possible as they will cope with the local conditions better and require less maintenance and/or resources while making less impact on local ecosystems. Resort management should provide support to biodiversity management and, when possible, set aside land as a private reserve or conservation area. Furthermore, when considering available measures, a number of benefits can be associated with the use of passive techniques if introduced to replace conventional HVAC systems. These benefits have multiple environmental implications at global, site and individual (even indoor) building scales manifested at every stage of the resort's life cycle.

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1.4

Eco-tourism rating schemes

International organisations and the tourism industry have introduced a number of initiatives to regulate claims regarding environmental performance of eco-tourist establishments. Preliminary research carried out in several countries revealed widespread concern among industry stakeholders regarding the plethora of tourism bodies, the wide range of assessment and accreditation systems, and the casual use of 'eco-terminology' for marketing purposes. In addition, while there are broad design guidelines for tourist infrastructure, there has been little work done to relate them directly to environmental and economic performance indicators. The Collaborative Research Centre in Australia undertook the work of customising a GBC ('Green Building Challenge 2000') building assessment tool to fit the needs of the tourism industry. Without an appropriate tool, it is difficult to link design guidelines and industry standards, and to arrive at performance benchmarks for environmental strategies.

The GBC tool uses measurable parameters such as resource (water, raw materials, and energy) usage and efficiency, reduction of waste, and the uptake of improved environmental practices. The list of the main areas and some indicative parameters includes:

- resource consumption (net energy, net land uses, etc.);
- loadings (emission of greenhouse gases, VOCs, etc.);
- indoor air quality (moisture control, daylighting, thermal comfort, etc.);
- quality of service (flexibility and adaptability, control of systems, etc.);
- economics (capital cost, life cycle cost, etc.);
- pre-operational management (eco-efficiency in construction, design process control, etc.).

A similar tool, targeting specifically tourist operators, is the Nature and Eco-tourism Accreditation Program or 'NEAP', currently in its second edition (known as 'NEAP II'), used in Australia.

Work on suitable standards started in the early 1990s. Following the Rio Earth Summit in 1992, it was stated that the tourism industry needed to consider seriously its relationship with the environment and establish a long-term framework for sustainable development. The World Travel and Tourism Council (WTTC), the World Tourism Organization (WTO),

and the Earth Council – the organisations representing respective interests of business, government and non-governmental organisations (NGO) in tourism and the environment – subsequently established 'Agenda 21 for Travel and Tourism' and the 'Green Globe' programme. The 'Agenda 21' action plan set out a systematic framework to make the tourist industry more environmentally responsible and accountable. It urged governments to work with local authorities and the private sector wherever possible to develop environmental programmes for management decisions regarding the industry and tourist destinations. Cooperation among all interested parties was to be the key to developing successful management systems. In addition, many international funding agencies have established programmes to encourage tourism which favour the protection of the environment.

'Green Globe' was conceived as a membership-based programme where individual companies joined and implemented sustainable tourism practices based on 'Agenda 21' principles. Around 500 companies (airlines, hotel chains, tour operators, travel agents) joined in and it quickly gained a considerable profile within the industry, heightening awareness of environmental and sustainability principles. At the same time, the Pacific Asia Travel Association (PATA) established a similar programme called 'Green Leaf', with around 1000 of its members signing an environmental performance pledge. However, by the end of the 1990s both programmes had started gradually disintegrating amidst criticisms that some 'Green Globe' and 'Green Leaf' members were not delivering on their pledges. This highlighted a fundamental weakness in both programmes: there were no means of validation through certified adherence to their principles.

In 1999, the 'Green Globe' initiative was redefined, re-established and incorporated as the only worldwide independent certification programme for sustainable tourism and travel. It was soon merged with 'Green Leaf' and soon the Scandinavian 'Green Key' and the US-based 'Green Seal' followed suit. A couple of years later Green Globe also established a non-exclusive international partnership with the SGS (Société Générale de Surveillance) Group, the world's largest auditing and certification company, to carry out audits of Travel and Tourism (TT) companies and

destinations. Since then, national and international research has advanced a number of instruments for eco-efficiency through development of assessment tools and eco-efficiency agreement protocols. The GBC tool mentioned earlier, originating in Canada and now used worldwide, after the necessary adjustments has the potential to provide the universally accepted basis for assessing tourism and hospitality industry infrastructure.

March 2000 witnessed the birth of iiSBE (International Initiative for Sustainable Built Environment), the first international organisation dedicated to the issue of environmental assessment in the building sector. iiSBE is an initiative to respond to the need of a sustainable built environment from the perspective of environmental assessment. It intends to bring together scientists and practitioners active in the field, and to provide an open international platform for exchange of information, experiences and ideas. This is achieved by providing a platform for dissemination of knowledge stemming from the recent research findings, demonstrating practical solutions and improving cooperation between individuals and working groups active in the field of theory, design

and implementation of environmental assessment and rating. The scope of activities of iiSBE extends to the environmental assessment of buildings, built environment, and land use planning strategies.

Another welcome initiative was the attempt to move the assessment of eco-efficiency into the design phase of the development project. Rather than to measure the performance and/or impacts of buildings when complete or after retrofitting, the buildings are assessed at the point when the major strategic decisions regarding costs and environmental impact are made. The economic potential of this approach has been demonstrated through its effectiveness. Lifecycle analysis, necessary to fully evaluate and validate this method, requires that post-construction evaluation is carried out as well.

All the above initiatives achieved the elevating of worldwide environmental standards in tourism. They also gained a lot of publicity for the environmentally-friendly approach to tourist development and operations. Public interest in these issues caused eco-labels to become marketing tools bringing about a significant change in travellers' environmental sentiments.

Part Two

Indoor Environment Control in the Tropics

Typically, building design quality is assessed in terms of its compliance with respective building codes and standards. The problem appears to be that the codes and standards poorly serve our daily needs in this respect. Their role is to ensure that buildings meet the essential structural and service requirements so that these systems' breakdowns are prevented. This is absolutely necessary and quite understandable since these requirements ensure a building's integrity and the health and safety of its occupants. On the other hand, and from the viewpoint of the everyday user, it seems more appropriate to take a less catastrophist and more down-to-earth approach.

A building's design can and perhaps should be assessed in terms of its day-to-day environmental performance (which, in this instance, translates to thermal, visual, acoustic, olfactory and tactile) and achieved compliance with environmental comfort indices. The environmental performance of a building can and, in the case of eco-resorts, should be expressed as levels of the environmental comfort being achieved while unassisted by an HVAC system. This approach requires detailed knowledge of a local climate and its possible impact on comfort indoors. Hence, the design process starts with analysis of climatic data. Detailed knowledge of the climate is an essential input, which forms the basis of other analyses of the building's year-round performance.

Nevertheless, one must be aware that a regional climate's profile only indirectly relates to comfort in buildings. As discussed earlier in Part One, the mesoclimate of a particular area can differ considerably from the regional macroclimate due to site topography, continent-sea interface influences and vegetation characteristics, for example the forestation ratio. Hence, most often, a general climate description is inadequate or insufficient for building design purposes. Moreover, a great deal of effort, technical skills and good judgement, gained from experience, are normally required to bridge the gap between the raw climatic data and appreciation of its effects on the internal environment of a particular building design, as observed earlier. As also stated previously, the aim of the climate-conscious architecture is to provide protection from negative climatic factors

and to take advantage of the positive ones in order to meet the comfort requirements of building occupants and secure an economical level of energy consumption. Macroclimate data from the nearest airport or harbour, which usually are the only climate data available, can only serve as a very rough guide to the local conditions.

Local experience is invaluable in this instance. Ideally, it should be considered together with available information on the climate to fully appreciate positive and negative climatic influences. These can be assessed and utilised to modify the microclimate of the site around the building. Changes introduced by a design at this level can provide significant benefits, as opposed to attempts at macroclimate and mesoclimate levels, which are generally beyond the designers influence. This approach, in addition to improving the amenity and extending the utility of outdoor spaces, can help to minimise or even avoid what are often more complex and expensive measures in the design of the building itself.

Even if temperature and humidity are the most important environmental factors in comfort/discomfort perception, they are by no means the only ones having a perceivable impact. Air movement belongs in there as part of the thermal environment but there are also visual, acoustic (noise), olfactory (smell) and tactile (touch) experiences which, together with mental attitudes, build up a total impression tourists have of their tropical surroundings. These outdoor conditions are intrinsically linked with the perception of comfort indoors and can be further related to tourist behaviour.

The following sections focus on the specificity of users and their requirements connected to comfort in the tropics. Firstly, it has to be determined what properties of the tropical environment actually influence its perception, and what are the perceived constraints imposed by a particular environmental setting. Then, specific climate conditions relevant to the operation of tourist facilities located in the coastal tropics have to be looked at in some detail. Finally, we will pause briefly to consider some psychological factors and their role in influencing eco-tourist perceptions of the climate.

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2.0

A question of comfort

As eco-tourism develops and reaches out to tropical areas, it encounters conditions previously thought of as 'out of comfort limits'. For some time now, with the use of dedicated building systems, we have been able to provide indoor comfort even under the harshest tropical conditions. Nevertheless, air-conditioning cannot be considered an appropriate option for eco-resorts. Furthermore, comfort in the tropics can be achieved also with passive design, which appears to be a viable alternative. Passive means are quite capable of providing comfort levels acceptable to the majority of users of tropical eco-tourist resorts. Indoor climate modification with passive rather than power-supported design also means that comfort is provided in a way that goes hand in hand with the principles of this eco-friendly form of tourism. These issues are presented in more detail in Part Three.

When do we feel comfortable? What kind of environment do we consider to have this desirable quality? 'Comfort' is difficult to define. Hence, it is normally given a negative description as 'a lack of discomfort' or 'a state at which any change would cause discomfort'. Increasing sophistication in environmental engineering has given rise to the notion that it is possible to have an ideal environment, which would provide a condition of 'perfect comfort': a condition where all sources of discomfort are absent. However, there is growing evidence that strict control of comfort parameters does not necessarily contribute to our well-being. Human comfort escapes simplistic or sharp-edged definition. Too many facts indicate a very subjective and contextual nature of this phenomenon. It could be argued that problems of this highly individual nature of comfort/discomfort can be overcome with social survey methods, such as comfort-vote techniques or hybrid methods, which include similar sampling techniques, for instance the Predicted Mean Vote (PMV) or Predicted Percentage Dissatisfied (PPD). Nevertheless, both the various comfort definitions and the values proposed as the representation of this concept cannot be accepted without reservations.

For the following discussion, a new term has to be introduced. A set of favourable conditions will be referred to as environmental comfort. The basic literature of the subject uses for this purpose a concept of thermal comfort, which is only a subset of environ-

mental comfort. Thermal comfort, believed to be a dominant problem in tropical climates, represents acceptable conditions of heat exchange between a human body and its surroundings.

However, a case can be made that for considerations regarding climate-responsive architecture in extreme conditions, it is appropriate to include non-thermal factors, such as lighting and noise levels, as well. One could add smell and touch, which are no less important, and even time – in the form of seasonal and diurnal patterns – as all our senses are stimulated simultaneously. We feel warm or cool at the same time as we hear background noise, see the colour of surfaces, appreciate scents as well as the quality and the quantity of light entering through windows, and are aware of subtle changes in these and other factors while progressing through the day. The need for more inclusive definition is further emphasised once we focus on the environment for leisure. Many environmental conditions that are tolerable at work, domestic chores and other everyday activities can cause serious discomfort during holidays, and the opposite may also be found true.

The variables, having some impact on sensation of comfort, appear in two groups. In the first group, variables are related to the physical environment itself:

- air temperature;
- mean radiant temperature;
- atmospheric humidity;
- relative air velocity;
- light; and
- sound.

There are other contributing climatic factors (precipitation, cloud cover and air purity/turbidity) but they can be merely effects of the variables listed above working in combination with each other.

Variables in the second group represent human factors. They relate to differences between individuals and their behavioural adjustments that may affect perception of the building's indoor environment:

- thermal insulation of clothing;
- activity level (expressed as a corresponding metabolic rate);
- habituation and acclimatisation;
- body constitution (shape, subcutaneous fat);

- age and gender;
- state of health/fitness; and
- food and drink being taken in.

Factors in the latter group are beyond the influence of resort designers and can be used only as justification of certain design decisions. Below we provide a brief treatment of some of the issues involved (Figure 2.1).

Generally, the sex and race of an individual make very little difference to their perception of comfort. Even body build seems to be of little importance when individuals are at rest or engaged in light activity. What sets tourists apart from residents are their mental attitude, clothing and possibly lack of acclimatisation. The only two parameters which are shared by almost all 'inter-climatic' travellers going to the tropical coast are: a) very low levels of thermal insulation of their clothing once they get there, and b) negligible level of acclimatisation throughout a significant portion of their stay.

Thermal insulation of clothing is one of the most important factors in achieving and maintaining the body's thermal balance. Because the adjustment of the amount and disposition of their clothes provides people with a powerful means of behavioural regulation of their body temperature, clothing is the determinant par excellence of an acceptable thermal environment (Figure 2.2).

In the tropics people tend to wear less clothing and typically would be at $0.5\text{Clo} = 0.078 \text{ Wm}^2\text{K/W}$

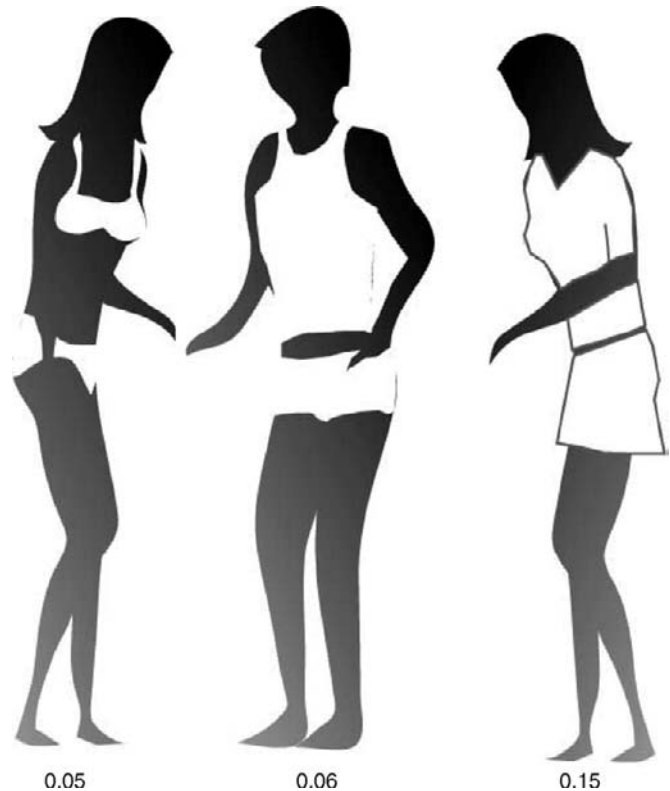


Figure 2.2 Tropical clothing insulation values.

level (light dress or light trousers and short-sleeved shirt) or even $0.3\text{--}0.4\text{Clo}$. Tourists in the tropics, and particularly on the coast, reduce their clothing even further as their behaviour is not normally bound by many formal constraints. Shorts or swimming suits represent a value of only $0.05\text{--}0.1\text{Clo}$. That moves temperatures, which are still comfortable, considerably up the scale for this group. The problem with most thermal comfort research is that it does not take this behavioural adjustment (i.e. lowering the insulation of clothing to such a low level) into account. In the working environment certain standards of clothing apply at all times, while for tourists (often greatly relaxed) standards are observed in only a limited number of situations – perhaps at meal times in dining rooms and in some common areas of higher standard resorts (Figure 2.3).

Another important factor to be considered is the individual's metabolism. Metabolism is the sum of chemical reactions which occur within the body. Amounts of energy required and released in these processes are minimised with the aim of maintaining a constant internal temperature. Generation of metabolic energy depends on the level of activity in which the individual is engaged: playing ball produces four times more heat than office work. High activity levels occur during activities that can be

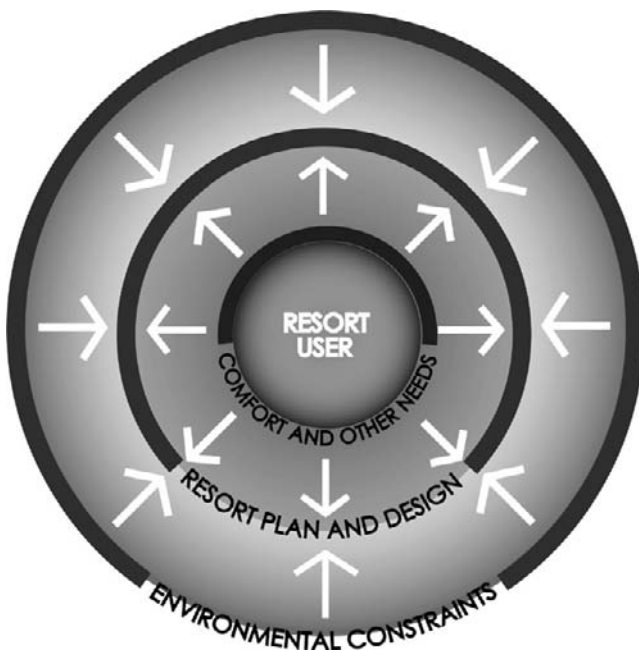


Figure 2.1 Resort design as a compromise between human needs and environmental constraints.

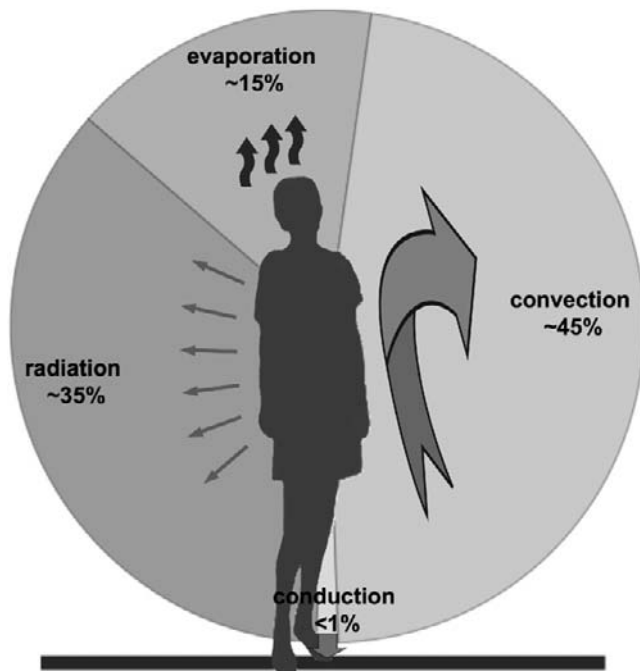


Figure 2.3 Various body cooling mechanisms (tropical values).

undertaken outdoors. Once indoors, activity levels among tourists correspond with those calculated for a person at rest (Figure 2.4).

The assumption that all people will be equally comfortable/uncomfortable under a similar set of environmental conditions should be questioned. In the past, it seemed reasonable to assume that results of laboratory tests can also be applied to people under similar conditions outside the laboratory. It must be noted, however, that the human variables listed above, along with subjective individual attitudes, impact on physiological thermoregulation. Hence, the main mechanisms of heat exchange can only be influenced by climatic parameters such as mean radiant temperature, air temperature, relative humidity and air movement. They will not be determined by environmental conditions in the absolute sense.

Furthermore, various combinations of the environmental and human parameters can achieve identical degrees of comfort. Under certain circumstances, it is possible to change some of the variables in such a way that comfort is increased without affecting the total energy balance in the building. Moreover, an argument can be mounted for taking the environment as an indivisible entity of which various parameters are only parts and factors interplaying with many others. Tourists' perceptions are also influenced, to a large extent, by their different attitudes, which we will discuss below in Section 2.4.

Thermal comfort equations include acclimatisation effects and describe a relationship created by long-term physiological reactions to external conditions (thermal comfort and its indices are presented in a little more detail in Section 2.1). They have proven quite accurate in predicting perceptions of local residents, exposed to given conditions for months at a time. For the local residents, all elements of the climatic setting are blended into an entity slowly revolving in annual cycles. Any changes in their thermal environment are gradual, consistent and slow enough for necessary adjustments. This is not the case when considering tourists. For them, changes are rapid and quite dramatic.

Furthermore, residents commit themselves to their home environment and resist change (for various reasons) even if they might not have accepted the tropics. Tourists, on the other hand, make conscious choices about their holiday destinations. It would be probably true to say that they would not go to the tropics if they felt uncomfortable about the anticipated heat and high humidity. Many go there in search of this 'tropical environment experience'. They do not come to a resort to work. They can come and go as they please. Almost all constraints of regular life are removed during holidays and tourists can actively participate in creating their own environment – in a broad sense of the word. What in most comfort prediction models would constitute a source of

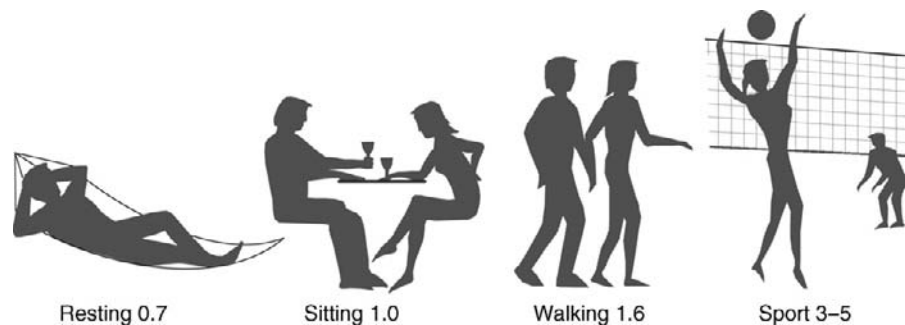


Figure 2.4 Various activities and corresponding metabolic rates.

dissatisfaction could be, in fact, an essential part and a source of pleasure associated with various leisure activities. As it seems, most recreation takes place in 'controlled discomfort' conditions: participants factor uncomfortable conditions in and tolerate them to a point of their choosing when they either temporarily withdraw (for instance, to rest in the shade of the nearest tree) or retire altogether.

People arriving in a tropical resort come from a variety of climates. Partial acclimatisation to local conditions requires approximately five to seven days and that is often about the total length of their stay. Therefore, for this group of people, acclimatisation is non-existent. Somewhat different is the question of their adaptation to local conditions. While acclimatisation is based on physiological mechanisms, adaptation happens in the psychological and behavioural spheres. Tourists, moving around the world, carry with them their specific expectations of the anticipated local conditions. It seems possible that they travel in pursuit of different experiences and quite often are prepared to pay for them with some 'discomfort allowance'. Their expectations and the 'physiological lag' of their climatic zone of origin pull the setting of what constitutes comfortable conditions of their holiday destination in opposite directions. Expectations of tourists, hence their preferences, can be quite unlike those of local residents.

Tourists do not behave in an 'average' way, either. Along with rapidity of change (coming from a cold/very cold zone to the tropics is for them a matter of hours rather than days or weeks) goes a specific behavioural pattern setting them in two different environments: one for the day and another for the night. Daytime activities usually are taken in open-air spaces, with deliberate and willing exposure to otherwise intolerable conditions of high solar irradiation and high temperatures. They retire to the shelter of their lodgings, where they seek conditions they are comfortable with, only for the night-time rest.

This behavioural preference also may be exploited as many traditionally indoor activities in the resort can be moved outdoors. The design may incorporate spatial arrangements for dining and social events, like entertainment and dancing nights, to be staged outside. Open-air siestas during the hottest part of the day could be a reasonable alternative to following the activities pattern typical for that part of a day in moderate climates, or to retiring into air-conditioned rooms. Provision of adequately arranged spaces can encourage taking rest in areas shaded by light (e.g. membrane) roofing. Even night rest can be (optionally) taken in open-to-air or even unroofed spaces after ensuring that a certain level of privacy

and security are provided. To enhance comfort derived from a well-designed indoor environment in a resort, a great deal of attention should be given to reinforcing such behaviour. This could include:

- generating a leisurely and relaxed mood through low-intensity activities;
- inducing lower metabolic rates rather than participating in an intensive sport-like style of holidaying;
- promoting siestas as a means of refraining from more vigorous activities during the hottest part of a day;
- shifting some activities, such as dining, to open-air areas;
- organising group activities early in the morning or late in the afternoon; and
- encouraging exposure to the natural environment.

These are just some of the ways to ensure that tourists feel comfortable at all times. This should be further emphasised by stressing the exotic nature and uniqueness of everything that visitors to the resort are experiencing. They should also be convinced that the detailed attention given to everything in the resort serves to protect a precious environment and the conservation of its scarce resources.

All the environmental variables mentioned above should be seen as parts of an indivisible environment in its entirety. They all contribute to individual perceptions of comfort/discomfort interplaying with each other – particularly in a holiday situation. Comfort depends on a global sensation of warmth and the relationship between the several factors that can affect the heat exchange between the body and the environment. The comfort of tourists in the tropics is more than that. The combined effect of all the influencing factors, namely environmental comfort, should be considered, particularly in reference to the design for itinerant users (Figure 2.5).

There are numerous reasons for the relatively little interest in the knowledge of comfort, and comfort of tourists in particular, in the tropics, as well as in the practical application of this knowledge. One of them is that design guidelines and available information on performance of applicable measures are inadequate and insufficient. Hence, the demand for the systematic knowledge is substituted by 'street-level' beliefs and opinions. The most popular of these are based on misconceptions, prejudice and a lack of true understanding of the tropical environment. There is a mistaken belief that an architecture unsupported by HVAC systems is absolutely unable to cope with 'unbearable' heat and humidity, which are

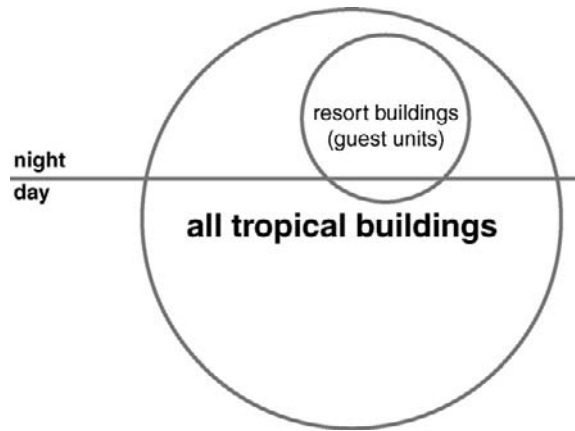


Figure 2.5 Resort unit's use in the context of other tropical buildings.

supposedly the permanent and unsurmountable biometeorological problems of low latitudes.

Moreover, it is believed that bioclimatic design involves unconventional, and in consequence unusual, expensive and unreliable, devices. Because of these 'non-standard' solutions, the design process is assumed to take longer and require more effort, which will be manifested through slow and costly construction. Developers also fear that lack of standard air-conditioning could be reflected in lower marketability. The latter belief is particularly damaging to the cause. It is also baseless as there has been a lot of market research done in the last two decades indicating that environment-friendly facilities attract more customers than those which cannot demonstrate sufficient care for the surrounding environment. Mechanical air-conditioning systems in tropical resorts are winning nevertheless. Most probably because their use requires no thinking – it is all too easy. This makes it very tempting, indeed.

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2.1

Thermal environment control

Key recommendations in brief:

- Utilise passive climate controls wherever possible;
- Design with night-time conditions in focus;
- Avoid unnecessary climate control: find out about the real comfort requirements;
- Consider thermal environment in context of other environmental factors.

Tourism developments in the tropics, as discussed previously, tend to concentrate on the coast. The common elements of the thermal environment, which contribute to the climate of the zone, are high temperatures, high humidity and high solar radiation levels all year round, displaying very small seasonal and diurnal differences. Moreover, winds (very strong at times) and perceivable sea breezes are a major factor. The biggest influence on the environmental comfort in the tropics comes from the perception of thermal comfort – usually understood as a condition where there is no sensation of thermal discomfort from cold, heat, excessive skin wetness or dryness, air stuffiness, or air moving at high speeds.

The tropics are popularly misinterpreted as an ‘unbearably hot and humid for visitors’ type of climate. Generally, this is not the case with the dry tropics where relative humidity is low and large diurnal temperature swings provide nightly relief during the entire year. In the wet tropics, on the other hand, while humidity is very high for most of the year, heat can be a significant problem during only two or three summer months. For example, one computer simulation (Bromberek, 1995) suggested that in Cooktown, the northernmost township in Queensland, Australia, temperature would be too high for 6.2 per cent of the year, if air only moved at speeds of 1.0 m/s or higher, and just 1.9 per cent at air velocities exceeding 1.5 m/s. This is only 4–5 hours a day during the hottest two or three months! Even then, however, tourists tend to stay outdoors and willingly expose themselves to those high ambient temperatures, humidity and solar radiation.

Places, where tourists prefer to be during the day, for instance on the beach or in the rainforest, can display much higher levels of mean radiant temperature or humidity than other places at the time. For this reason and a few others, it can be argued that, with respect to comfort, tourists should be considered a group of building users distinctively different from resi-

dents. Their perceptions of the climate seem to be influenced by their different attitudes. In tourist resorts, this psychological aspect of comfort perception should be emphasised much beyond its role in residential buildings. The survey carried out in Cairns, a short distance south from Cooktown, in the summer of 1994 (Bromberek, 1999) confirmed the author’s belief that a different (psychological) situation of tourists in the tropics made most of them see conditions there as acceptable, and the use of air-conditioners in their accommodation was not required. It follows that offering indoor conditions further improved by the means of passive climate control would make conditions acceptable to an even larger number of guests. Providing indoor conditions that are not much worse than outdoors in a breezy shaded area could be sufficient for the vast majority of them. Some of the preferences of tourists visiting the tropics in this respect have been investigated on their departure from the region.

Let us describe a full set of favourable conditions as the ‘environmental comfort’. The basic literature on the subject (for instance Fanger 1970, Koenigsberger *et al.* 1973 or ASHRAE 1985) uses the concept of thermal comfort for this purpose. Thermal comfort is believed to be a dominant problem in tropical climates. It is, however, only a subset of the environmental comfort. For instance, Forwood (1980:150) indicated that:

[t]he basis for the environmental comfort definition could be derived from the well defined concept of thermal comfort—usually understood as a condition at which there is no sensation of thermal discomfort from cold, heat, excessive skin wetness or dryness, air stuffiness, or air moving at high speeds.

Moreover, according to Macpherson (1980:13):

A thermal environment may be said to be ‘comfortable’ when the physiological strain resulting from the imposed thermal stress either does not impinge on consciousness, or if any sensation of heat or cold is evoked, this sensation is not unpleasant.

Macpherson elaborates further that whether or not any given situation is accepted as thermally

comfortable depends in part on the environment, and in part on judgement by the individual exposed to the environment. Also in ASHRAE's description (1985), human thermal comfort is 'a state of mind, subjectively assessing current physical conditions'. This is a very important statement. It allows for psychological factors, such as expectations and preparedness, to play a very special role in thermal comfort. These factors, generally expressed as attitude, could be the most important for comfort perception among tourists. Their impact on actual comfort/discomfort is little known. The subjectiveness, however, can be linked to physiological and objectively measurable responses of the human body.

The current understanding of thermal comfort follows a concept of 'universal uniformity' of human comfort, present in research on physiology since the nineteenth century. The concept was based on an objectively rational observation that the human body maintains a constant internal temperature of about 37.0°C independently of external conditions. To achieve such thermal balance, the body employs complex thermoregulatory mechanisms. They work well and ensure comfort in quite a broad range of conditions – much broader, in fact, than we tend to assume. For instance, Humphreys' (1978) and Auliciems' (1981) reviews of thermal data from around the world indicated a positive correlation of preferred indoor temperatures and outdoor climatic conditions. They have introduced a concept of thermal neutrality – a temperature at which a subject does not feel either cool or warm. It can, to some extent, represent thermal comfort conditions. Humphreys found a statistically meaningful relationship between the thermal neutrality T_n and mean monthly temperature of ambient air. Data, on which his linear regression was based, were later revised and supplemented by Auliciems, which led to a subsequent revision of Humphreys' equation. A similar result was obtained on the Indian subcontinent by Nicol (1995):

$$T_n = 17.0 + 0.38 T_o \quad (2.1)$$

where T_o represents outdoor monthly mean temperature. The range of application is 10°–30°C. Even the Nicol's equation, which was based on data from predominantly warm climates (the Humphreys' and Auliciems' equations were based on data from most climatic zones around the world, including the sub-polar zone), does not seem appropriate for use in predictions of comfort among tropical tourists. The reason is that their results are derived from

research on residents – they do not account for acclimatisation or other differentiating factors. The equations do not consider activity levels, and assumptions concerning only behavioural adjustments are inadequate. Furthermore, an important role played by psychological factors, such as climatic adaptation based on one's expectations has not been accounted for. Most importantly, the equations require monthly mean temperature as input while the average length of tourist visits to the tropics is no more than a few days. In tourist resorts, this psychological aspect of comfort perception should be emphasised much beyond its role in residential buildings.

The survey mentioned above delivered evidence supporting a view that most of the tourists see conditions in the tropics as acceptable, and the use of air conditioning in their accommodation is not required. It seems that conditions that exclude high levels of solar radiation and offer some air movement are acceptable and, when enhanced with just a few degrees cooler air, they satisfy a substantial part of this group of building users (Figure 2.6).

The thermal neutrality equation describes a relationship created by long-term physiological reactions to external conditions. This is not the case, however, when talking about tourists. Rapidity of climatic change is compounded by changing holiday behaviour patterns, putting them in two different environments: one for the day and one for the night. Daytime is spent mostly outdoors and resort buildings are occupied only during the night. Thus, we propose that for calculation of thermal neutrality different datasets are used. Instead of mean monthly temperatures, an average between monthly mean temperature and average monthly

minimum (night) temperatures can be entered into the equation. This will result in thermal neutralities lower than what they would be if calculated from all-day averages.

The achieved results will also show that – contrary to popular belief – mean daily temperatures in the majority of tropical areas do not require modification for most of the year. Furthermore, the data refer to non-air-conditioned enclosures where there is no significant air movement. Comfort can be improved using a bioclimatic response to air movement. In fact, even without this measure, there seems to be no need for cooling at the lower (i.e. night-time) end of the daily temperature range. Most enclosed spaces within a resort are used almost exclusively at night, and thermal comfort is assured so long as indoor conditions are not substantially different from those outdoors. This runs against traditional wisdom stating that average atmospheric conditions found in the wet (including maritime) tropics are beyond the geographic limits of human ability to achieve thermal comfort by purely passive design features.

Human health and comfort require that the environment displays seasonal and diurnal temperature variations. In air-conditioned buildings, adjustable temperature settings should follow changes in external temperatures. Auliciems (in Ruck 1989) suggests the use of a ‘thermobile’ (as opposed to a ‘thermostat’) and argues that it should be used instead of thermostatic control to reduce over-use of air-conditioning. However, this compromise seems insufficient in the case of remotely located resorts. Engineers’ concerns with machines and processes employing these machines to transform energy, rather than with actual human needs, make the latter a second-rated issue to them. Architects still have the responsibility for the design of indoor environments. The fabric that architects deal with, and the way they can manipulate it, offers plenty of opportunities to modify and control the thermal environment in a building.

During a tour of several tropical locations in the Pacific, a limited study of tourist resorts was undertaken with the aim of establishing the main characteristics of the response to the climate offered by those claiming to be ‘environmentally-friendly’. The study of indoor conditions, as reported in Part Four, delivered collateral findings on the use of, and resort operators’ attitudes towards, air-conditioning. The examined conditions were limited to a period, which was believed to be average for the year.

The study further focussed on night-time temperatures and comparisons with corresponding ther-

mal neutralities and Humidex indices. The night-time temperatures represent the environment as that being actually used by the tourists, and both thermal neutrality and the Humidex index (see below for definitions) accurately describe thermal stress accounting for the approval or otherwise of the conditions experienced. While this approach clearly had its limitations, it complemented the earlier survey mentioned above and further questioned the current position of air-conditioning in tourist resorts. Most units were found performing reasonably well without air-conditioning, which dented the established beliefs and delivered an argument against its use on a year-round basis. Changing this could help alleviate detrimental implications for the environment, economics and even operational aspects of using mechanical devices to provide indoor comfort to visitors.

A readily accessible way of presenting the relationship between thermal comfort parameters or thermal indices is by means of comfort/psychrometric charts. For example, many of the atmospheric indices and their inter-relationships can be shown together in a psychrometric chart (Figure 2.7; compare Auliciems and Szokolay, 1997). Air temperature, represented by dry bulb temperature (DBT), as well as wet bulb temperature (WBT), relative humidity (RH), absolute humidity (AH), dew point temperature (DPT), specific volume or volume of air–water mixture, enthalpy and other indices displayed in the chart can easily explain processes such as cooling, heating, condensation and dehumidification.

Following an earlier attempt by Olgyay at the ‘bioclimatic chart’ (1963; Figure 2.8), the ‘psychrometric chart’ offered by Givoni (1976) makes it possible to determine the effect of changing building-related parameters such as thermal inertia (‘mass effect’) and the ventilation rate on thermal comfort. It shows that, by making certain changes to these parameters, the comfort zone can be ‘expanded’. In effect, the range of outdoor conditions under which indoor comfort can be ensured is expanded by the use of appropriate design strategies. Indeed, they can expand them by a considerable margin even when the external climate conditions are less favourable. This way, it demonstrates that, by applying certain concepts of passive climate control (or climate-responsive architecture), effects of (external) climate changes on the interior environment can be minimised to the extent that they are, for all practical considerations, negligible.

One can look at the problem from a completely different perspective. We can compare tourists changing climatic zone with people staying at home

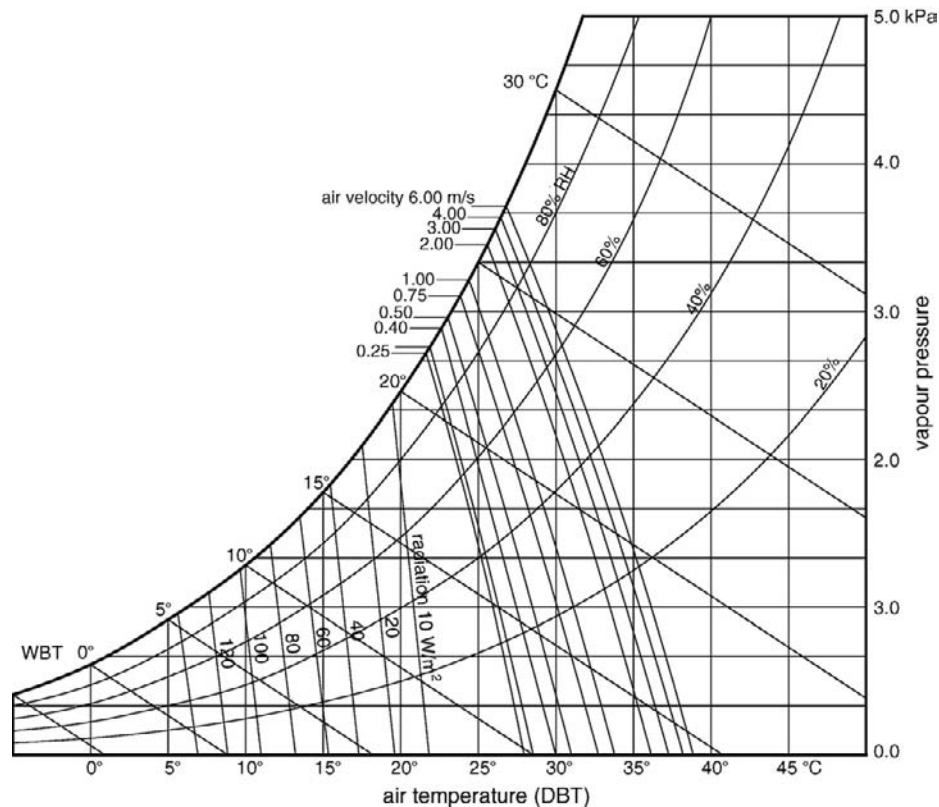


Figure 2.7 Psychrometric chart.

when the weather changes rapidly and the conditions persist for a number of days. An interesting thermal stress indicator, the Humidex was proposed in 1979 by Masterton and Richardson (in Lewis 1993) to combine effects of temperature and humidity during the so-called 'heat waves' in Canada (Table 2.1). A heat wave is defined by Canada's Atmospheric Environment Service as a period of three or more days with a maximum temperature greater than or equal to 29.5°C and a mean temperature of at least 24°C.

After a high correlation has been found between mean dry bulb temperature (DBT) and mean Humidex, the regression equation was suggested to base the indicator on air temperature only:

$$\text{Humidex}_{\text{mean}} = 1.13 \text{ DBT}_{\text{mean}} + 2.91 \quad (2.2)$$

In almost saturated air, a Humidex value of 40 can be reached with DBT as low as 27°C. This is because the indicator is based on data from

Table 2.1 Human response to a range of Humidex values

Range of Humidex values	Degree of comfort/discomfort
20–29	comfortable
30–39	varying degrees of discomfort
40–45	almost everyone uncomfortable
46 or higher	many types of activities must be restricted

Source: Lewis, 1993.

moderate to cool climates. A heat wave is defined by Canada's Atmospheric Environment Service as a period of three or more days with a maximum temperature greater than or equal to 29.5°C and a mean temperature of at least 24°C. There is some merit in applying Humidex or other similar indices to measure thermal stress in tourists. For a visitor to the tropics, local conditions involve a sudden increase in temperature and humidity – exactly the same way as a heat wave at home would. It appears that Humidex gives satisfactory indication of the degree of human discomfort likely to be encountered in given conditions of temperature and humidity increase. This is not to imply that Humidex allows for prediction of heat stress from temperature means alone. Nevertheless, it displays opportunities unlocked by this method. Yet, if the formula were to be used with tourists with any accuracy, it would have to be adjusted to take their psychological standpoint into account. Unlike at home, when going to the tropics tourists expect heat wave conditions and actively seek them. The results of applying the formula to several tropical locations are presented in Part Four and support a popular expectation of some discomfort brought about by brief exposure to tropical conditions (Figure 2.9).

We can recommend that parts of the resort used during the day or at night have their climate controlled in accurate response to the requirements of the moment. This control should utilise chiefly the simplest passive means, such as shading and ventilation. The parts used during the night should, however, employ all passive means available. Furthermore, the real needs should be established to avoid excessive thermal stress rather than aim at long-term comfort. Education of the users, focussed on environmental benefits and the extraordinary exotic experience of the tropics, should become a vital part of the resort's operational strategy.

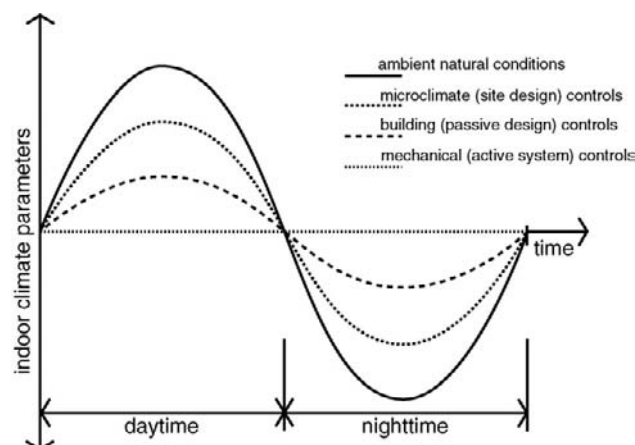


Figure 2.9 Environmental conditions vary to a different degree with different measures used to control them.

2.1.1 Heat flows

Key recommendations in brief:

- Minimise heat gains (through shading and insulation) in parts of the resort used during the day;
- Open up and maximise heat losses in parts of the resort used at night;
- Use room volume and convection to move hot air away from the occupant;
- Utilise available heat sinks such as the night sky, ground or large body of water.

Achievement of a desired cooling effect is possible and relatively simple using a range of well-known passive methods. Generally, there are two types of passive means to control indoor climate. The first are layout elements of the design (both in the horizontal and vertical planes) as in, for instance, inclusion of open-to-air rooms, open-plan design or widespread layout of the resort. The second type is made up of the detail elements of the building or its surroundings: openings, shades, wind deflectors and the like. Most of these passive features manifest themselves in a static or fixed-in-place form. Some of the most important controls, however, are dynamic: movable, adjustable, and generally operable. To achieve effective control with either of these means it would be sufficient to make use of a fundamental principle of passive cooling, which is the coupling of the building with some kind of heat sink. All that is then required is that this heat sink is at a lower temperature than the building itself. Typically, any one of three heat sinks (or their combination) – the ambient air, the night sky or the Earth – can be used. In all instances, arriving at the desired thermal balance

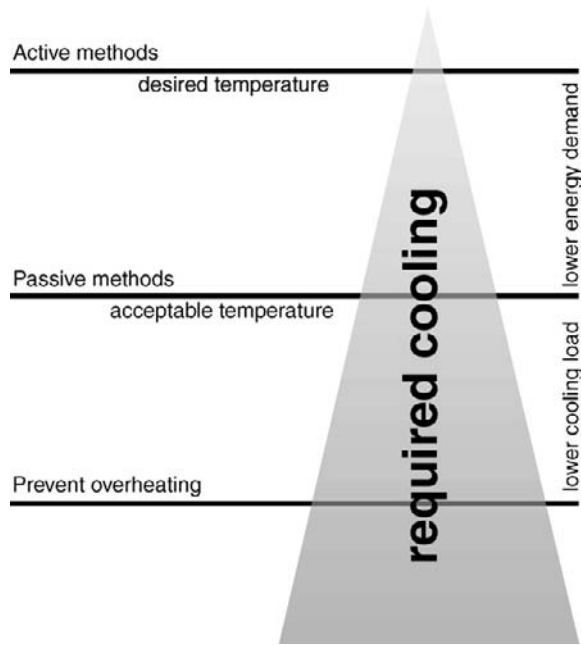


Figure 2.10 Cooling strategies in thermal environment control.

point requires that heat gained, or retained, by the structure is minimal (Figure 2.10).

2.1.1.1 Heat gain minimisation

A key issue in the tropics is reduction of heat gain from the solar irradiation. This can be achieved by appropriate orientation and using existing and/or planted vegetation for shading roofs and walls. Details of these solutions are presented in Part Three. Furthermore, wind incidence upon the building should be taken into account. The tropics are quite different from moderate and cool climates in that winds actually improve microclimate for most of the time. Thus, the air movement should be one of planning and design objectives beginning with a choice of appropriate site – exposed to winds prevailing in a given location – and selective use of vegetation and other landscape elements, such as earth contouring, for wind redirecting and channelling. To some extent landscaping can even induce air movement.

As mentioned above, the fundamental climate control principle that applies to the tropics is to exclude heat gain from external sources, and this should be understood chiefly as solar gain minimisation. Where solar radiation strikes the building envelope (roofs and walls) it will be partially reflected, and partially absorbed and subsequently transmitted into the structure. Utilising its thermal properties can control the amount of radiation transmitted through

the building fabric. However, the most effective way to minimise solar gain is by shading the surfaces, so that direct radiation does not reach them.

The quantity of energy falling on a horizontal surface due to solar radiation, sometimes called the 'energetic exposure', is a function of the irradiance, measured in watts per square metre. The global irradiance G has three components: the direct component (beam irradiance I_b), the reflected component (reflected irradiance I_r) and the diffuse component (diffuse irradiance I_d). The latter two can be considered jointly as the indirect component (indirect irradiance I_i):

$$G = I_b + (I_r + I_d) = I_b + I_i \quad (2.3)$$

The beam irradiance depends on the angle of incidence between the sun's rays and the normal – a line at right angle to the surface. Tilting a surface towards the mean position of the sun during any given period of time increases the irradiance on that surface for that period. For instance, in Cairns, Australia, in October, when the sun is at zenith, total daily irradiation on a horizontal surface is 6952 Wh/m^2 , which is the maximum across the year, but can be further increased in December, when the Earth is in perihelion, to over 7100 Wh/m^2 on a surface slightly inclined to the south at around 6.5° . The opposite also holds true and all surfaces tilted at other angles receive less solar energy. It is important to consider both direction and timing factors jointly to minimise exposure to the sun through the shape, orientation and tilt of the building's irradiated elements (Figure 2.11).

In the tropics, the greatest quantities of solar radiation are received by surfaces close to horizontal, followed by vertical surfaces facing west and east. Greater solar heat gains at west than at east walls can be explained by higher temperatures and usually lower moisture content in the air in the afternoon as compared with mornings. Curved surfaces, such as vaults and domes, in effect appear to 'spread' solar radiation over a larger area of which only a small part is perpendicular to the direction of the radiation. Some would argue that uneven surfaces, such as corrugated sheets or brick walls with alternate courses recessed, have an ability to 'dilute' effects of the solar irradiance. The amount of radiation received remains in fact the same, but the total effect can be diminished through increased dissipation by convection, on top of self-shading and the deflecting characteristics of such surfaces. This is a debatable question as, for instance, such surfaces are able to support heated

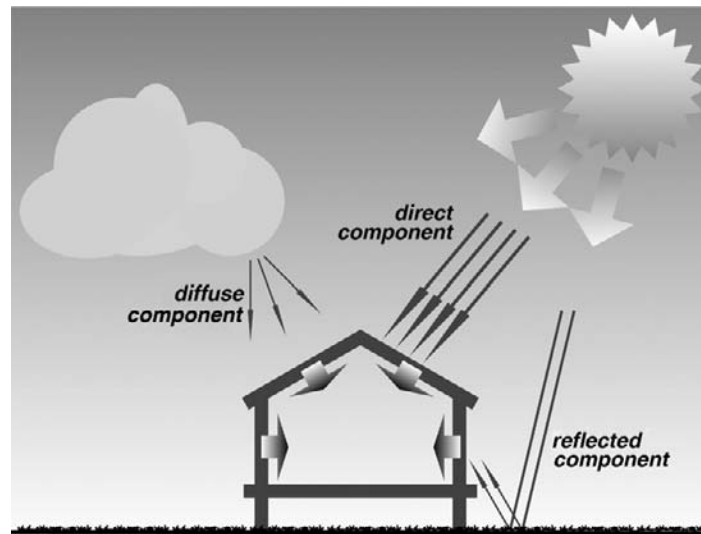


Figure 2.11 Components of solar irradiation.

air filling the recesses, thus contributing to increased heat flows (Figure 2.12).

Indirect irradiance is the sum of irradiance reflected and diffused by clouds, diffused by the atmosphere (water and dust particles) but, foremost, reflected from the ground, neighbouring landscape elements and adjacent buildings. The only way to reduce incidence of indirect radiation is to minimise reflectance of the ground and building surfaces, especially outside windows facing the sun. This can be achieved, for instance, with the help of low growing shrubs planted in front of the building's walls.

Compact building forms are subject to less heating when outdoor temperatures are high than ones that are spread out. This is because compact forms minimise roof and wall areas – limiting solar heat gains by their surfaces. In these terms, cube-like multi-storey buildings of medium height seem to have advantages over the single-storey ones. Presumably, compact buildings are advantageous in hot and dry climates, if they can be sealed for the day and the requirement of sufficient night-time ventilation can be met. In hot and humid climates, however, this strategy is not nearly as effective. It seems that minimising heat gains in the wet tropics should be achieved through appropriate shading and heat dissipation, for instance through ventilation, rather than through minimising the area of a building's perimeter, which also hinders heat dissipation. The roof is usually difficult to shade and instead it should be well insulated.

Any shading devices should be formed and placed so that they do not impede airflow through the building. For instance, vines growing on a trellis

should be avoided as a means of shading verandas and patios if they interfere with airflows – especially in and out of the building. It appears that trees and bushes can be very effective in shading east and west walls. Sunshading of entire east and west walls (as opposed to shading openings only) in the tropics seems to be a necessity. A somewhat more expensive alternative would be a good thermal insulation. At the same time, roof overhangs are the most practical and feasible means of shading north and south walls from direct radiation from the high midday sun. Although they are not very effective at shading east and west walls, at a depth of 1.2 m, in Cooktown (15°28'S) they provide complete shading of south walls 2.4 m high during summer months from around 8:00am to 4:30pm in December and from around 7:20am to 4:40pm in November and January. During the remaining 2–2.5 hours after sunrise and before sunset, the walls are partially shaded or out of the sun (Figure 2.13).

The contribution of solar heat gain by windows of a typical timber framed building is the major heat load, even if the windows constitute on average less than 8 per cent of the total envelope surface area. Openings, which are glazed with ordinary glass, are largely transparent to solar radiation. The solar energy that passes through such openings is absorbed by internal surfaces, which in turn become heat radiators. Because the re-emitted heat is a long-wave radiation, it cannot pass back through the glass – it is 'trapped' indoors. This phenomenon is known as the 'greenhouse effect'. To prevent rising mean radiant temperature (MRT) of the interior through this mechanism, it is necessary to carefully choose the

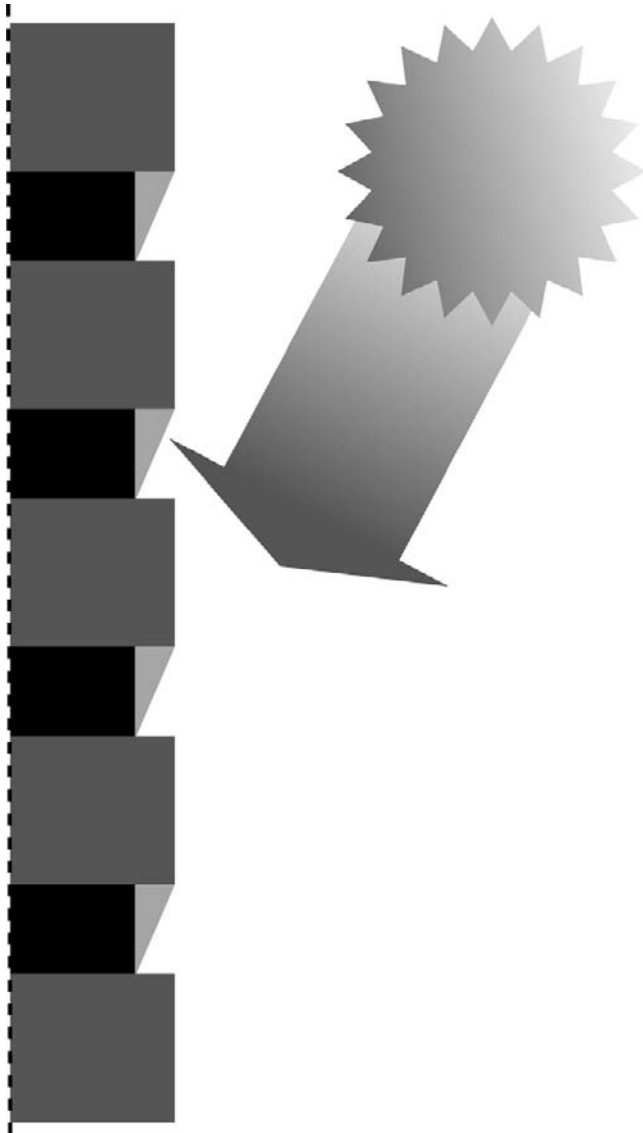


Figure 2.12 Self-shading of the wall.

location of openings and/or shade the openings exposed to sunshine. Generally, it is recommended that there are no openings in western and eastern walls and that plants do not obstruct the free flow of air over the building envelope (including air movement parallel to the wall surfaces). When windows are protected with shading devices, these are best placed on the outside of the glazed openings, so that they can lose heat absorbed from the sun to the ambient air rather than to the interior (Figure 2.14).

The effectiveness of shading is expressed by the shading coefficient: a ratio of the solar energy passing through a shaded opening to the energy that would pass through the opening if it were unprotected. Usually, a simple window (3 mm float glass) is taken as a

reference. Any shading coefficient above 0.2 must be considered too high in the tropics.

In both movable and fixed categories, there are three types of shading devices:

- horizontal, for shading from overhead sun radiation;
- vertical, recommended for shading from radiation falling sideways;
- a combination of both horizontal and vertical (sometimes called 'egg-crate' shades).

The most popular are shades of the first type. They can take the shape of large surface devices, such as awnings, or be designed as divisible screens, for example louvres. Vertical shades can be incorporated into the building structure as 'wing walls' or be used as blade screens, similarly to horizontal shades. Shading devices are often designed so that they can be operated to allow for seasonal or current desirable adjustments. In such cases, vertical louvres, when used at east or west sides of a building, have an advantage over horizontal ones in that they need adjustment less frequently.

Movable shades are better suited to conditions changing in a broad range. They can be most effective in providing the required shading although they can also pose problems of stability (and, as a consequence, safety during the cyclone season) and maintenance. There are few examples of fixed shades that are efficient at controlling the direct component of solar radiation and which, at the same time, permit a view. In the design of fixed shades a design procedure can be used in which the desired ('free') geometric form is compared with calculated (manually or by a computer) vertical and horizontal shadow angles for a given design period. The redundant parts can be then removed, which may result in original and attractive shapes for the shades (Figure 2.15).

Shading can also be provided by vegetation and topography of the site. Neighbouring landforms, structures and vegetation can all be used for this purpose. In the tropics, where overheating is likely throughout most of the year, it is sensible to take advantage of land features and construct the building on a part of the block which is best shaded during the year. To do this, the sun path as well as orientation and tilt of the land must be considered together with exact location and type of vegetation used.

Design aids for sunshading both manual, such as shading protractors, and various computer programs, have been available for many years, however there is no evidence of their widespread use. Likewise, many architectural designs exhibit total disregard for sunshading principles and a purely formal treatment of

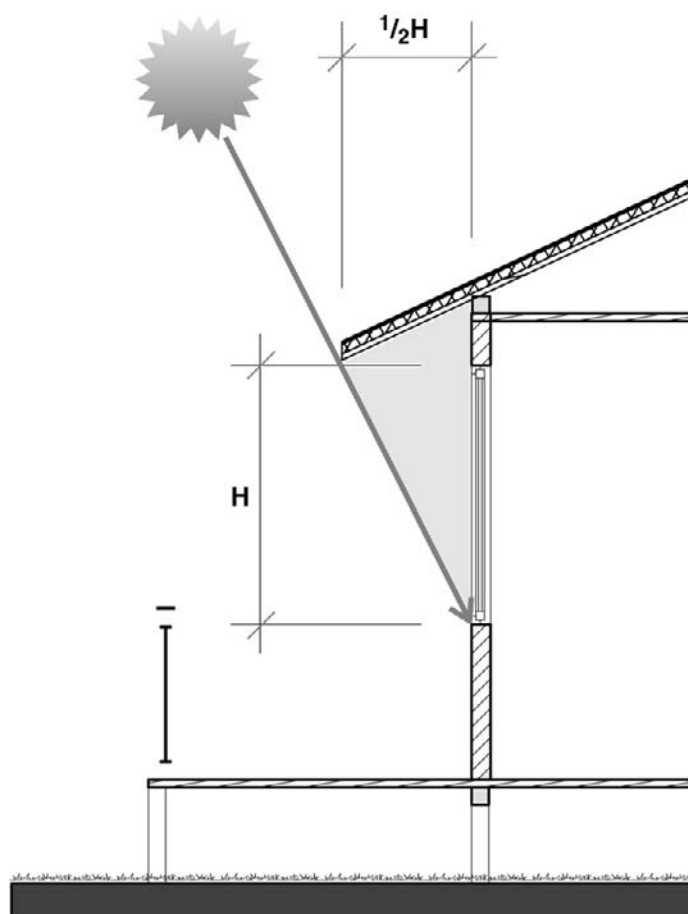


Figure 2.13 Rule of thumb: an overhang's size is effective in shading most of the wall area from high altitude sun.

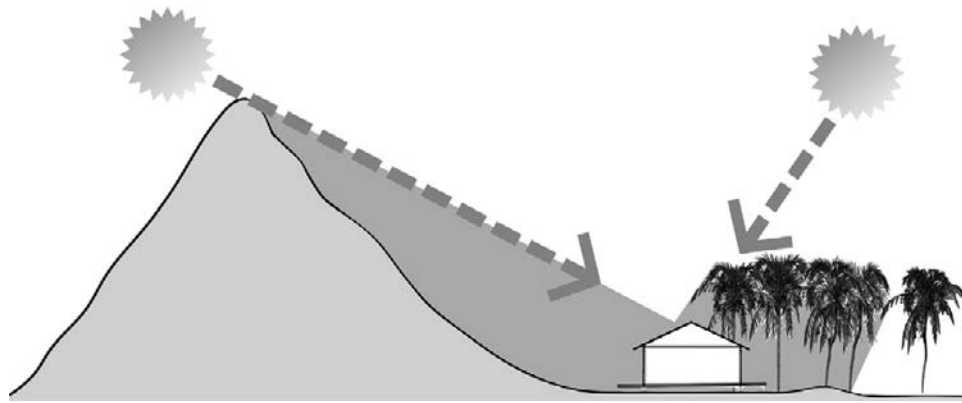


Figure 2.15 Shading should be sought from both vegetation and landforms.

this problem – so important in this climate (Figure 2.16). Sunshades should not be mere ornaments but offer effective protection against solar radiation at all periods when required.

The use of parasol roofs or ventilated roof spaces (attics) is somewhat controversial. Some would argue that the thermal benefit of such a solution does not justify the likely higher cost. As a heat gain prevention strategy, ventilated attics can only prevent convective heat flow from the roof, which is a minor part of a total heat transfer at less than 10 per cent of the total heat flow. Nevertheless, the role of the roof acting as a parasol for the ceiling – especially if the underside has a low-emittance surface (such as ‘coolclad’), thus effectively shading a ceiling structure from the impact of solar radiation – cannot be

discarded. A carefully designed parasol solution supported with appropriate materials can ensure that such a roof/ceiling assembly will provide internal ceiling temperature at not-higher-than ambient air level. This, in turn, would mean that radiation from the ceiling would not need to be taken into consideration. It would then be sufficient to remove hot air from under the ceiling to appreciably lower the temperature of the top layers of air within the building’s volume.

The final aspect of the heat gain minimisation strategy is a consideration given to the material solution. Direct solar radiation increases the temperature of sunlit surfaces. This accelerates the rate at which heat flows into the body of the material. The increase very much depends on the character of the sunlit

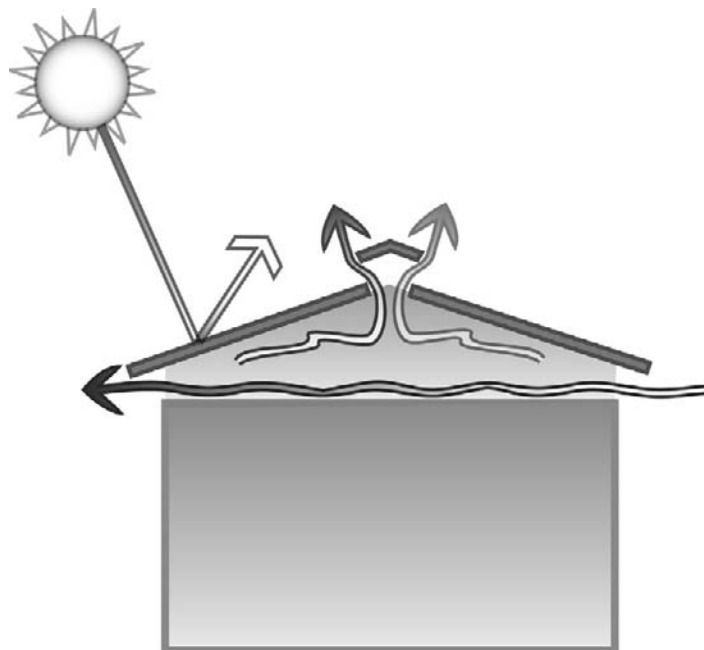


Figure 2.16 Ventilated attic.

surface. There are several material solutions to minimise solar gains occurring this way. Building materials used in construction of a particular element can either resist heat gain from solar radiation or re-emit it as soon as the sun moves into a position from which further irradiation does not take place. The former are basically materials insulating due to their surface qualities (absorptance/emittance), i.e. providing reflective insulation (see below) of the surfaces exposed to solar radiation. In the latter materials heat storage effects can be utilised: the majority of lightweight materials have very little storing capacity and easily give up any heat stored.

In naturally ventilated tropical buildings, where air temperature differences between outside and inside are low, the heat flow through the fabric is too small to consider thermal insulation as a means of reducing the heat flow. However, even in these conditions, insulating envelope elements can be worthwhile. Such a need must be established using a different criterion. In a heat gain situation, with strong solar radiation, it is the sol-air temperature value that must be used to find the temperature difference. In the sol-air temperature (SAT) concept, the SAT comprises the ambient air temperature value and a value which creates the same thermal effect as the incident radiation in question.

$$\text{SAT} = T + (G\alpha/f_o) \quad (2.4)$$

where T is air temperature; G is global irradiance; α is absorptance; f_o is (outside) surface conductance

Thermal insulation, as a material solution, can take the form of either reflective, resistive or capacitive insulation. The difference between them is that the first two resist heat flow instantly (that is, they insulate) while the third one operates on a time-lag principle, slowing the heat flow down. Thermal insulation is most effective under conditions of steady heat flow, i.e. when the direction of the flow is constant (occurs in one direction) for long periods of time. Thus, in the tropics, it has a bigger importance in the warmer half of the year.

2.1.1.2 Heat loss maximisation

Cooling techniques reliant on mechanical systems require fully enclosed spaces to ensure their efficiency. Some people believe that passively controlled buildings also must be super-insulated. While this might be true in the cool climates of Europe and North America, where energy losses are a major concern for a big part of the year, it does not work this way in hot climates. Preventing heat gains in the wet

tropics would typically mean preventing daytime gains from solar radiation, but ambient air is always a welcome heat sink – particularly at night. Most passive technologies may work reasonably well in an open-to-the-ambient-air environment at no additional operating cost. This way, expensive sealing of the building can be avoided.

Passive cooling techniques can be classified according to various criteria: the nature of the heat sink, heat transfer phenomena, the heat storage period, or the material involved. Cooling action can be direct, i.e. when a heat sink is in direct contact with the building structure and/or the interior air. It can also be indirect, i.e. when the cooling medium (usually air) is cooled first and later transferred, with or without intermediate storage.

Cooling effects are created by the rejection or dissipation of heat already present in the interior. After heat gains have been minimised – as far as practicable – several passive methods employing various cooling mechanisms can be used. They can be considered in four major groups (Figure 2.17):

1. Radiant cooling, especially to the night sky.
2. Evaporative cooling.
3. Storage cooling (usually combined with night convection).
4. Convective cooling, for example resulting from airflows around the building perimeter, cross-ventilation, or the inflow of cool air drawn through subterranean pipes.

Conductive cooling could also be considered, even if its actual physiological effect is limited as it requires that a part of the human body is in physical contact with a cooler surface.

2.1.1.3 Radiant cooling

Radiant cooling can be achieved by radiative heat transfer in two different ways:

- direct cooling by radiant transfer directly from people to cooler interior surfaces;
- indirect cooling by radiant heat transfer between building elements at different temperatures and from the warm air to cooler interior surfaces.

Direct cooling of people by thermal radiation has the great benefit of producing comfort at relatively high indoor air temperatures. This works, however, only if the internal surfaces are cooler than the skin, which is seldom the case in the tropics.

The transfer of heat by radiation occurs between two adjacent bodies at different temperatures. Radiant cooling of buildings utilises the situation when a

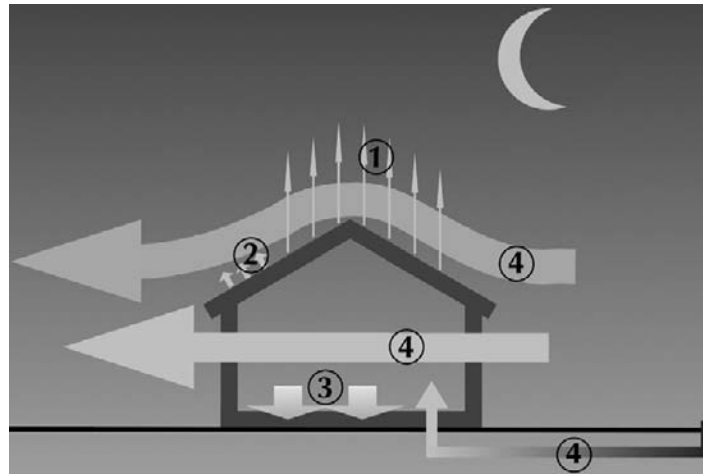


Figure 2.17 Various structural cooling methods (see text for description).

building or its part is warmer than its surroundings. The most prominent is radiation to the sky because clear night skies are (even in the summer tropics) invariably cold: for calculations, it is assumed that the temperature of the sky is equal to the temperature of cosmic void, i.e. $0^{\circ}\text{K} = -273.16^{\circ}\text{C}$ or 'absolute zero'. The cold upper atmosphere and the cosmic space are the ultimate cool medium for radiant cooling and the origin of all other heat sinks. Radiation to the sky is greatest on clear cloudless nights when the air is dry. As a result of the process, by the end of the night the building may be expected to have cooled down quite significantly. The effect is less marked in the wet tropics because humid air is less transparent to infra-red radiation than dry air. Also, in tropical humid conditions, low clouds can markedly impede the process. For instance, the temperature difference between the ground and the base of a cloud at 1 km is only 6K, at 4 km it is 23 K, and even high clouds at 10 km give an effective temperature difference of only 63 K, approximately.

The phenomenon of radiant cooling is put to good use in roof ponds and similar roof systems. The simplest form of such a concept is a heavy and highly conductive roof (for example, one made of dense concrete) exposed to the sky during the night but highly insulated externally by means of movable insulation during the daytime. Such roofs can be very efficient in losing heat at night both by long-wave radiation to the sky and by convection to the outdoor air. During the daytime, the external insulation – moved into place – minimises heat gains from solar radiation and from the hot ambient air. On the interior side, the heat accumulated in a building during the day can be absorbed ('trapped') and stored in the

roof mass to be removed at night, i.e. radiated towards the sky (Figure 2.18).

The roof is the only element of a building that has much exposure to the sky and therefore it is the natural location for a nocturnal radiator. High-mass roofs with operable insulation, either made of concrete or with roof ponds, are effective in providing daytime cooling in almost any region with low cloudiness at night, regardless of the air humidity. In arid regions, a temperature drop of about 3–5 K can be expected in the interior of the cooled building. In humid regions, the drop will be about 2–3 K.

A semi-commercial application of the principle was demonstrated by, among others, Harold Hay in his 'Skytherm', where thermal inertia of the roof is utilised in combination with reflective insulation to produce a variable thermal behaviour of this element (Smith, 1980). The main problem with the Skytherm (and all other similar systems) is the availability of a simple, inexpensive, convenient and trouble-free way to operate the movable insulation. A truly commercial system is yet to be developed.

There are also other possibilities of cooling accomplished through radiation. Roof overhangs, which are free to lose heat to the ambient air, can act as heat sinks. Uneven surfaces, like corrugated steel sheets, experience greater heat loss than a flat sheet, due to the greater area exposed to the ambient air. In addition, the use of special selective coatings can emphasise the heat emission from building elements at lower ('cool') temperatures. Of particular interest should be white painted (especially with titanium oxide) surfaces, which are as reflective to solar wavelengths as shiny aluminium,

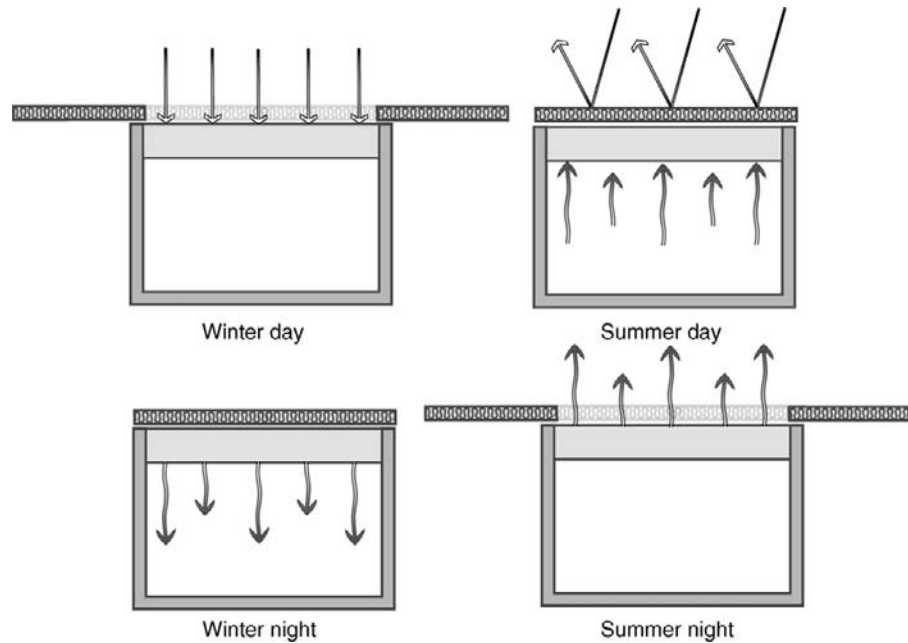


Figure 2.18 Roof pond technology.

but their emittance at terrestrial temperatures (long infra-red) is almost as high as that of a black surface.

In some Mediterranean and Middle East countries it is common in summer to sleep on the flat roof of the house, exposed to the sky at night, which is a behavioural example of comfort cooling by direct radiation. Generally, however, the use of radiant cooling in hot and humid environments has been found to be technically difficult.

2.1.1.4 Evaporative cooling

When water is brought into contact with non-saturated hot air, a simultaneous mass and heat transfer takes place in the course of phase change, which can be defined as the change in the physical state of a substance from solid to liquid, liquid to gas, or solid to gas. The heat transfer from hot ambient air to cooler water has the effect of increasing the water temperature while the latent energy absorbed by the evaporating water cools the air down. Once the water reaches the equilibrium temperature for given conditions, the heat required for phase change (i.e. evaporation) must come from the air and, consequently, its temperature decreases. The process of evaporation absorbs significant amounts of heat: the latent heat of evaporation of water at around 20°C is approx. 2400 kJ/kg. This latent heat of evaporation can be utilised in suitable climatic conditions. Best effects can be expected in hot arid

areas; in these areas systems for evaporative cooling are quite popular. On the tropical coast, or in the wet tropics in general, the process not only will be limited because of limited evaporation potential, but it can add to already unwanted high humidity.

There are two types of cooling systems using evaporation as the main mode of heat transfer: direct systems and indirect ones. The difference is in the contact of air and water. Direct evaporative systems make sense in hot arid areas, where increased humidity, resulting from their operation, can be considered beneficial. In the wet tropics, however, this would not be acceptable, and indirect systems must be employed. In order to effectively apply evaporative cooling in such areas, it is necessary to isolate the process of evaporation from the controlled environment and, possibly, to increase air temperature to achieve a higher rate of evaporation. Both tasks are quite difficult when we contemplate their application in eco-resorts.

Evaporation, whether direct or indirect, is a principal cooling mechanism employed in active powered systems. An example of a passive indirect system is the roof pond discussed previously. The ceiling is an element, which cools the space below by convection and long-wave radiation. As an alternative to roof ponds, roof sprays or combination pond/sprays can be used. Cooling of approx. 2–3 K by reduction in the indoor MRT is achieved this way without elevating the indoor humidity. This enables

application of indirect evaporative cooling in places with higher wet bulb temperatures (WBT) and higher maximum air temperatures.

There are several commercial and semi-commercial passive systems which utilise evaporation as a cooling mechanism. Some of these systems can only be recommended for daytime cooling as they do not operate efficiently in the absence of direct solar radiation. They even tend to elevate indoor temperatures slightly during the night and hence they are not suitable for application in a resort's guest units, which are used mostly at night. Most evaporative cooling systems have their applicability relatively limited, anyway. The performance of these systems depends on WBT: the temperature of the humidified air has to be above the ambient WBT by about 25 per cent of the WBT depression. Indirect evaporative cooling can be applied in places where WBT is up to the mid-20°C range and the maximum dry bulb temperature (DBT) does not exceed about 45°C – over this cooling is still provided but it will not achieve improvement in comfort.

2.1.1.5 Storage cooling

The thermal mass of a building is a tool that a skilful designer can use for timing of heat flows. The concept of using thermal inertia and its practical application were known in vernacular architecture for centuries. Honan Chinese or Saharan Tuareg dwellings, which employ earth for storage cooling, command respect for their ingenuity. The logical explanation of those solutions virtually underground, however extreme, is that the mass of the ground below the surface retains temperatures close to the yearly average – much lower than the observed daily maxima.

The 'thermal mass effect' is created as a consequence of using materials which have significant thermal capacity – this being a result of combining

high density with high specific heat. In principle, the 'mass effect' is a way of providing indoor temperatures at a not-higher-than-outdoors level by the temporary storing of heat in the mass of a building element. Usually, when the effect is deliberate, it is enhanced by intensive ventilation at night, and by keeping the mass cool by shading or external insulation during the day. Following variations of temperature on at least one side of a massive element, the flow of heat is delayed by a period known as 'time lag'. The quantity of heat being released by the element to the inside is different (reduced) from the quantity gained as the heat input at the outside surface. The reduction is derived from the speed of heat transmission, which is slower than the diurnal changes in temperature. Hence, the heat flow through the element occurs not only to the interior but also back to the cooler exterior at night. The measure of this difference (ratio Q/Q_0) is known as the 'decrement factor' or 'amplitude decrement' (Figures 2.19 and 2.20).

With adequate design, it is reasonable to expect a drop in the average indoor maximum temperatures to about 60–65 per cent of the average outdoor maximums as long as there are no significant internal heat loads. The curve of actual heat flow can be determined if the values of time lag and decrement factor for a particular element are known. As the heat flow through the zero-capacity wall can be calculated by the steady-state method, its daily curve can be plotted. This, in turn, makes the base for the actual heat flow curve. Newton's law of cooling applies to this process. Newton established the law stating that the rate of heat loss (cooling) is proportional to the difference in temperatures between the body being cooled and its surroundings. The law explains the mechanism of a rapid response to changing conditions, as in the night cooling. It is achieved by transfer of heat from the building's volume, at relatively high temperature, to the relatively

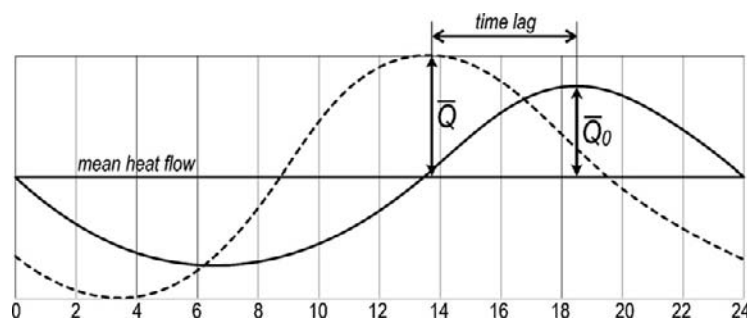


Figure 2.19 Time lag and decrement factor.

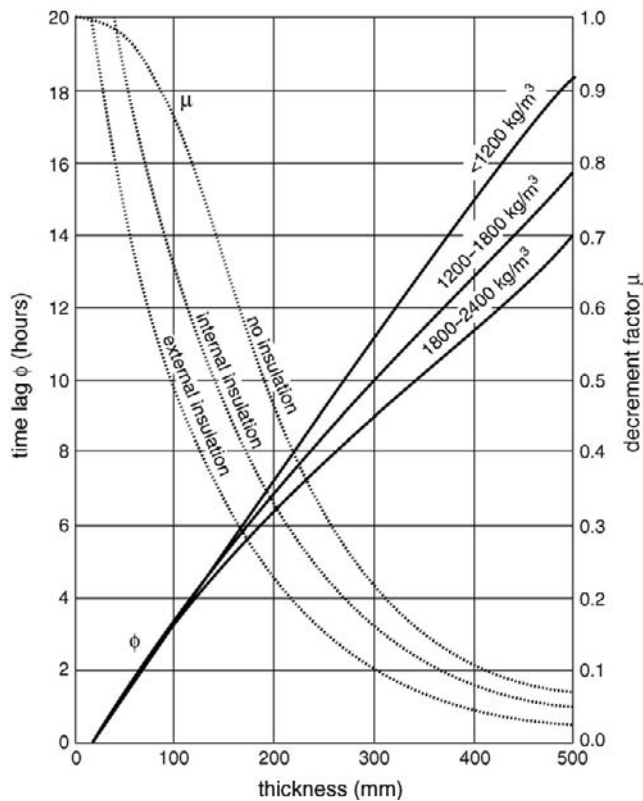


Figure 2.20 Time lag and decrement factor in relation to element thickness.

cool night sky and air through the envelope having a small heat capacity and thus enabling high transfer rates (Figure 2.21).

Integrating the building with the ground through slab-on-ground floors, earth berms or underground structures, in effect means tapping into the thermal inertia of the earth. Ground temperatures at some depth tend to approach the mean annual ambient temperature, which is a favourable situation for the summer extremes (Figure 2.22).

One of the few applications of storage cooling available to tropical eco-resort designers is through the use of ground tubes. Sufficient length and depth of the tube can ensure that the air drawn into the

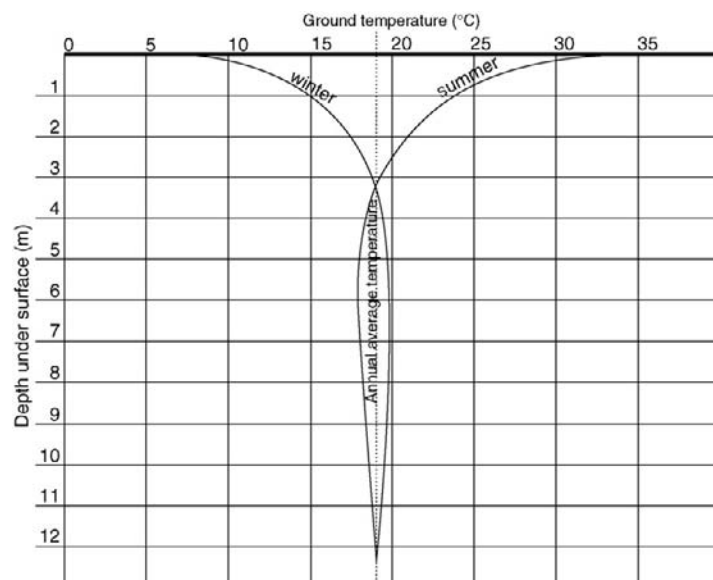


Figure 2.22 Ground temperature variability at different depths.

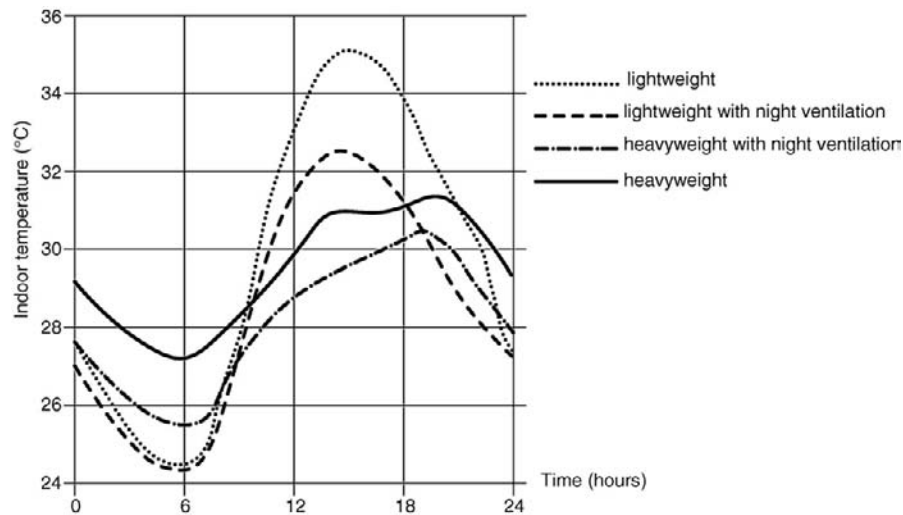


Figure 2.23 Thermal performance of lightweight and heavyweight structures.

building will be a few degrees cooler (see Convective cooling section below).

Excessive building mass in tropical conditions may be counter-productive: it could cause an increase in the average indoor minimum temperature as a result of time lag being extended beyond the desired 6–8 hours. Ultimately, no cooling effect will be observed at times when it is needed and uncomfortable conditions are aggravated. Moreover, heavy structures of high thermal capacity are disadvantageous when it is essential that indoor temperatures follow closely even small drops in the outdoor temperatures. The effect of cross-ventilation for cooling could also be reduced by large thermal mass. Clearly, if cross-ventilation is to be effective for relief in hot conditions, low thermal inertia is preferable.

The mass effect can be utilised better in climates of large diurnal range. Heavy structures and created mass effect do not seem as well suited to the tropical eco-resort as they could be to dwellings in the same environment. The reason for this is that guest unit performance criteria do not have to include the hottest part of the day when the mass cooled during the night lowers daytime temperatures. If anything, the mass effect could become an unwelcome modifying factor by raising the night-time MRT within the guest unit. The situation would be a little different in a winter season when the diurnal temperature swing increases and when night underheating of lightweight structures could be a problem. That, however, can be overcome in lightweight structures with relatively small heat storing elements strategically placed to maximise winter gains. The use of mass for winter storage would have to be very carefully considered since it should not be located

in places exposed to solar radiation in summer (Figure 2.23).

2.1.1.6 Convective cooling

Convective cooling is a process in which the ambient air is the major source of coolness and where convection is the major mode of heat transfer. Heat loss by convection from the building fabric is a procedure particularly worth considering in hot humid climates.

Some improvement to indoor conditions can also be accomplished whenever the room height allows for the convective rise of warmed air. A vaulted or pitched ceiling, where exhausts installed at its highest point eject hot air from the room into the attic space or, preferably, above the roof, are the best options. The rate of cooling will be further accelerated by air movement around the building and cross-ventilation in the attics and under the building (when raised above the ground).

The movement of air caused by temperature difference between intake and exhaust points located at different levels is usually referred to as the 'temperature gradient effect' or the 'stack effect'. Basically, it is a vertical movement of warm air through the building. Full utilisation of the stack effect may provide considerable cooling if, for instance, the designer is able to ensure that the inflowing air, which replaces warm air rejected from the room, is cooled down before entering the building. Provision of cooling paths (shade zones) for breezes prior to their entry to internal areas is one of the simplest ways to reduce ambient air temperature entering the building. Such a procedure is not so much cooling, strictly speaking, as the temperature achieved inside is never

lower than outdoors. It is, however, an important element of an overall strategy of providing indoor temperatures at a not-higher-than-outdoors level.

Another method is to use 'ground cooling', where the air drawn into the building passes through underground tubes or pipes. The ducts are buried at a certain depth (usually around 2–3 m) and their length varies typically between 10–40 m, while the tube diameter is between 0.1–0.3 m. In humid regions, air thus sourced is not only cooler but it can also be drier than the ambient air due to condensation of excess moisture, when the underground duct is buried at the depth where temperature is lower than the dew point of the air taken in (the difference required in practical applications is around 6–7 K). Because cool air is much heavier than the air in the building, it must be propelled into the room using, for example, a low-power fan. Such a solution therefore falls outside the 'purely passive design' category. Nevertheless, with low energy required to obtain a substantial cooling effect of typically around 5–7 K, it is well worth considering (Figure 2.24).

2.1.1.7 Conductive cooling

Physical contact with cool surfaces is a known means of alleviating heat stress in the tropics. In warm humid conditions, slab-on-ground floors generally remain much cooler than the air during the day. A common behavioural response in these areas is the customary removal of shoes on entering the building thus enabling the body to lose heat to the floor by

conduction. At night, the massive floor remains above air temperature, making comfortable sleeping difficult. Hence, it would be an advantage to have the conductive cooling phenomenon utilised in daytime rooms, and have bedrooms displaying fast thermal response in order to cool quickly at night. Vernacular houses in the equatorial tropics often have living areas with a massive floor downstairs and sleeping areas with a timber floor upstairs. Generous allowance for cross-ventilation ensures that the upstairs area cools quickly.

Conductive cooling is not a phenomenon of great physiological importance. Its effect – relief through physical contact with cool surfaces – is more of a psychological than physiological nature accounting for less than 1 per cent of total heat loss.

2.1.2 Air movement

Key recommendations in brief:

- Begin to design for ventilation outside the building, with adequate siting and supporting landscaping;
- Utilise cross-ventilation as the most effective method of moving air through the building;
- Cross-ventilation is most efficient in narrow, open-plan buildings orientated at around 45° towards the oncoming winds and breezes;
- Avoid creating obstructions to airflows both inside and outside the building.

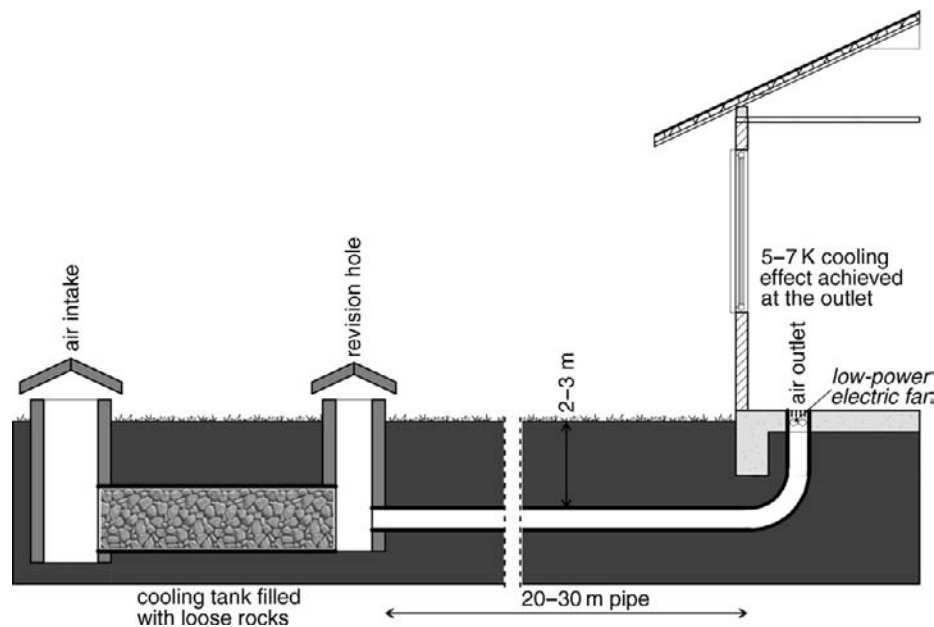


Figure 2.24 Ground tube cooling.

Relative air velocity, a measure of air movement over the skin, influences heat loss by convection and, if the skin is wet, further cooling results from evaporation. Its physiological effects, and hence its importance, is bigger in warmer climates where clothing is normally being reduced and the body is more exposed to air movement, and where increased air motion can greatly increase the tolerance for higher temperature and humidity levels. Still, the air temperature, to a great extent, affects the body's perception of air velocity. When it is close to the temperature of the skin, an air current of 0.5 m/s may be imperceptible but individuals may vary quite markedly in their perceptions and reactions to air movements.

There is no doubt that this climate can be seen as uncomfortable when most of the time is spent indoors and rather pleasant when we can retire to the shade outdoors. They are mainly due to one reason: reduction of air speed within a building – usually limited to well below 1.0 m/s. Within buildings, air speeds are generally less than 0.2 m/s and air movement above 1.5 m/s may cause inconvenience in most domestic situations. The heat loss corrections (chill effect) for various wind speeds given in literature are adequate for conditions typical in moderate climates. In the tropics, where clothing is normally much reduced, one can use the following formula combining effects derived from several different calculation methods for air speed up to 2 m/s (Szokolay, 2000):

$$dT = 6v_e - v_e^2 \quad (2.5)$$

where v_e is the 'effective' air speed (slightly less than the actual air velocity $v_e = v - 0.2$ m/s). The resulting correction to the perceived air temperature may take a value of up to 5.6 K.

When relative humidity levels are high then the air movement becomes the most important mechanism for removing the heat that the body generates. Fanger (1970), for example, demonstrated that – conservatively defined – comfort can be maintained at 27.7°C and 100 per cent RH or at 32.2°C and 50 per cent RH as long as air movement of approx. 1.5 m/s is provided. Others suggest still higher temperature/humidity values. Practically all beneficial effects disappear at air temperature above around 34°C (approximate skin temperature), when body heat gain results regardless of air movement speed (Figure 2.25).

It should be noted that certain parts of the body (back of the neck, feet) are more sensitive to air movement and, if the stream is directed onto them, the cooling effect is increased. The cooling effect can also be improved by elimination of directional changes of the air stream. The drying effect of higher air veloci-

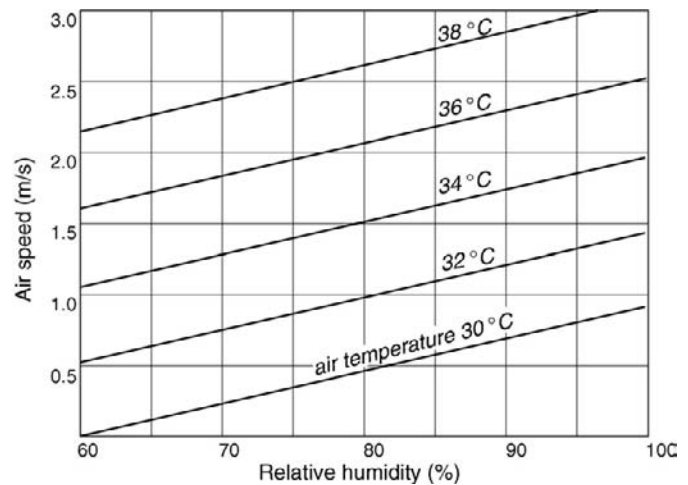


Figure 2.25 Estimated minimum air speed required to restore thermal comfort for a range of air temperatures and relative humidity values.

ties, which in cooler climates would be associated with discomfort, in the hot and humid conditions of the tropics is beneficial and generally improves comfort perception. It is worth remembering, however, that when air temperature is higher than that of skin, the benefit of the enhanced evaporative cooling is countered by the detrimental effect of increased convective heat gain.

Air movement can influence the thermal performance of buildings in various ways. One such influence, evident in the tropics, is the variation in heat transfer rate with different air speeds over surfaces of building materials (Figure 2.26).

There are two methods of estimating airflows through large openings in buildings resulting from winds or breezes. One is to use wind tunnel studies of scaled models to determine velocity coefficients at critical points inside the model. These coefficients relate speed of an indoor air movement to a reference wind speed outdoors. When related to long-term records (speeds and directions) of air currents near the building site, the method is quite accurate. Another method of estimating velocities of air movement through the building is to use wind pressure differences and discharge coefficients. Wind pressure can be estimated from pressure coefficients and local wind speed data using techniques such as the one described in Australian Standard 1170 Part 2 (the current wind loading code). Discharge coefficients for typical openings and other formulas to estimate air-flow rates due to pressure differences caused by wind and/or stack effect can be found in many sources.

The wind velocity readings at meteorological stations apply generally to heights of 10 m. They need to

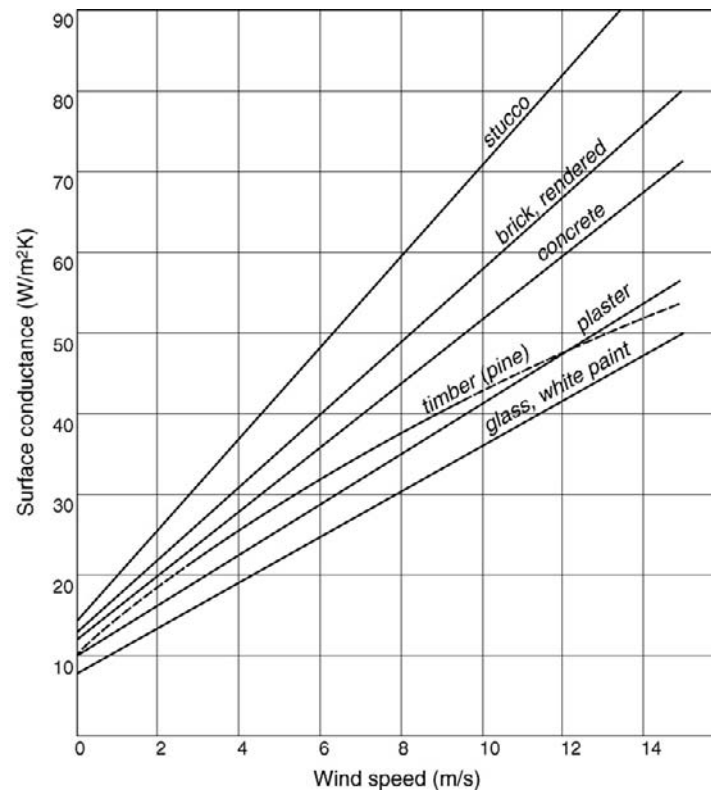


Figure 2.26 Surface conductance as a function of wind speed.

be reduced to a level appropriate for a given building. This can be done using a formula, for example one taken from the British Standard Code of Practice CP3:

$$v_h/v_{10} = 0.2337(1.00 + 2.81 \log[h + 4.75]) \quad (2.6)$$

where h is height above ground; v_h is wind velocity at height h ; v_{10} is wind velocity at a height of 10 m

The formula has been subsequently revised and in open flat country, such as on the coast, the following simplified version can be applied:

$$v_h/v_{10} = c h^a \quad (2.7)$$

where, in the given type of terrain typical for the coast (flat and open), $c = 0.68$ and $a = 0.17$ (Santamouris, 1993).

Unfortunately, the number of stations supplying wind velocity data suitable for the present considerations is very small. Most stations that make such observations provide wind data only for 9am and 3pm, and some do it only for 9am. This situation poses a considerable problem of assessment of night-time wind velocities, which are the most important from the point of view of tourist accommodation design.

Air movement can be referred to as wind, breeze or draught. Wind is the air movement caused by mac-

ro-scale changes in atmospheric pressure due to the heating effect of the sun. Air movements caused by localised phenomena are usually called 'breezes'. Unwanted air currents present inside a heated room (in cooler climates) would normally be described as draughts. In this publication, 'draught' will be the term given to any directionally consistent flow of air indoors.

There are a number of ways air movement could be taken into comfort considerations. It can influence the physiological and mental state of people, but it can influence the thermal and acoustic performance of a building as well. In warm and humid climates, it is the former that is more apparent. Air movement is probably the most important comfort-bringing component of the climate in the wet tropics. Some experts believe that in hot and humid climates, air movement is most often the only natural method of reducing heat stress. In these conditions it comes second only to adjustment of clothing as the most popular means of improving thermal comfort. In warm weather, the air can be utilised as a cooling medium when hot indoor air is replaced by cooler air from the outside. In addition, the 'chill factor' of the movement, in both cooling of the body and cooling the building structure, can be taken into account.

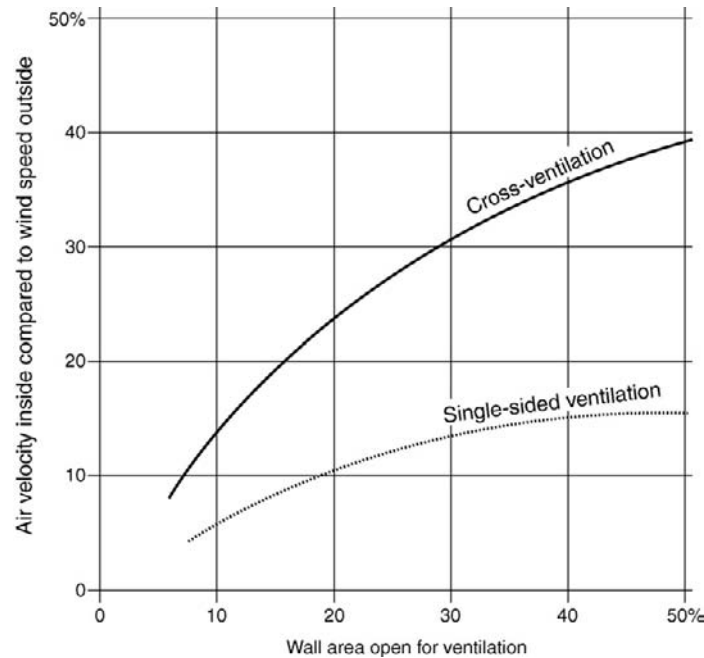


Figure 2.27 Effectiveness of stack/single-sided ventilation and cross-ventilation expressed as the recorded indoors air speed.

There are three ways to induce and promote air movement. This can be done either through differing temperature (the 'stack effect'), by differing air pressure ('cross-ventilation effect') between two or more points, or by redirecting the existing airflows. Ventilation and accompanying cooling effects can be accomplished by creating conditions for the induction of air movement, or through deflecting winds and breezes in the desired direction. There are a number of factors that determine whether sufficient air exchange can be achieved by natural means or if mechanical ventilation has to be provided. In still-air conditions, ventilation is due to buoyancy. The ventilation rate is determined by the area and height of openings, and the temperature difference between indoors and outdoors. In wind assisted airflow, the rate is determined by the speed and direction of the wind at the building face, and by the number, area and type of openings providing passage for the air through the building (Figure 2.27).

When available, air movement due to ventilation can be a significant factor of improvement to the indoor environment. The airflow can increase the rate of evaporation of perspiration from the skin and hence induce the physiological cooling effect. However, it can be argued that achievement of the desired velocities maintained across the full 'living zone' (up to 2 m above the floor level) would require several hundreds of air changes per hour. This seems to cast doubt over the feasibility of cooling using this

method. Moreover, when outside air temperatures are high, ventilation and the resulting admission of hot air add to undesirable heat load. In tropical climates, while physiological cooling occurs at any temperature below skin temperature, ventilation is advantageous when it enables the warm indoor air to be replaced with preferably cooler air. Although the air moving from the outside will remove heat only if its temperature is lower than the air indoors, sensible velocity produces physiological cooling even when its temperature is slightly higher. On the coast, for instance, such cooler air can come with afternoon breezes off the sea.

Several factors need to be considered if ventilation is to be fully utilised:

- direction of prevailing winds and breezes;
- effect of the surrounding area on speed, strength, direction and temperature of airflows, for instance obstructions;
- design and location of openings; and
- internal layout of the building and the resulting air paths through it.

2.1.2.1 Driving force: wind pressure

The movement of air across a site is from high pressure zones to low pressure zones. When wind strikes a building, a high pressure zone results on the exposed side and a low pressure zone on the opposite – or sheltered – side. Usually, both the speed and direction

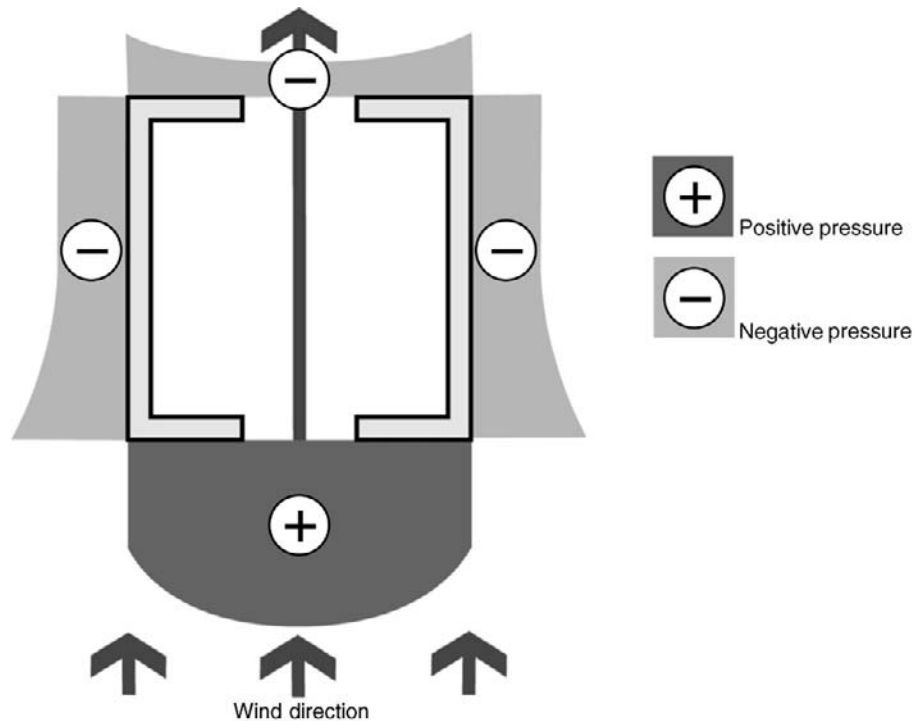


Figure 2.28 Cross-ventilation is facilitated by areas of positive and negative pressure around buildings.

of local winds are variable. However, a building can often be positioned in relation to neighbouring buildings, planted vegetation, and other obstacles, so that the wind is moving in a known constant direction at a reasonably steady rate. Orientation broadside to prevailing breezes provides the greatest effect. Nevertheless, it is the size and position of the openings that will determine the availability, speed and direction of air currents within the building. The resulting air speed indoors is greatest when the wind strikes the wall with openings at an angle of around 45 degrees, and when the apertures by which air leaves the building are bigger than (adequately sized) inlets. The best distribution of fresh air throughout the building is achieved when openings are diagonally opposite each other and airflow is not hindered by partitions and furniture (Figures 2.28 and 2.29).

Further improvement to air movement through the building can be accomplished by application of 'Venturi-' or 'ridge-effect' ventilation. This effect is created by air moving over a pitched or vaulted roof. Since it has a longer distance to travel than the surrounding air, it must travel faster. It cannot gain momentum, which results in a pressure drop (this phenomenon is known in fluid mechanics as the Bernoulli principle). Consequently, air pressure near the ridge is always negative, irrespective of wind direction. If exhaust points are provided in the ridge, the suction caused by the Venturi effect would ensure

considerable rates of air extraction from relevant spaces (Figure 2.30).

Obstructions to breezes by incorrect placement and structure of walls should be avoided. Any partitions located in the internal flow path impede air circulation. In order to promote unrestricted air movement, partitions should be adjustable and located so as to offer least resistance to airflow. The best is an 'open-plan' strategy, which seems quite

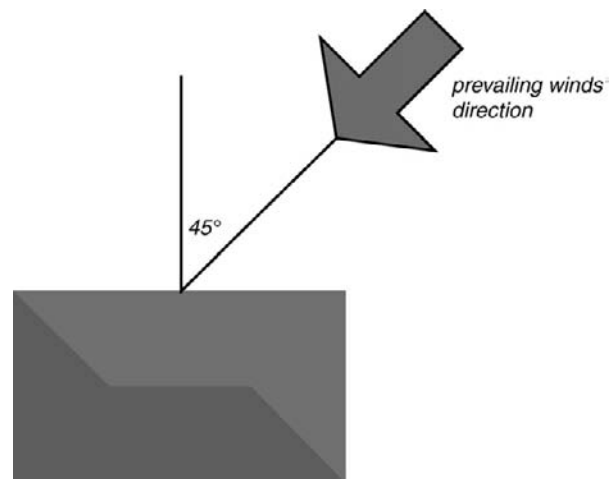


Figure 2.29 Recommended orientation for best ventilation results.

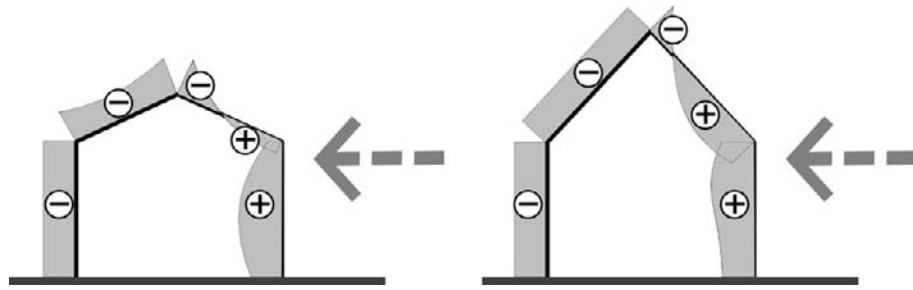


Figure 2.30 Irrespective of roof pitch, the ridgeline experiences negative pressure (suction) also known as the 'ridge' or 'Venturi' effect and this can be utilised to induce air extraction (compare with Figure 3.17).

appropriate for many functional components of a resort (Figure 2.31).

In general, wind speed increases with height above ground. This increase, or wind velocity gradient, is greater in an open area than among trees or buildings, which cause turbulence in airflows.

2.1.2.2 Driving force: buoyancy

Middle East wind towers, which can be considered vernacular examples of solar chimneys, use the enhanced temperature gradient or stack effect as the

principal mechanism to move air through the adjoined building. Their thermal action is invoked by deliberate exposure of their massive structures to solar radiation. This results in heating the air they contain, inducing air movement from the building through the towers. The mechanism of interacting with the environment for indoor climate control demonstrated in wind towers in the Middle East is very complex and the temperature gradient effect is only one aspect of this mechanism. Anyway, convective movements of air resulting from stack effects are rarely sufficient to induce appreciable airflows. For

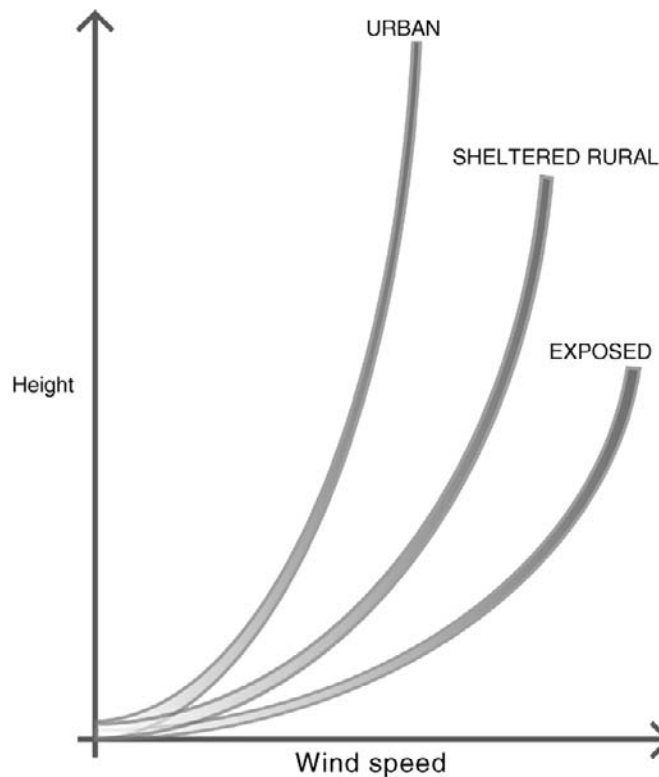


Figure 2.31 Wind gradient in various terrains.

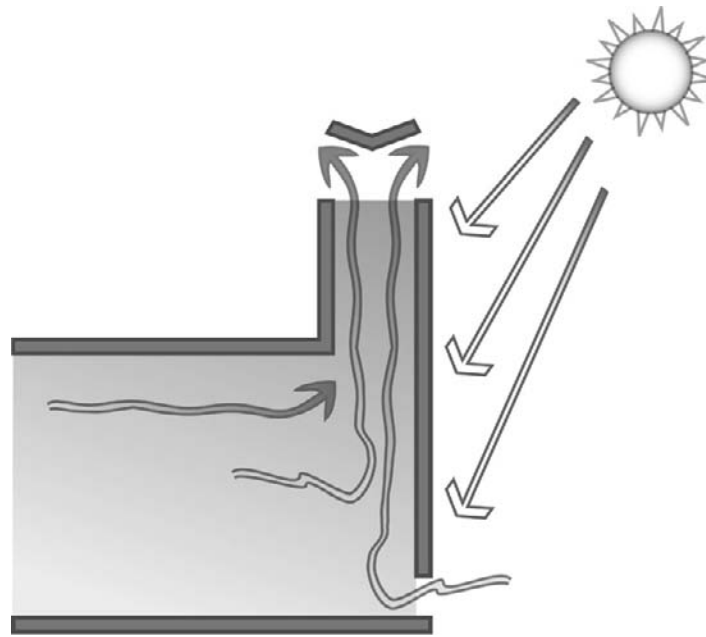


Figure 2.32 Solar chimney principle.

this, pressure differential or hybrid pressure and temperature gradient systems must be utilised (Figure 2.32).

The stack effect is being employed also in the Trombe-Michel wall, a passive solar heating and cooling device useful in buildings occupied during the day for substantial periods of time (Figure 2.33).

Kenyan researchers disproved an earlier belief that a high-ceilinged room (above 2.4 m) was necessary for comfort in hot regions. They argued that increases in the height of a room resulted in an increase of the external wall area to be shaded. It

appears that subsequent heat gains would substantially increase and ultimately cause an even greater discomfort. As it follows, improvement of indoor comfort would then require roof insulation or venting hot air from under the ceiling. Nevertheless, we have to stress that provision of space for air convection is quite important as it might be that the Kenyan findings are applicable only to the daytime scenario. It will be a different case in the absence of daytime heat gains.

Cathedral and other high ceilings allow hot air stratification above the occupancy height. Moreover,

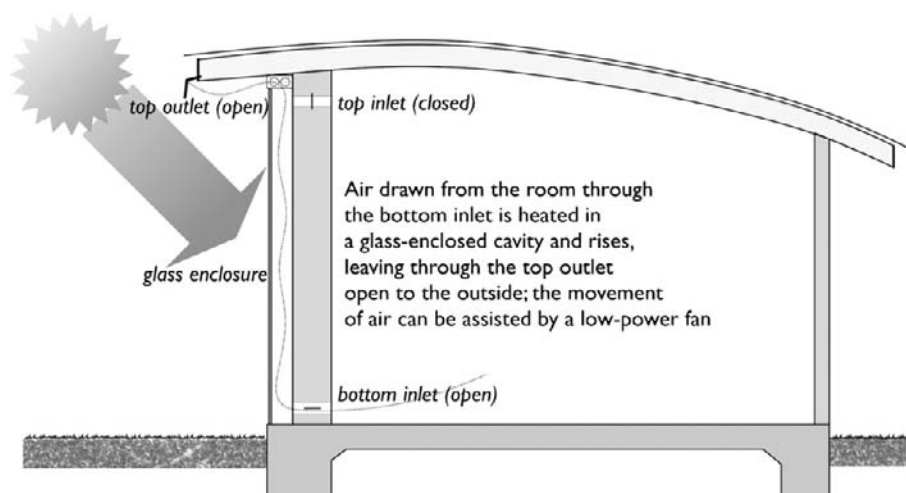


Figure 2.33 Trombe-Michel wall's cooling action.

high ceilings promote useful rates of air exchange. Some promising results have been reported from experiments in rooms with the thermal shade partially drawn while leaving the window open at the top so as to get both sun control and sun-boosted venting. Incorporation of supplementary means of airflow generation, such as ceiling fans, also assists, provided that they are energy efficient and move the air up rather than push it down.

2.1.2.3 Insect control and airflows

Although insects and pests do not in themselves constitute a climatic factor, preventing their presence impacts on bioclimatic design. Fly-screens, for instance, can severely restrict internal airflows, especially when winds or breezes are light. Reduction in total airflow caused by a typical wire screen is about 25 per cent at wind speeds in excess of 2.75 m/s and about 60 per cent at 0.7 m/s. Cotton screens can reduce the velocity of incoming air by 70 per cent, while smooth nylon screens reduce it by 35 per cent. They reduce the rate of structural cooling at night and comfort ventilation at all times. This undesirable effect may be reduced if fly-screens extend over a larger area than the opening alone, and if they are placed at some distance from them. Screening an entire veranda/balcony (i.e. screen area larger than opening area) is better than screens installed in the respective door/window frames (Figure 2.34).

2.1.3 Humidity

Key recommendations in brief:

- Avoid locating accommodation units close to moisture-generating decorative ponds or large masses of dense vegetation;
- Use natural materials for humidity control: untreated timber and other natural surfaces;
- Good ventilation is the best way to deal with excessive humidity;
- Move higher-intensity activities to lower-humidity part of the day.

Thermal comfort is, basically, a response to a combination of temperature and humidity factors. In the wet tropics, improvement in thermal comfort will follow a decrease of either. And to put it in simple terms, humidity control is very much like dealing with heat: prevention of build-ups in the first instance, and then dissipation of as much of the remainder as is possible in the given conditions.

Best location of fly-screens for ventilation is furthest away from the window (A); the worst is in the window's frame (C)

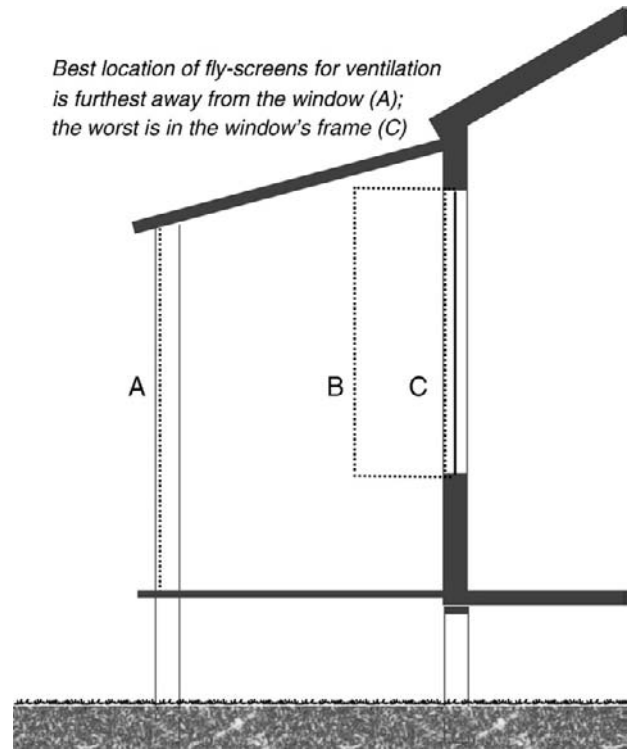


Figure 2.34 Recommended location of fly-screens.

Preventing excessive humidity build-up in naturally humid climates can be done by allowing for free air movement and locating humidity sources (swimming pools, decorative ponds, etc.) away from resort buildings. Locating the buildings as far away as practicable from large masses of vegetation can also help.

Some form of dehumidification should be considered as this will limit the need for a high ventilation rate. This, in turn, allows the use of more options such as storage cooling. Dehumidification methods, which can be implemented in hot humid climates, fall into two broad categories: firstly, water can be removed from the humid air with the use of desiccants, either solid phase absorbents or adsorbents or hydrophilic solutions and, secondly, by cooling the air below its dew point. Dehumidification is usually considered a mechanical (i.e. active) process although a few passive methods with the use of natural desiccants have also been tested. Desiccants are materials, which absorb moisture from the air. This occurs either through the process of adsorption, where water molecules are attracted to the surface of the material, or absorption, where moisture is attracted by a desiccant in a chemical process.

Desiccants in passive systems are exposed to the controlled space at night and left to dry out in the sun during the day. Interesting results have been reported

from experiments with wool used as the desiccant. Apparently, wool is so far the only known material that does not display significant deterioration of its hygroscopic properties with continued use. While studies using wool have been quite promising, current large market fluctuations in this commodity make pricing difficult and estimating its cost and a feasibility analysis is beyond the scope of this book. Other materials, such as silica gel, activated alumina, calcium chloride and lithium chloride, have a short active life and show significant deterioration after a certain period of use. Some of them are also highly toxic or corrosive. The only other usable natural desiccant is rice, which attracts vermin and also deteriorates relatively quickly.

No passive commercially viable method of dehumidification has been found for the tropical climate as yet. As with radiant cooling roof systems, passive and low energy dehumidification with desiccants awaits cheap and reliable solutions for movable insulation or separation screens. Since the early 1980s, when solar-regenerated desiccant dehumidification was first tested, such systems have gained recognition but their feasibility can still be questioned.

The methods in the second category either make use of environmental 'humidity sinks', in particular ground-coupled fluids, or prevent humidity build-ups by appropriate site planning. The use of environmental sinks for dehumidification is most effective when the underground annual average temperature is below 20°C. This natural latent cooling method can still be applied at higher underground temperatures but must be complemented by the use of desiccants.

The level of absolute humidity is consistently high in most areas of the coastal tropics. Nevertheless, relative humidity varies not only with seasonal changes, but during the day as well. Usually, it moves in direct opposition to temperature variations, i.e. a higher level of humidity occurs in the morning when the temperature is low and low relative humidity accompanies the high temperatures of the early afternoon. When superimposed on tourists' activities patterns, humidity does not seem to matter as much as in the working environment.

Some researchers argued that the role of air humidity by itself – in comfort considerations – was ambiguous. In their opinion, prevailing humidity was an important determinant of the level of heat stress but, paradoxically, it played only a minor role in thermal comfort. They maintained that, since sweating does not occur in the thermally comfortable, 'in consequence, thermal comfort, as distinct from discomfort, is largely independent of humidity'

(Macpherson, 1980:17). This view is largely abandoned nowadays and even a cursory glance at the psychrometric chart will explain why: most composite comfort indicators, such as Standard Effective Temperature (SET), vary with humidity (at 80 per cent RH the difference between air temperature at 30°C and the corresponding SET is around 2 K, and at 35°C it increases to around 3 K).

There are two other sources of evaporative heat loss besides sweating, namely insensible perspiration and respiratory water loss. The amount of water lost in the process of passive diffusion, which is known as 'insensible perspiration', is not large and evaporative heat loss this way is usually negligible. Respiratory heat loss is around 10 per cent of the total heat loss, depending primarily on the absolute humidity of the air and the volume of respiration.

Humidity refers to water vapour contained in the air. It may be described in many ways, for instance it can be considered as:

- relative humidity [per cent];
- absolute humidity [g/m³];
- specific humidity [g/kg];
- dry and wet bulb temperature [°C];
- vapour pressure [Pa];
- dew point temperature [°C];
- humidity ratio or moisture content [non-dimensional: kg of water vapour/kg of dry air].

It is the first one, above, which is the most popular and the most disputed measure. While scientists have no problem with the definition of physical relations between relative humidity and various temperatures, interpretations given to these findings by practitioners differ markedly. It is worthwhile to note that the differences are most significant when related to the tropical range of conditions.

Relative humidity (RH) can be calculated as the ratio of the current vapour pressure to vapour pressure at saturation that would exist at the same dry bulb temperature and at the same barometric pressure. It was believed that air saturation with moisture, i.e. the difference between the relative humidity of 100 per cent and the current RH (so-called 'humidity deficit'), determines potential for evaporation and, subsequently, possibility of body heat dissipation this way. Currently, it is accepted that as the vapour pressure at the surface of wetted skin is almost constant, the vapour pressure of the atmosphere alone determines the evaporation potential (Szokolay, 1985). High vapour pressure in hot weather exerts a strong influence on comfort in that it affects the rate at which perspiration can evaporate and therefore limits the rate of heat loss [Table 2.2](#).

Table 2.2 Saturated water vapour pressure at selected temperatures

Temperature (°C)	−40	0	23	28	33	35	37	40
Vapour pressure (kPa)	0.01	0.61	2.81	3.78	5.03	5.62	6.27	7.37

Based on data in RK Macpherson (1980).

Vapour pressure of the saturated air (RH = 100 per cent) at 28°C (3.78 kPa) is roughly the same as that for 50 per cent RH at 40°C (3.69 kPa). The temperature of a freely sweating skin, on the other hand, is approximately 35°C and the vapour pressure of the sweat consequently 5.6 kPa. We should expect that, if other factors such as rate of air movement are held constant, evaporation of sweat will proceed at the same rate in these two (very different) conditions. It appears that the comfort sensation can also be modified because of specific properties of a protein, keratin, of which hair and the outer layers of the skin are composed. Keratin is very sensitive to changes in humidity. It is at least possible that these changes are perceivable and, to some extent, influence our thermoregulatory system.

It is generally believed that for most people comfort limits can be established at 4.14 and 11.63 g/kg, or 4 and 12 g/kg respectively after rounding, of moisture content in the dry air (ASHRAE Standard 55–74). Many experts prefer to assign – as comfort limits – certain values of relative humidity irrespective of the temperature or air movement. Typically, they will be 20–30 per cent as the lower limit and 60–80 per cent RH as the upper comfort limit. Day-to-day observations indicate however that, no matter how defined, humidity is an important consideration only when the air temperature is close to or above the upper limits of thermal comfort.

According to Szokolay (1980), humidity of the atmosphere has little effect on thermal comfort sensation at or near the comfortable temperatures and within the vasomotor regulation zones, unless it is extremely low or extremely high. Givoni (1976) and researchers from Florida Solar Energy Center are also flexible on this point and their expanded comfort zones include conditions existing at very high and very low RH values (close to 100 and 0 per cent) at a broad range of temperatures. They argue that, as long as the air temperature is lower than the skin temperature, evaporation from the skin (and thermal com-

fort achieved through evaporative cooling) can occur even at very high relative humidity.

Anyway, in all attempts at assigning particular RH values the role of human comfort limits seems to be rather arbitrary. For instance, in Olgyay's chart of schematic bioclimatic index (1963), conditions of 70 per cent RH at 103°F (39.4°C) or 90 per cent RH at 98°F (36.7°C) are defined as unbearable. They may seem unbearable to someone living in moderate climates. The majority of beach-goers would, most probably, disagree. In the tropics, and even in the subtropics, this type of conditions can be experienced without much discomfort throughout summer and possibly good parts of 'spring' and 'autumn', for a good measure. This observation, i.e. experiencing little or no thermal stress related to the above conditions, has been supported by a study on stress from 'heat waves' in a range of locations throughout North America (Lewis, 1993). We may conclude that high humidity can become a problem only when – combined not so much with temperature as with metabolic rate – it intensifies sweating to a point and in such conditions that it cannot evaporate, thus impeding desirable 'fresh' feeling.

Similarly, attempts to link relative humidity averages as 'geographical' limits to human comfort may seem doubtful. For instance, a belief that 40 mm precipitable water vapour isopleth defines the geographic limits of human ability to achieve thermal comfort by purely passive design features in the tropics seems questionable. One should note that the majority of the tropics are located within the 4 cm isopleth. Yet, conditions there stay comfortable for extensive periods of time.

A light-hearted example of human endurance in this respect can be seen on a daily basis and around the world in any Finnish sauna, Turkish *hammam*, Russian *banya*, or Japanese *mushi-buro*. Normal conditions in a sauna are 60–100 per cent RH at 80–110°C. In the others, the conditions are very similar. That seems unbearable even to seasoned inhabitants of the tropics. . .

2.2

Visual environment control

Key recommendations in brief:

- Provide daylight as a principal means of lighting wherever and whenever possible;
- Use vegetation and external devices for shading;
- Use task lighting rather than general lighting to prevent light pollution;
- Carefully select building form, material types and colours for their visual impacts.

Light and sound are seldom seen as elements of comfort, which is most often understood as thermal comfort. And when a project does include considerations of light and sound, it is usually based on data which have not been gathered in tropical latitudes. We have to see this situation as a big mistake – particularly in relation to light.

Natural light is composed of direct, reflected and diffuse light. The former would be usually called 'sunlight' and the latter two constitute 'daylight'. Diffuse light is received from the sky after it has been scattered by the gases and water droplets in the atmosphere. For daylighting considerations, the sky can be regarded as the integration of an infinite number of light point sources. Daylight is then a function of a solid angle of visible sky. To simplify sunlight calculations, on the other hand, it is assumed that direct light beams are, by the time they reach the Earth, effectively parallel.

Natural light (a continuous spectrum white light) brings out the natural contrast and colour of objects. It is also believed that exposure to natural light can have beneficial psychological effects and is required for maintaining good health. Availability of natural light can make an all-important contribution to energy saving; one could say that in recent years it has been rediscovered as an important energy conservation measure, reducing reliance on electrical lighting. Moreover, it can significantly improve the quality of the visual environment as well as influence general perception of comfort.

In the tropics, there is a tendency to limit admission of daylight – mistaken for sunlight – to the interior. Subsequently, extensive – often overdone – shading results in limited quantities of daylight available in tropical interiors. Differences in light levels, which then follow, can more often than elsewhere cause 'discomfort glare' – the phenomenon of luminances much higher than the average appearing in a field of

view. Glare is caused by the introduction of a very intense light source into the visual field. It can be mildly distracting or visually blinding for the person concerned. Whatever its level, it always produces a feeling of discomfort and fatigue.

Glare can be caused directly, indirectly or by reflection. Direct glare occurs when a natural or artificial light source with a high luminance enters directly into the individual's field of view. It can be experienced when light sources are incorrectly placed in the interior, or when the sun or sky is seen through openings either directly or after reflection from an exterior surface. Indirect glare occurs when the luminance level of sunlit walls is too high. And, finally, the reflective glare is caused by specular reflection of sunlight from reflective surfaces located indoors or outdoors.

The ability of the eye to adapt to changes in lighting level and character is very important to lighting design. A rule of thumb is that the eye can easily adjust to the change from bright exterior to an artificially lit room when the drop in luminance (the technical term used in lighting for objective brightness) level between outdoors and indoors does not exceed 100:1. Then it takes about 15 minutes for the eye to adapt, of which the first 90 seconds is required for at least 70 per cent of the adjustment. The figures are determined by the need to adjust not only to a change in brightness level but also to a change in the character of light. In the case of a daylighted interior, the eye adaptability is much better as it can cope comfortably with luminance distribution displaying a ratio of 200:1 between the light brightness levels outside and inside.

Colour rendering is also very important for visual comfort. Even if this is less significant, it is probably always tiring to have one or two colours predominate. Colours are identified by photopic vision and the human eye sees them best in daylight. This is yet another reason to ensure daylight availability whenever it is possible.

Sunlight in the tropics, more than anywhere else, is associated with heat generated by solar irradiation. This popular opinion is generally correct, considering that to reach the ground level, solar beams travel a much shorter way through the Earth's atmosphere at low latitudes (close to the equator) than they do at high latitudes. Long-wave radiation (including the

so-called 'short infra-red' or 'short IR', which is the actual 'heat carrier') is easier diffused and absorbed by the atmosphere than radiation of shorter wavelengths. Thus, with the same amount of 'sunlight', more of short IR is received in the tropics than in high latitudes. Another unwelcome effect of sunlight is health hazards brought by its UV component. It has been found that solar radiation can cause serious health problems, ranging from skin cancers to irreversible damages to the retina.

In terms of visual comfort, which should be the main determinant of lighting requirements, greatest attention must be paid to lighting that is most appropriate for the activities carried out in a particular space. Visual comfort needs in a guest unit section of a resort would not be significantly different from those in dwellings. Lighting conditions created there should be adaptable to the performed activities, to the time of day and to individual needs. To achieve this, the breakdown of a visual environment into its constituent parts must be carried out and an indication given of how optimum conditions can be created for each part and for different types of activity. These requirements focus on:

- orientation, organisation and geometry of the spaces to be lit;
- location, form and dimensions of the openings through which daylight will pass;
- location and surface properties of interior elements which reflect the daylight and participate in its distribution;
- location, form and dimensions of movable or permanent devices which provide protection from too much light and glare;
- light and thermal characteristics of the glazing materials.

Regarding effects on indoor comfort and environment quality, daylight has a stimulating effect that allows us to fight fatigue and stress. Hence, visual comfort should be closely related to spatial and temporal circumstances.

The amount of energy required for artificial lighting in a conventional building is fairly high; for instance, across Europe it typically represents an almost constant fraction of 35 per cent of total energy costs throughout the year – in spite of climatic differences. Correct daylighting design could not only reduce these costs but also reduce the need for cooling rooms overheated by low-efficiency lighting appliances. Daylight is the most efficient known source of light: its luminous efficacy – even in moderate latitudes – is in excess of 110 lm/W while typical values for efficient fluorescent and LED (light-emitting diode)

lamps are about 50–80 lm/W while incandescent lights do not exceed 40 lm/W. Thus, a given amount of natural light is achieved with no more than a half of the associated total energy input required for operating artificial light sources.

The light distribution in a space should be such that excessive differences in light and shade, which could disturb occupants and prevent them from seeing adequately, are avoided. Sufficient contrast should, however, be retained for the relief of each object to be brought out. Window openings and artificial light sources should be placed in a way that minimises glare. Finally, particular care should be taken in relation to the quality of light to be provided. Both the spectral composition and light constancy should be appropriate for the task to be performed (Figure 2.35).

The need to limit the total environmental impact of the resort, including optimising the use of daylight, should be a primary concern, and use of artificial light should be considered only to complement daylight. It is important to consider both the quantitative and qualitative aspects of light in the building design at its earliest stages. Although the energy aspect dominates daylighting considerations, daylight's influence on human well-being is gaining importance as a design issue. The core performance criterion for daylighting design is to obtain pleasant daylit spaces as often as possible, and for the largest fraction of the building interior. In this respect, the variability of daylight, the quality of its spectral composition, its psychological and health effects on occupants should also be looked at when determining what role it will have in passive control of the indoor environment.

In comparison with artificial lighting, daylighting can be considered a technique with risks. Lighting levels are difficult to predict and can change in one location from very low to uncomfortably high. Reactions to sunlight are equally unpredictable. Affected individuals can react to it as differently as to heat and cold. Interesting psychological effects have been observed in situations where users were in charge of their visual environment. When occupants are given control of their lighting, they often delay switching to artificial light until light levels are very low (often down to 50 lux). This situation demonstrates the principle of tolerance when the natural cause is understood and optional control is available.

Daylighting is also one problem that illustrates how application of design principles valid in moderate latitudes can bring undesirable effects in the tropics. In a standard procedure, computing daylight

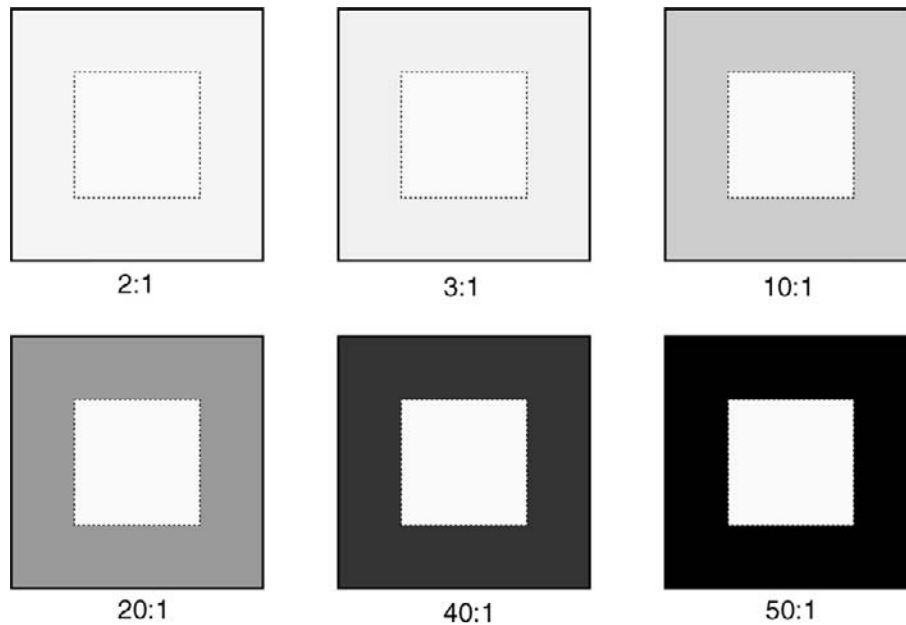


Figure 2.35 Contrast (brightness ratio) can vary from a barely distinguishable value of 2:1 to an unacceptable value of 50:1 which excludes everything else in the field of view.

factor contours is based on an assumption of the CIE (Commission Internationale de l'Eclairage) Standard Overcast Sky. In low latitudes, however, a window providing enough light on an overcast day would typically give too much light in sunny weather. Moreover, designs for overcast skies do not take into account the position of the sun, the time or season variations, and window orientation. These factors in the tropics have primary importance. The CIE International Daylight Measurement Programme is intended to address location differences.

The most general guidelines for daylight control in the tropics are:

- permit view of sky and ground near the horizon only, within $\pm 15^\circ$;
- exclude bright ground and outside surfaces of sunlit louvres or shading devices from the field of view;
- daylight should preferably be reflected from the ground or louver surfaces onto the ceiling, which itself should be of light colour.

Preventing admission of direct sunlight with the use of shading devices and vegetation can control excessive reflection and glare. Internal shading devices are thought to be more effective at natural light control than most external ones. This, however, contradicts good practice for heat gain control, which should take precedence in this instance (Figure 2.36).

Penetration of solar radiation into a building still contributes to high quality lighting, as long as the

sun's rays do not reach the occupants' eyes, either directly or by specular reflection. The problem of penetration of natural light can be controlled in three ways:

- by reducing the incident flux;
- by reducing the amount of contrast in the field of vision; and
- by reducing the luminance of the apertures (i.e., the view through such apertures) as light sources.

Control of direct or reflected sunlight is important to comfort because it reduces glare. It can be achieved either by incorporation of permanent or movable exterior devices into the building design to reduce the view of the sun and bright sectors of the sky, or by using movable interior translucent screens to reduce the luminance of the openings. Reduction of excessive contrasts can be achieved by using light coloured walls and ceilings to give better light distribution. In particular, light coloured finishes should normally be used for walls containing window openings.

In the tropics it is quite possible to exclude direct sun but to make satisfactory use of redirected sunlight: sunlight reflected from the ground and again from the ceiling can provide adequate daylight levels while still reducing solar heat gain. Another approach is to redirect incident (direct) sunlight from the window on to a white ceiling, from which it is further bounced into the interior. If the sunlight can be made to reach the ceiling near the rear of the room, the

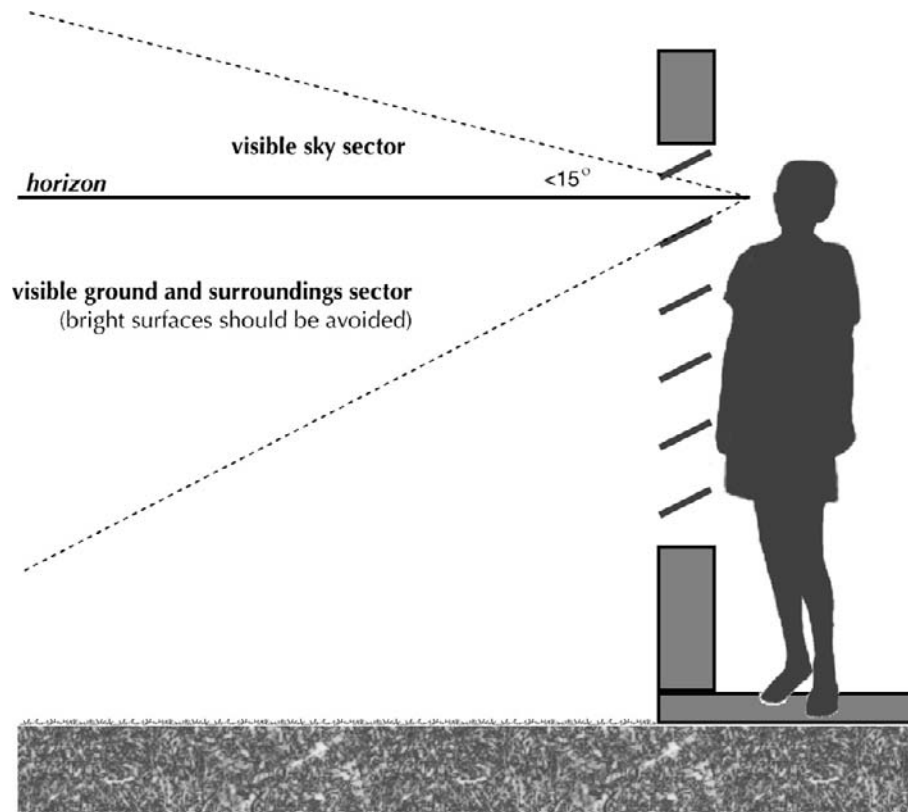


Figure 2.36 Daylighting principles.

reflected light will be received where it is most needed. Most schemes working along these lines propose sunshades or special 'light shelves' covered with some reflective materials and adjusted to redirect incident sunlight towards the rear of the ceiling. Other schemes use special prismatic glazing for that purpose. It is not difficult to provide adequate daylight, often of excellent quality, whenever roof-lighting can be used, which is yet another option.

All radiation, whether visible or not, is ultimately converted to heat when retained within the interior of a building. Because daylight exhibits the highest light efficacy (the ratio of luminance level achieved and total energy radiated) among all light sources, there is some inverse interdependence of daylighting and cooling needs. There is an overall decrease of required cooling when reliance on daylighting increases. This is further enhanced through the related reduction of heat generated by artificial lights.

A key design use of light in a resort is to produce an impression of a cheerful and pleasant environment. This effect can be reinforced by the use of light coloured indoor materials, reduction of indoor partitioning, and appropriate spatial arrangements. Good daylighting design will optimise the collection of nat-

ural light, ensuring its distribution about the building to provide levels appropriate to each activity while avoiding visual discomfort associated with high contrast or glare.

The conflicting requirements of adequate daylighting and preventing solar heat gain have led to the fairly recent development of various forms of transparent insulation such as aerogels, transparent honeycombs and laminar structures. These systems work well in cool climates, but in warm climates their use can cause serious overheating. One of the recent technical advances is the development of special spectrally selective coatings for glazing. For example, low-emittance ('low-e') coatings are transparent in the short-wave (visible) end of the spectrum but their transparency is limited in the long-wave (i.e. infra-red or thermal) end. Low-e coatings are most often used in double-glazed window systems with low-conductance gas filling the cavity to provide added thermal resistance. All these high-tech solutions remain relatively expensive with the cost of a single sheet of low-e or absorbing glass at 30–50 per cent more than conventional glass (Figure 2.37).

The positive effects of natural light on our health have been proven as well as how both an excess of and

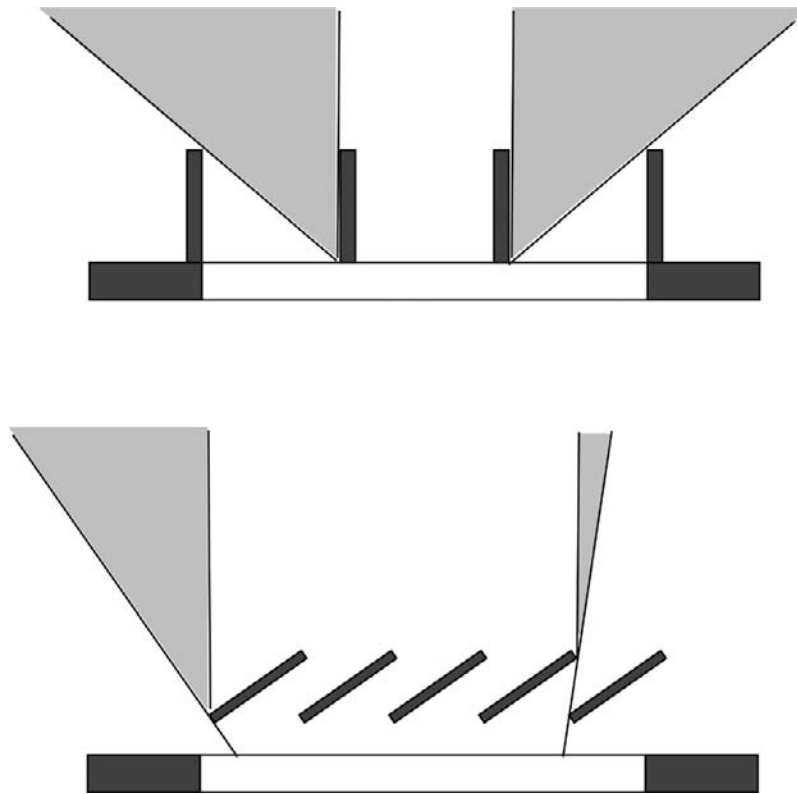


Figure 2.37 Shading principles: marked in the diagram are the 'exclusion angles' where the shade is effective.

being deprived of sunlight affects our psychological condition. Research has shown that 'poor light conditions lead to fatigue of the eyes and brain'. The psychological affects of light reach far beyond the short-term, with 'short, dull days in winter often causing a negative affect on our mood' and lack of sunlight leading to SBS (Sick Building Syndrome). Although artificial lighting can help alleviate these symptoms, it can never fully replace natural lighting.

The requirements for shading devices/light screens include:

- permitting a view of the sky and ground near the horizon only (within $\pm 15^\circ$);
- excluding view of bright ground and sunlit louvre surfaces;
- daylight being reflected from the ground and blades up to the ceiling (which should be light in colour).

The major and most commonly used way to filter natural lighting from entering a building is to use screens. Screens can vary from allowing no light through to allowing almost all light through. The purpose of a screen is to filter light and heat to a level that is acceptable and comfortable for the user (Figures 2.38 and 2.39).

Eaves and overhangs are a simple and effective way to shade an opening during the warmer parts of the day. Depending on the size of the overhang, the shadow created can encompass the opening for the entire day or for just a designed period of time. Eaves and overhangs are an efficient way to create shade, and are an easy and affordable addition to the design (Figure 2.40).

Louvres not only work as an effective shading device but in many cases double as an architectural feature. The openness of louvres allows natural ventilation and helps to create an internal-external visual link. Operable louvres suit a wide range of circumstances as they can be manipulated to suit the prevailing conditions: when the sun is low, the louvres can be closed; when it is high, they can be opened. With operable louvres, the user has control of the amount of light entering a room. Louvres come in a wide range of materials, including metal, glass and timber. The many different properties of these materials can be used to advantage: the reflective surface of metal can be used to allow more light into a room, while timber's matt surface will only reflect a small amount of light (Figure 2.41).

Slats are another common form of shading. Vertical or horizontal members break apart direct

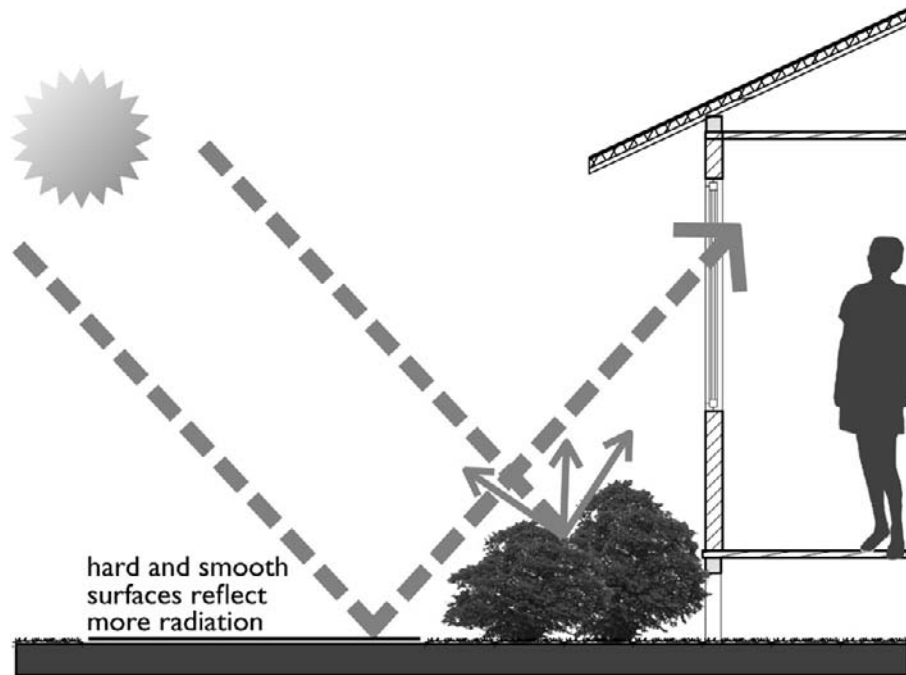


Figure 2.38 External reflections: plants in front of openings prevent most of the unwelcome reflections.

sunlight and, depending on the spacing between the slats, can reduce sunlight and glare factors considerably. Timber and metal are the most common materials used and, like louvres, their use can be determined by their properties. Unless widely spaced, slats are not easily seen through, which means they can double as a visual barrier.

Glass alone has almost no effect on light and heat. Light and heat pass through with very little

hindrance. Tinted insulation glass reflects the majority of heat and allows less than half as much through as normal glass: about 87 per cent of heat passes through normal glass, compared with only 42 per cent of tinted insulated glass. A further step up is reflective insulated glass, which only allows about 22 per cent of heat through (Figure 2.42).

Internal and external reflection depends greatly on the surrounds. If reflected off a surface like metal,

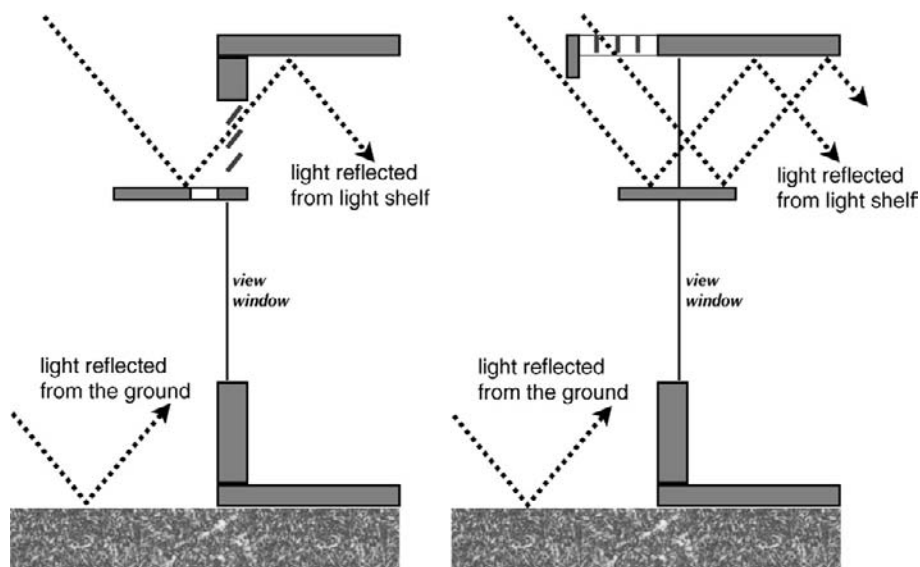


Figure 2.39 Light shelves are quite effective in providing sufficient daylighting levels without associated glare.

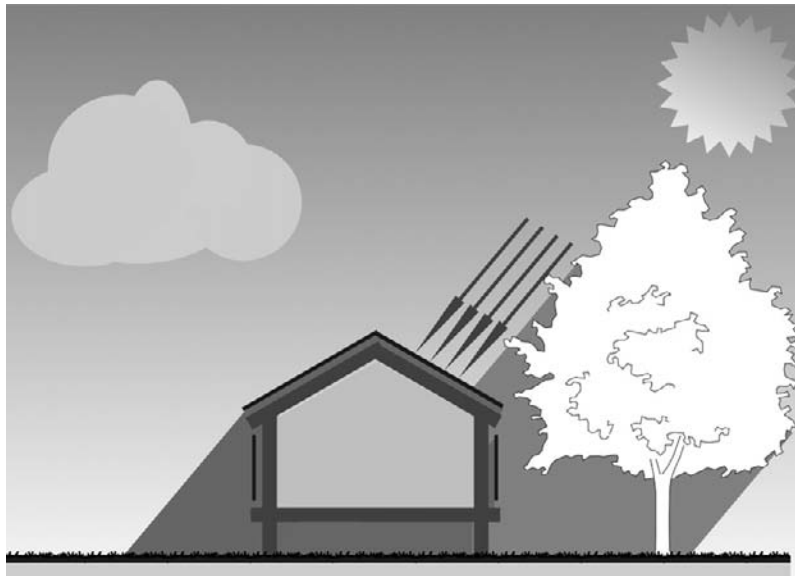


Figure 2.40 Prevention of solar heat gains requires not only eaves or overhangs but, preferably, shading the entire building envelope, which can be done with vegetation as well as a 'parasol' roof and double-skin wall systems.

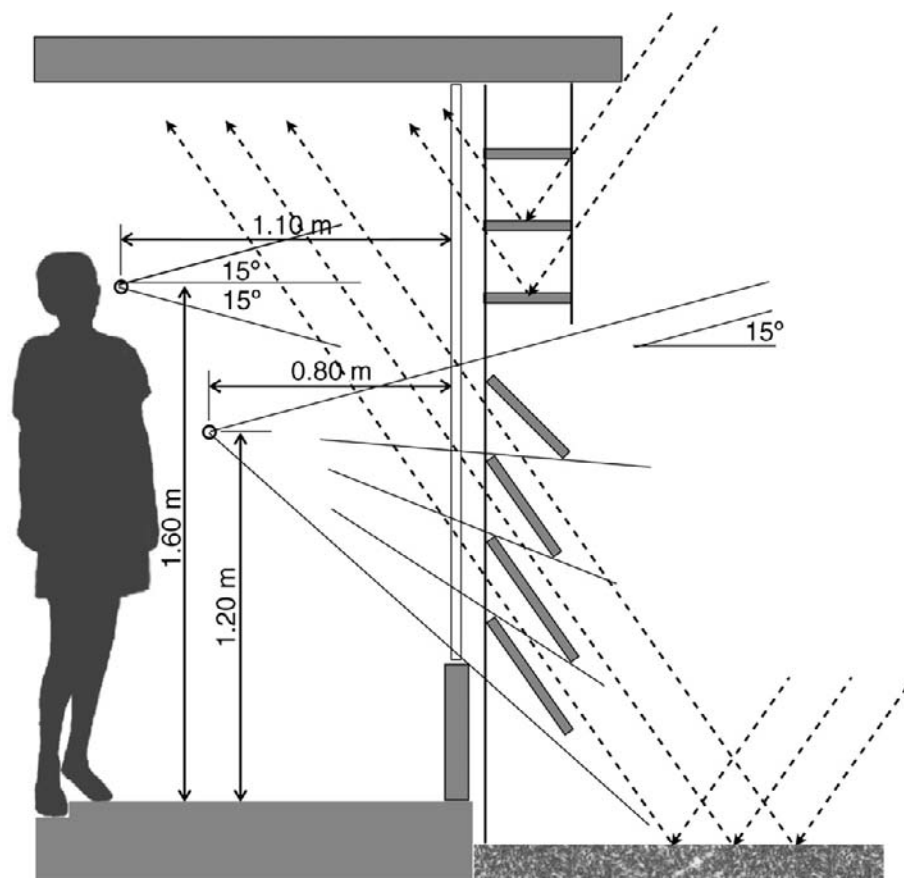


Figure 2.41 Louvres in lighting control.

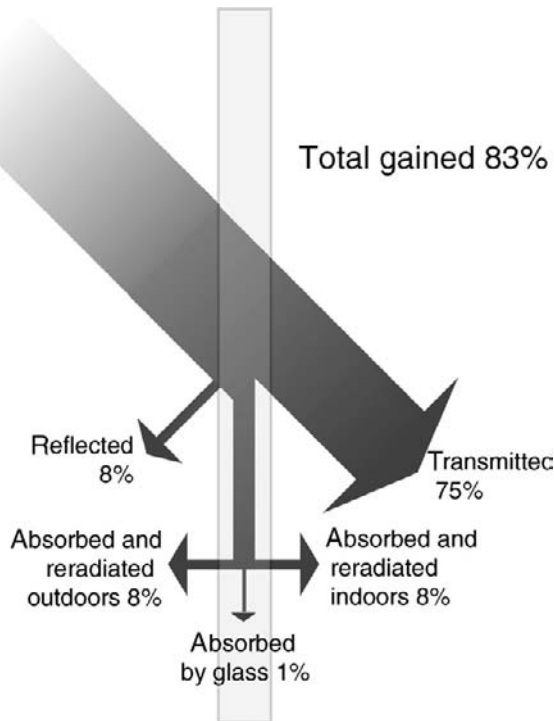


Figure 2.42 Heat transfer through ordinary glass.

the light and glare levels can be just as high as direct sunlight. Likewise, lighter coloured surfaces reflect more light than dark and can create an uncomfortable environment. Internal reflection dims the light source (opening) and in most cases disperses it at an acceptable level.

2.2.1 Artificial lighting systems appropriate for a tropical eco-resort

To implement an appropriate lighting system for the eco-resort there must be consideration given to: the size of the area intended to be illuminated, the times at which artificial lighting is necessary, and the type of light for the application and the energy used by these systems.

Some strategies to lessen the impact of artificial lighting on the environment are:

- Only install the appropriate number of lights in a room and only use the minimum required luminosity for each globe. This can be achieved by taking into account the luminance level and the radius of the effective operation of each light source. Once this is determined, a suitable lighting

diagram can be applied to the space. This removes any excess lighting while ensuring adequate light throughout the buildings.

- Lessen the amount of time that artificial light is used by installing devices such as timed lighting, that switches off after a predetermined amount of time, and light sensors that only turn on when there is insufficient natural light.
- Choose the correct type of lighting for the application. There are currently four major types of lighting systems on the market: incandescent, fluorescent, halogen and light-emitting diodes (known as LEDs). [Table 2.3](#) identifies the amount of energy used by each. A fifth lighting type, the electroluminescent panel, is already in use in specialised applications where soft diffuse light is required, and may find wider acceptance as prices fall.

It is clear from [Table 2.3](#) that the better choice is between fluorescent and LED lighting systems. However, when the times that artificial lighting is to be used in the eco-resort are taken into consideration, it becomes apparent that (with appropriate natural lighting) this would almost certainly be only in the evenings, from around 6pm to midnight, and needed even less in the bedrooms and bathrooms. Considering the relatively short time during which lighting is used, it is slightly more advantageous (cost-effective and energy efficient) to use LEDs. This recommendation has been made because the amount of energy used by a fluorescent tube during its ignition and warm-up phase means that to be energy-efficient the tube must be on for an extended period of time whereas LEDs, even if more expensive to buy, display consistent high performance instantaneously. LEDs also have the advantage of providing a more natural light without the flickering associated with fluorescent tubes, and they have a virtually indefinite lifespan (shortened a little in high ambient temperatures).

Finally, there is also consideration of the aesthetics of what we expect to see as part of the visual environment quality, which is a factor of tremendous importance in the eco-resort setting. Eco-resorts are all about nature and any artificial elements in the surrounding landscape should fade into the unobtrusive background. Powerlines, wind turbines and resort structures should be well hidden from view, preferably using vegetation as visual barriers. Choice of material type and colour should help in blending them with natural elements of the environment.

2.3

Acoustic environment control

Key recommendations in brief:

- Contain sound at its source;
- Introduce functional zoning as a means to control noise;
- Use vegetation and soft surfaces in sound barriers;
- Use masking background sound (ocean waves, rustling leaves) to ensure acoustic privacy.

The importance of the acoustic environment in buildings is often overlooked. Acoustic comfort, however, is as important as thermal or visual comfort since there is a quite apparent significance of the acoustic environment quality in leisure situations. It must be emphasised that the decision whether to use an air-conditioning system or passive control of the indoor climate instead has considerable acoustic implications in a tropical setting. Sound differs from other components of the environment in that it is both a passive and active element of our interactive contact with the surroundings. Furthermore, sound waves are not a part of the electromagnetic spectrum; their origin is purely mechanical and they travel relatively slowly through the air.

Normal sound levels in a resort do not impede its principal functions. Noise levels that could cause nervous tensions or physiological damage are never an issue in this type of environment. The 'sound privacy', however, may become a serious problem. The sounds with information content infringe privacy more than a random noise of the same level. Insufficient acoustic privacy can make occupants annoyed and psychologically stressed. Resort design requirements appear contradictory when, ensuring the privacy of guest rooms, we attempt to provide sufficient number and area of openings for good cross-ventilation. Annoyance or disturbance can appear in a resort environment when sound levels are still relatively low. Such perceptions depend on stimulus quality and information content, duration, past experience, expectancy and number of disturbing events, as well as on personal attributes like physical, emotional and arousal levels.

Responses to a disturbing acoustic stimulus can also vary depending on the activity of the individual and its interaction with other stimuli. For instance, people trying to sleep or relaxing are more concerned and annoyed by intermittent sounds (such as a diesel generator switching on and off) than by continuous

or steady ones. A reliable indicator of human response linking all those parameters is yet to be found. The use of either an air-conditioning system or passive controls can have considerable acoustic implications. An operating AC system can generate a lot of noise audible inside the guest unit, outside (near its location), or both. The majority of passive designs rely on ventilated (open) spaces, which allow sound to penetrate easily from the outside into the building and spread from the inside out.

Three methods of determining acceptable sound levels inside buildings are:

- prevention of noise-induced hearing loss;
- ease of speech communication; and
- prevention of noise annoyance, including sleep disturbance.

Of these three methods, only the latter seems to have a practical meaning for resort design. Rest disturbance, caused by low-level noises, can occur without people being aware of it. Studies suggest that people who are unwell may be more sensitive to noise than others. Since many holidaymakers go to resorts to recover from their mental and physical condition at the end of their annual work cycle, they should be put in the category of occupants oversensitive to noise. For this category, acceptable noise levels have been established at fairly low 25–30 dB(A) in bedrooms and at 30–35 dB(A) in living rooms compared to an average domestic situation where 65 dB(A) still feels comfortable.

The primary aspect of the acoustic design in a resort is the control of noise level at the receiver. The sound environment has a temporal aspect similar to the thermal one. It displays distinctive diurnal differences and the control strategies should take this into account. Both the building envelope and landscaping can be used as a filter and a means of control. The required acoustic quality of a building depends on two factors:

- the acoustic environment in which the building is situated; and
- the acoustic design criteria inside the building's various areas.

It is extremely important that designers understand that there is no point in enveloping the building with components displaying high sound

reduction quality if there are to be windows or other apertures open for ventilation purposes.

In the external environment of a resort building, there are noises that should be excluded from guest units, such as those from the dining room, entertainment areas and playfields. A logical consequence of the 'design for noise control' is grouping of resort functions with similar requirements. Sometimes sounds which might be otherwise quite acceptable, such as the sound of waves or wildlife, must also be controlled. The appropriate zoning plan can be implemented at the resort level as well as at the guest unit level. Indoors, control of noise applies to sounds from neighbouring units, from corridors or other common spaces, and from lavatories. Effective acoustic environment control depends on the successful separation of functions generating excessive noise from areas requiring lower sound levels.

This can be done in three ways: either by moving the relevant parts away from each other, by introducing sound barriers, or both. Once again the use of vegetation is suggested, this time as a noise filter and barrier, to remedy most of the potential problems. It is equally important not to over-design, i.e. not to specify noise levels that are too low. Over-design requires the building envelope to be considerably more massive than it otherwise would be, and hence more expensive. It can also compromise acoustic privacy. Ultimately, it can negate the possibility of using passive control of the thermal environment.

2.3.1 Noise pollution and effective countermeasures

As the objective of the eco-resort is to be a retreat from the noise and clutter of the city, it is important that each unit is not only visually private but also quiet. A simple way to deal with this is to have the units spread over a large area; however, this disadvantages other environmental considerations such as power, water, construction, etc. For these reasons, it is an advantage for the design as a whole to limit the effects of sound travelling between units and other areas of the resort.

The lower density of people commonly found in a resort situation ensures that there is a greater distance between noise source and listener, resulting in a lesser disturbance when compared to an urban setting.

The management of sound can be broken down into:

- handling of the wanted sounds, i.e. creating environments that favour sounds we want to hear,

usually within a room or building, known as 'room acoustics';

- control of the unwanted sound or noise.

In tropical regions, a great deal of life occurs outdoors, outside the building design and its envelope, making noise more difficult to control. Buildings designed to promote wind flow and cooling, with large openings, offer very little in the way of sound insulation. Sound barriers must be utilised instead to help reduce the spread of noise.

When designing to stop noise, it is easier to separate sound as coming from external and internal sources. Passive solutions for control and protection from external noise in a tropical eco-resort can include:

- Distance: granted this is not ideal in this situation but as much distance as possible should be allowed between units to achieve a 6 dB drop every time the distance is doubled.
- Avoid the openings in the building envelope facing sound sources; this can be as easy as turning the units away from each other and away from the noisier zone in the resort.
- Screening: not in the form of artificial objects but rather with the use of vegetation; this is one of the best sound reduction measures – for such screens to be most efficient they should be as close to the sound source as possible.
- Take advantage of the landscape: use ground shaping (and utilise the natural contours and existing forms of the terrain) to form barriers and break the direct line between the sound source and the potential receiver.
- Zoning: by such location of the parts of the building that are unlikely to be occupied for long, for example bathrooms, storerooms, etc., it becomes possible to use these areas as sound buffers; this approach can be used inside buildings to shield rooms which require such protection, or outside, through site planning, where such rooms can be used to buffer noise from other units and noisy resort areas.
- Avoid creating spaces and using building fabrics that are prone to producing sound reflections; for example, giving plywood a texture or punctuations will diffuse the sound rather than reflect it.

Solutions for control of internal noises generated from within the building include:

- enclosing and isolating the source;
- planning: separating noisy areas and quiet ones or placing neutral areas in between;
- reducing airborne sound transmissions by airtight construction and a noise-insulating envelope.

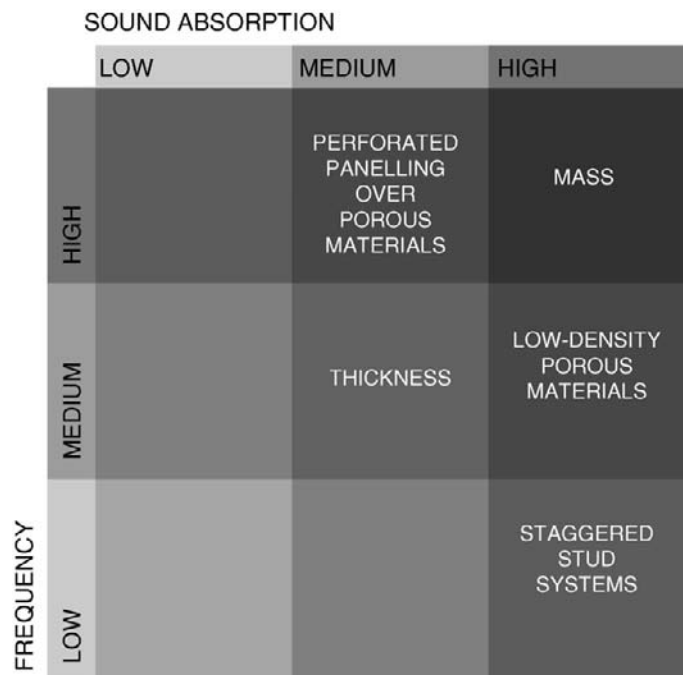


Figure 2.43 Effect of various sound barriers.

Noise within a space can be broken down into its direct and reverberant components. When insulating against noise, both aspects of sound propagation must be considered. Direct noise can be diminished by the use of a screen between the source and the listener, as mentioned earlier. Reverberant noise can be attenuated using absorbent materials. The absorptive ability of different materials is based on the fre-

quency of the noise to be screened out and the mass of the material used in the barrier. Porous absorbers (fibrous or interconnecting cellular plastic forms, etc.), such as loosely packed earth, absorb higher frequencies. Membrane absorbers, such as plywood, absorb the lower frequencies better. Therefore, the material used must be selected to match the frequency of the sound (Figures 2.43 and 2.44).

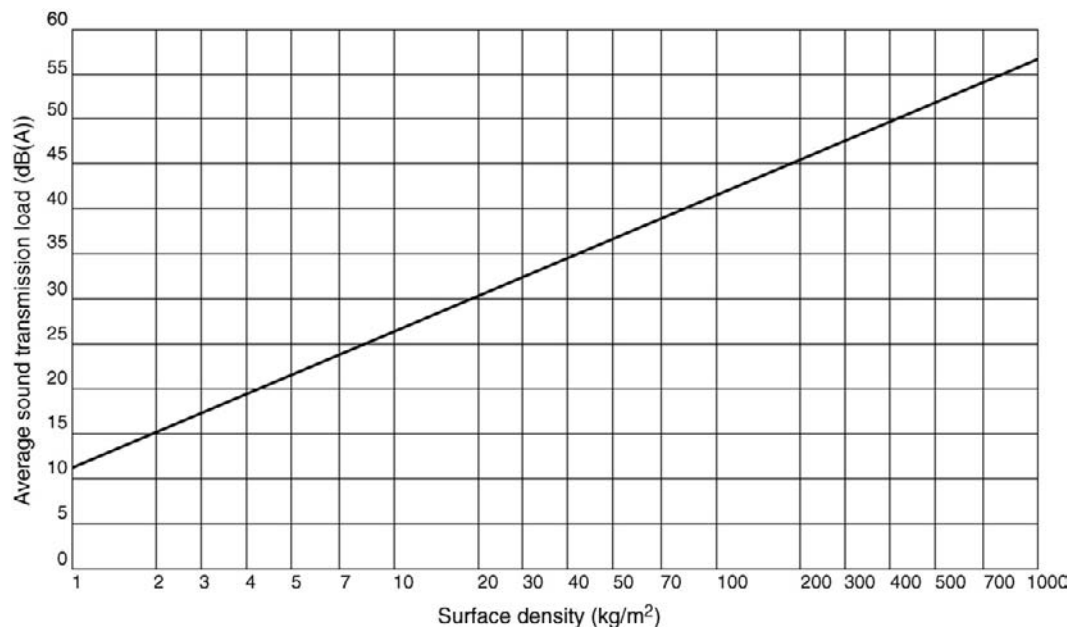


Figure 2.44 'Mass law' of sound insulation.

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2.4

Control of smell, touch and psychological factors in environmental perceptions

In acting as a filter between internal and external environments, the building enclosure modifies the climate not only in terms of heat, light and sound, but psychological factors as well. Several different effects of design and material solutions can be included. In broad terms, they can be presented as forces leading to certain behaviour, for instance complaining, or as modifiers of certain perceptions – normally related to physiological responses. The desire to achieve comfort, or more precisely to avoid discomfort, is perceived as a powerful motivational drive supported by a sophisticated psycho-physiological control system.

Tactile and olfactory environments play an important role in overall comfort as psychological reactions may be expected in response to all sorts of stimuli carrying information. Vision, hearing, smell and touch are the senses through which our control system's perception of the environment can be altered. The input from any receptors influences the entire system and can produce output information related to, for example, the thermal environment. For instance, light colours (light blue, white) of walls can change the perceived indoor air temperature, making an impression of 2–3 K lower than the actual one. Similar effects can be expected from the touch of smooth surfaces as opposed to rough ones.

In addition, large open spaces give an impression of being somewhat cooler than they in fact are. Higher-than-actual temperatures are associated with stimuli of high noise or light levels. On the other hand, if people are dissatisfied with some aspects of their environment, their tolerance to noise decreases. It has been demonstrated that general satisfaction with a neighbourhood can make people tolerate sound levels 5 dB(A) higher than otherwise they would.

Sunlight and daylight are not just sources of light. They are required for their thermal, visual and psychological benefits. They are associated psychologically with the inflow of visual information about the outside world. The importance occupants attach

to daylight and view seems to depend on subjective assessment and individual preferences. Nevertheless, one may expect that the role of sunlight and daylight in satisfying people on holiday will be far bigger than in most other situations. Interiors can be made to look gloomy or cheerful depending on the quantity and quality of available light. The mood generated by the environment undoubtedly affects the mood of its occupants.

The physiological reactions are important but they are not the only factor determining comfort in humans. Standard ISO7730 of the International Standards Organization (ISO) and ASHRAE's Standard 55–81 redefined human thermal comfort in the early 1980s as a certain state of mind, following subjective assessment of the current physical conditions. Both the physiological thermoregulation and the mental attitude started to be considered equally important in adapting to a given set of conditions. Thus, the possibility to influence comfort by utilising that 'subjective assessment' had to be incorporated in thermal modelling. A very significant step in that direction was taken when A. Auliciems proposed the Psycho-physiological Model of Thermoregulation in 1969 (final version published in 1981). For nearly two decades it remained the most comprehensive representation of human responses to conditions in the surrounding environment.

The significance of the role that is played by behavioural adjustments in the process of environmental adaptation, however, is undisputable. Adjustments such as changes to clothing and eating habits, and changes to energy expenditure and to one's daily pattern of activities are all considered important means to avoid or diminish thermal stress. On the other hand, as indicated above, it does not seem possible to escape consideration of mental attitudes. In the summer, for instance, the same conditions may appear uncomfortably hot and/or humid to someone compelled to stay at home or go to work, but rather delightful to someone resting on the

beach. Their (very) different thermal judgements will be influenced by their attitudes derived from their (very) different personal circumstances.

This undoubtedly complex issue becomes particularly important in certain situations. The indoor environment in tourist facilities offers a context that is an example of such a situation. If one accepts that behaviour is one of the fundamental methods of body temperature regulation, it is immediately apparent that behaviour and mental attitude, two factors differentiating leisure from work and domestic chores, are, in principle, the factors responsible for different perception of environmental conditions. The psychological position of a person who is able to make a choice about their particular environment could present the exceptional case – by ‘disabling’ their ‘early-warning’ physiological systems.

This was evidently present in the famous Hawthorne experiment that produced the ‘Hawthorne effect’ – psychologically-driven satisfaction as a result of socio-engineering and irrespective of changes to various environmental (for example lighting) conditions, as long as, for instance, the environmental controls were made available (McConnell, 1986; Sommer, 1969). It is the building occupants’ intellectual understanding of the situation that allows them to realise that the conditions will not prevail for a dangerously long time. This position is quite different from the one of a person subjected to discomfort, about which they can do nothing, and who can see no reason to believe that the experienced discomfort is temporary. It was Macpherson (1980:30) who noted that:

...whilst thermal comfort rests on a firm physical basis, it is ultimately a subjective judgement much influenced by the past experience and the prevailing emotions of the person concerned.

One must agree that psychological attitudes, expressed as preparedness for given conditions, related prejudices, biases and preconceptions, significantly impact on comfort perception in the period preceding accomplishment of initial acclimatisation. The adaptation hypothesis, developed by Auliciems, explains how techno-culturally-based expectations and average outdoor conditions act as:

negative feedback which attracts the thermal perceptual system’s set point, thereby damping load

error (discomfort/dissatisfaction) within the behavioural thermoregulatory system (de Dear, 1994:108).

Since purely physiological models appeared to offer a rather inadequate explanation of a great many comfort and discomfort manifestations, the Psychophysiological Model (Auliciems, 1981) proposed incorporating psychological control, which was exercised at four levels of integration: discriminatory, affective, cognitive and effective. The role of the modifications introduced by a building enclosure has been very difficult to establish. Figure 2.45 presents the first attempt at incorporating this consideration in the model.

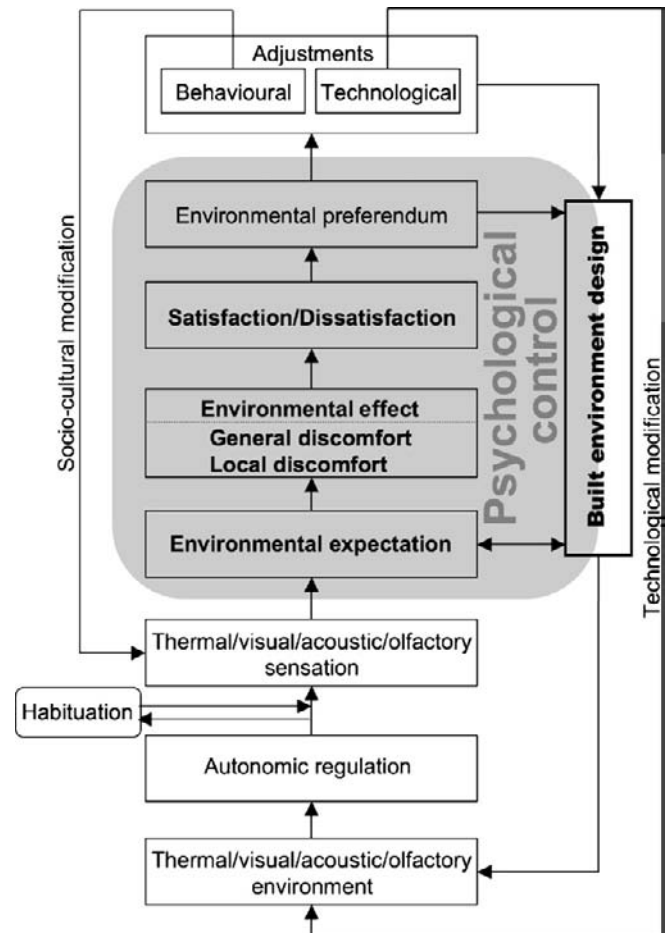


Figure 2.45 Built environment design in a biotechnological model of environmental adaptation.

Part Three

Tropical Eco-resort Design

There is an alternative to energy-consuming mechanical air-conditioning: passive climate control can improve the interior environment while conserving energy. If air-conditioning is used, it can be made more responsive; computer-operated controls can be used to adjust the climate settings indoors to changes in the external environment. When artificial lighting systems are operated, their use also can be based on computer-controlled monitoring and precise measurements of the environmental conditions. Alternatively, we could return to a greater use of daylight and natural ventilation, at least in the relatively smaller buildings of the eco-resort.

Part Three presents a catalogue of solution ideas to help in overcoming the identified problems. Interclimatic tourism is a relatively new use for tropical buildings and offers a mix of requirements, which is very challenging to designers' skills and knowledge. The difficulty is compounded by the hybrid nature of tourist and recreation facilities – being also the workplace for the locals. This situation creates an almost infinite number of variables, making the task of systematic research on a global scale extremely difficult. The problem is further obscured by the current climate comfort standards – substantially different in different sources.

Low-budget establishment designs, as the vast majority of eco-resort projects are destined to be, rarely attract top designers, because typically architect fees are paid in proportion to the total cost of the project. Many architects and developers claim that their clients are not interested and will not even consider the climatic qualities of a passive design. Accordingly, in the area of bioclimatic design there are very few examples of outstanding architectural quality. Thus, even if this has nothing to do with the technical aspects of passive climate control provided within such buildings, there are very few designs to act as exemplars. While bioclimatic design offers much potential for innovation and market-conscious differentiation, only a handful of designs draw on the character of the site and wider geographical region.

Even more difficult is to find a design that explores opportunities arising from interdependence and interconnection between the architecture and the natural environment. Taste and social behaviour continue to be forged by the

North American and, to a lesser extent, European models of 'mass culture' – as portrayed by TV. In the light of an increasingly aggressive push for world markets, local communities and concerned individuals are often unable to differentiate their own interests from those of international investors. Characteristically, low energy architecture and related issues receive more publicity well away from the tropics. This could be linked to the current situation where most of the research and publications on passive and low energy design attract government support in the cool-moderate climate countries of Europe and North America. The very near future might show this to be a somewhat blinkered view.

Speculative builders and developers construct the majority of tropical resorts; eco-tourist accommodation is produced by an uncoordinated industry; and little real research is carried out and even less acquired knowledge is passed on. Very little effort (if any at all) is related to the important design criteria and considerations such as climate aspect, ventilation, insulation or specific needs related to different uses. Most resorts are poorly sited and poorly designed to cope with the climatic conditions of the tropics. Generally, effort is spent on style, features, frills and extras without any understanding of the actual tropical design requirements.

Because of the mass culture-driven market, building types and elements are designed with little or no regard for their effect on human comfort, or even to the performance of materials. It is no surprise that more often than not they do not reflect the regional character, but present themselves as transplanted misconceptions evolved in different climatic settings and for different kinds of use. Perhaps the most decisive impact has come from technological advances following World War II. The 'internationalisation' of tropical architecture started in the 1950s with the introduction of new building methods and a number of new ancillary services, chiefly the widespread use of air-conditioning. Ultimately, this led to a crisis, manifested in abdicating the architect's responsibilities to mechanical engineers, and diminishing the role of the architect's imagination in the design process. Widespread acceptance of mechanical means for providing desired comfort levels is

interpreted as 'one of the more unfortunate aspects of modern global development? As R Punch (1994:6) put it:

One result [of the revolution in building systems] as far as buildings are concerned has been an almost 'international conspiracy' to impose standards for people and equipment. [...] So that if architecture had a sense of location based on climate, had a sense of tradition based on understanding a way of building, then the new technologies moved new buildings in the opposite direction, i.e. denying architecture any sense of location, denying tradition any sense of continuity, denying materials any sense of place, and

above all defying climate with equipment and technology.

On the other hand, nostalgia in architecture is manifesting itself as a fashionable 'return to the roots?', to a large extent poorly researched but in big demand, adding little to the discussion about the way forward. The proper but much more difficult way to achieve progress would be to define precisely the problems, their scientific constraints, their cultural and social backgrounds and respective building traditions, so that the resulting architecture would match the needs of the users. This is not to say that design must be deterministic, as architecture is always about creative design.

3.0

A question of environmental response

Variety and novelty are what people seek in their leisure environments. To satisfy our recreational needs we often feel that we have to go to some other place, one that offers something new and different from our daily experience. For our recreation, we usually leave behind our well-known, standardised and uniform everyday surroundings. In doing this, we pursue other cultures and other climates. Tropical environments have a lot to offer in this respect and are very different from what tourists experience at home. However, while most facets of a tropical holiday are desired and enjoyable, the extremes of the climate can easily become a major concern.

The built environment is usually created to modify the impact of a climate. The extent of this modification can vary. It is recommended that the process of 'climatic filtering' begins outside the shelter: deliberate choice of plant types and landscape elements as well as siting and the juxtaposition with surrounding buildings can maximise potential for shade, wind and other microclimatic changes. Initial design decisions should focus on the siting of the building, its basic form, the arrangement of the space (its functional design), the type of construction and the quality of the indoor environment to be provided. A high quality outcome will depend on the harmony of these elements with each other and with the building's environmental setting.

Although we understand the laws of physics which determine the behaviour of the individual elements of the environment (heat, light and sound) we know very little about the apparent complexity of their behaviour in the building environment situation. Mathematical models used for that purpose contain many simplifying assumptions, which render them too generic except for the very simplest static cases. Moreover, comfort should be perceived dynamically; its parameters vary spatially in a building and appropriate application of this knowledge may be used for necessary modifications. Comfort parameters also vary in time and tend to influence the occupants' perceptions in accord with seasonal and diurnal changes. The latter calls for the users' involvement in provision of comfort. Occupants themselves

may take appropriate action to adjust passive controls to improve indoor conditions more accurately corresponding with their needs.

Why do we need to respond to the environment and how can we go about it? The answers must be given in terms of a holistic integrated design approach and include location, site planning, constructional design, envelope design, building design, materials, functional programme, room design, and operations' management.

The objectives of passive environmental control in tropical coast conditions can be expressed by the following broad strategies:

- to prevent heat gain;
- to maximise heat dissipation;
- to optimise lighting levels;
- to reduce levels of noise and vibration;
- to influence tourists' perceptions of the environment in such a way that local climatic conditions are readily accepted.

In the era before mechanical systems, environmental comfort in the tropics was achieved by means of passive climate control supported by adjustment of behaviour to particular conditions. There are still in place a number of vernacular solutions in regions that represent a variety of tropical climates. Undoubtedly, some of them can be adapted to a tourist resort's environment, emphasising its regionality and enhancing its low energy design. It can be proposed that replacing 'conventional' building design, together with its fossil fuel-powered heating, ventilation and air-conditioning systems, with 'bioclimatic' design is the most appropriate approach. The main feature of the latter design is its passive control of indoor climate. In such buildings, creating rather than breaking links with the building's surroundings forms the indoor environment. As a result, passive design is able to provide an indoor environment quite similar to the conditions found outside. Such conditions, in turn, can be quite adequate for satisfying the needs of leisure travellers to the tropical coast.

Undoubtedly, the major concerns in the design of indoor environments in the tropics are temperature,

humidity and air movement; and that is where powered HVAC systems fit in. Air-conditioning removes any need for caring about indoor climate from the catalogue of the architect's responsibilities. Architectural design might appear to developers as a process simple enough to be handled by less qualified (and cheaper) designers or even drafters. That tendency shows its results particularly in the quality of the functional design and the ubiquitous presence of HVAC systems. Alternative attitudes on the part of the designers, rather than alternative technologies, are what is required to solve many of the energy problems in buildings. It appears to be the last moment for the architectural profession to intervene. In terms of energy conservation, architects can again play an important part in determining the energy efficiency of buildings – by designing building enclosures that play a positive role in the creation of the internal environment. What can also be done is to seek inclusion of human adaptability into the practice of climate control.

Architectural design is an indivisible entity which, one could say, is about achieving best performance in all aspects of the 'big three': function, form and structure. Those three components are common assessment criteria for any architectural design. What is different and specific, when referring to architecture in the tropics, is the emphasis on response to climate in order to achieve the best results in any of the three. To design architecture means to design a number of interdependent systems embedded in their surrounding environment. These systems are, in turn, subject to a range of interactions affected by daily and seasonal changes in the outside environment, and by the requirements of occupants, varying in time and space. From this viewpoint, it also appears that architectural design is yet another possible method of energy conservation.

Appearance is frequently the only aspect of any concern to many architects. On a global scale, but more often as a very local issue, some radical views have emerged demanding that aesthetics should give way to energy conservation considerations. It is worthwhile to note that some built-in energy-saving devices, particularly shades, can be employed to obtain aesthetic effects far beyond those available to architects in higher latitudes. This is because shading must be used so extensively. Even otherwise dull and uninteresting architecture can become appealing, lively and vibrant as a result of the play of light and shadows created by the shades. Elements brought by passive design to the buildings cannot only be functionally adequate in performing a specified task but the effect can be creative and 'refreshingly sculptural',

resulting in interesting texture on the facades. However, examples of tropical architecture seen around the world demonstrate that there is seldom a satisfying functional dependency which fenestration design for a particular facade shares with orientation.

One has to accept that the natural environment is the primary interest of the visitors to the tropical eco-resort, and that the economic results of a tourist enterprise depend on both consumer satisfaction and the facility's operating costs. It then becomes obvious that architects should apply their skills to making experience of the environment possible and to taking advantage of what the environment offers 'for free', i.e. the sun, breeze and vegetation, to enhance the resort's unique microclimate. It is through the way the building interacts with the environment that architecture of any epoch and locale would normally be perceived, understood and appreciated.

But in a special position that the wilderness areas of the tropics hold for international communities, there are two other very important considerations. Firstly, architecture is there to be a frontline zone, where visitors come into contact with the remnants of this environment, which perhaps also has a world heritage quality. The architecture of tourist facilities, their perimeter and closest surroundings are a space where most of the visitors experience the differences that attracted them to the tropics in the first place. And secondly, it is expected that the location of the resort and the way in which the facility operates will not hinder efforts to preserve what is left of this unique environment.

On the part of designers, the fundamental requirement is a greater understanding of the total nature of the physical environment in buildings, how it is created and, in particular, what role is played by the building enclosure, the system of walls, roofs, floors and windows, manipulated by the architect in creating this environment. Appropriate decisions made by the designer about perimeter elements of the enclosure have a direct influence on the amount of energy consumed by the environmental plant and can completely remove the need for external energy. Clearly, the design of the physical indoor environment is very much an architectural problem and needs to be considered at the earliest stages of the design process.

As stated previously, adequate passive climate control can be achieved by appropriate responses of resort buildings to the local climate. This process of control can be accomplished through thoughtful placement of functions within the resort and its buildings, orientation, landscaping and envelope

design. Moreover, passive climate control should correspond with specific needs of the users and exploit the identified differences between tourists, who are only short-term visitors to the tropics, and the (acclimatised) residents. The different requirements apply not only to the volume, shape and functional layout organisation of the building, but there is also a difference between physiological responses. Some early research findings suggest that tourists' attitudes could be the most important factor influencing their perception of comfort. The process of 'psychological acclimatisation' occurs alongside the physiological one, and building design can reinforce both.

Passive design is a viable option for tropical resorts and this has been demonstrated in many places. This can be taken also as proof that biases against tropical conditions might have been built upon experiences derived merely from the use of resorts built to the wrong design. A detailed analysis of user preferences implies that a resort's design should be considered a success when the indoor climate is not significantly more stressful than the outdoor conditions. Such an outcome is achievable with the use of passive means. One might even think that a combined effect of all the features proffered would ensure conditions that are actually better than outside. Improvements may be accomplished in areas of mean radiant temperature (where there may be substantially lower air movement) available even in still weather conditions, light and sound levels – better responding to comfort requirements, and others. There is a widespread belief among researchers that passive climate control is an economically and environmentally justified alternative to mechanical systems.

Architects who would like to influence indoor climate through enclosure design have a broad range of means at their disposal to do so. Their design decisions regarding the building's form, design of envelope elements, materials used, and others can minimise the impact of extreme conditions found outside and the difference between outdoor and indoor conditions. This can be accomplished without input from powered systems. Grouping and separating various functions within a resort can meet some of the specific indoor climate requirements. Varying building volume and/or envelope design in line with different functional requirements can then further enhance the desired outcome. Many means of passive climate control are a heritage brought to modern design theory and practice from vernacular architecture. Hence, their use could bring back the distinctive regional character to the design. Both the quality of architecture and the natural environment would greatly benefit from maintaining this

character – wherever there is the local architectural heritage to draw on.

It appears that interest in passive design has already grown into a whole industry. Alternative energy sources are increasingly attractive to the public. Depletion of natural resources and subsequent energy price increases, combined with the economy of scale, could soon result in a significant improvement of economic indicators for those solutions, which are already quite competitive. Economic feasibility lays down a solid foundation on which arguments for implementation of such solutions can be based. What is even more important is that economic benefits of passive systems do not have to be achieved at the expense of the environment.

It seems worthwhile to note that there is probably nothing that shows more variety than individual preferences. On the other hand, there is probably nothing more prone to generalisation than such preferences. Hence, the most important conclusion that can be drawn is that satisfying comfort requirements must be approached with caution. It is not desirable to design for the 'ideal environment'; it is more beneficial to limit extremes, devise simple and visible relationships to the natural climate and provide means for individual occupants to control conditions in their 'personal environments'. The indoor climate should respond to the human need for variety rather than opt for satisfying some sort of uniform and unanimously 'acceptable' conditions, whatever these might be.

Efficiency of the resort design depends on an accurate response to the environment in which it is located. The environmental response should address concerns that are related to both abiotic (climate and topography) and biotic (flora, fauna and human factors) environments.

Efficient resort design starts with careful, well-researched site plan and landscape design, which are vitally important to an environmental response offered and to enhancing features of the site. All facets of the design have to take the environment as a broad context for the tourist development and address its many aspects: physical, social, cultural, historical, legal, and economic, to list a few. All tasks have to be carefully planned and coordinated. This requires a thorough investigation of local conditions, their evaluation, and analysing possible impacts that the development might make. Only then can decisions be made about positioning of buildings and their type, circulation routes, facilities to cater for uses other than accommodation, building materials, technology to be used for construction or, indeed, whether to proceed with the development at all.

A sequential design process, in which dynamic interaction with the environment is being considered long after the building's 'function, form and structure' have been fixed, is also wrong. A product of this process will inevitably deny links with the environment and, consequently, will depend on cooling/heating and lighting devices instead of responding to the changing conditions by virtue of its form and intelligent use of materials. It should be expected that the design context is integrated from the outset and that a designer should respond to the environment; this response will serve as a basis of the human livability in an expressively aesthetic manner. We prefer to think that passive design, energy conservative design and good design are the same thing.

The design principles discussed in this book can be applied to many projects in various situations. Some of them have been introduced to various building schemes and have proven to operate successfully and without any special problems, benefiting their users. Using these approaches, it is possible to formulate goals for architectural design in the tropical world aiming at short-term visitors. To begin with, it would be meeting actual needs of the users and not the needs that are presumed to be theirs from a perspective of different climate zones or different positions against the investment (the developer versus user 'conflict of interests' should always be resolved in favour of the latter). This involves:

- providing comfort levels acceptable for a significant majority of users;
- offering an environment able to cater for lifestyles compatible with expectations of visitors to the tropics;

- ensuring construction and operation at the lowest possible cost over the entire life of the project, primarily in terms of demand for energy and, subsequently, an impact on the natural environment and facility's operating costs;
- use of passive climate control devices and other means to control indoor climate, such as landscaping and building layout, in an aesthetically pleasing manner;
- satisfying not only requirements of indoor environmental comfort, but safety and privacy as well as functional and structural integrity.

Some of the above objectives can prove very difficult to accomplish but the effort should be made because climatic responsiveness ensures health and sustainability at low cost. Also, central to appreciating architecture on the tropical coast is how it fits the climate and how it takes advantage of the sun, wind, and vegetation. This can be done only if particular needs of the users are assessed and satisfied.

The indoor environment is created by a large number of building elements interacting in a rather complex manner. From a physical processes standpoint, a building and its environmental control systems are a microcosm of complexity, where the only independent variables are the space and time dimensions. All other parameters are dependent variables and so each must be considered in relation to the others. This means that the fabric conduction processes, air movements and short-wave flux injections, for example, must all be treated in a simultaneous and time-dependent manner.

3.1

Location

Key recommendations in brief:

- Analyse climate factors including sunlight, temperature, precipitation/humidity and winds;
- Avoid locations that have a history of unstable weather conditions;
- The selected location should have potential for good all-weather access;
- Preferable locations should offer a variety of local resources from supportive communities, through some building materials, to food and water.

Many tropical areas yield to recent trends and open up to tourist developments. Many such 'new areas' lack access and infrastructure and are not very attractive to local dwellers. A good example of this can be seen in northern Australia. The number, character and variety of coastal environments in the region can be illustrated with a sample taken between Kennedy Bay (lat. 18°00'S) and Donovan Point (lat. 16°00'S).

In this part of the coast there are 34 islands and islets close to the continent. Most of Great Barrier Reef islands are small (with an area less than 4 hectares) and lack suitable landing places and fresh water. They differ in size, geological origin, appearance, vegetation cover, soils, available water sources and a great many other aspects. Distances between some of them and the continent are very small; in several cases the distances do not exceed 1 km but this is enough to deny them a bridge connection. For most of the year, they are infested by sandflies and mosquitoes. Given the difficulties, it is not surprising that until 1956 all island resorts closed for the humid summer months. And yet now, there are several all-year island resorts operating in the area and a number of others are to be developed. Tourist developments bring with them opportunities, which attract residential interest and other uses.

The choice of location is an aspect of a design endeavour that architects normally would not be able to influence. Nevertheless, it is this kind of decision which must be thoroughly analysed. Each location has unique abiotic (topography and climate) and biotic (flora and fauna) characteristics. Most notable in the tropics is the climatic factor. The location climate, both outdoors and indoors, will be perceived though the subjective filter of the visitor's attitude. In comfort considerations, the importance of psychological factors influencing perceptions of the environment is

greater than elsewhere. Nevertheless, even the most expansive tolerance limits do not cover all conditions. The bioclimatic strategies hence should be employed to improve building performance and remove or limit the need to provide comfort with mechanical devices.

The designer should have a better understanding of the microclimate and this, in turn, requires a method to extrapolate its characteristics from regional data. A relationship between the external climate, as presented through available climatic data, and indoor requirements should be developed into various measures to prevent overheating, induce cooling effects, reinforce airflows, and prevent excessive light and noise with the aim of improving the environment-building interaction.

The location climate is the averaged (over a relatively large area and for extensive periods of time) weather condition derived from data collected at one or more stations. It describes the condition that prevails in that location. Hence, choice of a location for the development, from a climatic point of view, determines only the general climatic characteristics. The tropics have been subdivided, based on climatic factors, for several different purposes: local government, regional development, weather forecasting, or tourism administration. In several tropical countries, climatic zoning has been suggested to enable preparation of guidelines for response to the climate through the building design.

It appears, however, that the zones, based on climate-only characteristics, can only be used as very general guidelines for the building design response recommended in local conditions. Small island locations in particular have been largely overlooked in this respect and the description of climatic conditions in these places is based mostly on a mere extrapolation of data from meteorological stations hundreds of kilometres away. Islands should be considered individually since their microclimates are shaped by the sea rather than by the land, with all the consequences of this fact; for instance, wind incidence is higher and it can come unimpeded from any direction. Although annual average humidity in island locations is high, in summer it is usually lower than at corresponding land locations, and the temperature range is moderated by the masses of surrounding water.

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3.2

Site planning

Key recommendations in brief:

- Analyse characteristics: topography, soils, geology, hydrology, vegetation, and wildlife;
- Prepare an Environmental Impact Assessment;
- Evaluate infrastructure to determine whether resort location is ecologically appropriate;
- Locate buildings, roads and walkways to minimise environmental impact.

In general, site planning should be conducive to reducing unavoidable impacts. Besides the actions listed as key recommendations, the designer/developer should: cluster buildings or build attached units to preserve open space and wildlife habitats, avoid especially sensitive areas including wetlands, and keep roads and service lines short. Leave the pristine areas untouched and look for areas that have been previously damaged to build on. Situate buildings to benefit from existing vegetation: trees on the east and west sides of a building can dramatically reduce cooling loads. Hedgerows and shrubbery can help channel cool breezes into the building.

3.2.1 Hill influence

Many locations on the tropical coast contain two distinct topographical features: a beach and a hillside. Hills and other small differences in topography, whether natural or artificial, can create large modifications in the microclimate. Many of them can be attributed to the cool air behaving somewhat like a liquid. The topography of a site, plants and buildings can create 'pools' where air cooled at night can 'flow in' (catabatic airflows) and gather, or 'dams' impeding free flow of the air through the site. Topography that would promote air movement is preferable because of the importance that the breezes have for comfort restoration in hot and humid areas. Slopes can generate air movement through uneven air temperature distribution. Many architects prefer a mid-slope location of buildings for its aesthetic qualities and views. The phenomenon of the 'warm slope' or 'thermal belt', i.e. mid-section of the slope being warmer, particularly at night, than the top and foot of the hill, however, makes such a choice questionable when considering its effects for night-time use. While such a location is bioclimatically beneficial in cool and moderate cli-

mates, it may not be right in regions where higher temperatures are a disadvantage.

Hills also modify winds' strength and direction as well as precipitation distribution. They can deflect wind in both its horizontal and vertical stream patterns. Measured wind velocities are higher near the hilltop on the windward side and at the sides on the crest. In sunny weather, these places will experience the smallest temperature rises: the wind will rapidly remove heat by forced convection, substantially reducing potential warming. The lowest speeds will be recorded near the bottom of the hill on its lee side. Similar differences can be observed in precipitation distribution: rainfall is more intensive on the windward side and weaker on the lee side of the hill. Such a precipitation pattern follows adiabatic processes of condensation and precipitation in the ascending air.

In terms of radiation effects, hillsides receive an impact depending on the inclination and direction of the slope. The east and west sides of a hill receive more radiation than the south or north ones. It is because, in the tropics, the sun takes positions that are perpendicular or almost perpendicular to hill slopes in its east and west positions rather than while at the zenith when its beam is at a sharp angle to any inclined surface. However, the problem of radiation can be dealt with by designers in many ways and therefore wind incidence, much more difficult to control, remains the dominating consideration.

3.2.2 Sea influence

In the absence of winds generated by macro-scale weather phenomena, large bodies of water can remarkably influence local air movements. It is because water (having a higher specific heat than land mass material) is usually cooler than land during the day and warmer at night. In the diurnal temperature variations, air cooled by the body of water moves low over the land during the day creating a cooling effect of as much as 5 K. At night, the direction of such breezes is reversed. Water also moderates extreme temperature variations raising winter minimums and lowering summer heat peaks. The effect is measurable throughout the entire coastal zone and is the main climatic factor differentiating the zone from the surrounding hinterland areas ([Figure 3.1](#)).

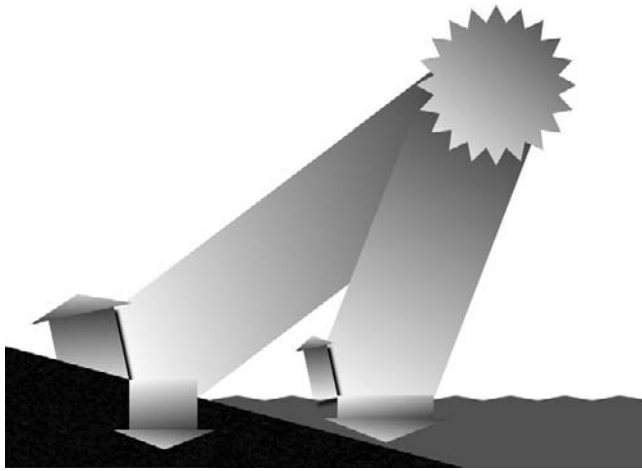


Figure 3.1 Every large body of water acts as a heat sink during the day.

3.2.3 Vegetation influence

The natural vegetation cover of the land tends to stabilise temperatures and decrease extremes (similarly to water) while artificial surfaces tend to exaggerate them. Plants are a natural absorbent of heat, light and sound. Heat radiation is followed by much less re-radiation from vegetation due to converting a large portion of the heat energy in several biochemical and biophysical processes. Temperatures at 0.3 m above

grass – moist grass in particular – tend to be 5–8 K lower than those above exposed soil (Figure 3.2).

Extreme care should be exercised when removing and/or planting trees. The trees should offer shade for roofs and walls but should not obstruct air movement around buildings. Varieties with high canopies and few or no branches below (for instance most palm trees) are a good option. Dense shrubs and low growing trees can be used to create walls of ‘wind funnels’, i.e. formations increasing wind speeds and channeling them along the desired paths. The speed increase actually achieved will depend on the size of the funnel’s ‘walls’ (length and height), their density, wind direction and other factors. This effect is disputable as it is only effective for one wind direction. For others the ‘funnel’ could become an obstacle to effective site ventilation.

3.2.4 Spatial organisation

The development site should be as large as possible. It can be proven that damage to the natural environment is directly linked to the density of the users’ population. Furthermore, a large size of the resort site will allow for (relatively) unconstrained positioning of the resort buildings and generous space left between them. This should allow for adequate exposure of the buildings’ broad side to the winds prevailing in the area. Generally, in hot humid regions such as the coastal tropics buildings should be fully exposed to cooling winds (Figure 3.3).

In order to ensure free movement of air through the site, resort buildings should be located a fair distance from each other; this also avoids obstructing land–sea breezes. In the layout organisation, a parallel tendency is preferred. Probably the best solution would be to set the buildings in a single row following a shoreline. However, one must remember that their sun–wind orientation is, in this climate, crucial to their thermal performance. Generally, the long axis should be aligned in an east–west direction. The preferred orientation is that of the long axis of the building pointed west -5° in the southern and $+5^\circ$ in the northern hemisphere with a 10° tolerance (i.e. facing from $255-275^\circ$, or $265-285^\circ$, direction). Longer walls would then face south and north, limiting their exposure to ‘low-angle’ solar radiation (Figure 3.4).

Another important factor is the prevailing wind direction. Orientating buildings so that their long facades are exactly perpendicular to the wind direction (i.e. facing the wind) is not required. It has been shown in some studies (compare Givoni, 1962) that a

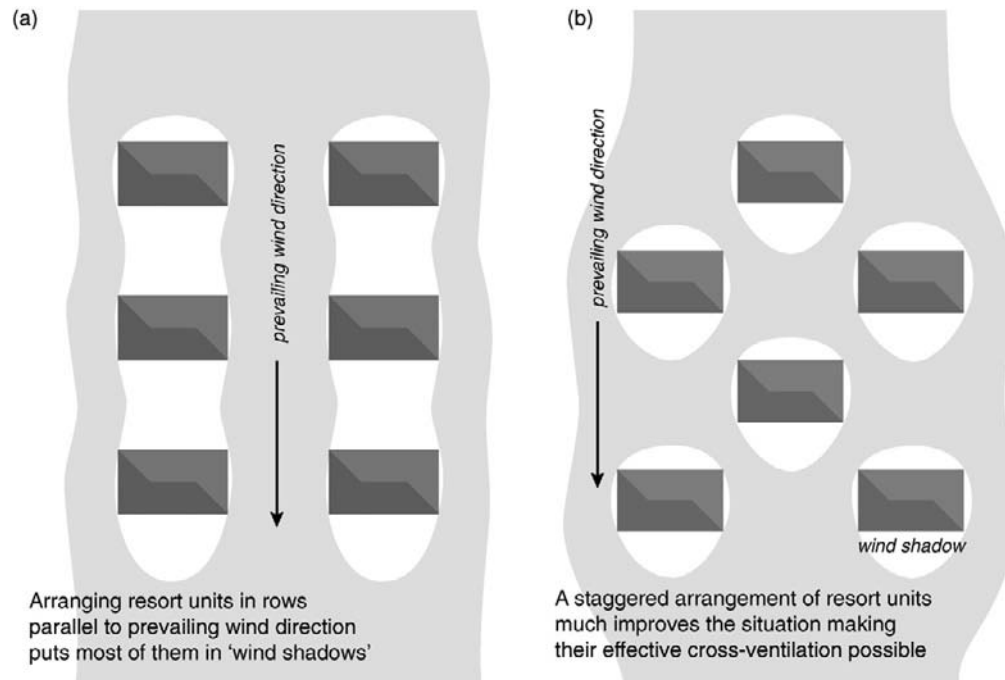


Figure 3.3 Flow of air around a group of buildings.

better and more even distribution of air flowing through the building, without compromising air velocity, is achieved when the wind is oblique to the inlet openings – at approximately 45° . Further improvement can be observed when inlet and outlet openings are located in opposite walls. If the openings were located in adjacent walls, better cross-ventilation resulted from the inlet opening being

perpendicular to the wind direction. Furthermore, for best ventilation effects, the area of openings serving as outlets should be maximised (Figures 3.5–3.8).

Buildings of the resort should be connected by shaded pathways. Paving, however, should be avoided. Both the vegetation and topography should provide maximum shade and support air movement through the site. Whenever possible, buildings should occupy either the crest or foot of a hill (the two locations where wind and breeze speeds are recorded at their highest) and avoid its west and east

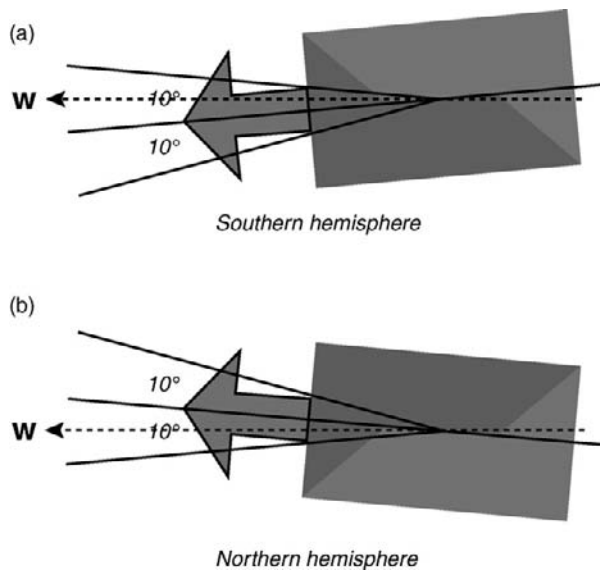


Figure 3.4 Recommended orientation for best shading effects.

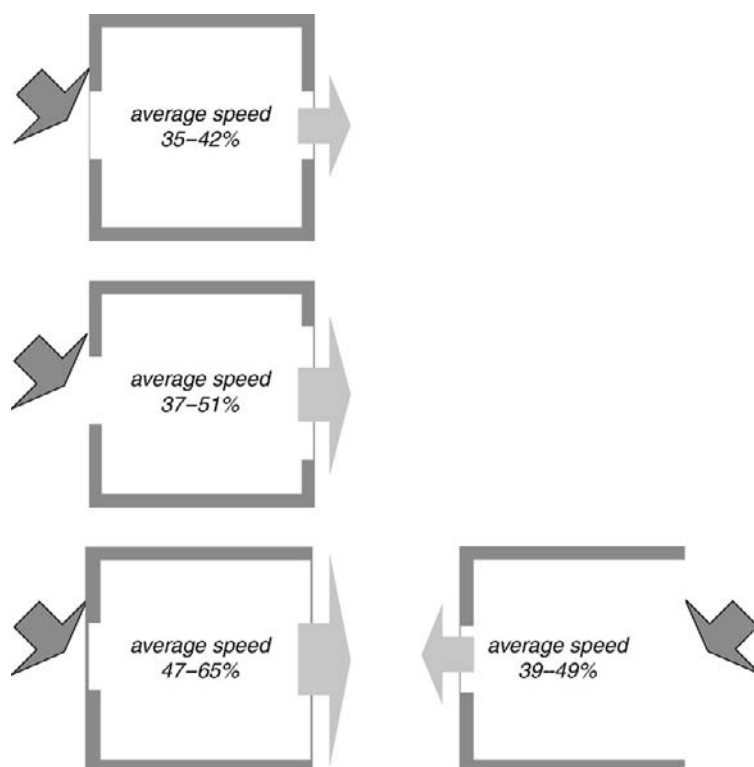


Figure 3.6 Comparison of air speed inside the room achieved by varying inlet and outlet sizes.



Figure 3.7 High-branched trees, such as palms, provide shade and let the air flow freely around the building.

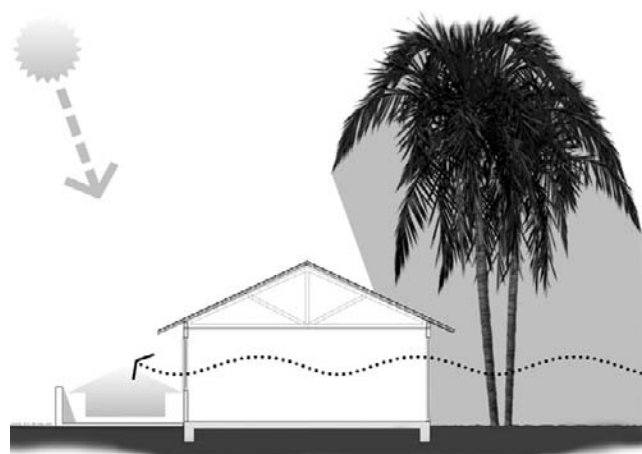


Figure 3.8 'Cooling path' provided for the breeze before it enters the building. Hard surface heats the air, which rises drawing more air through the building.

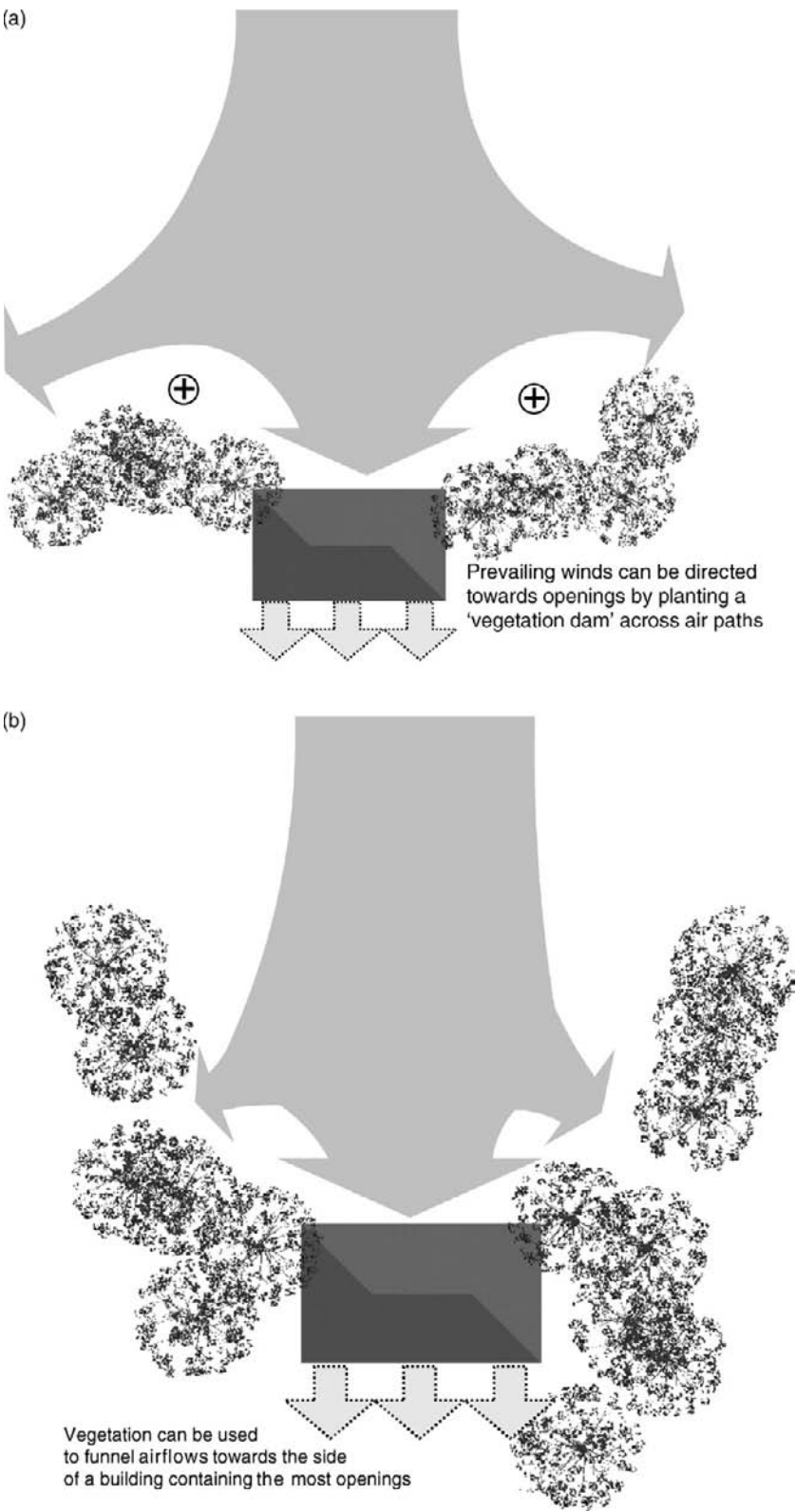
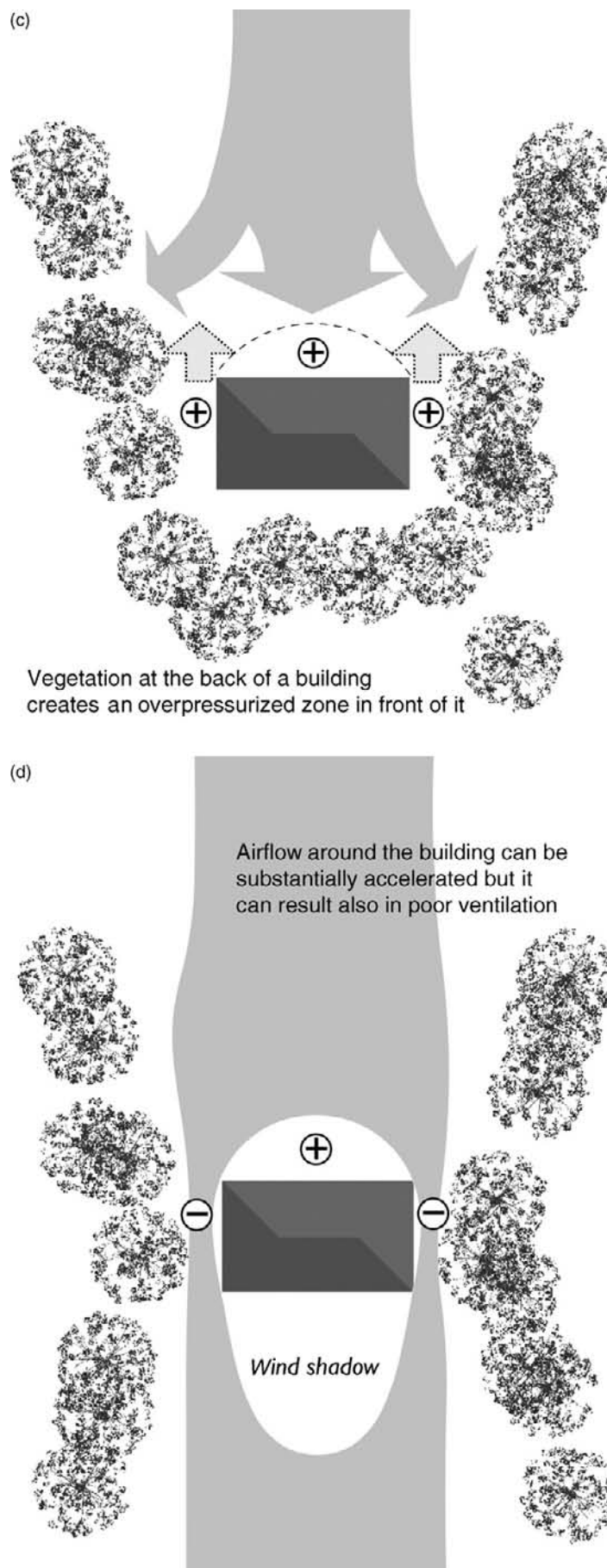


Figure 3.9a–e Use of vegetation in redirecting airflows through the site.

**Figure 3.9** (Continued)

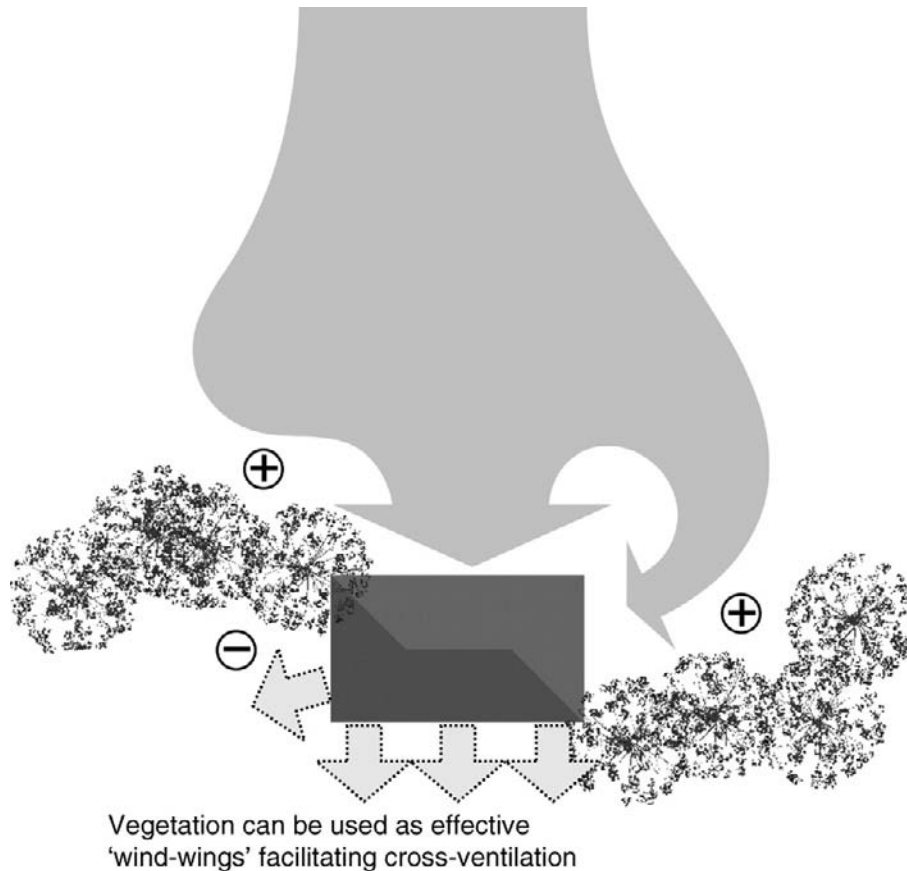


Figure 3.9 (Continued)

side, which are the worst in terms of exposure to solar irradiation. Furthermore, moving buildings as close as practicable to the shoreline (but beyond the zone endangered by tides and storm surges) is recommended. Ideally, a building location would be in a 'saddle' between two hills, particularly if both sides were open to wide and flat areas, for example to the sea. The funnelling effect at such a position is virtually guaranteeing nearly continuous air movement through the site.

Care should be taken in planting new trees and shrubs to achieve maximum shading benefits on the east and west sides. This could be combined with the enhancement of breezes through a 'funnel effect', although the benefits can be expected for a rather narrow wind incidence angle only (see above). Elements of the landscape design (including vegetation) can also create high and low pressure areas around a building in reference to its openings, directing and accelerating beneficial air streams into the building. It is important that landscape elements effectively shade 'air paths' to ensure that air entering the building is of a relatively low temperature (Figure 3.9a-e).

Taking advantage of wind/breeze incidence could be more important than protecting the building's perimeter from solar irradiation. In the tropics, the sun at noon can take either a south or north position. It stays very high over the horizon for most of the day, twice a year directly overhead, and even small eaves are sufficient to shade vertical elements of the building structure, with the exception of east and west orientated walls. The roof is the element receiving most solar irradiation and this does not change much with its tilt or orientation. Problems related to irradiation of walls are caused by the sunrays coming at lower angles. The solution could be to position the long axis of a building as close as practicable to an east-west direction. That would decrease the area of surfaces exposed to this insolation. Still prevalent is the opinion that the problem of insolation can easily be dealt with by shading the east and west walls. This would suggest that in any case wind consideration should take precedence over sun-related orientation. Nowadays, however, some experts question this opinion.

Appropriate site planning can help reduce the problem of humidity build-ups. Preventing excessive

humidity on the site in naturally humid climates can be done by allowing for free air movement through it and by locating humidity sources (swimming pools, decorative ponds, etc.) far from resort buildings. Locating the buildings away from larger masses of vegetation would also probably be beneficial in this respect.

One of the more important planning issues is functional zoning of a resort. Its 'naturally noisy' parts, such as dining rooms, playgrounds, entertainment areas, the reception and roads, should be separated from guest units. Moving them apart and/or introducing vegetation as sound and visual barriers can do this.

3.3

Constructional design

Key recommendations in brief:

- Lightweight structural systems should be selected ahead of heavy ones for most eco-resort applications;
- Heavyweight, well-insulated and sealed systems should be used in all air-conditioned buildings;
- Consider hybrid structure for guest units: lightweight for night-time use part and heavy for the daytime one;
- Provide good insulation for roofs with the 'parasol' option as an alternative.

There are three competing views regarding the most appropriate climate-responsive building structure in warm and humid climatic regions. They champion the following structural types:

- low mass or lightweight structure;
- large mass or heavyweight structure;
- a combination of both former types in a hybrid structure.

The most popular views, supported by vernacular building traditions in the wet tropics, give preference to lightweight solutions. It has been argued that the lesser mass of such buildings reduces the structure's thermal time lag, which in turn causes internal temperature swings to follow more closely the external temperature profile. This short response time has been seen as necessary because of the relatively small diurnal temperature differences characteristic of the zone. With this view, the indoor environment benefits from small drops in evening/night temperatures occurring without significant delays. The same views hold that small diurnal temperature ranges do not warrant use of thermal mass. The mass is almost certainly counter-productive when used in the structures of guest bedrooms. Lightweight constructions are preferable there because they do not support stabilising temperatures at concurrent high relative humidity (night-time) conditions. In these conditions, the envelope should also have a low insulating value if the building is fully cross-ventilated.

In this type of building the indoor temperature can never be lower than the one outdoors but lack of insulation – allowing for unimpeded heat transfers – ensures that it will not be significantly higher either. Nevertheless, surfaces exposed to solar radiation, especially roofs, should be well insulated. It is worth

noting that well located mass inside the structure can help to overcome undesired temperature fluctuations and winter overcooling, which can and does occur even in tropical environments.

The second view favours heavyweight buildings. Research carried out in tropical Australia (Cox, 1993) found that heavyweight buildings were the least overheated. Therefore, it was concluded, a heavyweight structure is climatically the most suitable solution when used in combination with other passive measures, such as shading and night-time ventilation. While the research findings demonstrated the superiority of a predominantly heavyweight structure, factors like siting and orientation were excluded from considerations. This limitation may have been acceptable in the case of a building project undertaken in an urban environment where limited size and restricted orientation of building sites are their dominant and usually predetermined qualities.

Locality microclimate's characteristics have a much greater impact on the building's performance if one can remove these urban limitations. This is often the case with resort sites. There are also significant differences between residents' dwellings and the resort in terms of time of use. Furthermore, a psychometric comfort zone (see Figure 2.8) specified for a dwelling, being different from that of a resort, influences lengths of periods accounted for as 'overheated' and 'underheated'. This can substantially distort our view of comfortable conditions in the resort. Finally, the research only compared lightweight versus heavyweight buildings. Cox's study, although acknowledging such a possibility, did not attempt to test the thermal performance of the third option: hybrid light-heavy structures (Figure 3.10).

The hybrid structure uses heavyweight fabric for daytime living areas downstairs and a lightweight superstructure for spaces used at night. The concept was first offered by Drysdale in the late 1940s (Drysdale, 1975) and since then the hybrid approach, developed along the lines of logical deduction, has gained much support. It has been argued that a heavyweight daytime part of the building, without mechanical ventilation but using its capacitive insulation, offers a level of performance which is on par with that of a mechanically ventilated lightweight structure. The bedroom part of the building, on the other hand, benefits from the thermal behaviour of a

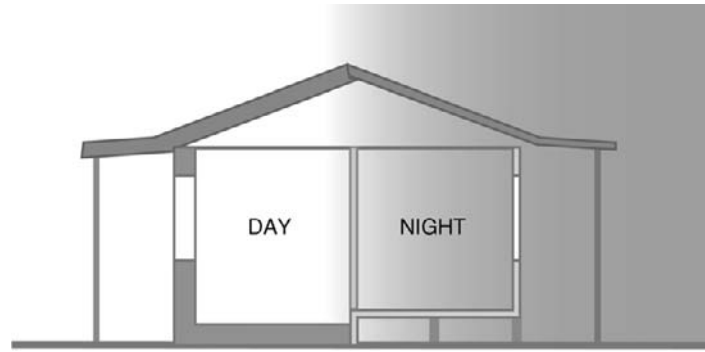


Figure 3.10 Section showing the principle of a hybrid structure.

lightweight structure. The concept has undergone very limited testing in practical situations and remains largely a theoretical conjecture. Nevertheless, the hybrid alternative could prove to be the most appropriate solution for eco-resorts in the coastal tropics.

In the case of some resort buildings, however, it does not seem necessary to use this type of structure. A number of behavioural differences between residents and visitors to the tropical coast make it possible to consider only a part of a resort as the one crucial to the tourists' perception of comfort. As we have argued, it is the part designated for night-time use, i.e. the guest units. Constructional design of other buildings should give priority to limitation of the impact that the buildings and associated construction processes make on the environment. From this point of view, lightweight structures seem to be a better option than heavy ones by a large margin.

Builders themselves can move elements of a lightweight structure and, because of this, the need for lifting equipment is usually substantially reduced. Furthermore, these elements can be brought to the site using all means of transportation including burden animals – there is no need for roads or cranes. Most technologies used in lightweight structures do not require powered machinery or tools, which results in less environmental impact during the construction stages. Having been traditionally used in vernacular tropical buildings, these technologies, more often than the heavyweight ones, can draw on locally available materials and utilise locally available building skills. Flow-on benefits include low embodied energy and less undesirable socio-economic impacts. Finally, yet importantly, lightweight structures can be removed leaving almost no trace behind – a feat not as easily achievable with heavyweight ones.

3.4

Building design

The building envelope – a system of roofs, walls with all openings, and floors both on the ground and suspended – is the ultimate barrier between the indoors and the world outside. The barrier works like a filter, employing building fabric and various design features.

In a hot and humid climate, there appear to be only two considerable ameliorating effects achievable with the help of purely passive climate control. They are:

- reduction in the amount of total radiation; and
- increase of airflow.

Other effects, such as supply of cool air and dehumidification, are difficult to achieve without some support from powered devices and would probably require conscious cooperation on the part of the occupants. This, in turn, would require some sort of preparatory measures, such as instruction and training. Thus, an attempt to achieve such effects is seemingly impractical in a tourist resort. There are also psychological consequences (see Section 2.4) of certain design solutions, which also could be employed. However, these solutions appear to be largely past experience/culture-dependent and require much more research before conclusive results, leading to their practical implementation, can be expected.

Let us pause for a moment and consider the actual magnitude of the design task. A brief developed on a basis of climatic recommendations alone would become, most probably, a document full of mutually exclusive demands. For instance, in order to reduce roof area and solar irradiation and to increase exposure to sea breezes, it would be advisable to build multi-storey buildings. However, this is contradictory to the resort character and, quite obviously, invasive to the landscape. Moreover, high-rise buildings demand, on average, more energy than any others, present a more difficult-to-control acoustic environment, are much more expensive in difficult foundation conditions so frequently found on the tropical coast, and are more intrusive (to say the least) in environmental terms.

A compromise solution would be to accommodate tourist resorts in buildings of a few storeys. Guest bedrooms could be located upstairs while rooms requiring more defined thermal control during the daytime could be moved downstairs. The upper parts of

the resort buildings should preferably be lightweight structures designed to prevent any considerable heat gains. Such a solution could be problematic when looked at from another angle: cyclonic winds occurring in the tropics during the summer season can cause extensive damage to light structures and endanger their occupants. Other examples such as better daylighting, achieved by increasing the size of windows, in most instances will increase heat gains. Larger windows, on one hand, will increase intrusion of external noise but, on the other hand, provide psychologically beneficial visual contact with the outside. Noise in the background is undesirable in itself but potentially useful to aid speech privacy as a masking sound. Sunshades would control the period of solar irradiation but reduce the level of available daylight. This list of contradictions could be extended.

V. Olgyay (1963) carried out studies for optimum building shape for a range of climatic zones. For hot-humid zones he recommended rectangular building shape with the short to long wall aspect ratio of 1:1.7. This recommendation applies, however, primarily to dwellings as it improves their overall day-night performance. Resort performance emphasis is on the night-time, and the ability to dissipate heat (by means of effective cross-ventilation easiest available in narrow, spread-out buildings) is, perhaps, more important than preventing heat gains. Notwithstanding, exposure of eastern and western walls to the sun should be minimised and the building elongated to catch prevailing winds and to aid cross-ventilation.

A catalogue of means available to architectural designers is presented in this section. Some of these means could greatly influence the indoor climate of a resort. In the given conditions, some may only produce marginal changes and others would make no measurable impact. However the range of available means seems to be large enough to select the ones, in most locations, that will control parameters of the indoor environment to a desired extent.

3.4.1 Building layout

Key recommendations in brief:

- Promote air movement through narrow single-bank layout;

- Open the plan and design free of interior obstructions in both horizontal and vertical planes;
- Open the building up by providing ample openings;
- Designate open-to-air (without walls) spaces for dining, entertainment and (alternative) sleeping.

For all types of buildings within the resort, one of the most important design factors is provision of considerable air movement. Air movement is considered the only effective way of ameliorating thermal conditions in warm and humid climates. Hence, both the internal plan and envelope characteristics should provide for numerous effective air paths through the interior. The rate and volume of cross-ventilation airflows through building interiors as a result of plan/section design has not been well researched but some general advice in this regard can be put forward.

To ensure adequate airflows, buildings should be narrow and rooms should be lined up ('single-bank' layout) or branched-out rather than double-sided or clustered as the economics of internal communication would stipulate. Some of the spaces, like the dining area, can be designed as rooms without walls. Even if privacy requirements discourage true openness of the plan in resorts, which consist of a large number of relatively small spaces, the design should offer as much area open to the external environment as possible. For example, it is advisable that access to secure outdoor areas (such as on a flat roof) is provided from bedrooms. Such spaces could then be used as alternative open-sky night-time sleeping areas or for day ('siesta') rest. The problem to be resolved in this arrangement would be to provide adequate water drainage from such roofs during the rainy season. A safe removable shade would also help to control heat gains; large balconies are also an option (Figure 3.11).

Openings should be ample as the volume of air flowing through the building is correlated with its size and, to a lesser extent, with its shape. The size of an opening (and the height of its sill, if any) on a windward side should promote air movement at body height, while even bigger openings should be provid-

ed in a leeward wall. In the case of guest units, used mostly at night, the 'windward' side on the coast would be an 'inland' side – because of the direction of night breezes. Breezes coming from the sea in the evening are also beneficial in dissipating daytime heat build-ups that, in turn, makes openings in the 'sea-ward' side of the building important.

Moreover, a slight change of the air current direction between inlet and outlet, both in plan and in section, is beneficial for a distribution of airflows. This way the air flowing through the guest unit moves through the largest part of its volume and reaches into what otherwise would become pockets of 'dead air'. Further improvement would result from using louvre type windows, which can be made to open downwards (on the room side) to 10° below the horizontal position. It is also helpful to install warm air exhausts from under the ceiling or, better still, create a stack effect to allow for vertical convective air movement as well.

Some resort functions can be moved to spaces which are open to the air. The overall strategy in this respect should be to maximise the number of such rooms. This principle applies not only to the resort functions producing high metabolic rates in participants, such as physical recreation and entertainment, but also to functions where activities are moderately demanding, such as dining. With sufficient effort, a solution to the problem of providing secure and private sleep-outs for guests can also be found. In most situations, removable fly-screens would have to be installed to provide protection against mosquitoes and sandflies (Figure 3.12 and Figure 3.13a–c).

3.4.2 Envelope design

Key recommendations in brief:

- Consider the roof as the most important part of the envelope, requiring all 'climatic defences' available;

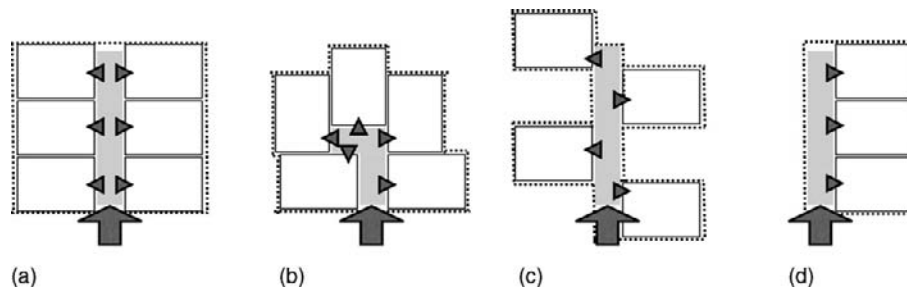


Figure 3.11 Building layouts: a. double-sided, b. clustered, c. branched-out, d. single-bank.

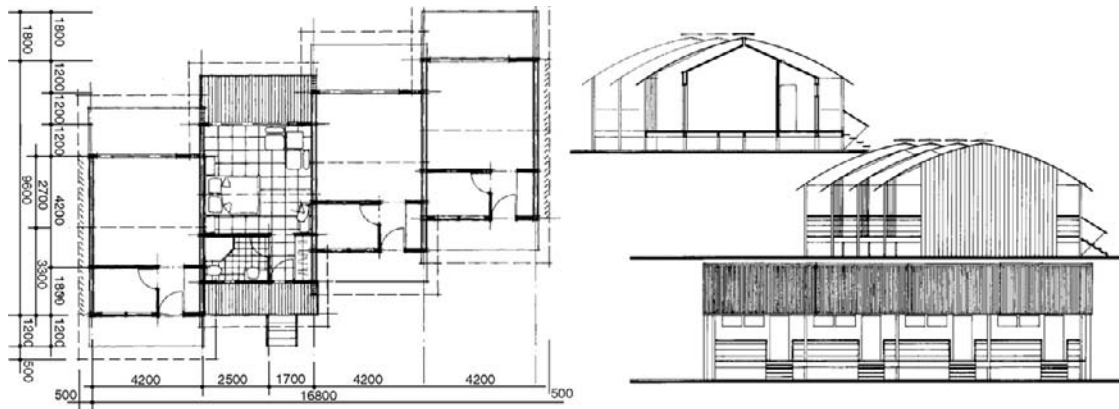


Figure 3.12 Theoretical set of four guest units incorporating some of the recommended features (parasol roof, ridge vents, raised floor, entire eastern and western wall shades): plan, section and elevations.

- Open the envelope to provide relatively free air-flow through the building;
- Provide shade to east and west walls and avoid openings in these walls;
- Raise buildings above ground level to take advantage of airflow under the floor and over cool ground/sea.

At the functional level, the building envelope separates the building interior from the external environment and, in conjunction with building services, maintains desirable internal conditions. The design of the envelope and, in particular, the selection of insulation and air barrier materials can have a major impact on energy expenditure and operational performance of the building. Thermal insulation of the envelope is particularly important in air-

conditioned buildings. It minimises conductive heat flows and can significantly reduce energy consumed in cooling or heating the building. Similarly, an effective air infiltration control will reduce heat flows as a result of excessive air leakage through the envelope.

Over the life of a building the environmental benefits of these savings in operating energy will, probably, more than compensate for any negative impacts associated with the embodied energy of the insulation. Materials used in envelope assemblies are subject to significant daily swings in temperature and vapour pressure and – in the case of air-conditioned interiors – to large gradients in these indices. The cladding, being affected by the external environment, is exposed to many forces that can degrade building materials. Durability becomes a major issue

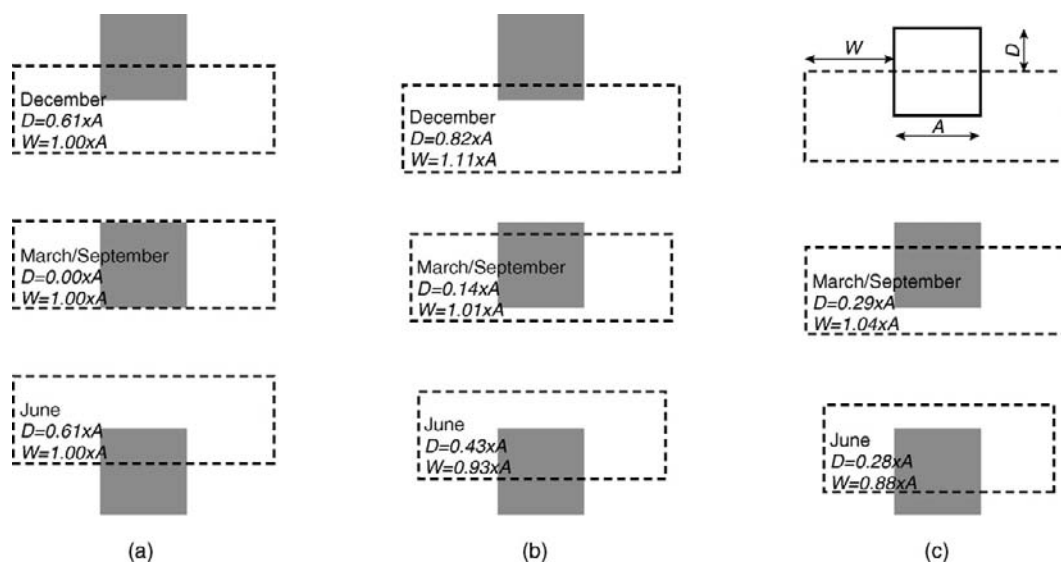


Figure 3.13a–c Shading that would be required to continuously shade the area shown in grey: a. at the equator; b. at 8°N; c. at 16°N (Brown and DeKay, 2001).

as lifecycle environmental impacts are increased if frequent replacement of cladding materials is necessary.

The following envelope design guidelines are aimed at the resort guest units. It should be understood that they are different from other resort buildings as they serve a different functional purpose. The crucial differentiating factor appears to be the time of use. The unit's environmental performance is the result of the interaction of its envelope components, for the most part, with the night-time environment. Nevertheless, a unit's daytime performance cannot be simply disregarded as heat build-ups during this part of the diurnal cycle substantially contribute to its overall thermal profile.

3.4.2.1 Roofs

In the tropics, roofs receive more solar radiation than any other surface of the building. The significance of solar heat gain through the roof increases with the roof area to building volume ratio. If possible, the roof should be shaded by high-branched trees and have a white or other high-emittance finish. The design of the roof is of the greatest importance for keeping indoor temperatures at a not-higher-than-outdoors level. Some solutions will perform in given conditions better than others. For instance, in predominantly high daytime temperatures, an uninsulated

double-shell envelope, also known as the 'parasol' roof, can function well. The outer skin shades the cavity, keeping the temperature of the air contained lower, and subsequently reduces the temperature of the inner skin. Ridge outlets should be provided for 'ridge effect' ventilation. Due to lack of insulation, night-time heat transfer from the interior into the cavity promotes cooling. There exist vernacular examples of 'parasol' roofs, almost detached, which perform well in hot conditions. Such a 'shaded' roof system can cut total heat gains through the envelope by several per cent. The addition of even a very thin sheet ceiling impacts dramatically on the thermal performance of the roof system. The underside of the roof and the topside of the ceiling, in such a case, should be reflective to minimise both emission and absorption (Figures 3.14–3.19).

Some research indicates that the thermal performance of the roof in hot climates might depend more on its surface colour and other properties than on its insulation (Givoni, 1994; see also Section 3.4.3). This is a contested issue that requires more research before a recommendation can be made. Nevertheless, it seems that a combination of a high-emittance (i.e. fairly reflective) surface and insulation could be a safe compromise (Figure 3.20).

Because of the danger from cyclones occurring in the tropics during the summer season, it is necessary to ensure adequate structural integrity, particularly to

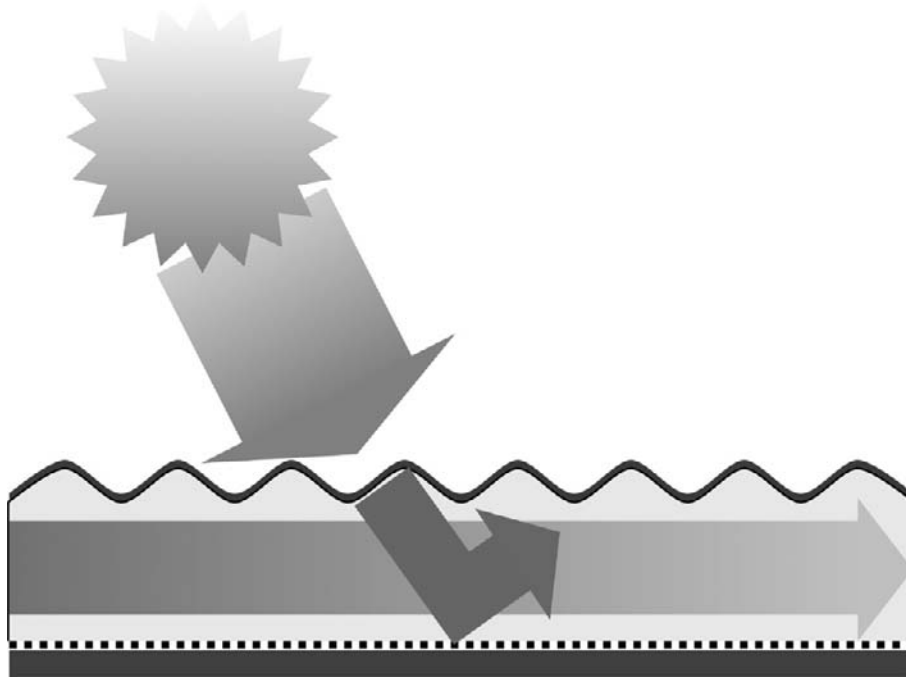


Figure 3.14 The 'Parasol roof' principle: the ventilated void under the external skin stays at a temperature close to the ambient temperature; placing reflective insulation on the internal skin greatly reduces gains from the radiative heat flow.

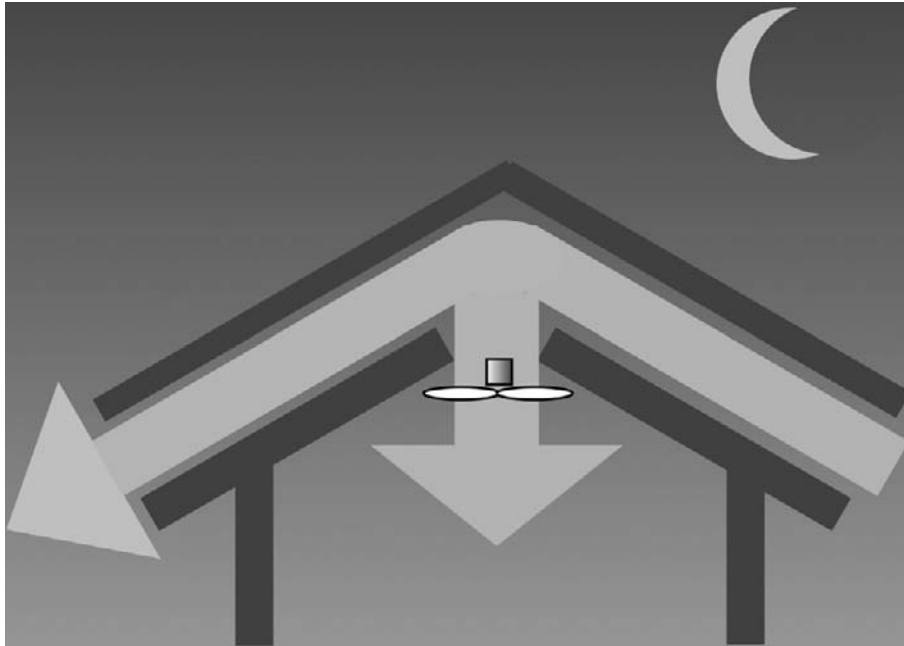


Figure 3.15 A parasol roof can be used in night ventilation.

uplift. Normally, it would be expected that the roof has an even and smooth surface, and that all elements subjected to increased (positive or negative) pressures, such as eaves, porches and verandas, are appropriately tied down.

3.4.2.2 Walls

Wall structure in the humid tropics has less thermal importance than in any other climatic region. This is because heat flows through this part of the envelope are diminished by small diurnal swings of temperatures. In a resort, walls are used primarily to ensure the privacy and safety of occupants, and for screening

from insects and animals. Their thermal qualities should make it possible that night-time drops in temperature are followed by their (wall) cooling without significant delays and to prevent morning condensation. Expansive wall areas enhance night cooling, although increasing the envelope's surface as a means of improving its overall thermal performance is questionable because of unavoidable heat during the day. Shading the entire east, and especially the west, walls is definitely beneficial as it helps to avoid morning and afternoon heat gains. These walls (and any openings in them) are most effectively shaded by fixed 'egg-crate' devices where vertical fins are turned 45° towards the equator (i.e. South-East



Figure 3.16 A parasol roof on a guest unit at Amanwana Resort, Indonesia.

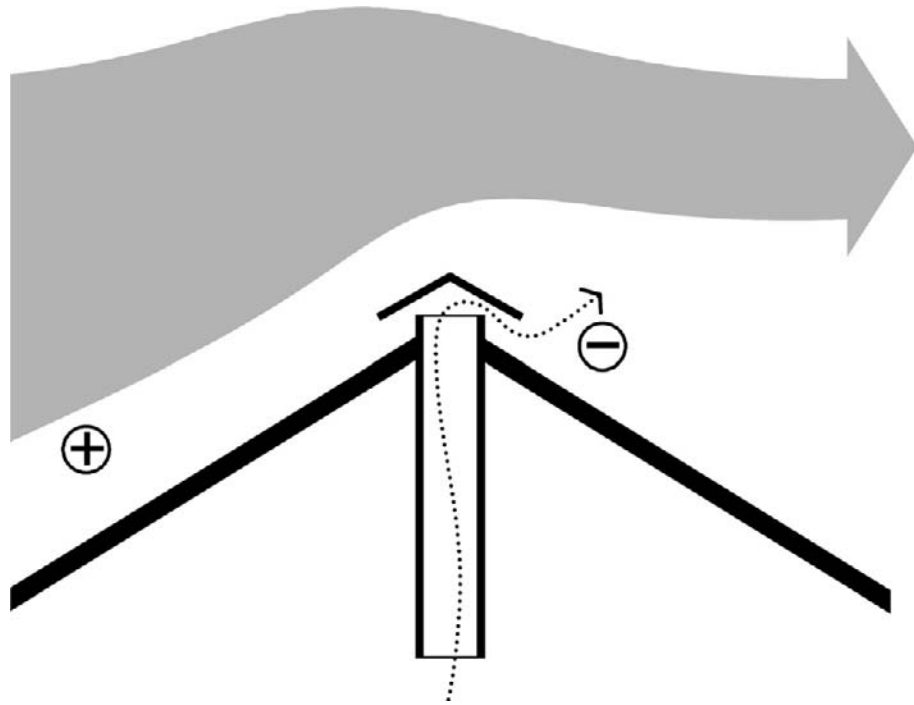


Figure 3.17 Roof vents and monitors utilise suction near the roof ridge (Venturi effect).

and South-West in the northern hemisphere and North-East and North-West in the southern one). Shading also makes insulation of these elements redundant. It is recommended that external surfaces of all walls are painted white (or other light colours), or should even be reflective, to further reduce heat gains (Figure 3.21).

Double-skin walls can provide performance improvement similar to the parasol roof. The cavity in such walls should be well ventilated to prevent any

possible heat build-up affecting the interior (Figure 3.22).

Internal walls within guest units should be as light as practicable, with consideration given to the requirement of appropriate sound attenuation. Masonry 'party walls' or similar wall types should be used to separate adjacent units even with an otherwise light construction. However, several commercial products, providing relatively high values of Sound Transmission Loss (STL) combined with low mass

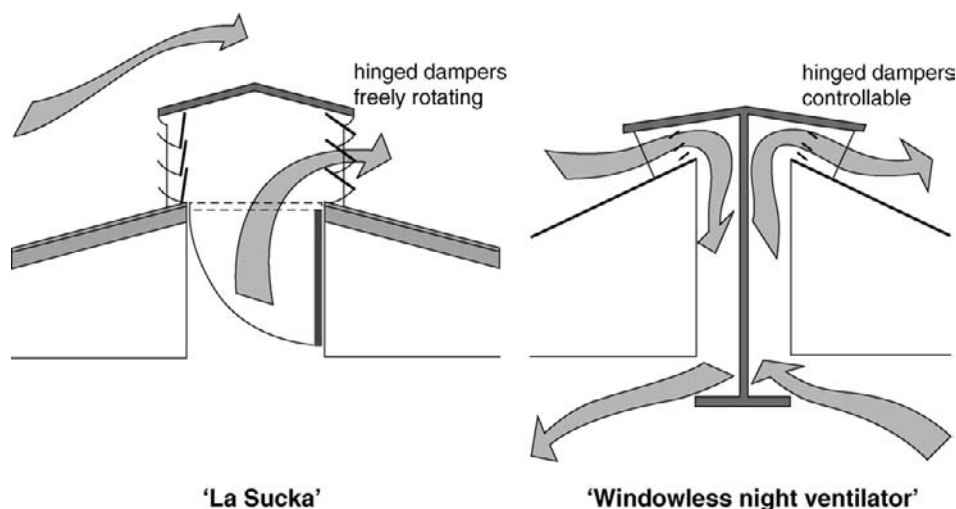


Figure 3.18 Examples of roof monitors 'La Sucka' and 'Windowless night ventilator' (based on Florida Solar Energy Center, 1984).

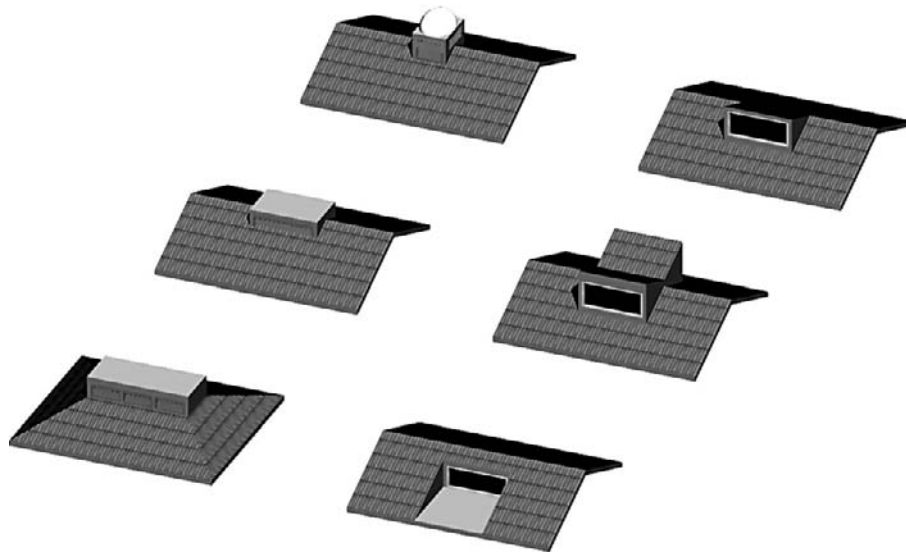


Figure 3.19 Various shapes of roof monitors (based on Watson and Labs, 1983).

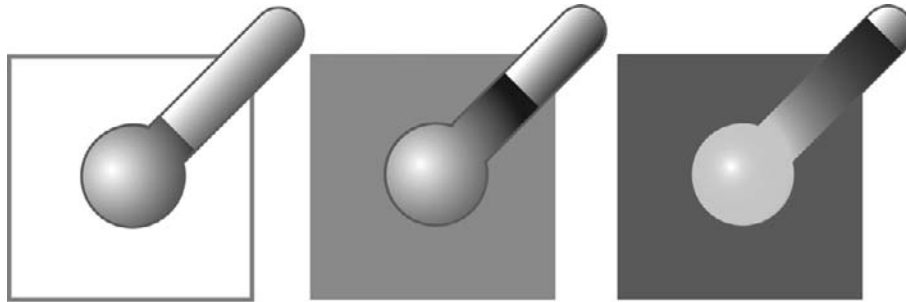


Figure 3.20 As a rule of thumb, lighter colouring of the roof surface produces its lower temperature.

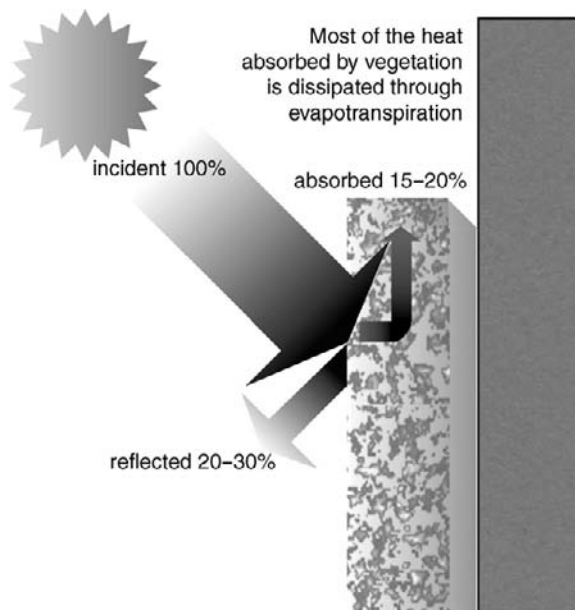


Figure 3.21 Wall shading by vegetation.

(such as plasterboard clad staggered stud walls with 'lead-core'), are commercially available ([Figure 3.23](#)).

3.4.2.3 Openings

Most windows combine three functions: they provide views and admit daylight and air. To improve their performance, it is recommended that these functions are separated and openings in the envelope are created in the best locations for views, lighting and ventilation, respectively. For instance, the 'view windows' do not have to be openable, and venting openings can be located well below or well above eye height as well as have view obstructing mesh built in.

Adequate orientation and disposition are the most important aspects of openings design. Protection against solar penetration through openings appears to be one of the most important means to prevent unwanted increase of indoor temperature. The glazing must ensure a desired balance between the heat gains/losses resulting from transmission of

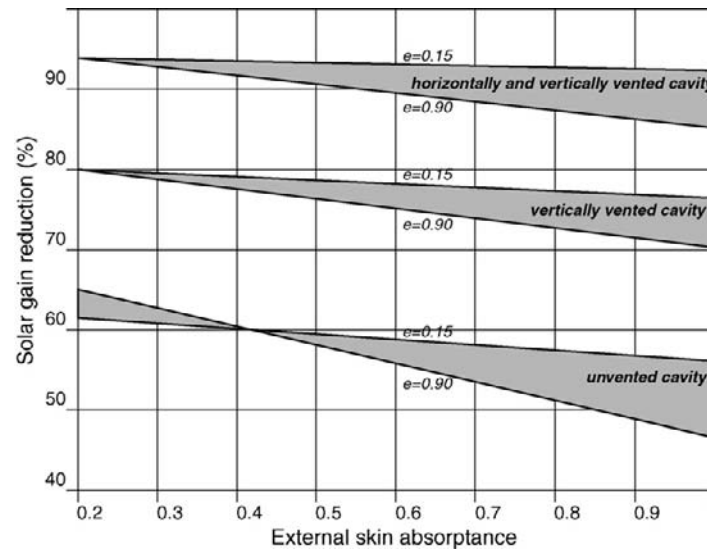


Figure 3.22 Double-skin thermal performance depends on its ventilation and surface qualities.

thermal radiation in and out of the building and the light entering the building. The sunshading of openings is obviously very different from that of walls. Sunshades protecting windows not only affect the thermal environment of a building, but also impact on visual, aural and psychological comfort as well. In a resort, it is very important to provide openings which, on top of other requirements, ensure extensive, and preferably interesting, views. Avoiding windows in east or west walls in the tropics appears to be an absolute imperative.

Window shading can also influence the thermal environment indirectly, by affecting airflows through the building. When insect screens are used, they should be mounted at the largest practicable distance from the protected opening (e.g. the screen could be mounted on a veranda rather than at a wall face). This helps to lessen the effect of blocking airflows with the

screen. Shading devices should be operable to allow for individual adjustments by the users. The colour of the shutters does not seem to greatly influence the heat gains; however, white shutters are better from the daylighting point of view as they allow more reflected light into a room and offer less contrast. Placing and size of windows should allow for free air movement through the 'living zone' (up to 2 m above the floor). It is recommended that they be taken up to the ceiling. It is also important that windows are high rather than wide. As a rule of thumb, openings on a windward side (air inlets) should be larger than on the leeward side (air outlets) of the building (Figure 3.24).

In addition to reducing heat gains, windows and skylights can positively affect building energy performance characteristics by facilitating solar heat loss, and by allowing natural light into the building and reducing the need for artificial lighting. Appropriate

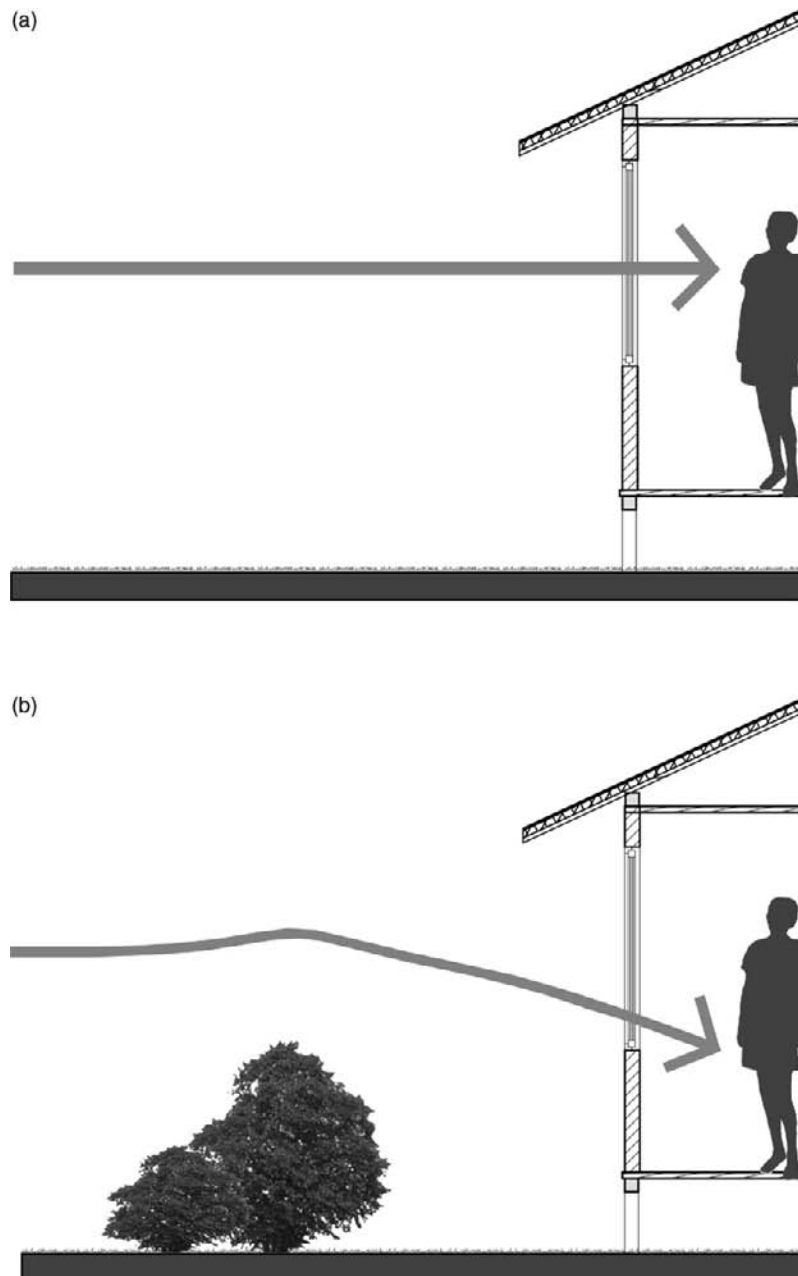


Figure 3.24 Vegetation near a building is capable of affecting airflows through nearby openings.

selection of glazing materials to control heat gain/loss can play a significant role in determining overall building energy efficiency. Windows and glazed elements should be carefully selected, and integrated with other building envelope assemblies, and with the building's operating systems. Windows will typically have less resistance to conductive heat loss than adjoining walls and as a result represent one of the best opportunities for reducing overall envelope energy losses.

As is the case with insulation, the environmental benefits of improved thermal performance of windows should be offset against the impacts associated with window materials. Overall window performance is a function of the characteristics of both the frame and the glazing. It is worth noting that significant environmental impacts can be associated not only with all glass and window frame materials, but with their embodied energy and manufacturing technologies as well (Figure 3.25).

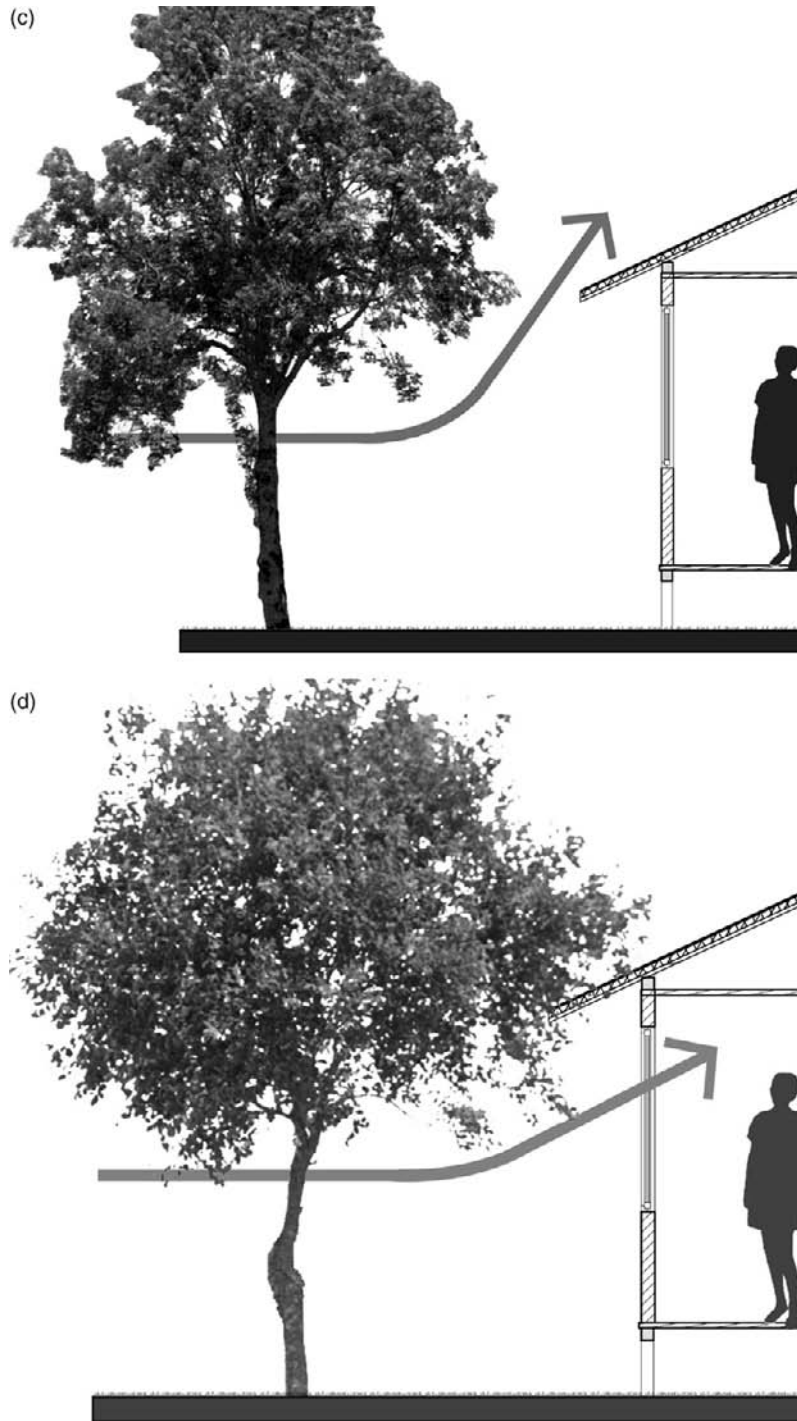


Figure 3.24 (Continued)

3.4.2.4 Floors

Floors should be raised to avoid obstructions to air movement at ground level and to take advantage of wind velocity increased further from the ground. Raised floors perform in a way similar to the double-shell roof. The ground, being always in shade, is rel-

atively cool. The air passing over the cool ground in turn keeps the floor cool. A similar recommendation can be extended to structures built over the water; in this instance, being an immense heat sink the sea maintains relatively low temperatures throughout the day/year. Another advantage of a raised floor over a slab-on-ground is that it prevents condensation of



Figure 3.25 Cooling the building with flowing air.

moisture likely to occur on a cold mass of the slab. With a raised floor, one can also utilise under-the-floor supply of air to rooms on the leeward side of the building.

While raising the floor seems an obvious solution for hot humid conditions, it has been argued that in climates where night temperatures can drop to 20°C, and on occasion to 10°C and lower, as they do in northern Florida and North Queensland, it is necessary to use slab-on-ground as a protective measure against excessive cooling in such low temperatures. The earth berming suggested by some authors for this purpose must be seen as an extreme measure when combined with otherwise lightweight construction methods.

3.4.3 Building fabric

Key recommendations in brief:

- Make selection of building materials based on consideration of the widest possible range of environmental impacts;
- Use local materials, traditional technologies and local builders;
- Use materials in support of the selected passive climate control strategy;
- Use materials sparingly.

There are a number of factors other than thermal, visual or acoustic properties that can influence the choice of building materials. Among the criteria that

should be considered for the use in a tropical eco-resort are availability (including ‘transportability’ in difficult terrain), fire resistance, termite resistance, required maintenance, durability in cyclonic conditions and current fashion. Materials introduced to the building industry in recent years offer various possibilities that can be utilised by passive technologies. The knowledge enabling the prediction of physical behaviour by building materials, particularly in relation to elements composed of several different components, is a relatively recent acquisition. Nevertheless, architects and builders can be equipped nowadays with extensive scientifically-based knowledge about materials and their properties. Some allow for improved sunshading and better solar control, others are more efficient in thermal insulation. The thermal mass of a passive solar building can be substituted by phase-change compounds installed in panels or tubes, and air heat exchangers work more effectively than ever before. The building envelope can now be constructed with materials designed for specific predictable output.

Vernacular architecture from around the world offers excellent examples of material design, which efficiently cope with the local climate in many climatically different regions. However, most of these solutions appear to result from a natural selection process, ‘forced’ use of locally available materials and accomplished technology levels rather than from any deliberate decisions. The developed designs were initially, incidentally rather than deliberately, climate-responsive. Vernacular climate-responsive material solutions were searched for and found, not

because certain needs were noticed and then had to be responded to. And, once these solutions were adopted, they have been subsequently improved, refined and enhanced throughout centuries of trial and error. Today, it is the role of science to help in choosing the best material for the task.

Passive climate control in the wet tropics requires a strategy that is different from those utilised in cooler climates and focuses on controlling heat gains rather than heat losses. Preventing heat gains would typically mean preventing daytime gains from solar radiation, while ambient air is a welcome heat sink, particularly at night. The building's perimeter can be constructed from various materials, and the choice of materials should support the concept of an envelope as a selective filter of the outdoor climate. The envelope consists of elements that belong to two groups: solid (or opaque) elements such as roofs as well as (solid) walls and floors, and transparent ones, such as windows. Ambiguity can arise when considering elements that are semi-transparent or very thin. Walls made of glass bricks and most door types including mesh, as well as many other opaque elements, display similar specific thermal behaviour – differentiating them from typical solid barriers.

The effect of direct solar radiation is an increase in the temperature of sunlit surfaces. This accelerates the rate at which heat flows into the body of the material. The increase depends very much on the sunlit surface's character. There are several material solutions to minimise the solar gain. Generally, in tropical wet and maritime (i.e. coastal and island) climates, building materials used for construction of particular elements can either resist heat gain from solar radiation or reject it as soon as the sun moves to a position from which further irradiation does not take place. The former are basically insulating materials – providing reflective insulation of the surfaces exposed to solar radiation. The latter are lightweight materials – very low thermal mass – with small thermal decrement and negligible time lag, easily giving up any heat gains. The thermally insulating materials can be further grouped as reflective, resistive and capacitive insulation. Materials that reduce humidity and ones that are used for sound insulation are also of particular interest in a tropical resort.

Environmental benefits can be gained by using materials which may or may not be inherently green. By controlling heat loss, and contributing to building energy performance, insulation can significantly improve the environmental profile of buildings. Reductions in greenhouse gas emissions, achieved over the lifecycle of a building, will be generally more important than the impacts associated with the

manufacture of most insulations. Nevertheless, there are significant differences in the range of insulation materials commonly used in construction, and in associated environmental impacts.

3.4.3.1 Reflective insulation

Reflective insulation provides resistance to heat flow by virtue of the surface characteristics. Thermal reflectance is a surface property of some, usually opaque, materials and can be defined as an inability to absorb the incident heat:

$$\rho = 1 - \alpha \quad (3.1)$$

where ρ is reflectance and α is absorptance.

Reflectance, for short-wave radiation, is related to the surface colour. For the same material, a surface can show a reflectance value of 90 per cent if painted white and 15 per cent if painted black, in typical hot conditions. For example, external white walls increase the air temperature in the spaces between them (and – in the same process – the long-wave radiation to which people staying there are exposed) substantially less than black painted ones. On the other hand, white unshaded walls contribute to the reflected component of daylight and thus can increase available light levels, but also may cause glare and visual discomfort problems.

Absorptance and emittance characteristics of materials vary according to the wavelength of the radiation. Absorptance equals emittance for the same length of wave, which describes the fraction of heat emitted from the surface to the heat emitted from a 'perfect' emitter. Shiny metallic surfaces, for instance, have a low thermal emittance when compared with any organic surfaces. However, both absorptance and emittance can vary markedly for different wavelengths. This phenomenon is referred to as 'selectivity'. When the selectivity is fully utilised, the external surfaces can constitute a very effective defence against solar radiation impacts.

In the tropics, where overheated periods predominate, materials whitewashed or painted white are more appropriate than materials such as grey coloured galvanised iron. This is because white is reflective to short-wave (solar) and emissive to long-wave radiation, while grey is absorptive to short-wave and non-emissive to long-wave radiation. White painting utilises the specific absorptive property of the so treated surfaces: while reflectance of a white coat is among the highest in a short-wave range, its emittance in a long-wave range, i.e. re-radiation of the daytime heat gains, is almost the same as that of a black coat. This is because emittance of long-wave

radiation is dependent more on density and molecular composition of a surface than on its colour. In particular, paints based on TiO_2 , 'titan white', demonstrate such characteristics. It is particularly important in the coastal tropics, which typically experience a large number of hot nights. In the coastal tropics white painted materials show effectively lower surface temperatures during the day and help cooling at night. Roof surface temperature for various roof colours in standardised conditions is given in Figure 3.26.

Reflective insulation is most important when considering thermal performance of roofs. In the tropics, the roof typically presents the largest surface exposed to direct solar irradiation. Reflective properties of such surfaces, however, should be dealt with carefully since they might cause an adverse effect on their environment through specular reflection, i.e. the reflection of the entire incident radiation. Fortunately, only a few materials commonly used in low absorption roofs, i.e. materials that have a high reflectance, exhibit specular reflective characteristics. The mechanism of heating a solar irradiated roof system is affected not only by the intensity of the solar radiation and reflective properties of the roofing materials, but also by wind speed, roof surface orientation and insulation. These all influence the temperature of the roof surface and the amount of heat absorbed or re-radiated by the roof system. The absorbed solar radiation heats the roof, which in turn convects heat to the adjacent air. If this air is moving, it will be replaced by more air – at a lower temperature. The dissipation of heat from the roof is controlled by its thermal emittance.

Heat-reflecting materials can be used not only for external surfaces but also in all other places where heat is transferred primarily by radiation, such as an

attic space. Heat transmission barriers in these locations are particularly effective. Highly reflective materials are good barriers to heat transfer by both absorptance and emittance. Where a space or wall cavity has both emitting and absorbing surfaces, for best insulation effect both should have a reflective lining. Reflective foil installed in cavities is particularly effective in limiting transmission of radiation through the roof: a single sheet of such a foil with 100 mm air space (foil itself has a very low resistivity of about 0.005 mK/W) is equally as effective in reducing the downward flow of heat as a 11 mm layer of extruded polystyrene or 15 mm of mineral wool (Tables 3.1 and 3.2).

Reflective and tinted window glass coatings (films) are increasingly used for reduction of heat gain through windows in air-conditioned buildings. While they do limit the quantity of light entering this way, they are not as effective in heat gain control as external sunshades because they do not significantly alter emittance values of the barrier. There is a considerable development in photochromic, thermochromic and electrochromic glasses. These are able to modify the sunrays coming through so that spectral composition and hence, to a limited extent, some properties of the radiation are changed. These special glazing types are also called 'optical shutters' because of their ability to change some characteristics (usually colour) in response to heat, light or electric current. Nevertheless, commercial availability of such glasses is still very limited and their use is restricted chiefly to air-conditioned spaces (their effectiveness requires temperature difference between external and internal surfaces or exposure to direct sunlight). However, careful consideration of glass is required since using

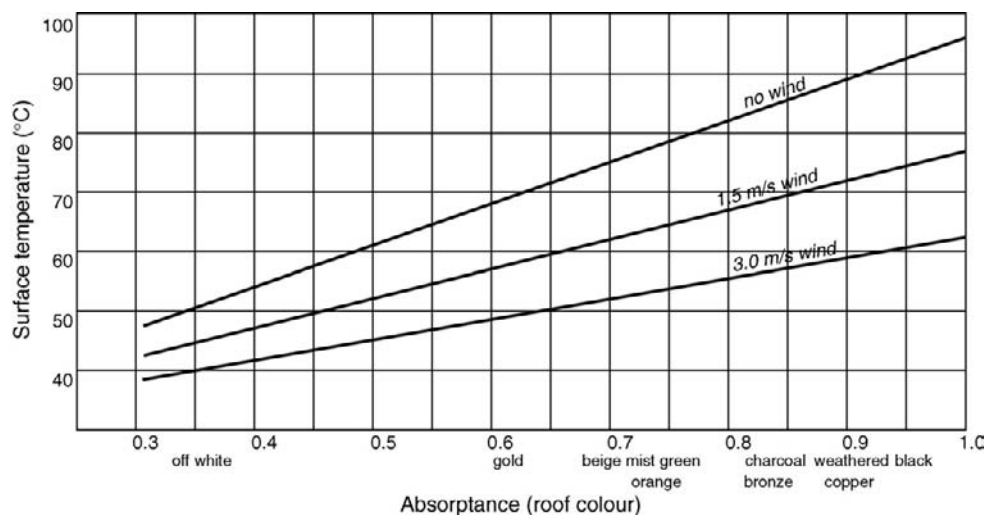


Figure 3.26 Roof surface temperature for various roof colours (absorptance), at air temperature $T = 30^\circ\text{C}$ and global solar radiation $G = 1 \text{ kW/m}^2$.

Table 3.1 Absorptance and reflectance characteristics of various materials and finishes

Material	Absorptance	Reflectance
optical flat black paint	0.98	0.02
black asphalt	0.95	0.05
flat black paint	0.95	0.05
black lacquer	0.92	0.08
dark brown bitumen	0.92	0.08
dark grey paint	0.91	0.09
black concrete	0.91	0.09
dark blue lacquer	0.91	0.09
black oil paint	0.90	0.10
Stafford blue bricks	0.89	0.11
dark olive drab paint	0.89	0.11
dark brown paint	0.88	0.12
dark blue-grey paint	0.88	0.12
azure blue/dark green lacquer	0.88	0.12
brown concrete	0.85	0.15
medium brown paint	0.84	0.16
asbestos cement (old and dirty)	0.83	0.17
glass	0.83	0.17
red concrete	0.82	0.18
medium light brown paint	0.80	0.20
brown or green lacquer	0.79	0.21
grey bitumen	0.78	0.22
medium rust paint	0.78	0.22
timber (smooth planed)	0.78	0.22
sand	0.76	0.24
green leaves	0.75	0.25
light grey oil paint	0.75	0.25
red oil paint	0.74	0.26
red bricks	0.70	0.30
uncoloured concrete	0.65	0.35
red clay tiles	0.63	0.37
moderately light buff bricks	0.60	0.40
grey coating	0.60	0.40
medium dull green paint	0.59	0.41
medium orange paint	0.58	0.42
medium yellow paint	0.57	0.43
asbestos cement (new)	0.55	0.45
granite	0.55	0.45
medium blue paint	0.51	0.49
medium green paint	0.51	0.49
light green paint	0.47	0.53
lime clay bricks	0.46	0.54
white marble	0.44	0.56
white silicon polyester	0.41	0.59
galvanised steel	0.39	0.61
aluminium	0.39	0.61
cream brickwork	0.36	0.64
white metal tiles	0.33	0.67
white semi-gloss paint	0.30	0.70
zinc-oxide oil paint	0.30	0.70
gravel	0.29	0.71
white glazed bricks	0.26	0.74
white gloss paint	0.25	0.75
silver paint	0.25	0.75
white lacquer	0.21	0.79
whitewash on galvanised steel	0.21	0.79
light yellow coating	0.21	0.79
aluminium paint	0.18	0.82
polished aluminium reflector	0.12	0.88

TABLE 3.1 (Continued)

Material	Absorptance	Reflectance
aluminised Mylar film	0.10	0.90
lab vapour-deposited coatings	0.02	0.98

the appropriate material with only a moderate increase in cost can halve the solar heat gain at the glass/outside interface.

3.4.3.2 Resistive insulation

Resistive insulation is provided by low-conductivity materials and low-transmission construction systems. Insulative quality of materials is expressed as their thermal conductivity (λ values). Materials that conduct less than 0.1 W/mK can be considered 'insulators'. The best insulator of those easily available is dry still air ($\lambda = 0.026$ W/mK). Other materials showing low values of λ are those containing large amounts of air 'trapped' by their porous internal structure. These can be referred to as 'bulk insulation' materials. They form poor heat stores and diffuse heat badly because of their open and cellular structure. The insulating quality (resistance or R-value) of a material changes with its thickness:

$$R = b/\lambda = (A|t_o - t_i|)/Q \quad [\text{m}^2\text{K/W}] \quad (3.2)$$

where b is breadth (thickness) of material measured in a direction of heat flow [m]; λ is thermal conductivity [W/mK]; A is area of the element [m^2]; $|t_o - t_i|$ is temperature difference between faces, taken as a positive [K]; Q is heat flowing through the element [W].

Total resistance of a multi-layer element is the sum of its layers' (cavity is considered a layer) resistances plus the outside and inside surface resistances:

$$R_{tot} = \sum R_n + R_o + R_i \quad (3.3)$$

where R_{tot} is total thermal resistance of an element $\sum R_n$ is the sum resistance of individual 'n' layers R_o is outside surface resistance R_i is inside surface resistance.

The U-value or transmittance (given in $\text{W/m}^2\text{K}$) is a reciprocal of this total element resistance:

$$U = 1/R_{tot} \quad (3.4)$$

Resistive insulation should be used in construction of light roofs along with external reflective insulation. The resistive insulation task in roof-ceiling systems is to prevent an unacceptable rise in the ceiling temperature of 4.5 K above the ambient air level

Table 3.2 Insulating materials and their environmental characteristics

	Description	Major advantages	Major disadvantages
Autoclaved aerated concrete (AAC)	Concrete blocks, panels and boards made from cement, lime, sand and small amount of aluminium paste	Fire-resistant; good acoustic and thermal performance; relatively high structural strength; can be cut and shaped with hand tools	Thermal performance is worse than that of plastic foams; residual moisture can cause corrosion of reinforcing steel; negative impacts are related to high energy requirement in manufacturing aluminium paste
Cellulose fibre soft board	A rigid, low-density material made from recycled newspapers, woodchips or sugar cane fibres and a binder	Low cost	Thermal performance is worse than that of plastic foams; needs to be protected from moisture; has little structural strength or stability; highly flammable
Composite insulating board	Sandwich layer of foam plastic and other materials such as perlite board, glass fibreboard, and saturated felt	Combines the high insulating efficiency and moisture resistance of foam plastics with the fire resistance, structural rigidity and/or bitumen compatibility of other materials	Negative impacts are related to raw material extraction and manufacturing of components being petrochemical derivatives
Expanded polystyrene (EPS)	A low-density closed-cell foam of polystyrene plastic extruded into rigid boards	High insulating efficiency; resistant to moisture; easily formed in moulds of any shape; potentially reusable when recovered	Combustible (fire retardant needs to be added to the mix); high coefficient of thermal expansion; deteriorating with time; poor performance if not protected; negative impacts are related to raw material extraction and manufacturing as petrochemical derivatives and to the use of HCFCs
Foam glass (perlite board)	Granules of expanded volcanic glass and a binder pressed into rigid board	Inert; fire-resistant; compatible with hot bitumen; dimensionally stable; can be sawn and shaped with hand tools; rot and vermin proof	Insulating efficiency much lower than that of plastic foams
Glass wool (fibreglass)	Rigid, low-density boards, batts or blankets of glass fibres and a binder; available with recycled content	Inert; fire-resistant; non-decaying; dimensionally stable; ventilates moisture freely	Insulating efficiency lower than that of plastic foams; negative impacts are related to raw material extraction and manufacturing; possible health impacts
Lightweight concrete/gypsum fill	Concretes made from very lightweight mineral aggregates, a cementing agent (Portland cement or gypsum) and a high volume of entrained air	Can easily produce a tapered insulation layer for positive roof drainage	Much lower insulating efficiency than plastic foams; residual moisture from mixing water can cause blistering of membrane
Mineral wool (rock wool)	Lightweight boards, batts or blankets made of mineral aggregate with bitumen binder	Low cost; high recycled material content if manufactured from slag	Much lower insulating efficiency than plastic foams; fibres are possibly carcinogenic
Open cell polyisocyanurate/modified polyurethane foam	A closed-cell rigid foam, sometimes with glass fibre reinforcement, available as boards or foamed in-situ	Very high insulating efficiency; easily cut and shaped with hand tools	Combustible (needs to be combined with other materials to increase its resistance to fire); high coefficient of thermal expansion; loses some of its insulating value over time; negative impacts are related to raw material (petrochemical derivatives) extraction and the use of HCFCs in manufacturing
Wool	Stabilised sheep wool batts	Renewable; good performance	Hygroscopic; attracts vermin

(at which point it would become a sensible heat radiator), and preferably less, to arrive at no more than a 1 K increment at the ceiling. The insulation required to achieve this would have to perform at R2.7–3 levels.

3.4.3.3 Capacitive insulation

The ‘thermal mass’ effect is produced by envelope elements of considerable thermal capacity; such elements are referred to as ‘capacitive insulation’. Although there is no direct relationship between the resistivity (or conductivity) and the density of a material, dense materials tend to have low resistivity values, hence low insulative properties. However, they can be used for insulation in a different way. Thermal capacity is a product of specific heat capacity (heat stored in a unit volume per degree of temperature rise) and the density of the given material. For example, the storage capacity of masonry ranges from 0.204 kWh/m³ K for cellular concrete to 0.784 kWh/m³ K for heavyweight concrete. Most liquids show considerable thermal capacities. For instance, water, which has the highest thermal capacity, can store 1.157 kWh/m³ K at 20°C.

The thermal capacity of building elements having n different components may be calculated from the following equation:

$$C = \sum m_n c_n = \sum \rho_n V_n c_n \quad (3.5)$$

where C is thermal capacity [Wh/m³K]; m_n is mass of ‘ n ’ component of a building element [kg]; c_n is specific heat capacity of ‘ n ’ component [Wh/kgK]; ρ_n is density of ‘ n ’ component [kg/m³]; V_n is the ‘ n ’ element’s volume [m³].

Capacitive insulation can be employed as materials of two different types. With traditional materials such as concrete and brick, the storage process makes use of sensible heat, that is, heat that can be measured as it results in an increase in temperature. Phase-change materials, on the other hand, make use of the latent heat of fusion, i.e. the heat required to change the state of the material from a solid to a liquid without a change in temperature. In the construction field, it is usual to choose a material which changes phase at a temperature somewhere between 2° and 50°C (normally around 27°C). Very large quantities of heat (typically 38–105 kWh/m³, i.e. up to 15 times more than for masonry) can be stored when the phase-change occurs. Therefore, a much smaller volume is required for phase-change storage than for conventional storage.

New materials are currently being developed which change their molecular structure without

changing state. This transformation also uses latent heat and can therefore be used to store heat. The advantage of the new materials over phase-change materials is that they remain solid. Currently, however, they are expensive, not very reliable, and can only be used over a limited number of charge–discharge cycles.

3.4.3.4 Materials reducing humidity

Thermal comfort is, in principle, a combination of temperature and humidity factors. Thus, in the wet tropics, improvement of the thermal comfort will follow a decrease of either. Some form of dehumidification could limit the need for a high ventilation rate. This, in turn, would allow for use of storage cooling. Dehumidification methods that can be implemented in hot humid climates fit in two broad categories. The methods in the first category depend on the use of desiccants: either solid phase absorbents or adsorbents, or hydrophilic solutions. Dehumidification techniques belonging in the second category make use of various environmental ‘humidity sinks’, in particular ones that are ground coupled. The use of environmental sinks for dehumidification is most effective when the underground annual average temperature is below 20°C. At higher ground temperatures this natural latent cooling method can still be applied but must be complemented by the use of desiccants.

Dehumidification is usually considered a mechanical process in all its aspects and phases, although there are a few experimental passive methods using desiccants. Desiccants are materials which absorb moisture from the air. They do this either by the process of adsorption, where water molecules are attracted to the surface of the material, or absorption, where moisture is attracted by a desiccant to dissolve chemically.

Desiccants in passive systems are exposed to the controlled space at night and left to dry out in the sun during the day. Interesting results were reported about experiments carried out with wool as the desiccant. Apparently, wool is so far the only known material which does not display significant deterioration of its hygroscopic properties with use. While the results were quite promising, the current large fluctuations in this commodity market make pricing difficult, so estimating the cost of this solution and performing a sound feasibility analysis have yet to be done. Other materials such as silica gel, activated alumina, calcium chloride and lithium chloride have a short active life and show significant deterioration

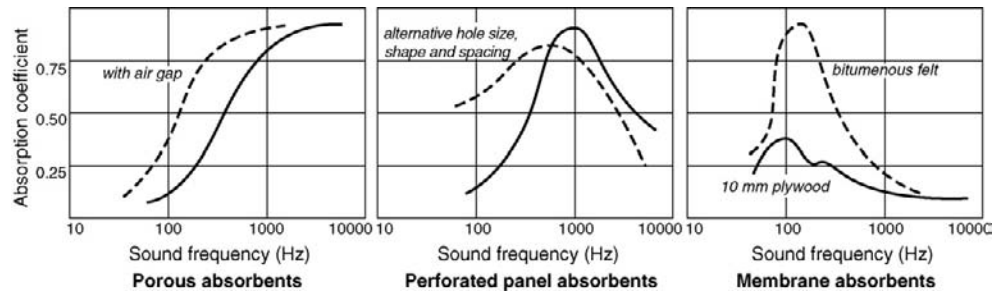


Figure 3.27 Sound absorption characteristics of some typical absorbents.

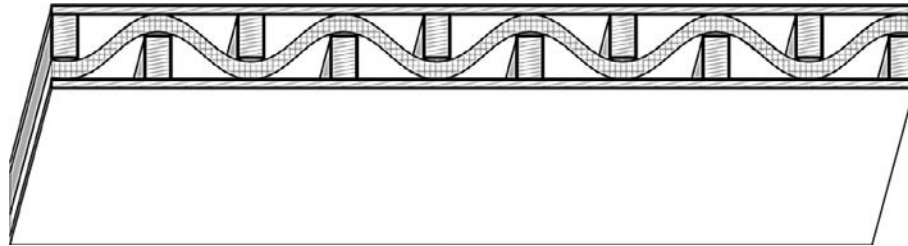


Figure 3.28 Section through a staggered stud acoustic wall.

after a certain period of use. Some of them are also highly toxic or corrosive.

No fully satisfying solution has been found yet. As with radiant cooling roof systems, desiccant systems await a cheap and reliable solution to the problem of operating the system, i.e. moving screens for temporal exposure/insulation. In the early 1980s, solar-regenerated desiccant dehumidification was a new field and complete economic analyses were not available. Today, such systems have gained acceptance although their feasibility still can be questioned.

3.4.3.5 Materials assisting in noise control

Building materials have to be looked at also from an acoustic property point of view. Sound impedance (the material's sound insulating quality) is related to the surface density and the speed of sound in the material. Generally, the greater the mass of the material, the greater the impedance ratio and the higher

the sound attenuation. As a rough rule of thumb, a doubling of surface density is required to improve sound insulation by 5–6 dB in the mid-frequency range. The transmission of sound through an element varies also with the angle of incidence – being lowest at the normal incidence and greatest at the glancing or oblique one. In various materials, it also varies with different frequencies. Some building elements show better absorption of sound in a low-frequency range and better reflection of high-frequency sounds; others have opposite characteristics. Generally, low-density porous materials are good absorbers of high-frequency sounds and to absorb low- and/or medium-frequency sounds as well they must be relatively thick. Considerable improvement of the latter characteristic can be achieved with 'Helmholz' resonators, membrane or panel absorbers, or perforated panelling over porous materials. Staggered stud systems are also beneficial as is any double-leaf wall arrangement where surface impedances are utilised (Figures 3.27 and 3.28).

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3.5

Functional programmes

Key recommendations in brief:

- Determine type of activities performed within a given space;
- Consider different indoor climate requirements attached to different functions;
- Adjust cooling needs in accordance with time of use and activities performed within the space;
- Offer open-air spaces for dining, entertainment and sleeping/rest.

To be effective, modification of design information based on climatic data (as suggested in Section 3.2) should be supported by adjustments based on usage type. The energy used in buildings is tied to and influenced by the building usage patterns. Different functions, such as dwelling, work, leisure, and others, create different use patterns and have different related requirements. In terms of building physics, tourist facilities are among those buildings that pose design problems of the highest complexity. One example of this is the indoor environment–function interrelationship. It is possible to identify a number of different functions that require very different approaches while dealing with the design of their respective environments. The major functional groups in the resort are:

- sleeping;
- recreational activities of various intensities;
- dining;
- food processing/cooking;
- cold storage;
- (non-cooled) storage;
- office work; and
- laundering.

Looking at the way that a tourist facility in the tropics operates, basic differences are visible in the time, duration and manner in which the spaces for housing these functions are used. Subsequently, volume and the usual occupation time of these spaces also vary. Normally, enclosed spaces in a tourist resort would include (Figure 3.29):

Spaces used mostly at night (volume of typically sized rooms is given in parentheses):

- small one-, two- or four-bed guest rooms, commonly detached or in detached groups (20–50 m³)

Spaces used during the day and at night:

- bathrooms and toilets in guest units (5–15 m³);

- (non-cooled) storage space (15–100 m³);
- cold storage enclosures, usually in groups (10–50 m³)

Spaces used mostly during the day:

- reception and lobby (200–250 m³);
- dining room (250–400 m³);
- kitchen (100–200 m³);

Spaces used in the daytime only:

- office rooms (20–40 m³);
- laundry (30–50 m³);
- service rooms (15–20 m³).

Spaces used mostly at night require design strategies supporting fairly quick heat dissipation. Effective cross-ventilation (coupling to a heat sink such as night air or ground) and envelope design (enabling rapid heat transfers) are among the most suitable design strategies. Spaces used mostly during the day have to be designed with heat gain prevention as the principal strategy. Adequate shading and perimeter insulation are among the most successful simple passive means of achieving this. Spaces used both during the day and at night will benefit from strategies that best respond to the mixed requirements of limiting solar heat gains and promoting heat losses whenever external temperatures drop. Furthermore, it is absolutely necessary to realise the extent of required intervention into the indoor environment. Not every space in the resort requires cooling or heating and, when it does, the requirement does not extend to all times.

The following discussion introduces proposed design adjustments to the comfort range of temperatures calculated from thermal neutralities (equation 2.1) expanded by 2.5 K. The suggested adjustments should be understood as an illustration of thermal tolerances to be expected within the given space, thus indicating scope for the apparent cooling/heating need (compare Figure 2.8).

Both the kitchen and laundry in a resort are used all day long and have numerous heat and vapour input sources. They can be conveniently located, quite often in separate building(s). However, in the resort's kitchen (and to some extent in the laundry) constraints of hygiene are also stricter and full clothing is required (approx. 0.5–0.6 Clo). Also, activities performed in both these spaces raise one's metabolic

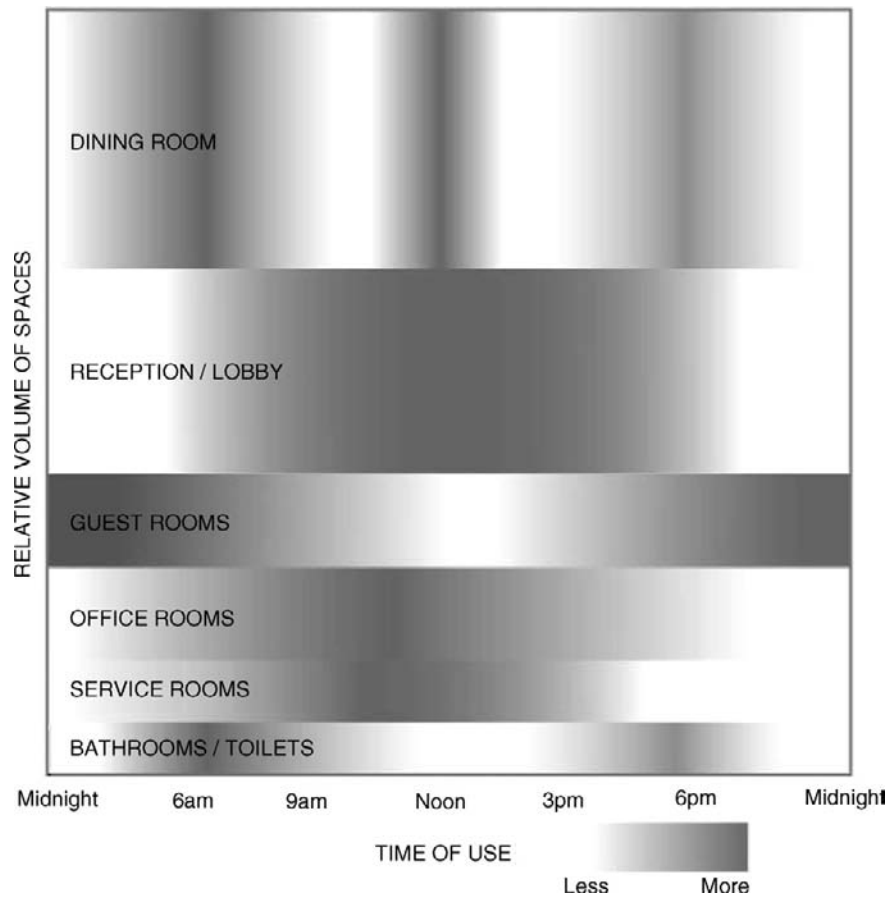


Figure 3.29 Time of use and volume of various resort rooms.

rate to not less than 2.5 Met or 145.5 W/m^2 , pushing the range of acceptable temperatures down the scale by some 8 K (intensive cooling of the space is required) – in comparison to the thermally neutral temperatures calculated with the use of comfort equations (see Section 2.1). For instance, if $T_o = 30^\circ\text{C}$, then $T_n = 28.4^\circ\text{C}$ and the range of acceptable temperatures in a kitchen or laundry after adjustment is $20.4^\circ\text{C} \pm 2.5 \text{ K}$. This means that these spaces should be designed for the range of approximately $18\text{--}23^\circ\text{C}$ calculated after disregarding heat input from their equipment in operation.

It should be noted that kitchens and laundries are staffed by local residents who normally are not willing to compromise on their working environment conditions. This combination makes the kitchen, followed closely by the laundry, probably the most demanding place in the whole resort in terms of indoor climate control. It is not tourists, however, that we are concerned about here. The comfort sensations of local residents are more predictable and have been better researched; hence the task of designing the appropriate environment is somewhat easier. The

problem lies in the functional separation of spaces with such high heat and humidity incidence from the rest of the resort while maintaining the integrity the resort's site plan.

A resort's dining room is used by large numbers of people at meal times. Guests are usually required to put on some clothing that builds the clothing insulation up to a value of 0.4–0.5 Clo. As the metabolic rate corresponding to this activity level is around 1.2 Met or 69.8 W/m^2 , in given conditions the design range can be adjusted up to +1 K in comparison to neutral temperatures. This can be read as the possibility to relax the cooling requirement for this space a little without much discomfort to the users.

It is in the bedrooms, however, where design for comfort is most important. Despite similarities with residential buildings, one can point to a number of significant differences. Bedrooms in a resort are definitely multi-functional however, they serve their principal purpose almost exclusively at night. Sleeping and resting are the activities that take place here and these can be rated at 0.7–0.8 Met or $40.7\text{--}46.5 \text{ W/m}^2$ metabolic rate level at night, i.e. the lower end of

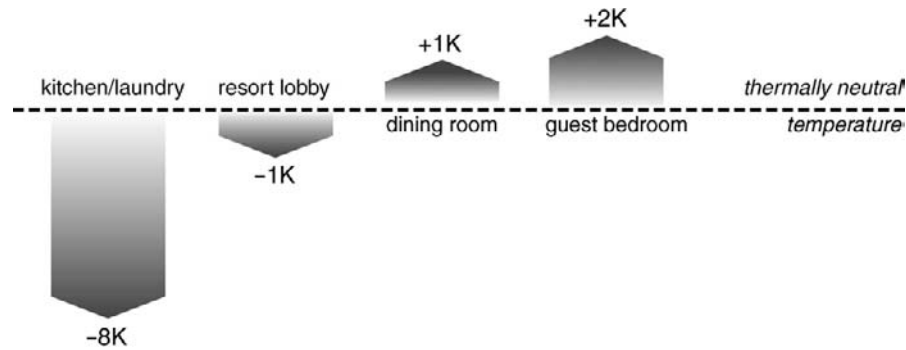


Figure 3.30 Function vs. thermal conditions adjustment.

the outdoor temperature spectrum. This value is opposed to a bedroom in a family house, which tends to be used as a study or playroom for a big part of afternoons during the week and all day at the weekends. Thus, possible adjustment of the temperature range, for which the resort bedroom should be designed, may be as high as +2 K thermal in comparison to temperatures considered thermally neutral in a given location.

This recommendation can be translated into a very relaxed requirement for cooling since much of the adjustment comes with, and is supported by, regular night-time drops in temperature. For example, if the average outdoor temperature for January (the hottest month) in Cairns, northern Australia is 28.1°C, thermal neutrality for this month is 27.7°C and the adjusted range of 'design temperatures' is around 27.2–32.2°C meaning that, probably, no cooling at all will be required. This suggestion is very much in agreement with some research carried out in the region (Bromberek, 1999).

A resort's lobby can have quite a complex functional purpose. On the one hand, it is a reception area where the arrival and departure of guests is taken care

of and as such is a workplace for the administration staff of the resort. For security reasons, the place would usually be staffed 24 hours a day, 365 days a year. On the other hand, it is often a meeting place for groups and individuals involved in various activities both organised by the resort and informally. The staff and arriving and departing guests would be relatively heavily clothed (not less than 0.5 Clo), and activities performed (light office work) would be at 1.35 Met or 78.6 W/m² metabolic rate. These factors combined require temperatures to be adjusted to around –1 K. This kind of cooling is easily achievable by opening the lobby to allow breezes through (Figure 3.30).

Rooms in a resort vary not only in size and time of use but also in requirements concerning temperature, humidity, lighting, air exchange and other characteristics. Hence the answer to a fundamental question: 'Do the conditions provided throughout a tourist facility and/or at all times have to be uniform?' can only be 'No'. The only appropriate approach would be to tailor the provided conditions to the documented needs. This should be understood as defining these needs and determining the adequate response.

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3.6

Room design

Key recommendations in brief:

- If possible, separate guest unit areas for daytime and night-time uses;
- Ensure that the plan of guest unit is open and uncluttered for effective cross-ventilation;
- Make optional open-to-air spaces for sleeping or resting private and secure;
- Provide access for mobility impaired people to at least 10 per cent of all units.

It is advisable to utilise local materials and local building crafts, skills and knowledge whenever possible. When designing a resort, 'going beyond the usual' quite often means that locality influenced features such as roof form, window frame, railing and interior detail will take a more prominent position. There is a risk of local builders, craftspeople and artisans having difficulty going beyond their 'usual', i.e. domestic type architecture, but this problem can be overcome with robustness of the resort design and by the designer drawing on a local vocabulary of building solutions.

Interiors in a resort should support and extend the general idea of eco-friendly, self-sufficient and efficient design. Thoughtful planning, good organisation and uncluttered detailing are required to offer living conditions compatible with the character of the tropical location and lifestyle of its itinerant occupants. As is the case with many other aspects of the resort design, requirements relevant to interiors have to reconcile many contradictory needs. Their design should draw on vernacular architectural traditions, yet be contemporary in their response to the guests' needs. It should be rich in detail exposing visitors to the local culture but unpretentious, comfortable and sparingly economical. The interiors should provide a variety of experiences without introducing a cacophony of disjointed and unrelated elements.

Guest units in a resort serve a limited number of functions. At least three of the following four functional parts can be distinguished in most units:

- sleeping with limited storage (bedroom);
- hygiene (bathroom);
- circulation space and storage;
- sitting/living (optional).

The part of the guest unit devised for all-day use can be separated from the bedroom in as far as it has

different thermal and visual requirements. Typically, it comprises a dedicated sitting/living area, storage, a bathroom and necessary circulation. A kitchenette can be added in the so-called 'self-contained' units. However, the use of individual cooking spaces in tropical eco-resorts should be discouraged because they contribute to unwanted heat and humidity problems, and further draw on the limited energy available. The daytime functional part of the unit has quite a limited use in the tropics and its functions are best moved to roofed open-air rooms, such as lanais, verandas, balconies or covered terraces, with access to amenities shared with the night-time part. From an environmental design angle, the only requirement for this part is the provision of shade and sensible airflow, which are relatively easily provided by any covered space outside.

Night-time part requirements are a little stricter and, besides thermal environment, include also noise control and safety. Apart from walls separating guest units, acoustic solution is a resort plan domain and is best considered at that level. In addition, safety of unit occupants is best resolved at the resort level. The unit should be open as wide as possible to invite breezes and allow dealing with the thermal environment problems by passive means. The issues that can and should be tackled at the room design level are the health concerns. These concerns can be presented as material selection issues (compare Sections 1.3.4 and 3.4.3). The majority of such concerns are adequately addressed by using traditional construction technologies in conjunction with locally obtained materials.

This functional scheme appears in all 2- to 5-star resorts, typically differing only in size of spaces allocated to particular functions and the standard of finishes. The sizes of guest units vary due to economic and/or site considerations. The recommended minimum structural grid width is 3.3 m, which leaves about 3.0–3.1 m of space available between the walls – depending on the wall type. Most rooms would therefore be designed at a 3.6 m grid span at lower end and 4.2–4.5 m at higher end resorts. Unit lengths are less critical from an economic point of view. Typically, they range between 6–9 m. At such room depths and with openings at both opposite walls, effective cross-ventilation and daylighting are available, while floor area is sufficient to fit in the required functional parts. Usual room heights should be about

3.0–3.3 m, which allows hot air to rise above the usable volume height. Making the room higher significantly increases the cost and adds to the difficulty of stabilising the structure; it can be recommended only if cathedral ceilings are used and the increase in height is a natural consequence of this design arrangement.

The only 'modern addition' to design considerations in resorts is the issue of universal access. The

access for people of various vision or mobility abilities is a concern that requires adjustment of unit design in terms of installation of access ramps, doorway widths, direction of the door opening and room to manoeuvre around it, sufficient space provided in bathrooms, location of switches and a few others. Being dependent on help from the resort staff is not a desirable option and the universal access issues are clearly a designer's responsibility (Figures 3.31–3.34).

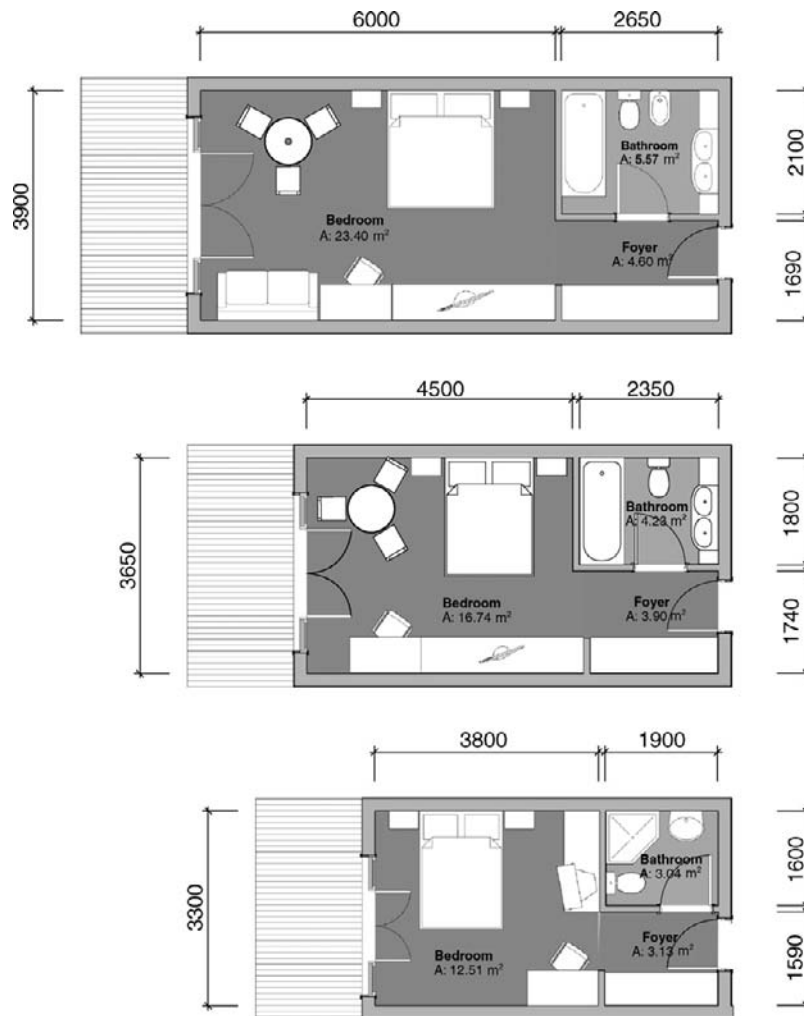


Figure 3.31 Typical sizes and layouts of resort units for 2–3 people: a. high-grade; b. mid-grade; c. budget.

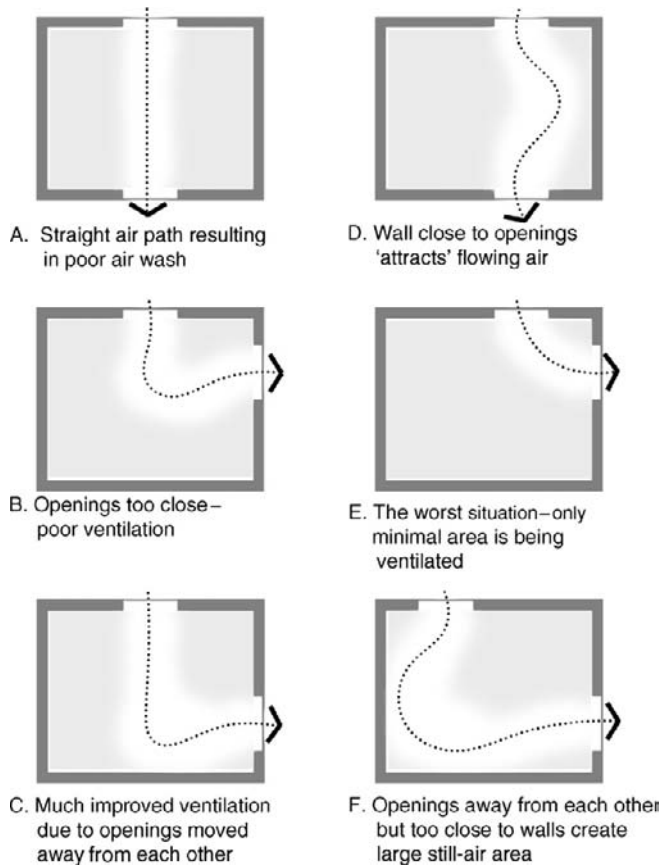


Figure 3.32 Air wash achieved in various configurations of openings.

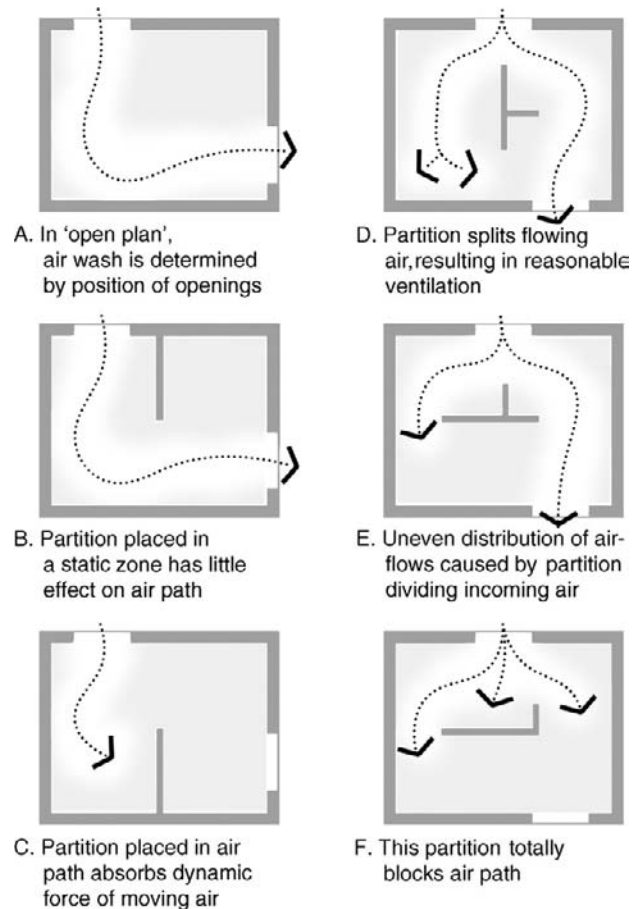


Figure 3.33 Airflow through the plan with partitioning walls.

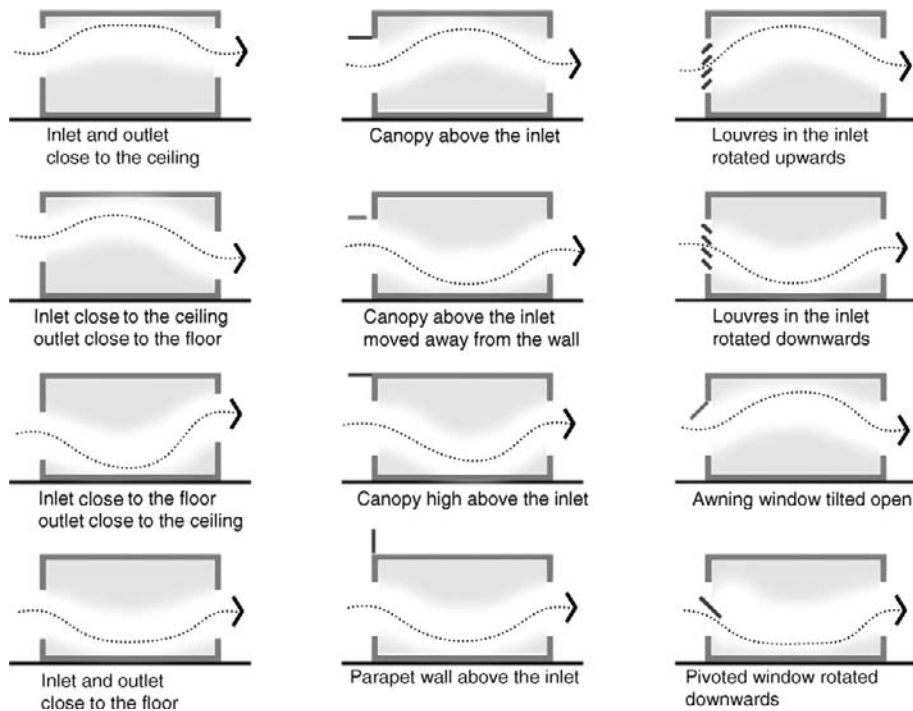


Figure 3.34 Airflow can be vertically redirected by a variety of controlling measures.

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3.7

Resort operation in planning and design objectives

Key recommendations in brief:

- Support biodiversity of the site by maintaining its original character and, possibly, allowing for 'green corridors' to interweave through the resort;
- Consider direct and indirect impacts from guest activities;
- Prevent air, water and soil pollution by containing resort activities to only a part of the site;
- Limit light and sound pollution with adequate building design and by incorporating acoustic/visual barriers into the resort's plan.

Resort operations affect the environment and their impacts should be thoroughly considered at planning and design stages of the development. The list of potential operational impacts can be quite extensive, almost certainly starting with the disturbance to natural cycles – seasonal and diurnal – in the surrounding ecosystems. The resort is most economical when it operates for 365 days per year. It is this superficial continuity brought to the environment, which is naturally cyclical, that is disturbing. Continuous operation means additional water discharge in the dry season and light being available at times when the sun has already set. Many activities also break natural links, for instance by scaring both prey and predators, and reduce the size of many original habitats. Resort operations tend to generate waste and pollution, with the site being contaminated by fumes, insecticide chemicals, cleaning agents and micro-organisms (viruses, bacteria and fungi) brought in by humans moving through. Some vegetation is being damaged and some animals injured or killed – deliberately or in accidents.

Humans and their food attract pests and vermin, while the resort structures present a convenient shelter to many species otherwise very vulnerable in the open. People discard a variety of nutrients, intentionally and unintentionally, which might remain in the place where they were left or discarded but can also be washed into waterways, groundwater or into the ocean. These nutrients may support flora or fauna naturally absent in the area. Resort operations are most often associated with the noise generated by guests and equipment used on site.

However, the problem of light pollution is not any less serious. Both noise and light have the capacity to considerably disturb wildlife in the area. Other undesirable effects of operating a resort are the geological changes that come with compacted or destabilised soils. There are also impacts brought about by energy generation (see Section 1.3.1), water collection (Section 1.3.2) and selected strategies of the indoor environment control (Section 2.1).

Many of these impacts can be contained, limited or avoided altogether. They can be dealt with in either a temporal or spatial dimension or, preferably, both. Certain resort operations can simply be restricted to times and areas that have the least impact on the environment. Some other operational aspects should be translated into the resort plan or design features. For example, drawing on the environment to obtain some of its resources required in resort operations, such as sunlight, water or air, should have a direct impact on design in terms of building form and roof shapes and their orientation. Water tanks can become a visible part of resort architecture giving it a distinctive appearance, and raised walkways can create a specific and respectful outlook towards the nature and ambience. An important aspect of eco-resort operation is that, ideally, there should be no conflict between the commercial interest of the resort developer or operator and environment conservation objectives. The resort has to be designed and operated to minimise waste and emissions discharged into the environment.

Two problems referred to earlier require a special mention. Sound generated by the resort can come from many sources. The only way of dealing with most noise in an eco-resort is by education of the guests. Clear guidelines and an explanation of the difference that considerate behaviour makes on the nature of their anticipated experience should be offered. The resort operators should discourage use of internal combustion engines, mobile phones, musical instruments, radios and tape/CD players while staying at the resort. The resort itself should rely on power generation methods that are silent or low-noise, for example photovoltaics, fuel cells or water turbines.

Transportation of holidaymakers and supplies should use carefully plotted routes and vehicles/vessels using electric rather than internal combustion engines. Where the latter seem unavoidable, they should be placed in soundproofed enclosures. Parts of the resort that are sources of increased noise levels by the nature of their function, for instance dining areas or swimming pools, should use buffers created by dense vegetation planted around them, and be moved away from areas where noise impacts are most disturbing. Other resort buildings should use natural mufflers, such as the sound of waves, whenever possible.

The problem of light pollution is often underestimated even in eco-resorts. Artificial light in the resort can be used for security reasons or for users' convenience in periods of daylight absence or simply when daylight is insufficient. Light pollution, i.e. light introduced in places and/or at times artificially superimposed on the natural cycles of daylight availability, however, can cause serious environmental damage by invading wildlife habitats and disrupting animals' normal living patterns. This is particularly evident in coastal areas where incorrect placement

and excessive intensities of artificial lighting can influence the behaviour of animals kilometres away. Turtles, whales and many sea birds are particularly sensitive to non-natural light sources. To limit the impact it is highly recommended that only minimum artificial lighting be provided and that this should light minimum areas at the lowest usable illuminance.

Outdoor lighting should be avoided and even interior luminaires should be placed so that their visibility through openings is limited. Motion sensor activated lamps should be used instead of continuous all-night lighting of areas sensitive from a safety or security point of view. Driveways should have reflective posts installed along the edges rather than lit ones. Great care should be taken to ensure that light beams are task directed and that upward ones are cut off entirely. All lighting that potentially could be visible from the sea should be excluded. Windows facing the beach should have heavy tinting or opaque blinds installed for light control. In places where lighting is unavoidable vegetation should be planted with the aim of limiting its obtrusiveness.

Part Four

Case Studies

A study of several different resorts in various tropical locations was conducted to investigate a selection of designs, randomised from the environmental response by design point of view. This review also delivered information about the current understanding of eco-tourism principles in the surveyed regions as well as revealing current trends and attitudes among tropical resort stakeholders: designers, developers and operators. The study uncovered a large variety of buildings being used for accommodating eco-tourists. In virtually all eco-resorts, designers decided to dip into the richness of the vernacular architecture treasure trove for inspiration and to visibly mark them as environmentally-friendly developments.

It appears, however, that using the vocabulary of the vernacular does not necessarily mean that developers fully understand the role of all the features or the benefits of using this approach in their modern adaptations. For example, certain features that will have an obvious and significant impact on the indoor environment, such as roof monitors, thick insulation in the roof, effective cross-ventilation or high ceilings, were often introduced in the investigated resorts quite by accident, rather than by intention. Sometimes they were an artefact of copying fashionably traditional forms and sometimes they came about only through the developer using local labour because they were unaware of building in any other way. Some of these highly effective elements have been subsequently removed from the comfort equation by sealing the indoor environment in order to have effective air-conditioning, if demanded.

The end result is a haphazard mixture of passive design features either performing their original role by happenstance or being reduced to mere ornaments. Despite this, the study results indicate that many of these incidental creations do in fact cope reasonably well with the tropical climate, at least during the night-time. Many apparent errors in this approach to design do not necessarily render the resultant indoor conditions unacceptable either, at least not over brief periods of time. But, even allowing for the relative success of the somewhat indiscrimi-

nate and unsystematic application of various regimes and technologies, one is left with the distinct feeling that it should be possible to do the job better with a more informed approach.

The study did not find justification for air-conditioning, particularly in those tropical resorts laying claim to 'environmental friendliness'. To begin with, indoor conditions, which are much the same as the average tropical weather outside, seldom are uncomfortable enough to require a mechanical device to modify them. Running air-conditioning in a typical resort location is expensive, both in the financial and in the environmental sense of the word. Fuel-powered systems generate noise and pollution, and fuel supply (to remote locations in particular) carries an inherent danger of fuel spills and other environmental hazards. Moreover, numerous examples from vernacular architecture have delivered sufficient proof that comfort in the tropics is achievable with passive measures only. It should also be stressed that eco-tourists are usually happy to adjust their behaviour and thus reduce any perceived discomfort; ultimately, they can leave the resort at short notice. It is a low price to pay for being truly environmentally-friendly.

There is a widespread belief among experts that passive climate control solutions are economically and environmentally justifiable alternatives to mechanical systems, and this applies in the tropics as well. It seems that traditional biases against tropical conditions may have been built upon experiences derived from instances where resorts have simply been built to a wrong or inappropriate design. The review reported in the following pages delivers further proof that indoor conditions in the tropics can fall well within the comfort range without mechanical support.

It is worth noting that each of the case study resorts has features that make them worth listing in this review. They are among the best examples of eco-resorts in their respective regions. If not actually strictly, they provide a well-meaning interpretation of environmental friendliness in their design and application.

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4.0

A question of practicality

The following case studies are a cross-section of various attempts at somewhat more eco-friendly approaches to design and operation of resorts in the tropics. The author visited 15 tropical resorts in four countries in November and December 2005. The period was a transitional 'between the seasons' time, when temperatures are usually close to annual averages. In fact, in all but one location annual minima were lower than the observed minimum temperatures and annual maxima were higher only in the Mexican locations. The timing of the visits corresponded with 'early summer' in the southern hemisphere and 'early winter' in the northern. Precipitation is the main indicator of the seasonal change in the tropics, even if the frequency and intensity of the rainfall is more often determined by the specifics of the location, for instance its topography. Precipitation directly influences relative humidity (RH) but readings of RH taken during the study tour were consistently very high, even if significant rainfall during the visit was noted only in some Fiji and Cook Islands locations.

The resorts were selected because of claims of their 'environmental friendliness'. Their locations also represented a fairly typical selection of tourist destinations in the tropics, with all but one resort built directly on a beach. The environmental friendliness claims were investigated, various design features were photographed and/or described, operational data were collected, managing staff were interviewed and air temperature readings were taken both inside and outside the allocated unit over 24-hour periods, together with relative humidity readings indoors. Four of the visited resorts were found to be no different from other resorts in the area, and therefore to have no basis for the claimed eco-friendly status. Subsequently, they were discarded from the sample. Eight of the remaining eleven are presented in more detail in the following pages.

A digital thermometer/hygrometer with memory was used in the assessment of thermal conditions found during the visits. The use of device memory allowed the recording of the highest and the lowest temperatures as well as the highest and the lowest relative humidity readings during the diurnal cycle of the visit. The indoor temperature and RH readings were taken at the bedside at bed mattress height (approximately 0.5 m above the floor). If there was

air-conditioning and/or a fan in the unit, they remained switched off during the entire period. All windows fitted with fly-screens, on the other hand, remained open during the night (see Section 2.1.2 for the negative effect on airflow produced by fly-screens). External temperatures were measured directly outside the allocated unit. Since the Stevenson screen was not available, attempts were made to find a spot shaded during the entire day for this purpose. The temperature readings are presented in Table 4.1 (RH readings were over 95 per cent, at least at some point in time during the night, in all locations).

Half of the resorts visited offered mechanical air-conditioning (AC) in guest accommodation as an option. Despite their environmental claims, managers in nearly all resorts were willing to provide air-conditioners as they felt 'compelled by their markets' to do so. Furthermore, in all resorts that offered AC, room service was instructed to ensure that the air-conditioner was switched on before a new guest arrived (generating a rather negative impression of eco-friendliness and a big impact on energy demand: see Section 2.1). All the managers admitted in their interviews that the cost of providing AC was very high. Nevertheless, AC has not been seen as a factor having an impact on the environment.

The 'eco-resort' status was seen as being achievable through strategies such as controlling tourist impacts, using natural building materials or blending their resorts, as a business endeavour, with the local community. Impacts from a resort's operations, including noise and pollution generated by a power plant, were seldom perceived as being part of the 'eco-friendly' package. Even less so were the environmental costs of providing supplies, for instance fuel. It is worth noting that due to the unreliable nature of their power generation capabilities, fuel-free power generators would usually be supported by back-up diesel generators – even in eco-friendly resorts.

Not a single resort amongst those visited was designed to utilise passive means of climate control. Features coming from vernacular architecture that were replicated in their designs often seemed superficial and dishonest (the pastiche approach). An example was a palm leaf thatch covering metal decking on a roof to give it a traditional hut appearance, or a roof monitor blocked to seal the interior for effective air-conditioning. Yet in nearly all instances

Table 4.1 Comparison of climatic annual averages with temperatures indoors and outdoors, corresponding Humidex indices and comfort ranges in the studied locations

Resort location	Air-cond. availability	Minimum temperature (°C)				Maximum temperature (°C)				Humidex	Thermal
		Average ^(a)	In	Out	Diff.	Average ^(a)	In	Out	Diff.	index ^(b)	neutrality ^(c)
Vanua Levu, Fiji	Yes	21.6 ¹	26.4	26.1	+0.3	27.9 ¹	29.1	31.1	−2.0	34.3	26.4
Naigani, Fiji	No	22.4 ²	25.9	23.5	+2.4	29.0 ²	34.9	33.0	+1.9	37.3	26.9
Rarotonga 1, Cook Islands	No	21.9 ³	25.9	25.6	+0.3	26.3 ³	30.0	30.9	−0.9	34.5	26.2
Rarotonga 2, Cook Islands	Yes	21.9 ³	25.9	23.9	+2.0	26.3 ³	29.4	29.6	−0.2	34.2	26.2
Aitutaki, Cook Islands	No	22.1 ⁴	27.4	26.9	+0.5	28.8 ⁴	34.5	32.6	+1.9	37.9	26.8
Moorea, French Polynesia	Yes	21.0 ⁵	27.4	26.1	+1.3	30.7 ⁵	32.0	32.3	−0.3	36.5	26.9
Bora Bora, French Polynesia	Yes	23.4 ⁶	28.9	27.4	+1.5	29.0 ⁶	30.9	33.6	−2.7	36.7	27.0
Tulum, Mexico	No	20.9 ⁷	21.3	18.9	+2.4	30.9 ⁷	27.6	28.0	−0.4	30.5	26.0
Bahía Permejo, Mexico	No	21.9 ⁸	24.6	22.9	+1.7	30.5 ⁸	27.4	26.4	+1.0	32.3	25.9
Rio Indio, Mexico	No	21.9 ⁸	24.6	24.3	+0.3	30.5 ⁸	27.4	26.6	+0.8	32.3	25.9
Chichén Itzá, Mexico	Yes	19.3 ⁹	26.0	23.9	+2.1	32.5 ⁹	30.1	29.9	+0.2	34.6	25.6
Average for 11 resorts		21.7	25.8	24.5	+1.3	29.3	30.3	30.4	−0.1	34.6	26.4

^a Annual average minimum/maximum temperature at a meteorological station nearest to the resort: 1-Savusavu, 2-Nausori, 3-Avarua, 4-Ootu, 5-Papeete, 6-Motu Mute, 7-Tulum, 8-Chetumal, 9-Dzitas.

^b Humidex index as calculated for the observed indoor air temperatures.

^c Determined with the Nicol's equation (see Section 2.1, eqn (2.1)); results in this column ± 2 deg give 80 percentile acceptability; compare this with the observed night-time (minimum) air temperatures indoors.

the indoor climate was remarkably comfortable. Minimum (i.e. night-time) indoor temperatures recorded were always higher than the corresponding temperatures outdoors. This effect of building mass was most evident in the heavyweight structures of the Rarotonga 2, Tulum, Bahía Permejo and Chichén Itzá resorts. Even these higher indoor temperatures were within the comfort range determined by the thermal neutrality equation (see Chapter 2.1). In the only resort where the night-time temperature was outside the range, it was actually lower than the ones called for by the equation (Table 4.1).

The author's own perceptions were in line with predictions arrived at using the Humidex index. Mild discomfort was felt in conditions resulting in Humidex values of 36.5 or more (as in three out of the eleven resorts surveyed). However, the perceptions were based on conditions achieved with no air-conditioning or fan working in the unit. Cross-ventilation was not always possible, either. It is easy to imagine that the conditions would be greatly improved if only a slight air movement was induced or, better still, if the resorts were designed to depend chiefly on passive climate control.

Most resorts relied on cross-ventilation, cathedral ceilings and, in a few instances, shading to create comfortable indoor conditions. This did not seem a deliberate part of some 'grand plan' to utilise passive design features. Instead, it seemed more like the accidental result of pursuing a romantic image that some of these resorts wished to evoke by reference to

the vernacular. As one of the resort owners put it, 'Tourists come to my resort for a dream and I'm selling them that dream'. Lack of understanding of visitors' comfort perceptions in tropical climates was also evident. When one of the managers agreed to a little experiment involving raising the temperature in his air-conditioned office by three degrees (to a level suggested by Nicol's equation discussed in Section 2.1), he was genuinely surprised how cool it felt after only a brief walk outside. His experience, on which he was basing his decisions about temperature settings for AC in guest units, was derived from working in the office all day long.

Findings from earlier research by the author suggest that passive climate control should involve specific requirements of the users. It should also exploit the identified differences between tourists, who are only short-term visitors to the tropics, and the residents of the region. The study strengthened the opinion that relative comfort is achievable in the tropics without help from mechanical devices. In all the resorts studied, night-time conditions, when extracted from all-day averages, fell within the comfort range determined by Nicol's equation.

In all resorts, some degree of discomfort was predicted with the Humidex index (for more detail on Humidex see Section 2.1); the average score of 34.6 indicates that the discomfort would only be mild for most tourists and, allowing for their attitudes, could be acceptable to them during a short-term visit. There

<i>at the single building level</i>	Resort:	1	2	3	4	5	6	7	8
Features supporting cross-ventilation: open plan and ample apertures		✓	✓	✓	✓	✓	✓	✓	
Room height and/or features supporting stack effect ventilation		✓	✓	✓	✓	✓	✓	✓	
Informed use of slats and louvers		✓	✓			✓			
Features providing sufficient daylight levels		✓	✓	✓	✓	✓		✓	
Careful orientation to avoid overheating						✓			
Extensive use of shading by vegetation and/or terrain features		✓	✓				✓	✓	✓
Building raised off the ground			✓	✓	✓				
Open-air covered space available for rest and/or other purposes			✓	✓	✓			✓	✓
Deliberate use of colour and texture influencing perception of indoor climate		✓	✓	✓	✓	✓	✓		✓
Energy-efficient lighting		✓	✓	✓	✓	✓	✓	✓	✓
Solar water heating		✓						✓	
Extensive use of locally sourced natural materials		✓	✓	✓	✓	✓	✓	✓	✓
Extensive use of materials requiring little or no maintenance		✓	✓	✓	✓	✓	✓	✓	✓
Extensive use of recycled materials								✓	✓

Figure 4.1 Summary of environment-friendly features in the case study resorts; building level and resort level.

<i>at the resort level</i>	Resort: 1 2 3 4 5 6 7 8							
Considerate solar orientation of structures					✓			
Considerate location relative to sea to benefit from temperature dampening effect	✓	✓	✓	✓	✓	✓	✓	
Deliberate siting to capture prevailing winds and breezes	✓			✓	✓		✓	
Functional layout and natural buffers utilised to prevent spread of noise	✓		✓	✓	✓			✓
Provision of open-air spaces for dining, entertainment and/or other functions	✓	✓	✓		✓	✓	✓	✓
Extensive use of native vegetation to improve microclimate (shading, breezes)	✓	✓	✓	✓		✓	✓	✓
Landscaping based on the original vegetation	✓					✓	✓	✓
Conservation efforts undertaken by the resort	✓					✓	✓	✓
On-site power generation from renewable sources	✓				✓	✓		
Water collection/harvesting on-site	✓	✓	✓	✓		✓	✓	✓
Considerate waste disposal	✓	✓	✓	✓	✓	✓	✓	✓
Grey water reuse	✓		✓	✓	✓	✓		✓
Local community involvement in construction, maintenance, operations	✓	✓	✓	✓	✓	✓	✓	✓
High-level support for the local community: crafts, artisans, staff and education	✓					✓		✓

Figure 4.1 (Continued)

could be spells of extremely hot weather when conditions are much worse but then the resort could respond to them as it would to any other disastrous event, that is, by taking them as an exception rather than a rule. The study did not find justification for air-conditioning in tropical resorts laying claim to

'environmental friendliness'. The indoor conditions during the night, i.e. the time when units are actually used by tourists, correspond with average tropical weather outside and are therefore seldom uncomfortable enough to require a mechanical device to modify them (Figure 4.1).

4.1

Jean-Michel Cousteau Fiji Islands Resort

Location:	Lesiceva Point, Savusavu Bay, Vanua Levu island, Fiji
Year of completion:	1987 (refurbished 1993)
Total cost of construction:	US\$5 million (approx.)
Architect/designer:	
Consultant:	Richard C Murphy
Builder:	local craftspeople
Number of guest units:	20, plus 5 superior bures (bungalows)
Max. number of guests:	80 (approx.)
Site area:	17 acres (approx. 7 ha)
Other facilities on site:	reception, two dining halls, club house, dive shop, three pools, tennis courts, pier
Access methods:	by air and road via Savusavu from Viti Levu island (Nadi international airport), by seaplane or launch
Principal attractions in the area:	the sea and reefs, diving sites, rainforest, villages, towns of Savusavu and Labasa.

4.1.1 In their own words

Strengthening its long-standing eco-friendly reputation, Jean-Michel Cousteau Fiji Islands Resort has been named the world's top eco-tourism destination in the October 2005 edition of the US-published *Condé Nast Traveler*.

Topping the magazine's Green List – and the only South Pacific destination included among finalists – the five-star 25-bure resort, located on the island of Vanua Levu, beat stiff global competition from tourism operators, resorts and lodges.

Condé Nast Traveler describes the Jean-Michel Cousteau resort as 'an exemplary marriage of opulence and eco-conscience'.

The resort prides itself on attention to water and waste recycling, environmental programs to assist local villagers and daily activities enabling guests to discover the island's pristine sea, rainforests and waterfalls. Visits to local villages and markets give guests a feel for the 'real Fiji' as it was several decades ago, while still enjoying the modern facilities of a luxury resort.

It's the only resort in Fiji with its own on-site marine biologist, Fijian born Johnny Singh who

trained at Queensland's James Cook University, to help visitors appreciate Fiji's underwater world at over 50 snorkelling and scuba diving sites.

With a range of accommodation options, the resort is a favourite destination for honeymoons and weddings. It also offers family enjoyment with an environmentally friendly Bula Camp to occupy children under 12 while parents enjoy this romantic, away-from-it-all location and gourmet dining. [Source: <http://www.ixplore.com.au/viewed> 15/10/2005].

The resort uses the coral reef as a conceptual model for sustainable and responsible design. Free services of nature are employed to minimise environmental impacts and to increase returns on economic investment. High levels of integration between resort systems and the resort's natural and cultural surroundings are designed to give guests a high quality environment for mental, spiritual and physical enrichment. Coral reefs, mangroves, rainforests and traditional Fijian culture offer guests a wide range of options for connection to nature and local people. The operators see their involvement as an opportunity to put into practical application many of the things the famous French explorer and environmentalist, who gave the resort its name, has been emphasising throughout his long career.

The design objective was to 'create an environmentally responsible facility, which was elegant, yet simple, so as to promote an appreciation of, and connection with, the natural and cultural qualities of Fiji'. The designers took a pragmatic approach to development and environmental protection. They did what was possible to protect the natural resources and ecological sustainability was taken as a guiding principle rather than a constraint. They also believed that reliance on the forces of nature was saving them money. As Richard C Murphy, Environmental Consultant to the resort, put it:

nature does work without [expensive] human input, renews and repairs itself for free, replaces itself for free, adapts to change naturally and runs totally on [free] solar energy.



Figure 4.1.1 General view of the resort from its pier. Traditional thatched roofs blend well with the tropical island surroundings.

The integrated biosystems and functional landscapes were designed to support energy sustainability, integrated food production, water conservation and waste reduction strategies. At the same time, the resort's operators are very sensitive to the fact that they are guests and members of the local community, and thus obliged to accept certain social responsibilities. In a very real sense, the operators and the local people have been partners in the resort's development and subsequent operations. The dialogue is ongoing to ensure compatibility of the facility with the regional culture, local traditions and community's aspirations for the future (Figure 4.1.2).

4.1.2 Site selection and landscaping

The underpinning philosophy was to keep additional development to a minimum and to make better use of what already exists. The JMC resort has taken advantage of an existing facility and revitalised it to meet new standards. The retrofitting process took the form of recycling, reuse and upgrading of a prime site resort constructed on the theme of a traditional Fijian village. The local natural habitats have also been restored in the process. The village theme was considered critical to the design ethic as it dignified the cultural heritage and utilised design features refined by generations to meet unique Fijian geography

and climate. The total site area is around 17 acres (almost 7 ha) (Figure 4.1.3).

Landscape management is seen as particularly important because of the potential for various coastal impacts. The original mangrove habitats are being restored to prevent erosion. Permanent ponds have been created to replace seasonal puddles of standing water. This helps to control mosquitoes as well as provides diverse animal and plant ecosystems. Recent tests showed a 100-fold reduction of mosquito larvae in the pond compared with the puddles. Edible landscaping is being implemented and it is estimated that once fully functional it will save the resort \$1000 per month by growing fruit, vegetables and herbs on site. Passion fruit vines are used to provide visual privacy between *bures*. Thoughtful area lighting is used sparingly to limit light pollution.

4.1.3 Construction and materials

Principal materials used in the development include local timbers, palm-leaf thatch, ceramic tiles, stone and concrete. The choice was guided by a number of principles: to minimise impact on the landscape, to use natural materials and systems when possible, to use materials fabricated in an environmentally responsible manner, to minimise construction waste and, finally, to design for flexibility and implement

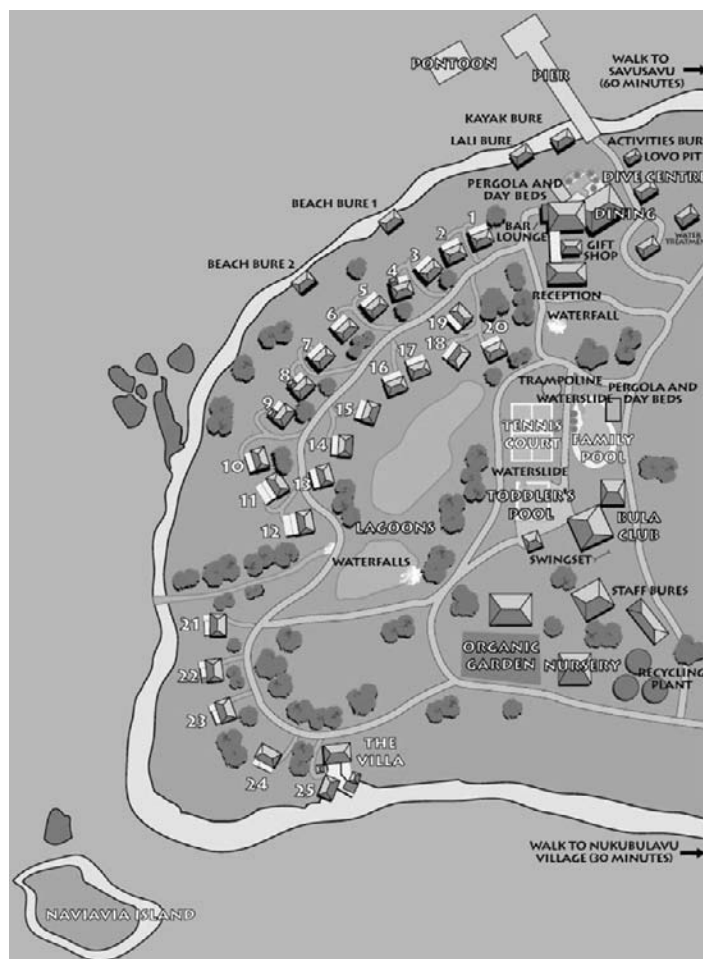


Figure 4.1.2 Plan of the resort (courtesy of the JMC Fiji Islands Resort).

more environmental technologies and systems as they become available. The materials and technologies used also employ local building knowledge and skills thus minimising the need for external expertise, providing local artisans with employment as well as cultivating and preserving local traditions (Figures 4.1.4–5).

4.1.4 Energy management

Passive solar design maximises the utilisation of nature's free services to cool and refresh the air, to heat water and dry the laundry. Thatched roofs, high ceilings, louvred windows and shading vegetation deliver the entire required air-conditioning (air-conditioners are not provided in guest rooms). Solar hot water systems and solar assisted systems deliver hot water during most of the year. The

remaining required energy comes from the town grid powered by a hydroelectric power station. A wind monitoring station, established in cooperation with the Fijian Department of Energy, looks to wind as an additional source of power, perhaps supplemented by photovoltaic cell banks, in the future. Energy-efficient compact fluorescent and halogen lighting is used throughout the resort together with energy-efficient appliances. A solar oven is used for native food cooking demonstrations and in children's programmes.

4.1.5 Water management

Water management includes a number of strategies for water conservation and water pollution prevention. Used water is treated in constructed wetlands and reused in irrigation systems. The objective is to



Figure 4.1.3 *Bures* (guest units) strung along the shoreline enjoy good sea breezes and visual privacy.



Figures 4.1.4–5 Thatched roof over the dining area; constructed, maintained and repaired by the local craftspeople.



Figure 4.1.6 Dining halls at the JMC resort are open-air traditional Fijian structures. The pool deck also doubles as a dining space at dinner time.

keep nutrients cycling in the system rather than releasing them into the sea. Further purified, treated fertilised water is used in fruit and vegetable gardens and ultimately returns as wastewater, completing the cycle. Both the constructed wetlands and multi-crop agricultural systems are based on strategies developed and coordinated with the international University of South Pacific to ensure that the tried theory and developed practices will be of use to others in the region (Figure 4.1.6).

4.1.6 Waste management

Waste minimisation, reuse and recycling are at the core of the resort's operations. Grey water, kitchen waste and sewage are considered resources to be utilised for beneficial purposes. Staff education and buying procedures dramatically reduce packaging waste. Local staff find uses for most cardboard and metal packaging, and waste is limited primarily to plastics. A local distributor of bottled water recycles plastic bottles and recyclers in the Fijian capital of Suva recycle paper and batteries. Furthermore, photographic processing chemicals are rendered inert and the silver

is extracted and sent to Suva for reuse. Nearly all kitchen waste is composted.

The major difficulty with adequate waste management, as identified by the resort, is that due to the resort's efficiency its waste stream became so small as to be rendered uneconomical to process by specialised companies. Consequently, the resort is cooperating with local schools and businesses in the nearby town of Savusavu to increase, for instance, paper volume to a level sufficient for an external enterprise to become interested in getting involved (Figures 4.1.7–8).

4.1.7 The control of other impacts

New construction was kept to a minimum and an attempt was made not to impair the visual environment, in particular the scenic views out to the bay.

The resort uses carefully selected non-toxic chemicals on a limited scale. Chemical fertilisers are not used. The use of pesticides and insecticides has been reduced by 90 per cent in comparison to similar areas in the region. Guests are educated about the environmental impact of totally eliminating tropical wildlife



Figures 4.1.7–8 The design of individual guest units is based on traditional Fijian houses. Their high cathedral ceilings, lightweight thatched roofs and generous louvered windows on both long sides ensure an excellent thermal environment even without air-conditioning.

encroaching on their space (ants, cockroaches and geckos), to understand the unavoidable consequences of such actions. The pest management programme uses pest parasitoids and breeding habitat reduction as a means of control.

All dive sites are rotated, with some of them temporarily closed, to control diver impacts. When in use, they all have moorings to prevent damage from boat anchors. Others are only accessible to experienced eco-divers.

The resort conducts regular seminars for staff as an essential part of its environmental ethic. The popular perception of luxury associated with carelessness and waste is challenged to make up for the bad examples the world conveyed to them about so-called 'success'. The resort owners are also committed to disseminating ideas and findings throughout the wider region. A relationship established with the University of South

Pacific allows educational benefits to spread beyond the island of Vanua Levu or even Fiji.

4.1.8 The resort's climatic performance

During the visit to the resort in late November (early summer), the external temperatures ranged from 26.1–31.1°C and corresponding internal temperatures (with fans switched off) were in the range 26.4–29.1°C. This indicates minimal heat storage and short time lag occurring in some materials used in *bures* (ceramic tiles on concrete floor slab) as well as fairly efficient shading and natural ventilation – dampening temperatures indoors by a sensible two-degree margin.

at the single unit level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				

at the resort level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				
Socio-economic dependencies				

Figure 4.1.9 The extent of the resort's potential environmental impacts. (**Note:** The extent of the resort's impacts [ranging from positive through neutral to negative] should be read in conjunction with the information in [Figure 4.1](#)).

4.1.9 Concluding remarks

The most important feature of the Jean-Michel Cousteau Fiji Islands Resort is its integration with the local community. The resort is designed to support and be supported by the local community. It draws on local building knowledge, local traditions and local building materials. Design of guest units (*bures*) follows the design of traditional huts utilising some of their advantageous characteristics, such as very high cathedral ceilings and thatched roofs. *Bures* are strung along the shoreline taking in breezes coming from the sea. Native vegetation

provides hedges, which act as both a visual and acoustic barrier between the units. Also, planning issues are well resolved, with dining rooms (doubling as an entertainment area) and playgrounds for the children moved well away from the 'residential' part. Finally, most of resort operations are in tune with the overall image of this multi-award winning resort. The ostentatious opulence could draw some criticism and guests could also be more prominently encouraged to open their units up to the environment, but the overall assessment of the JMC as an eco-resort could not be more positive ([Figure 4.1.9](#)).

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4.2

Are Tamanu Beach Hotel and Muri Beach Hideaway

Are Tamanu Beach Hotel

Location:	Amuri Village, Aitutaki, Cook Islands
Year of completion:	2001
Total cost of construction:	US\$1.2 million (approx.)
Architect/designer:	Des Eggelton of Frame Group, Cook Islands
Consultant:	Michael Henry
Builder:	Maru Ben
Number of guest units:	12 self-contained <i>ares</i> (studio bungalows)
Maximum number of guests:	30 (approx.)
Other facilities on site:	café-bar, office, laundry
Site area:	1 acre (0.4 ha)
Access methods:	by road (from Rarotonga International airport or Aitutaki atoll harbour)
Principal attractions in the area:	the lagoon and reefs of Aitutaki atoll, the island's nature, water sports

Muri Beach Hideaway

Location:	Muri Beach, Rarotonga, Cook Islands
Year of completion:	2001
Total cost of construction:	US\$400 K(approx.)
Architect/designer:	Des Eggelton of Frame Group, Cook Islands (concept by Mike Henry) in cooperation with Pauline MacFarlane (resort owner and manager)
Builder:	local craftspeople
Number of guest units:	5 self-contained studio bungalows
Max. number of guests:	10
Other facilities on site:	office, laundry, owner/manager accommodation
Site area:	0.375 acres (0.15 ha)
Access methods:	by road (from Rarotonga International airport at Avarua)
Principal attractions in the area:	the lagoon and reefs, culture and art tours, dining

native mahogany trees from which it is named (Figure 4.2.1).

In keeping with its name, Are Tamanu's luxurious self-catering individual *ares* feature tamanu floors and Cook Island style thatched roofs. Tamanu is also used for the carvings in each room and is a feature of the popular poolside bar.

[The resort's] private white sand beach borders Aitutaki's superb lagoon providing endless opportunities for swimming, snorkelling and canoeing. Around [the] freshwater swimming pool is a large deck providing a pleasurable venue for evening cocktails and Sunday BBQs.

[All] individual *ares* offer first class appointments including luxurious king-size beds, full kitchens, refrigerator/freezer, gas cooker, microwave oven, quality cutlery and crockery, and IDD telephones.

Each *are* has a separate bathroom with hairdryer, kitchen, breakfast bar, room safe and outdoor decks with dining settings for four. All rooms are air-conditioned and have insect screened windows. [Source: Are Tamanu Beach Hotel] (Figure 4.2.2).

The Muri Beach Hideaway is an example of a small owner-operated resort. Apart from the original building – a two-storey family house, doubling nowadays as a laundry, storage space and the owner's accommodation – there are only five small bungalows built on the site. The Are Tamanu, on the other hand, is a fairly typical medium-size resort, more than twice the size of its Rarotongan counterpart. Both share the same unit design with only a few small modifications introduced at the Muri Beach Hideaway.

4.2.1 In their own words

Are Tamanu Beach Village has a history going back hundreds of years. Like all lands in the Cook Islands, the land the [resort] is built on has a traditional name and it is Are Tamanu. The literal translation of Are Tamanu is 'House of the Mahogany Tree' and this land still retains some of the

4.2.2 Site selection and landscaping

Both resorts are sited in locations of a suburban character, and resort development has brought about an improvement rather than destruction of the original sites. Both sites were already extensively modified before the resorts were built.

The Are Tamanu is located on the principal island of Aitutaki atoll, on the major road running



Figure 4.2.1 Both the Are Tamanu and the Muri Beach Hideaway share the same bungalow design; the resorts differ in size, positioning, some material and operational details as well as in landscaping design.



Figure 4.2.2 The Muri Beach Hideaway started as an ordinary suburban block. The original house is still in use as the owner/manager's accommodation, storage space and a service block.

north-south along the west coast linking the airport with the major settlements of Amuri, Ureia, Arutanga and Reureu. In total, the site modifications amounted to 13 coconut trees being removed, several ornamental trees and bushes being planted, three large volcanic rocks being brought to the site, an in-ground swimming pool and a fish pond being built, and a few walkways being paved.

The site of the Muri Beach Hideaway is also rather typical for the area: a suburban building block wedged between the coastline and the main road on the island of Rarotonga. In fact, only a third of the block has been set aside for development; the remainder constitutes a buffer zone, nearly 150 m wide, which shields the resort from traffic on a relatively busy road. The site has been extensively modified for a number of years now. Site development included establishing tropical garden patches, planting hedges, building an in-ground freshwater swimming pool and timber decks on the waterfront as well as laying out crushed coral and sand, timber and concrete walkways.

4.2.3 Construction and materials

The bungalows are an example of a very smart and efficient use of design, which makes excellent use of natural building materials such as engineered timber products (exterior graded Fijian plywood,



Figures 4.2.3–4 The Are Tamanu resort's *are* or bungalow design is the original, on which the Muri Beach Hideaway's bungalows were based; sharing the same envelope, a few modifications appear in the Muri Beach Hideaway floor layout and material solutions.

New Zealand pine poles, bearers and joists, timber decking and flooring), palm-leaf thatch and rattan matting as well as ceramic floor tiles. Roofs at Are Tamanu are metal decking covered with thatch, in which respect they differ from the Muri Beach Hide-

away. The thatch gives the units a traditional appearance and reduces the noise from the rain. Materials require minimal maintenance. The bungalow layout is also exemplary as an efficient and functional space design.



Figures 4.4.2.5–6 Large shaded verandas (Are Tamanu) and single-skin plywood walls (Muri Beach Hideaway) ensure a thermal environment within the comfort range during most of the year.

A thatched roof pitched at 35° shades the single-skin walls made of plywood. Available lengths of structural elements determined the angle but it still works well by allowing for ample overhangs shading external walls. The combination of single-skin plywood walls and high cathedral ceilings under thatched roofs makes efficient heat dissipation possible and accounts for very good thermal conditions at minimal cost. The *ares* are admittedly overengineered but this has been done for aesthetic reasons (Figures 4.2.3–4).

4.2.4 Energy management

Electricity for the Are Tamanu resort is generated by a diesel-powered island generator. The lighting system is a mix of energy-efficient low-voltage halogen

lights, fluorescent tubes and incandescent bulbs. All guest units are equipped with microwave ovens, fridge/freezers and hairdryers. They also all have air-conditioners installed although, judging by the performance of the nearly identical units at the Muri Beach Hideaway, they can provide thermally comfortable conditions without AC support (Figures 4.5–6).

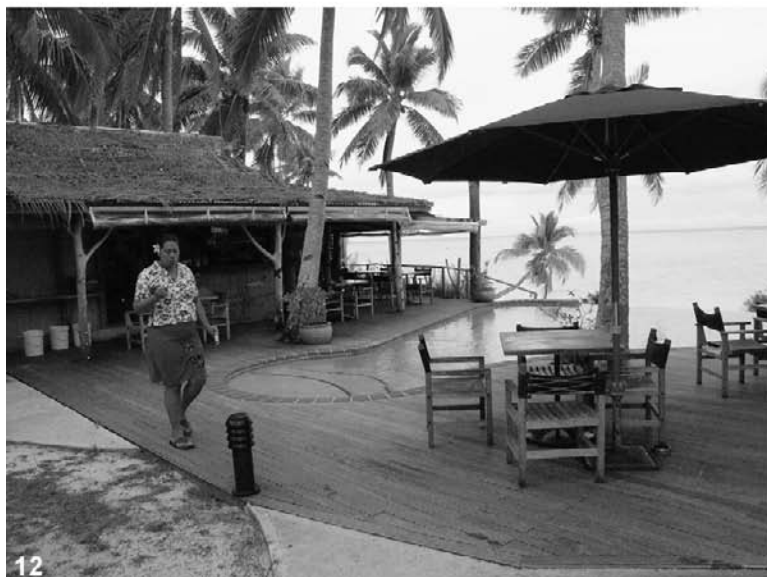
The source of electricity at the Muri Beach Hideaway is also a town grid. Occupied units use 4–5 kWh per day due to a wide range of appliances offered to the guest: fridge, ceiling fan, hairdryer, kettle, sandwich-maker, blender, range hood, iron and TV set. Water heating has been found to be most economical with the use of instantaneous gas heaters. Landscape lighting is provided with solar-powered lights. The indoor lighting systems utilise both energy-efficient low-voltage halogen lights and compact fluorescent tubes.



Figure 4.2.7 High quality plywood walls do not require finishing on the inside and their maintenance is inexpensive and easy (Muri Beach Hideaway).



Figures 4.2.8–9 Instantaneous gas heaters were found to be the cheapest and most reliable means of water heating at the Muri Beach Hideaway; energy savings are achieved by using solar-powered lighting of the site.



Figures 4.2.10–12 Are Tamanu's landscape design is quite typical yet efficient in the use of the narrow block of land; a central communication spine services two rows of bungalows with a beach café-bar, pool and deck at its ocean end.



Figures 4.2.13–14 The Muri Beach Hideaway replicates the basic layout of the communication scheme: a walkway services a single file of guest units due to the narrowness of the site.

4.2.5 Water management

Most of Are Tamanu's needs are covered by water coming from an artesian source through a town mains. There are also two rainwater tanks capable of storing 108 000 litres each. Water for irrigation is recycled grey water. The content of grey water from the sewage treated on site is too high in nutrients and this issue is going to be addressed in the near future by an improved purification system.

Similarly to the Aitutaki resort, the Muri Beach Hideaway water comes from town reticulation. There is also an underground rainwater tank capable of storing 10 000 litres. On average, an occupied unit uses 120 litres of water per day. Savings are achieved by restricting usage of water from the town grid to human consumption. Water for irrigation is recycled grey water. All toilets have dual flush systems and virtually all liquid waste is processed on site and recycled, depending on its source, in either flowerbeds or for fruit and vegetable patches (Figure 4.2.7).



Figures 4.2.15–16 Site edges in the two resorts represent very different approaches serving the same purpose of securing acoustic privacy and safety for the guests: Are Tamanu has a stone wall while the Muri Beach Hideaway hides behind a dense vegetation along a stream.

4.2.6 Waste management

Waste management at both resorts is similar. A local contractor takes solid waste generated at Are Tamanu away to a local tip. Liquid waste is processed underground on site. At the Muri Beach waste is collected and carted away by a local contractor to the capital town of Avarua where plastic, glass and metal waste is recycled; organic waste is composted on site. The liquid waste is processed on site in the resort's own underground sewage purifying system (Figures 4.2.8–9).

4.2.7 The resort's climatic performance

During the visit to the Muri Beach resort, very late in November (early summer), the external temperatures ranged from 25.6–30.9°C and corresponding internal temperatures (with fans switched off) were in the

range 25.9–30.0°C. This indicates very efficient thermal design and nearly no heat storage in the lightweight structure of the unit. Conditions inside were very similar to those outside in the shade, i.e. without the effects of direct solar irradiation.

4.2.8 Concluding remarks

In both the Are Tamanu Beach Hotel and the Muri Beach Hideaway we can see a very clever design. Resort planning provides reasonably good – for the given conditions – views and ventilation without compromising visual or acoustic privacy. Application of building materials is smart and efficient, and energy and water are used in the best possible way. The guest units are easy to maintain and their functional layout is highly efficient.

Both resorts occupy very narrow sites. Furthermore, both are enclosed within boundaries defined by high and dense hedges. Despite being open on

at the single unit level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				

at the resort level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				
Socio-economic dependencies				

Figure 4.2.17 The extent of the resorts' potential environmental impacts (Note: The extent of the resort's impacts [ranging from positive through neutral to negative] should be read in conjunction with the information in [Figure 4.1](#)).

their short ocean sides, this narrowness combined with constricting vegetation severely hampers penetration of breezes and air movement through the sites ([Figures 4.10–12](#)).

The *ares* of the Are Tamanu Beach Hotel are capable of operating with or without air-conditioning – both options demanded by the targeted markets and both offered in all units. The guest units rely on air-conditioning for most of the time, however, and

natural ventilation is not critical to their performance. On the other hand, the Muri Beach Hideaway units, which do not offer air-conditioning, demonstrate excellent quality of their design by providing indoor conditions well within the comfort range. They also prove that the design, shared by both, is capable of coping with the tropical climate without powered air-conditioning support ([Figures 4.2.13–14](#), [Figures 4.2.15–16](#), [Figure 4.2.17](#)).

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4.3

Sheraton Moorea Lagoon Resort & Spa

Location:	Papetoai, Moorea, French Polynesia
Year of completion:	2001
Total cost of construction:	US\$10.2 million (approx.)
Architect:	Pierre Lacombe
Consultant:	
Builder:	local craftspeople
Number of guest units:	106 bungalows (57 over-water, 42 garden, 7 beach)
Max. number of guests:	280
Other facilities on site:	offices and reception, restaurant and kitchen, spa, pool and poolside bar, 150 m ² meeting room, over-water bar, beach grill and bar, fitness gym, scuba centre, two tennis courts, 12 staff accommodation, five store rooms, maintenance shed, extensive network of walkways, helipad
Site area:	7.5 acres (3 ha)
Access methods:	by road and ferry or plane from Tahiti (Papeete International airport), or helicopter from Papeete
Principal attractions in the area:	the sea, lagoon and reefs, Moorea island with its rainforest and Polynesian villages, Tahiti

luxuriant tropical gardens, and right next to the azure lagoon of the island of Moorea.

The bungalows are fully-equipped with modern comforts: individually-controlled air-conditioning, fan [and many other electrical appliances], private terrace. The bathroom includes a bathtub and separate shower, a hairdryer, a make-up mirror as well as American and European plugs.

- 22 garden connected bungalows (37.25 m²)
- 20 superior bungalows (35.25 m²)
- 7 beach bungalows (35.25 m²)

In the intimacy of your over-water, you will listen to the murmur of the waves and contemplate through a glass opening in the floor the perpetual ballet of multicoloured fish. If you wish to see them closer, just descend the pontoon ladder into the warm waters of the lagoon.

For even greater intimacy, you can choose to stay in our Horizon bungalows with a 180° horizon view which are located closest to the coral reef.

The bungalows are equipped with individually-controlled air-conditioning, fan, private terrace with outside shower [and a range of appliances, similar to the Garden bungalows] (Figure 4.3.2).

- 57 over-water bungalows among which 30 are Horizon bungalows (35.75 m²) [Source: Starwood Hotels].

4.3.1 In their own words

Sheraton Moorea Lagoon Resort & Spa is a full service resort ideally located between Moorea's historical Cook's Bay and Opunohu Bay. The property offers a pristine white sand beach, crystal blue lagoon and lush tropical gardens (Figure 4.3.1).

At only 15 minutes from the airport, or 25 minutes from the ferry dock, wind your way along the scenic coast towards Papetoai. The garden and over-water bungalows are spacious, luxurious and are designed to provide maximum privacy. Double connecting bungalows are also available for larger parties travelling together or for families.

[...] The Sheraton Moorea Lagoon Resort & Spa has individual garden or twin bungalows. They are finely decorated in a Polynesian style and with exotic wood. They are located in the middle of

4.3.2 Site selection and landscaping

The resort occupies a former hotel site and the area has been extensively recultivated and replanted in adaptation to its current use. Other major changes include establishing a swimming pool and a fish pond (Figure 4.3.3, Figure 4.3.4).

4.3.3 Construction

Principal building materials used at Sheraton Moorea are timber, concrete (used for piling), *maiao* (pandanus) leaves replaced on a 5-year cycle, flagstone, and



Figure 4.3.1 Like many other Polynesian resorts, Sheraton Moorea Resort & Spa offers accommodation in over-water individual bungalows.

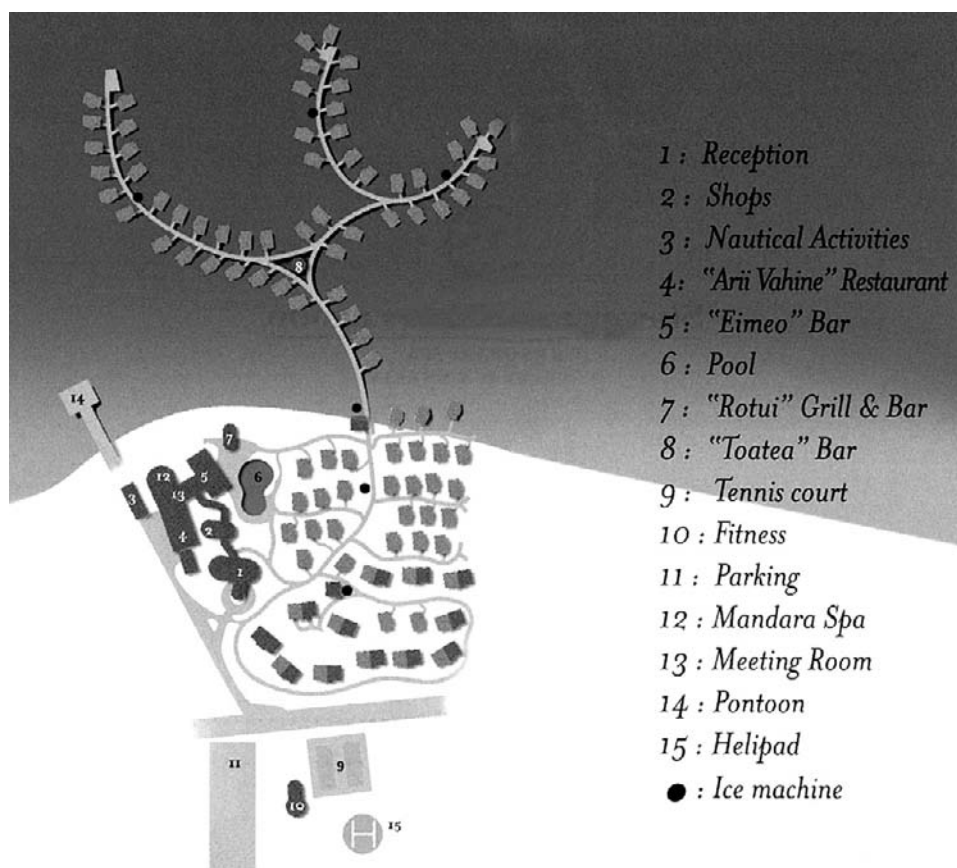


Figure 4.3.2 Plan of the resort (courtesy of Sheraton Moorea Lagoon Resort & Spa).



Figure 4.3.3 Open water ponds and pools cool the reception area and adjacent restaurant.



Figure 4.3.4 The architecture of all bungalows at the resort relates to local traditions not only in form and colour but also choice of materials, with prominent pandanus thatch and extensive use of timber.



Figure 4.3.5 Detail of bamboo wall cladding.

ceramic tiles, both on floors and walls (Figure 4.3.5, Figure 4.3.6, Figure 4.3.7).

4.3.4 Operational energy

The source of power is a town grid powered from a diesel generator. The resort uses 525 kWh per month, on average, at a substantial annual cost of 1.2 million Polynesian francs (approx. US\$12 500). The principal reason for such a huge demand is the large number of electrical appliances in both guest units and the rest of the resort. Energy saving is encouraged and low energy lighting is in use but future changes (extension of the banquet room, the addition of a kitchen to the beach bar and a jacuzzi to the pool area) planned by the resort will, most certainly, increase this demand even further (Figures 4.3.8–9).

4.3.5 Water management

The resort uses water from the town mains, supplementing it with rainwater from its own storage when available. The monthly cost of water supplied to the

resort is 350 000 francs (approx. US\$3600). This cost has started growing recently at a considerable rate and the resort's management encourages saving of this resource. All toilets are dual flush and grey water from washing is recycled in an irrigation system.

4.3.6 Waste management

Most solid waste is disposed of at the communal tip on the island. Most plastic, glass and metal waste is sorted out and recycled through a 'green programme' instigated by the local government, and organic waste is composted. The liquid waste is stored in septic tanks and removed monthly.

4.3.7 The resort's climatic performance

During the visit to the resort in early December (early summer), external temperatures ranged from 26.1–32.3°C and corresponding internal temperatures in a beachside bungalow (with air-conditioner and fans switched off) were in the range 27.4–32.0°C. This



Figure 4.3.6 Detail of roof thatch seen from the interior.



Figure 4.3.7 All bars and restaurants at the resort are open air to allow cooling sea breezes.



Figures 4.3.8–9 Guest units feature high cathedral ceilings, numerous openings and open-plan design for ease of ventilation (Figure 4.3.9 courtesy of Sheraton Moorea Lagoon Resort & Spa).

indicates minimal heat storage and short time lags occurring in some material used in the bungalows (ceramic tiles) as well as reasonably efficient shading and natural ventilation – bringing temperatures indoors very close to those outdoors (Figure 4.3.10, Figures 4.3.11–12).

4.3.8 Concluding remarks

The over-water bungalows and, to a lesser degree, beach bungalows take advantage of the moderating impact of the ocean on the resort's microclimate. They are elevated and fully exposed to cooling winds and breezes, and their lightweight structures quickly lose any heat gained during the day. Built to a design greatly influenced by the traditional Polynesian hut,

with high cathedral ceilings, thatched roofs and thin walls woven from pandanus leaves, the bungalows are superbly suited for the climate.

Unfortunately, the vast majority of holiday-makers staying at the resort prefer to trust the air-conditioning systems provided in each bungalow rather than its ingenious design. This makes resort operations prohibitively expensive since their design is inappropriate for air-conditioning. It also makes the outdoor environment of the resort less inviting as the air is filled with the muffled sound of working AC units. The temperature readings taken inside a beach bungalow demonstrate that this cost is totally avoidable, and that some effort made by management and staff to educate the guests can result in great benefits for all parties involved. The readings also demonstrate effectiveness of the traditional architectural solutions in their natural setting (Figure 4.3.13).



Figure 4.3.10 The reception area is naturally ventilated; stone and tiles are easy to maintain and help in moderating temperatures.



Figures 4.3.11–12 Siting of beach and over-water bungalows exposes them to cooling sea breezes.

at the single unit level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				

at the resort level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				
Socio-economic dependencies				

Figure 4.3.13 The extent of the resort's potential environmental impacts. (**Note:** The extent of the resort's impacts [ranging from positive through neutral to negative] should be read in conjunction with the information in [Figure 4.1](#)).

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4.4

Bora Bora Nui Resort & Spa

Location:	Motu Toopua, Nunue-Bora Bora atoll, French Polynesia
Year of completion:	2003
Total cost of construction:	US\$10.2 million (approx.)
Architect:	Pierre Lacombe
Consultant:	Lulu Wane (interiors)
Builder:	
Number of guest units:	120 villas and suites (84 over-water)
Max. number of guests:	240
Other facilities on site:	offices, over-water reception, restaurant and kitchen, spa, meeting room, 750 m ² pool and poolside grill and bar, beach bar, fitness gym, water sports centre, several gazebos, staff accommodation, store rooms, maintenance sheds, extensive network of walkways, helipad
Site area:	16 acres (6.3 ha)
Access methods:	by launch (from Motu Mute) and plane or boat from Tahiti (Papeete International airport), or helicopter from Papeete
Principal attractions in the area:	the sea, lagoon and reefs, Bora Bora atoll and <i>motus</i> (islets), town of Vaitape, neighbouring atolls

the most exclusive luxury resort in French Polynesia. With 84 bungalows set over a magnificent crystal clear lagoon, the resort sets a new benchmark for elegance and service, meeting the demands of even the most discerning traveler [Figure 4.4.1](#).

Suites & Villas

Bora Bora Nui Resort & Spa is the first 'all suite' resort in French Polynesia.

82 Horizon Over-water Villas (94 sq. meters)
2 Horizon Over-water Royal Villas (135 sq. meters)
12 Beach Villas (85 sq. meters)
Hillside Lagoon View Villas (85 sq. meters)
1 Hillside Lagoon View Royal Villa (135 sq. meters)
16 Lagoon View Suites (95 sq. meters), convenience with breathtaking views of the pristine lagoon

All villas and suites feature a very spacious bedroom and living room, separated by Japanese panels.

Decor

The 120 luxury suites or villas at [the Resort] are located on 16 acres of lush, terraced hillside and on the water of a private, protected cove. An amazing blend of Polynesian traditions and incredible luxury (exotic woods, pink marble, unique objects...). [...]

4.4.1 In their own words

Located on a volcanic islet, southeast of the main island of Bora Bora, just six miles by boat from Motu Mute domestic airport, Bora Bora Nui Resort & Spa is



Figure 4.4.1 Aerial view of the Bora Bora Nui resort with the main island of the atoll in the background.

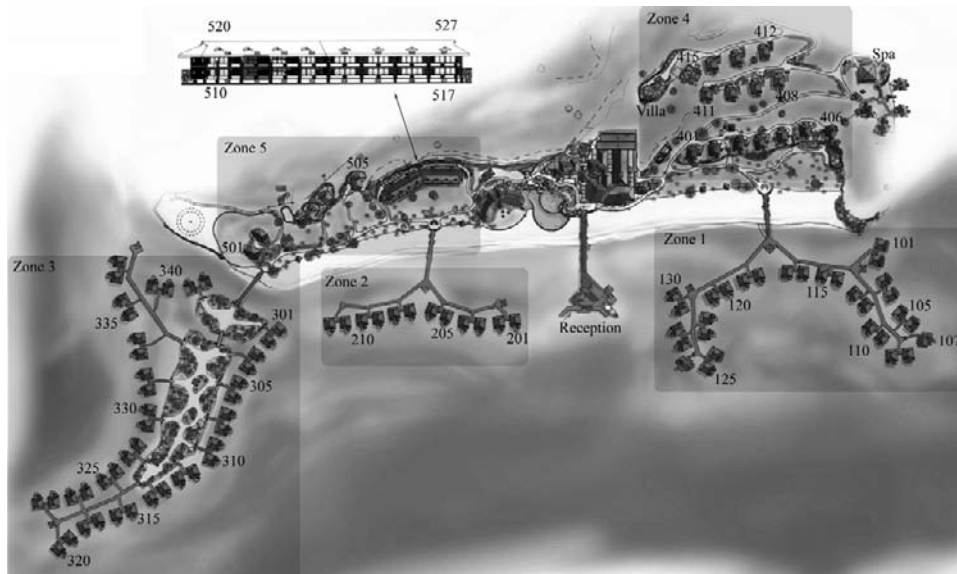


Figure 4.4.2 Plan of the resort (courtesy of Bora Bora Nui Resort & Spa).

Boutiques & Services

- Mandara Spa offers an extensive menu of spa treatments and services as well as four exquisite private bungalows each with its own jacuzzi, bathroom and massage table and a breathtaking view of Bora Bora
- Fully equipped fitness center
- Infinity swimming pool
- Private meeting room for up to 80 seated persons
- Over-water reception, set above a natural aquarium
- Laundry
- Dry cleaning service [...]
- Gift Boutique – Art Gallery
- Exclusive Black Pearl Boutique ‘Robert Wan Company’
- Beauty salon with manicure and pedicure
- Helipad for Tours and Private transfers
- Boat transfer between the airport and resort
- Shuttle boat service for Vaitape Village [...]



Figure 4.4.3 View of the resort from the sea.



Figures 4.4.4–5 Pathways and boardwalks are used by both pedestrians and light maintenance vehicles.



Figure 4.4.6 The 600 m long artificial beach was built with sand dredged from the atoll's shipping channel.



Figures 4.4.7–8 Details of roof structures suggest their inspirational origins.

- Extensive on-site water sports activities
- Tours desk [Source: Bora Bora Nui Resort & Spa]

Figure 4.4.2, Figure 4.4.3.

4.4.2 Site selection and landscaping

The Bora Bora Nui Resort & Spa was established on a volcanic *motu* or islet, which originally was (and in parts still is) largely devoid of notable vegetation. The resort occupies a site that has been extensively recultivated and replanted in adaptation to its current use. The 600 m long beach was created by pumping in sand from dredging operations in the atoll's shipping channel. Two small artificial islets linked by bridges have also been built. The hillside has been terraced and 600 coconut trees have been planted together with hundreds of other palms,

ornamental trees and bushes (Figures 4.4.4–5, Figure 4.4.6).

4.4.3 Construction

Principal building materials used at Bora Bora Nui Resort & Spa are *balau*, *marumaru*, *kahia*, coconut, teak and mahogany timber, concrete (for piling and hillside construction), *maiao* (pandanus) leaves (replaced on a 5-year cycle) flagstone, and ceramic tiles, both floor and wall ones (Figures 4.4.7–8).

4.4.4 Operational energy

The source of power is a town grid, brought to the *motu* as an underwater cable, and a back-up diesel generator. The resort consumes large amounts of



Figures 4.4.9–10 Bora Bora Nui’s claim to be ‘the most luxurious resort in the South Pacific’ is based on generosity of space offered to guests, quality of finishes and standard of service.



Figure 4.4.11 Barge ready to take resort rubbish to a communal tip on the main island.



Figure 4.4.12 The indoor environment of all guest units is hugely influenced by the sea.

energy owing to heavy reliance on air-conditioning and the extensive range of electrical appliances demanded by guests. Energy saving is encouraged and low energy lighting is in use. There are plans for a wider use of solar energy as the current sources are increasingly expensive (Figures 4.4.9–10).

4.4.5 Water management

The resort uses water from the town mains, supplementing it with rainwater from its own storage when available. A desalination plant delivers up to 100 m³ per day. All toilets are dual flush and grey water from washing is recycled in an irrigation system. External freshwater showers have automatic cut-off valves. Management plans to introduce a water-saving regime in the laundry (which is expected to save 30 per cent of the currently used water). The future of the swimming pool, the largest in this part of the Pacific, is also being considered as losses due to evaporation weigh heavily on the water consumption at the resort.

4.4.6 Waste management

Most solid waste is disposed of at the communal tip on the main island of the Bora Bora atoll (Figure 4.4.11). Most plastic, glass and metal waste is sorted out and recycled through a 'green programme' instigated by the local government, and organic

waste is composted on site. The liquid waste is initially stored in septic tanks and later pumped and processed at a sewage plant in Vaitape (Figure 4.4.12, Figure 4.4.13, Figure 4.4.14).

4.4.7 The resort's climatic performance

During a visit to the resort in early December (early summer), external temperatures ranged from 27.4–33.6 °C. Corresponding internal temperatures (with air-conditioning and fans switched off) were in the range of 28.9–30.9 °C. This indicates the dampening effect of the sea (measurements were taken in an over-water bungalow) on the temperature range, minimal heat storage and short time lag occurring in some materials used in the villas (ceramic tiles) as well as fairly efficient shading and natural ventilation – bringing temperatures indoors very close to those outdoors. This excellent performance far exceeds the expectations of the resort management who, for instance, encourages guests to use air-conditioning in their bungalows.

4.4.8 Concluding remarks

The Bora Bora Nui is very similar to the Sheraton Moorea Lagoon Resort. The local architect developed his original idea based on the local

traditional architecture but the resort is ostentatious in its energy expenditure. The result is the most luxurious resort in the Pacific region. The resort, quite probably, would be able to cope with the climate drawing on its own merits. Its site, on a windward side of the atoll, benefits from regular gentle breezes and trade winds as well as from the moderating influence of the ocean. The bungalows have very low thermal mass, cathedral

ceilings, roof monitors for expelling hot air, wide shading eaves, polished floors that are cool to touch and many louvred windows enabling adequate cross-ventilation. They are sited over water or near the crest of a low hill with both positions well exposed to air movement all year round. They are built from mostly local materials and blend well with the landscape (Figures 4.4.15–18, Figure 4.4.19).

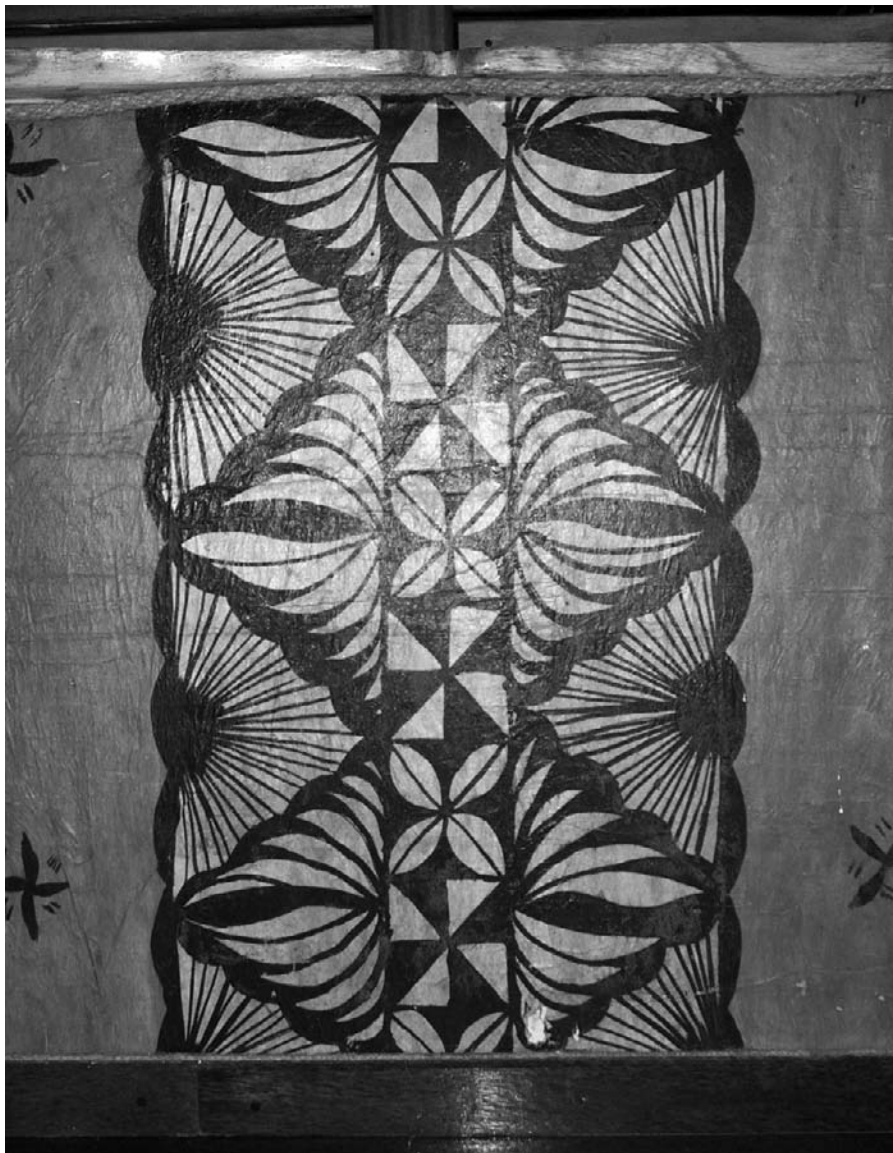
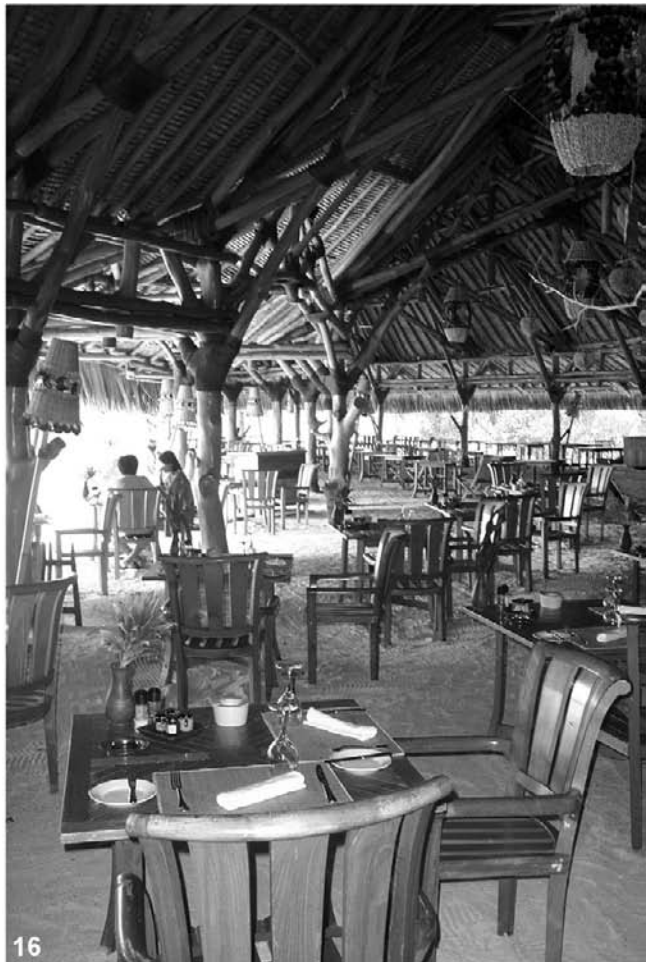
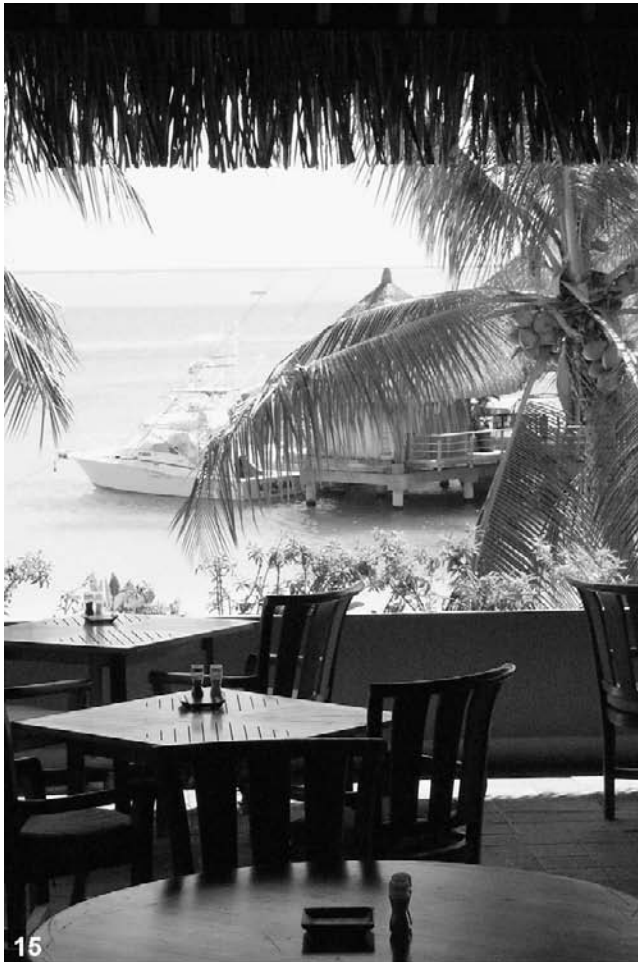


Figure 4.4.13 Resort designers sought to incorporate local Polynesian motifs as a link to and continuation of the regional traditions.



Figure 4.4.14 Bungalow design encourages guests to stay in the open where the tropical climate seems gentle and comfortable to face.



Figures 4.4.15–18 All resort restaurants and bars offer al fresco dining both during the day and at night (Figures 4.4.17–18 courtesy of Bora Bora Nui Resort & Spa).



Figures 4.4.15–18 (Continued).

at the single unit level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				

at the resort level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				
Socio-economic dependencies				

Figure 4.4.19 The extent of the resort's potential environmental impacts. (**Note:** The extent of the resort's impacts [ranging from positive through neutral to negative] should be read in conjunction with the information in [Figure 4.1](#)).

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4.5

Mezzanine

Location:	Hotel Zone, Tulum, Quintana Roo, Mexico
Year of completion:	2004
Total cost of construction:	US\$450 K (approx.)
Architect/designer:	Brendon Leach with Katrina Taylor
Consultant:	Jorge de Dios
Builder:	Andrew Fields
Number of guest units:	4 apartments
Max. number of guests:	8
Other facilities on site:	restaurant and kitchen, bar, mezzanine lounge, toilet block, office, caretaker accommodation, storage, battery room, pool
Site area:	0.2 acres (0.08 ha)
Access methods:	by road (from Cancún international airport)
Principal attractions in the area:	archaeological sites, the lagoon and beach, nature reserves: <i>cenotes</i> , caves, Sian Ka'an World Biosphere Reserve, nature and culture tours, dining

4.5.1 In their own words

Mezzanine's power source comes from 20 state-of-the-art solar panels and back-up natural gas generator. This enables us to provide 24 hour [services] and power.

You can charge your laptop and cellular as well as use your hairdryer; however we ask that your power consumption is not excessive and that you turn off all lights and fans when you leave your room (Figure 4.5.1).

We have provided a candle in your room [in case] there is a fault with the power supply. If it happens, full power is generally back up and running within 10–15 minutes.

For better efficiency our kitchen, refrigeration, hot water supply and Espresso Coffee machine are all gas operated.

Mezzanine also uses a 'wetlands' as a means to breakdown waste matter. All grey water is filtered through to the plantation that is beneath the decking. These plants absorb higher amounts of water than most other plants. All black water is flushed into a septic system where it is filtered through chambers and is used to nourish plants on top of the wetlands. For optimum efficiency we ask that you do not put paper products into the toilet. Please use the waste bin provided.

Our water is trucked in as we require it. The locals do not drink it and we recommend you don't drink it



Figure 4.5.1 General view of the Mezzanine from the water edge; retaining wall protecting the escarpment against storm surges is clearly visible as are wind turbine and solar panels.



Figure 4.5.2 The freshwater pool in the guest unit deck stays in the shade for most of the time.

either. We supply bottled drinking water to your room and your bathroom (for cleaning your teeth) daily. The ice used in Mezzanine's beverages is made from purified water and is safe to consume. [Source: Mezzanine].

4.5.2 Site selection and landscaping

The resort is located in the hotel zone of Tulum, one of the most popular tourist destinations on the Yucatán peninsula, in a suburban neighbourhood which has been extensively modified for a number of years. The site was totally transformed in the process of development. Some trees were removed, walkways were paved and an in-ground pool was built. Admittedly, some modifications followed repairs done after past hurricane damage as the site is very exposed. The escarpment occupied by the resort had to be reinforced with a retaining wall to stop erosion. The resort building is located right next to and above the beach, with its broad side turned east towards the ocean. Its two parts – the largely independent restaurant and the accommodation block – are separated with a 3 m wide gap. This helps to avoid late night noise from the restaurant penetrating into the residential part (Figure 4.5.2, Figure 4.5.3).

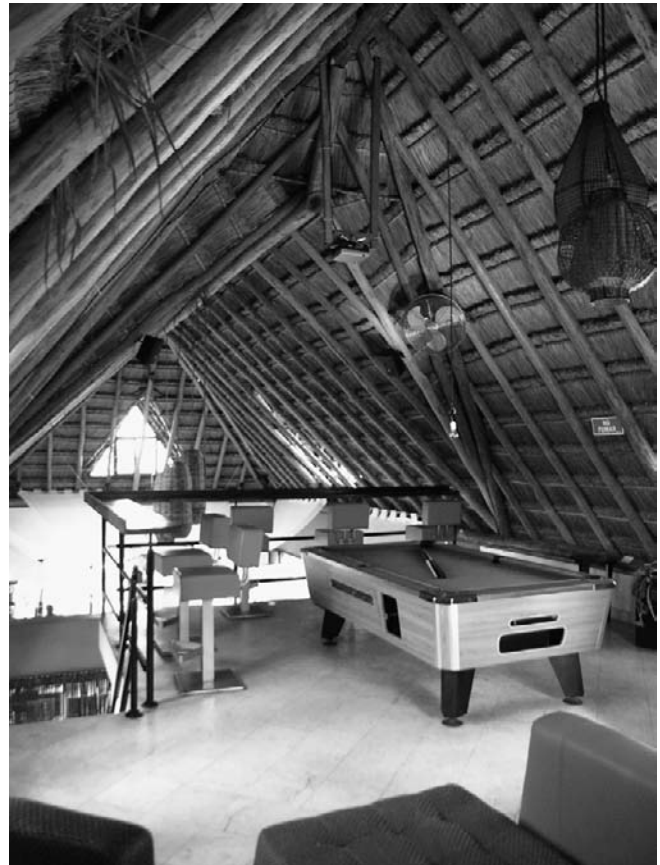


Figure 4.5.3 Generous mezzanine space directly under the restaurant's roof doubles as a resort lounge.



Figure 4.5.4 View of the resort from its mezzanine; the relatively narrow room is well cross-ventilated and naturally lit during the daytime.

4.5.3 Construction

The resort building is one of a few examples of passive design that is very dependent on the use of thermal mass. Local stone, concrete and ceramic tiles are extensively used in thick walls and floors. These materials require minimal maintenance but their principal advantage is their ability to slow down heat flows. This maintains temperatures within a fairly narrow range and makes for a building that is quite warm in winter and relatively cool in summer. Its summer performance gets a boost from stack effect – guest rooms have very high (almost 8 m) ceilings in a mezzanine arrangement of floors. There is also ample cross-ventilation with windows on the ocean side having louvred openings at a bed height and on the well shaded western side permanently open (un-glazed and secured with grills only) (Figure 4.5.4).

4.5.4 Energy management

The resort is, in terms of power supply, practically autonomous. Twenty 28 amp photovoltaic panels, 0.5 by 1.5 m each, provide the source of electricity. The daily gains are stored in a bank of 16 batteries for night-time use. There is also a wind turbine and propane back-up power generator. Efficient low-voltage lighting and gas appliances help to save energy. The management appeals to guests to save energy in order to limit demand (Figure 4.5.5, Figure 4.5.6).

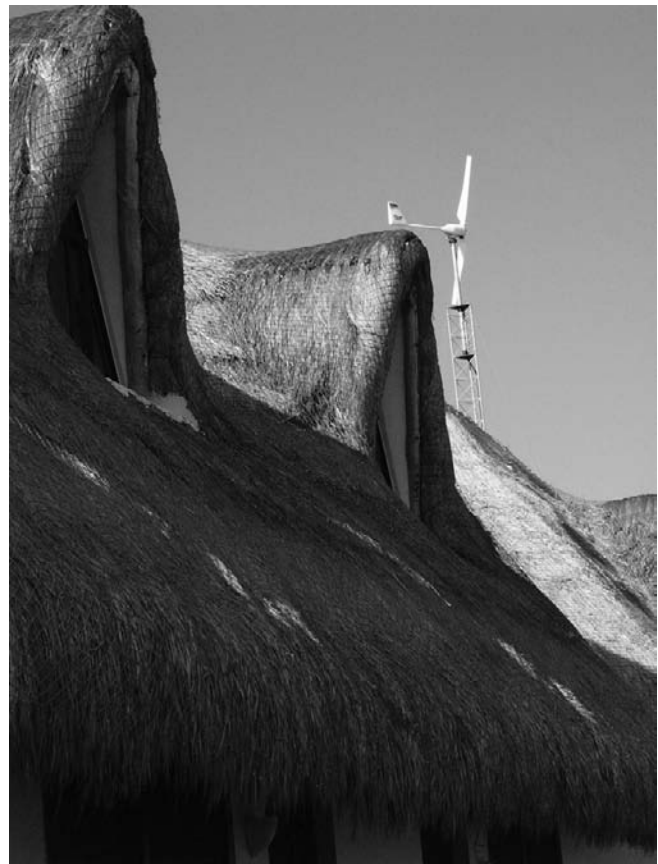


Figure 4.5.5 The wind turbine complements the PV array; however, winds in the area are often too strong or too weak for its efficient operating range.



Figure 4.5.6 The principal source of power is a set of 20 photovoltaic panels above the roofs of guest units.

4.5.5 Water management

Virtually all resort needs are covered by trucking water in: 30–50 000 litres per week. Water for direct human consumption is brought in to the resort bottles. Water for irrigation through an underground drip system is recycled grey water. All toilets have dual flush systems and virtually all liquid waste is processed on site and recycled in created wetlands under the sun deck. Water management should improve after the intended installation of water-saving shower rosettes (Figure 4.5.7).

4.5.6 Waste management

A local contractor takes most solid waste away to a municipal tip. The local government plans to commence recycling of plastic, glass and metal waste soon. Organic waste from the kitchen is composted on site or taken away, for the same purpose, by employees. The liquid waste is processed on site in the resort's own underground sewage purifying system.

4.5.7 The resort's climatic performance

The visit to the resort took place early in December (early 'winter'), when external temperatures ranged from 18.9–28.0°C. The corresponding internal



Figure 4.5.7 Standard dual flush toilets generate enough liquid waste for the created wetland to be viable.



Figures 4.5.8–9 Guest rooms rely chiefly on natural airflows through cross-ventilation; louvred openings are strategically positioned at bed level and the unglazed (permanent) ones, across the room, in circulation space.



Figures 4.5.10–11 Room height allows for vertical air movement and sensible cooling through stack effect ventilation making the indoor environment thermally comfortable.



Figure 4.5.12 The two parts of the resort – the guest unit one (on the left) and restaurant/office (on the right) – are separated, which, together with background noise from the breaking waves, ensures favourable acoustic conditions.

at the single unit level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				

at the resort level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				
Socio-economic dependencies				

Figure 4.5.13 The extent of the resort's potential environmental impacts. (**Note:** The extent of the resort's impacts [ranging from positive through neutral to negative] should be read in conjunction with the information in [Figure 4.1](#)).

temperatures (with fans switched off) were in the range 21.3–27.6 °C. This indicates quite efficient thermal design and some heat storage in massive elements of the structure (walls and floors). Conditions inside were quite similar to those outside in the shade and the range of indoor temperatures was a modified (dampened) reflection of the temperatures outdoors due to the ‘mass effect’ (Figures 4.5.8–9, Figures 4.5.10–11).

4.5.8 Concluding remarks

The resort’s architecture is a variation of traditional Mexican themes with its white slightly sloping walls

and small grilled openings. The heavyweight structure performs remarkably well in cooler conditions but it should respond equally well to the hot weather due to its unique double-storey open interior. The openness allows the warm air to move up beyond occupied height. A dominating colour scheme of white and blue, together with smooth tiled floors, psychologically reinforces the cooling effect achieved in this free-running building. Prudent energy and water management is also commendable (Figure 4.5.12, Figure 4.5.13).

4.6

Balamku Inn on the Beach

Location:	Bahía Permejo, Mahahual, Quintana Roo, Mexico
Year of completion:	2006
Total cost of construction:	US\$550 K+ (approx.), owner-built (no add-on costs)
Architect/designer:	Alan Knight and Carol Tumber
Consultant:	Dinah Drago
Builder:	Alan Knight with local craftspeople
Number of guest units:	4 double and 2 single storey units
Maximum number of guests:	30
Other facilities on site:	reception, breakfast screened-in porch bar, lounge, office, gift shop, owners' accommodation, <i>palapa</i> (roofed patio), <i>bodega</i> (storage and accommodation), water tank, wind tower, battery room
Site area:	4 acres (1.6 ha)
Access methods:	by road (from Cancún International airport, Chetumal airport or Mahahual harbour)
Principal attractions in the area:	Costa Maya, Chínchorro reef, the lagoon and beach, Sian Ka'an World Biosphere Reserve, archaeological sites, nature and culture tours

4.6.1 In their own words

Balamku's Mission Statement and Explanation of Ecological Sustainability Practices

Balamku is committed to providing comfort and quality services using the resources of nature without abusing the environment (Figure 4.6.1).

We believe that we have an obligation to protect the environment and reduce the impact of tourism by using eco-efficient energy and water systems, waste management practices and preserving the natural environment.

Energy

All of our energy is provided by one of the largest solar panel installations on the Costa Maya. Wind generation has been added to complement this solar system. Consequently, we supply you with 24-hour electricity without a generator pounding away in the background. For those of you who have visited



Figure 4.6.1 Balamku Inn comprises guest units housed in single- and double-storey buildings.

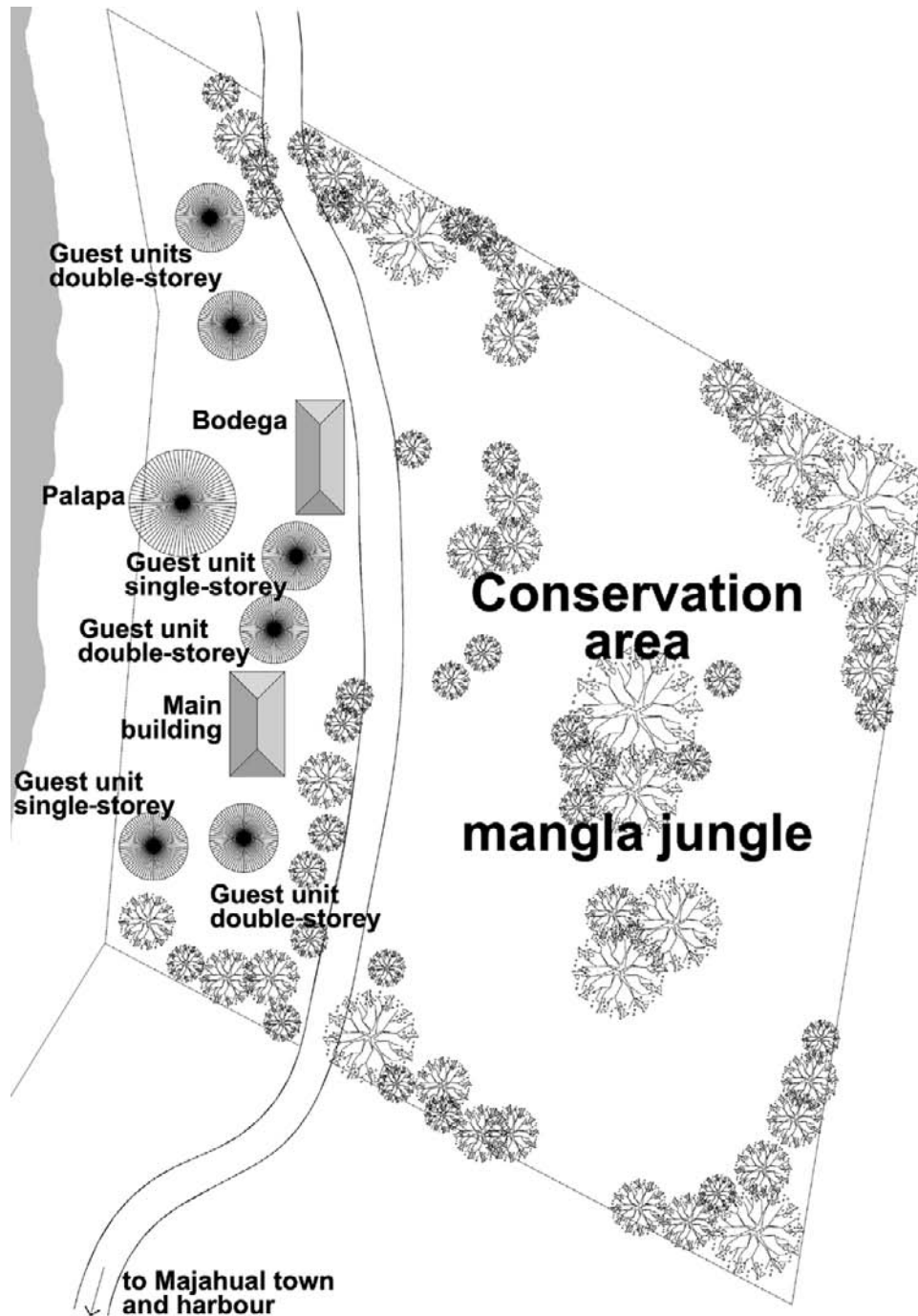


Figure 4.6.2 Plan of the resort.

this part of the world before, you will realize that this is quite a luxury. In return, we request you do not use energy-hungry appliances such as hairdryers (over 99 watts) and remember to turn off all lights and fans when they are not needed. All of our lights

are energy efficient and the coffee-makers are low wattage.

In case mother nature fails, we have a quiet, propane (clean) back-up generator, but we are doing all possible to limit our need for it.



Figure 4.6.3 The largest building contains the reception, resort dining room and kitchen, with the office and owner/operator accommodation on the upper floor.

Water management

The water in the shower and sink is very clean (a mix of purchased city water and rainwater) but is not potable. Please use the bottled water for brushing your teeth, drinking and making coffee or tea. Every day we will refill your bottles with drinking water, which will limit the plastic refuse. If you need more, please help yourself to the water in the restaurant.

All the water from your shower and sink supports a constructed wetland located at the back of your building. As the water is supplying nutrients to the plants, we would be pleased if you used the environmental soap and shampoo provided in your bathroom.

Toilets

These water-saving toilets are easy to use. If you need more water, as you sit, lift the lever and count to 5; then, to flush, push the lever down very gently. As the waste is all composted, please don't put anything other than toilet paper down the toilet. If you have problems with the lever, please let us know as it is somewhat fragile.

Water usage with these toilets is reduced from a normal gallon [3.8l] a flush to one pint [0.5l].

In the future, we will be installing a system to purify our well water. Imagine a freshwater table just metres beneath the sand and so close to the sea. This gift could be compromised if septic tanks leak, and many do. Therefore, we have installed composting units at the back of each unit to manage the water and solid waste from the toilets. This system was designed by a biologist from Puerto Morales who recognized, as a diver, the sad reality of waste leaking into the sea and destroying the coral reef.

Recycling

All bottles and plastics are separated from other waste to assist in recycling. Organics from food preparation is composted in the bins behind the kitchen.

Water is available for refilling bottles to reduce the need for a new plastic bottle every day. Only new clients receive a new, unopened bottle. Towels and linens are changed every 2–3 days to reduce the water consumption.

Property management

The planning design of Balamku considered the protection of the many local species of trees and plants. The units are situated to maximize natural ventilation. The beach has a beautiful



Figures 4.6.4–5 Second-storey units benefit from high cathedral ceilings allowing hot air to rise under the roof; ground floor units have their thermal environment shaped by the openness of the plan and staying permanently in the ‘shade’ of the upper floor.

stone wall to reduce the risk of erosion. Vines and shrubs have intentionally been left to assist in further reduction of soil erosion as well as for the enjoyment of their natural beauty. We are continuously planting local trees and shrubs as well as sugar cane, banana, mango, papaya, and lime trees.

We would be very pleased to give you a brief tour of our systems [Source: Balamku Inn] (Figure 4.6.2).

4.6.2 Site selection and landscaping

The management has worked to preserve the original vegetation on the site. Nearly a third of the site remains undeveloped and a reforestation project has been undertaken with the aim

of creating a wildlife refuge. Re-vegetation has been done with indigenous flowering plants but otherwise the landscaping scale has been quite modest. An attempt has been made to stop continuing beach erosion. In hindsight, the owners believe that the resort could do better with fewer buildings and lighter use of the land but with more vegetation (Figure 4.6.3, Figures 4.6.4–5).

4.6.3 Construction

The resort is built chiefly with heavy materials such as concrete blocks and concrete laid in-situ as well as ceramic floor tiles. Materials require minimal maintenance and are resistant to strong



Figure 4.6.6 The resort's dining room has substantial thermal mass and stays comfortably cool even in hot weather conditions.

winds, thus increasing the structures' stability and safety in the hurricane season. Double-storey buildings also have tiled concrete floors between storeys. Local grass and timber are used for roofing allowing for sufficient heat dissipation into the night sky. Many resort activities take place outdoors in a traditional open-air structure called a *palapa*, which has no walls and only a light-weight grass roof supported by timber poles (Figure 4.6.6).

4.6.4 Energy management

Forty typical photovoltaic panels, each 0.5 by 1.5 m, provide the source of electricity. The daily gains are stored in a bank of 32 batteries. The PV panel-generated power meets about three-quarters of the total demand, the remainder coming from a wind turbine and a propane 11 kW back-up generator. Efficient low-voltage lighting and gas appliances, for example instantaneous gas water heaters, help to save energy. Landscape lighting is light sensor-operated. There are only a limited number of appliances drawing energy. The resort management appeals to guests to save energy in order to curb demand (Figure 4.6.7, Figure 4.6.8).



Figure 4.6.7 A 'mosquito magnet', which attracts and captures mosquitoes, helps to control the insect problem on site.



Figure 4.6.8 Small on-demand hot water heater.



Figure 4.6.9 Positioning a holding tank on the roof provides gravity, thus pressurising the system.



Figure 4.6.10 Each building has its own composting toilet unit.



Figure 4.6.11 The created wetlands are used for purifying grey water from sinks and showers.



Figure 4.6.12 Rooms are decorated with work by local artisans.

4.6.5 Water management

Mixing rainwater, collected in 170 000-litre cement cisterns, with water brought in by trucks covers the resort's water needs. On average, the resort uses 100 litres of water per day for every guest, which includes cooking needs. Water for direct human consumption is brought to the resort in large plastic containers and locally bottled or distributed from the containers. Water for irrigation is provided from a well and supplemented by recycled grey water from showers and sinks. All toilets are special extra-low flush systems and virtually all liquid waste is processed on site and recycled in created wetlands. Toilet water is filtered into a tank for use on large plants. There are plans for expanded utilisation of well water on site and for enlarging the leach fields (Figure 4.6.9).

4.6.6 Waste management

A local contractor takes most solid waste away to a communal landfill. Plastic, glass and metal waste is separated for collection and organic waste from the kitchen is composted. The liquid waste is processed on site in the resort's own sewage purifying system (constructed wetlands). There is a waste



13



14

Figures 4.6.13–14 Resort buildings are built relatively close to each other leaving a large tract of land reserved for the resort's conservation effort.

reduction strategy in place that applies to plastic bottles. Bulk purchases of water and toiletries, soap and shampoo dispensers rather than single-use individual containers, and encouragement given to reuse and recycling further reduce waste generation (Figure 4.6.10, Figure 4.6.11).

4.6.7 The resort's climatic performance

During the visit to the resort in early December (early 'winter'), external temperatures ranged from 22.9–26.4 °C and corresponding internal temperatures (with fans switched off) were in the range 24.6–27.4 °C. This indicates quite significant heat storage in massive elements (structural walls and

floors) of the resort. Conditions inside were slightly warmer than those outside in the corresponding period and the range of indoor temperatures also was small. One would expect the performance to be equally good in warmer months (Figure 4.6.12).

4.6.8 Concluding remarks

The heavyweight structure design employs a strategy that relies on thermal mass for comfort. All ground floor rooms have concrete floors coupled to the ground for cooling, massive concrete walls to slow down heat flows, and they are also well shaded by the upper floor. The upstairs rooms, on the other hand, have high cathedral ceilings and lightweight

at the single unit level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				

at the resort level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				
Socio-economic dependencies				

Figure 4.6.15 The extent of the resort's potential environmental impacts. (**Note:** The extent of resort's impacts [ranging from positive through neutral to negative] should be read in conjunction with the information in [Figure 4.1](#)).

roofs fast dissipating any heat build-ups. Unit walls, built on a circular plan, present only a small section perpendicular to the direction of the sun's rays and, being painted white, reflect a lot of incident solar radiation.

The owner/operator's ambition is to provide environmental education by exemplary environmental practices. The emphasis is on a concerted conservation effort and the resort is a leader in the area in this regard ([Figures 4.6.13–14](#), [Figure 4.6.15](#)).

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4.7

KaiLuumcito the Campitel

Location:	Rio Indio beach, Mahahual, Quintana Roo, Mexico
Year of completion:	2001
Total cost of construction:	US\$110 K+ (approx.), owner-built (no add-on costs)
Architect/designer:	Clayton Ball
Consultant:	Arnold Bilgore
Builder:	local craftspeople
Number of guest units:	17 <i>tentalapas</i> (tent units)
Max. number of guests:	40 (approx.)
Other facilities on site:	<i>palapa</i> containing lounge, dining and kitchen, four staff units, two bath and toilet blocks, battery room
Site area:	5.45 acres (2.18 ha)
Access methods:	by road (from Cancún international airport, Chetumal airport or Mahahual harbour)
Principal attractions in the area:	Costa Maya, Chínchorro reef, the lagoon and beach, Sian Ka'an World Biosphere Reserve, archaeological sites, nature and culture tours

4.7.1 Site selection and landscaping

The principal reason for selecting this particular site was acquisition of exclusive rights of access to an inland lagoon, which is a nature reserve and a bird sanctuary. A small jetty for launching kayaks was built and a narrow path, leading through the jungle to the lagoon, was laid out (Figure 4.7.1).

The 'campitel' brings very little disturbance to the original farm site. A concrete slab has been removed and some native vegetation has been planted to improve visual privacy (Figure 4.7.2).

4.7.2 Construction

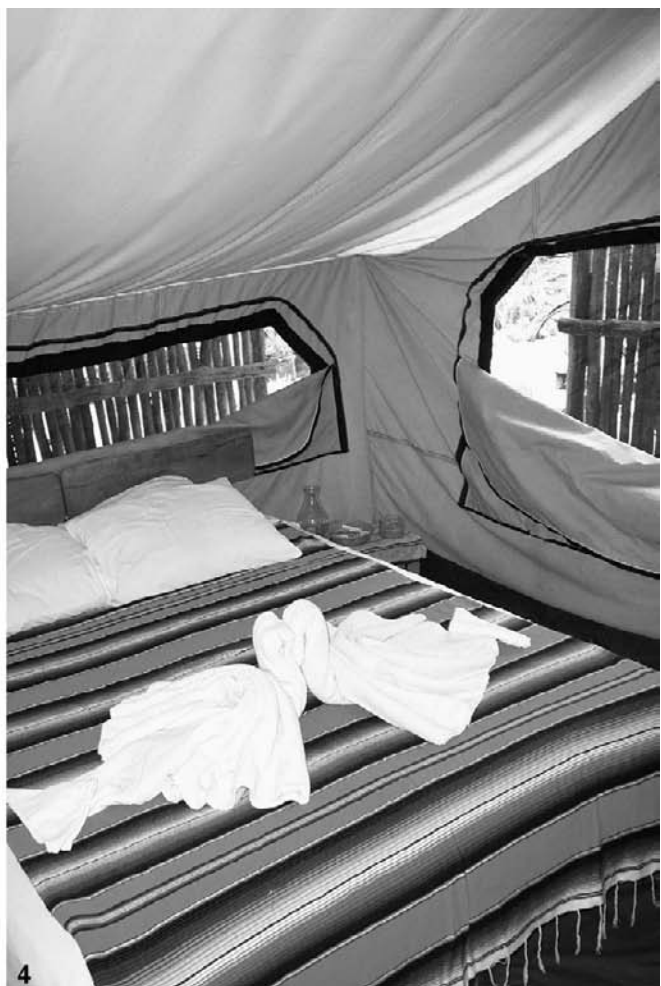
The resort is built chiefly with light and natural raw materials such as timber poles, grass or palm-leaf thatch and tent fabric. The conditions 'indoors' thus offered, very closely resemble those found in the



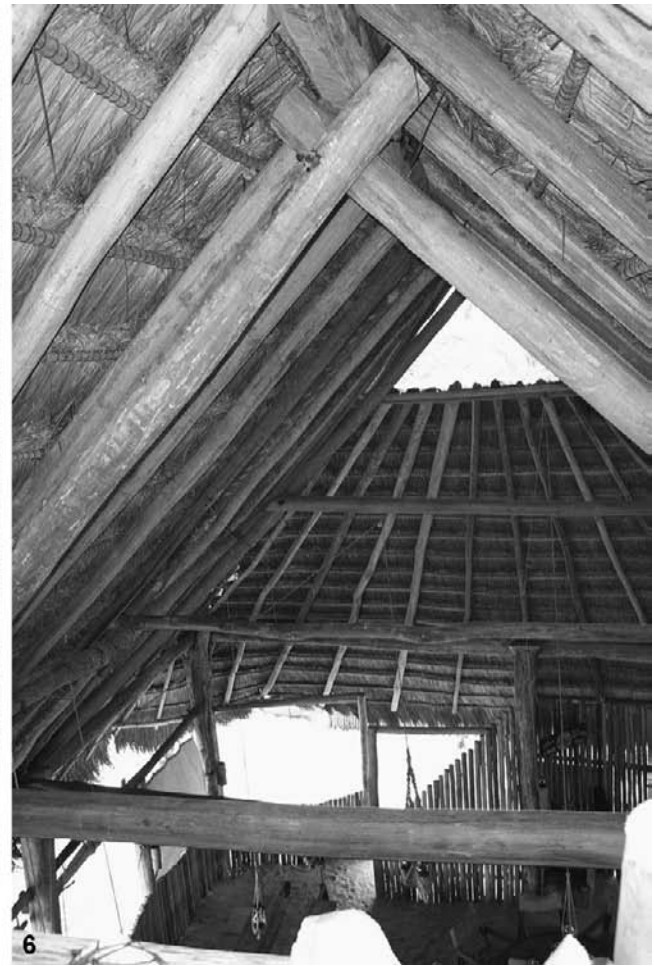
Figure 4.7.1 The super-low weight of KaiLuumcito structures allows them to sit right on the beach.



Figure 4.7.2 The main reason for bringing the resort to its current site was the natural lagoon and its wildlife.



Figures 4.7.3–4 The Kailuumcito accommodation is provided in *tentalapas* – a combination of specially designed tents shaded by *palapas* (traditional Mexican roofed structures without walls).



Figures 4.7.5–6 The resort structures have been erected using traditional local building techniques and the expertise of the local labour force.

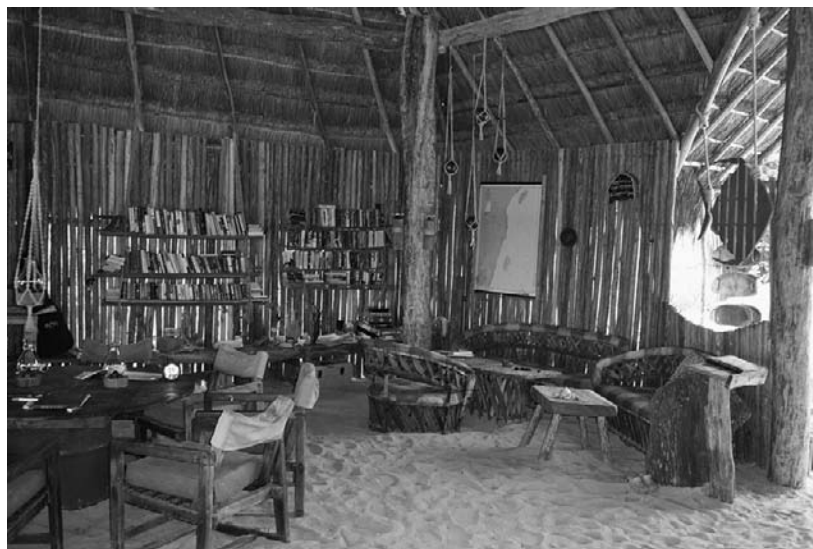


Figure 4.7.7 The resort's lounge in the main *palapa* has walls made with sticks arranged to provide visual privacy of the area.



Figures 4.7.8–9 Toilet blocks are rather conventional except for lighting, which comes from oil lamps; washing rooms are external parts of the toilet block entirely open to the air.



Figure 4.7.10 Diesel torches are lit at dusk and provide lighting until fuel burns out.



Figure 4.7.11 All structures at the resort utilise natural materials in their simplest unprocessed form.

shade outdoors. *Tentalapas*, which are tents erected under shading thatched *palapa* roofs, offer shelter from rain and wind but do not resist heat flows (Figures 4.7.3–4, Figures 4.7.5–6, Figure 4.7.7).

Lighting (including lighting of the area) is provided with diesel torches and candles, however a move to solar lighting is under consideration (Figures 4.7.8–9, Figure 4.7.10).

4.7.3 Energy management

There is no electricity used at the resort other than that coming from a single 75 W solar panel. In the kitchen, a propane stove, two ovens and a refrigerator are used, burning around 480 litres of propane per year. A gas heater also heats hot water for the kitchen.

4.7.4 Water management

The resort's own well delivers 375 litres per day. Rain-water is also harvested during the wet season from September to October and collected in a 57 000-litre tank. This water is filtered and mixed with the water trucked in (approximately 10 000 litres per



Figure 4.7.12 General view of the Kailuumcito shows both toilet blocks and a file of tentapalas along the beach.



Figures 4.7.13–14 Both the kitchen and the dining hall are housed in the main *palapa* of the resort; neither room has walls.

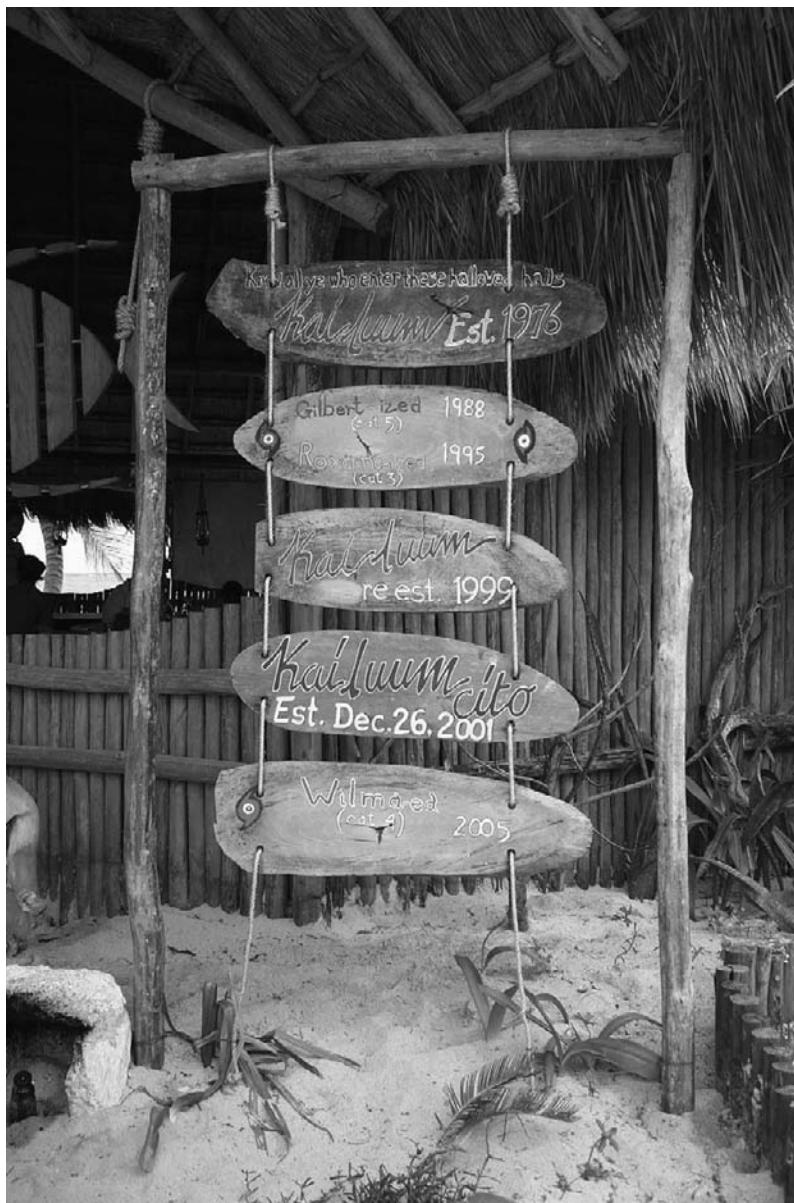


Figure 4.7.15 The history of Kailuumcito commenced in 1976; the resort has been devastated several times by major cyclones and has required rebuilding.

fortnight), to yield 145 litres per guest per day. Most of the water is used by divers for showering and washing their equipment (diving is the principal activity attraction offered by the resort) (Figure 4.7.11).

4.7.5 Waste management

A contractor takes most solid waste away to a local landfill. Plastic, glass and metal waste is recycled. Organic waste from the kitchen is taken away for composting by locals. The liquid waste is processed on site

in a septic system connected to a leach field (solids are carted away every six months). The operators plan installation of ecological mulching toilets. Buying in bulk reduces unnecessary packaging waste (Figure 4.7.12).

4.7.6 The resort's climatic performance

During a visit to the resort early in December (early 'winter'), external temperatures ranged from

at the single unit level				
Visual pollution	■	■	■	■
Light pollution	■	■	■	■
Noise pollution	■	■	■	■
Airborne pollution	■	■	■	■
Thermal environment-related impacts	■	■	■	■
Impacts on geology of the site	■	■	■	■
Impacts on soil: compacting, contamination	■	■	■	■
Impacts on water: surface, underground sources, run-off	■	■	■	■
Impacts on the original vegetation	■	■	■	■
Impacts on the wildlife	■	■	■	■
at the resort level				
Visual pollution	■	■	■	■
Light pollution	■	■	■	■
Noise pollution	■	■	■	■
Airborne pollution	■	■	■	■
Thermal environment-related impacts	■	■	■	■
Impacts on geology of the site	■	■	■	■
Impacts on soil: compacting, contamination	■	■	■	■
Impacts on water: surface, underground sources, run-off	■	■	■	■
Impacts on the original vegetation	■	■	■	■
Impacts on the wildlife	■	■	■	■
Socio-economic dependencies	■	■	■	■

Figure 4.7.16 The extent of the resort's potential environmental impacts. (**Note:** The extent of resort's impacts [ranging from positive through neutral to negative] should be read in conjunction with the information in [Figure 4.1](#)).

24.3–26.6 °C and corresponding internal temperatures in a typical *tentalapa* (guest unit) were in the range 24.6–27.4 °C. This indicates minimal heat storage in lightweight elements of the *tentalapa*. Conditions inside were only marginally warmer than those outside. The visit occurred in relatively cool and cloudy weather and we can predict that under sunny conditions the units will perform even better due to their 'umbrella roof'-shaded structures ([Figures 4.7.13–14](#)).

4.7.7 Concluding remarks

This very popular resort was among the earliest of its type in the world. It is absolutely unique in its rejection, in principle, of using electricity and in adapting

its operations to nature's own rhythm. Its structures have been built by locals, using local knowledge and experience. One must say that the KaiLuumcito appears to be more in tune with nature than any other resort in this review. Because of this, the owners' approach addresses issues not tackled well by the majority of the other resorts in this review, such as light and sound pollution. Light pollution from the resort is substantially limited by using only a small number of shielded candles and torches very close to the ground. And, in absence of discos, radios and TV sets, the sounds are practically all natural. This approach is increasingly popular and the offer has been extended even to the luxury segment of the market (compare Baum, 2007). Similar eco-resorts can be found in many places around the world from Puerto Rico and the Virgin Islands, through Namibia and the Seychelles to Australia ([Figure 4.7.15](#) and [Figure 4.7.16](#)).

4.8

Hacienda Chichén Resort

Location:	Hotel Zone, Chichén Itzá, Yucatán, Mexico
Year of completion:	2004 (the principal building completed in the 1500s, most buildings constructed in the 1920s)
Total cost of construction:	not known
Architect/designer:	Belisa Barbachano-Gordon
Consultant:	Bruce Gordon and Tim Harper
Builder:	local craftspeople
Number of guest units:	28 rooms in double bungalows
Max. number of guests:	60 (approx.)
Other facilities on site:	<i>casco</i> (main house): reception, dining, kitchen, lounge, gift shop, office, library; church, corral and stables, <i>bodegas</i> (service buildings), maintenance workshop
Site area:	approx. 6.5 acres of 1000-acre property (2.5 of 400 ha)
Access methods:	by road (from Cancún or Mérida international airports)
Principal attractions in the area:	Chichén Itzá and other archaeological sites, <i>cenotes</i> (sinkholes), Sian Ka'an World Biosphere Reserve, nature and culture tours

1920s and also utilises many of the original Hacienda buildings. It is a classic example of the recycling of the entire site, whilst maintaining its original purpose of providing an overnight shelter for visitors to the ancient Mayan city of Chichén Itzá (Figure 4.8.1).

The resort is located in a hotel zone. It occupies the site of a 500-year-old cattle ranch redeveloped and extensively modified in the 1920s for the purpose of housing the 'permanent' archaeological expedition. All the bungalows offered by the resort were built more than 80 years ago, but have been retrofitted and adapted to serve its modern purpose. In addition, some trees were removed, walkways were paved and an in-ground pool was built. A project currently under way aims at reforestation of the entire site. Nurseries of native trees such as *zapote* and *caoba* (native mahogany) have been established and seedlings are progressively moved to recultivated parts of the property. The resort owners intend to convert a large part of their property into a wildlife reserve supporting eco-tourism with a bird-watching trail (Figures 4.8.2–3).

4.8.1 Site selection and landscaping

The resort was created on the site of the Carnegie archaeological expedition's accommodation of the



Figure 4.8.1 The resort's main draw card is the fact that it is located next to the world famous Mayan ruins of Chichén Itzá.



2



3

Figures 4.8.2–3 Accommodation at the resort is also offered in buildings that housed the 1920s archaeological expedition to the area; the structures were erected chiefly with stone recovered from the ancient city.

4.8.2 Construction

In line with the local building tradition, the resort was built chiefly with heavy materials such as limestone (mostly recovered ages ago from the Mayan ruins), plaster and floor tiles. Concrete blocks and concrete in-situ have also been used as well as timber. The materials not only require minimal maintenance but are resistant to strong winds occurring in the hurricane season (Figure 4.8.4).

4.8.3 Energy management

The source of electricity is a town grid. The recorded usage averages 72 kWh per month. There is also a back-up generator hidden in a half-buried underground old storeroom. Efficient low-voltage lighting and gas appliances help to save energy. The resort appeals to guests to save energy in order to reduce demand (Figure 4.8.5).



Figure 4.8.4 The buildings have been ‘recycled’: the original building envelope was retrofitted with all modern conveniences and the interior brought up to modern standards.



Figure 4.8.5 The single-line tram was used by early twentieth-century tourists and awaits restoration.

4.8.4 Water management

The resort works on a water conservation strategy. The second stage of the cascading grey water purification system is under construction. The resort’s water needs are met by mixing rainwater with water from two ancient artesian wells. Three more Mayan wells will soon be unblocked. Recycled grey water provides water for irrigation through a drip and sprinkler system. A swimming pool doubles as fire-fighting water storage (Figure 4.8.6).

4.8.5 Waste management

All toilets have dual flush systems and all liquid waste is processed on site in a two-stage processing plant consisting of bio-digesters and created wetlands. A



Figure 4.8.6 Al fresco dining is offered at the main house of the Hacienda, which was built for its Spanish owners in the eighteenth century.

local contractor takes most solid waste away to a municipal landfill. Plastic, glass and metal waste is recycled. Organic waste from the kitchen is composted on site or taken away by employees for that purpose (Figure 4.8.7).

4.8.6 The resort's climatic performance

During the author's visit to the resort early in December (early 'winter'), external temperatures ranged from 23.9–29.9 °C and corresponding internal temperatures (with fans switched off) were in the range 26.0–30.1 °C. This indicates quite significant heat storage in massive elements (structural walls and floors) of the resort. Conditions inside were

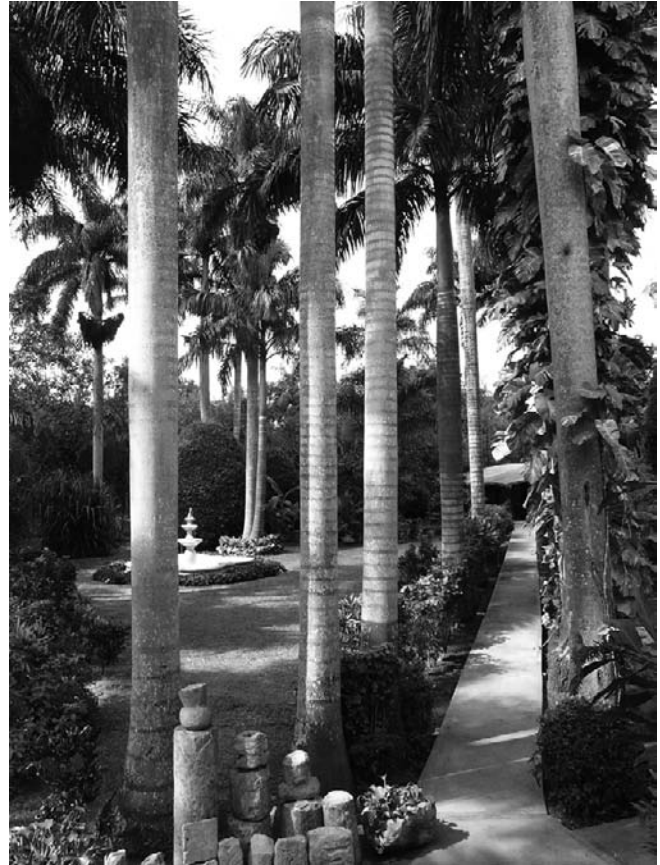


Figure 4.8.7 The change of character from a former cattle ranch to a tourist resort is most visible in the landscaping design; view from the restaurant deck towards one of the accommodation buildings.

warmer than those outside for the corresponding period and the range of indoor temperatures was fairly small. It can be predicted, with some level of certainty, that in warmer weather the indoors will offer an environment quite a lot cooler than on the outside. Lack of sufficient natural ventilation seems problematic but this could easily be resolved with low-powered exhaust fans installed near the highest points of the ceiling. The roofs, which are quite flat, would probably benefit from more insulation but, being reasonably well shaded by palm trees, this overlooked aspect does not cause the buildings to perform significantly worse (Figure 4.8.8).

4.8.7 Concluding remarks

The Ancient Maya were intimately connected with the natural balance of the environment and the resort's current operators are committed to restore

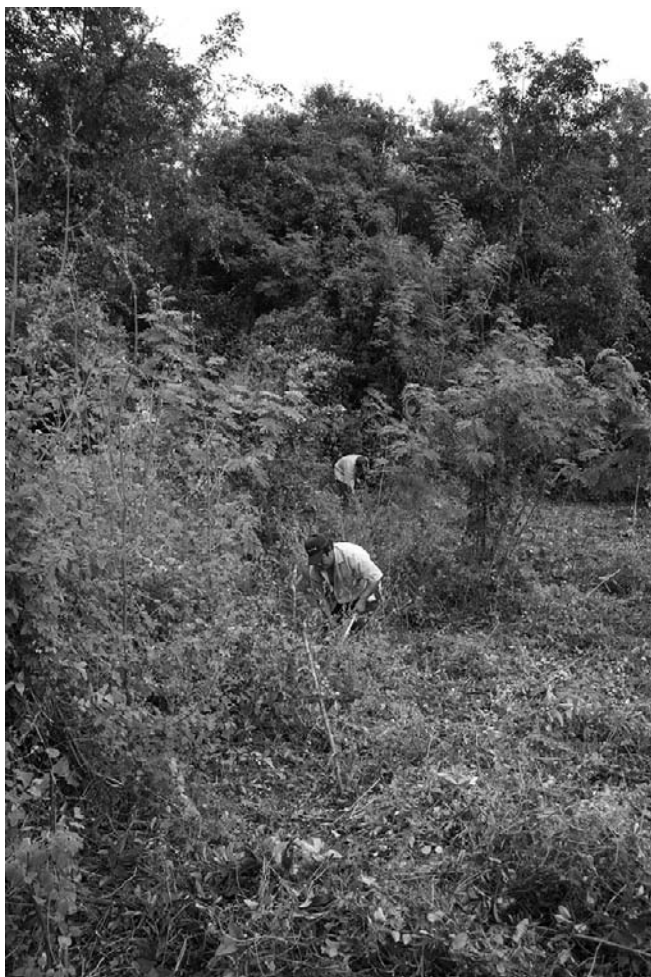


Figure 4.8.8 The Hacienda has undertaken a massive effort of re-vegetating degraded parts of the property with indigenous plants, giving employment to the local villagers in the process.

this tradition in today's Maya rural society around the Hacienda. The resort's spa, the Yaxkin Maya Retreat, offers guests a unique opportunity to experience some of the most healing organic traditions known today that are rooted in holistic Maya ceremonies and rituals. An old natural cave – the *rejoyada* or dried *cenote* (sinkhole) near the main gardens overlooking the nunnery and other Mayan temples – has been rescued for that purpose. The place was used in ancient times as an underground ritual cave and more recently (in the 1920s) as a storage site.

The resort's site is known also as 'Yaxkin', which means 'the place of renewal' and, as part of its mission, a percentage of its profits will be donated to the environmental protection and animal welfare efforts of the Maya Nature Conservation programme. This



Figure 4.8.9 The property has its own historic attractions including a small church built by the Spaniards in the seventeenth century.

programme has already reforested the area with over 2000 native hardwood trees and has vigilantly kept out illegal hunting of endangered animal species, such as the kinkajou, in the area. Work has also started on a *zumpul-che* (a sacred Maya sweat-bath similar to the Aztec's *temazcal*) to help regain understanding of the important relationship between steam (water) and heat (fire) to purify the spirit, mind and body to balance the inner energy flow or life force in us.

Another important part of the resort is the Merle Greene Gallery which has over 20 large 'rubblings' from her personal collection, donated to support the resort's commitment to continue fomenting the study and acknowledgement of ancient Maya cultural heritage in the region.

at the single unit level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				

at the resort level

Visual pollution				
Light pollution				
Noise pollution				
Airborne pollution				
Thermal environment-related impacts				
Impacts on geology of the site				
Impacts on soil: compacting, contamination				
Impacts on water: surface, underground sources, run-off				
Impacts on the original vegetation				
Impacts on the wildlife				
Socio-economic dependencies				

Figure 4.8.10 The extent of the resort's potential environmental impacts. (**Note:** The extent of resort's impacts [ranging from positive through neutral to negative] should be read in conjunction with the information in [Figure 4.1](#)).

Resort co-owner Belisa Barbachano-Gordon comes from a family whose roots have been running in the region for a few centuries. She is very conscious of the social impacts that the facility's presence and operation can make on the local people and entire

communities. The resort management plans to contribute to local education by accommodating groups on forestry, agriculture or hospitality training visits ([Figure 4.8.9](#), [Figure 4.8.10](#)).

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