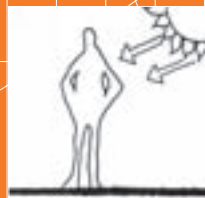
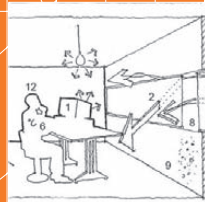
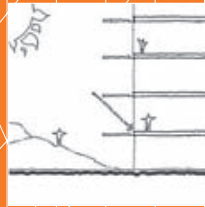
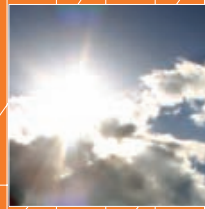


# Climate and Comfort

Passive Design Strategies for Lebanon



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Passive Design Strategies for Lebanon



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The aim of this document is to promote the understanding of issues and concepts related to passive heating and cooling as applicable to the Lebanese context in terms of climate and building characteristics.

For this purpose, the document looks at climate, thermal comfort and building characteristics in Lebanon. To address these issues, the document has considered a selection of concepts and strategies, with the objective of providing the user with a handy information tool and not an all encompassing reference.

The interaction between People, Buildings and Climate is dynamic and site-specific, and is investigated during a project's design process.

These 3 issues are interrelated and are addressed under separate headings in order to allow the user to selectively access the contents of each section.

The study of these parameters in relationship to each other, results in the definition of passive design strategies<sup>1</sup>. When integrated in a project, these strategies enhance thermal comfort, promote energy-efficient building design, and reduce energy consumption.

Reducing energy consumption minimizes the reliance on artificial cooling and heating devices that rely on electricity, the production of which releases CO<sub>2</sub> and greenhouse gases.

Adopting strategies such as orientation\*, massing, window positioning, etc. has low initial costs and provides long term savings in operational costs. These concepts are addressed in this document.

The more elaborate strategies involving the use of technologically advanced materials and systems will tend to increase initial capital costs but result in increased long term savings in operational costs are not mentioned here.

This document has been developed as part of the UNDP project 'Thermal Standards for Buildings in Lebanon', and includes data and information that have been developed in the context of this project. The other project documents are the Climatic Zoning Study, the Energy Analysis and Impact Assessment Study and the Thermal Standards for new Buildings in Lebanon.

Finally, the contents of this document do not give answers on 'how to design'. Such answers will emerge as each individual site and program is analyzed. Furthermore, the document's illustrations and diagrams should not be adopted as solutions. Rather, they provide ideas and concepts for passive strategies that enhance thermal comfort.

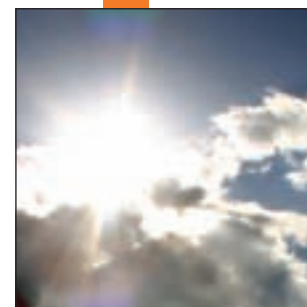


Figure 1: Sun

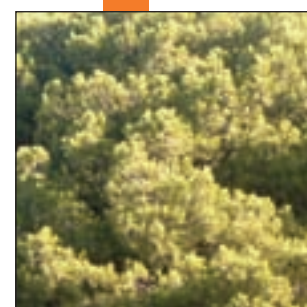


Figure 2: Vegetation

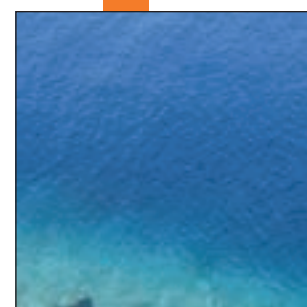


Figure 3: Sea

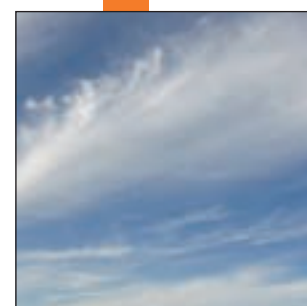


Figure 4: Wind

<sup>1</sup> All entries with an \* are further developed and explained in the glossary.



Climate is the combined result of all meteorologic variables that simultaneously happen in a particular geographical area.

The four elements affecting thermal comfort and passive design strategies addressed in this document are:

- Temperature\*
- Solar radiation\*
- Relative humidity\*
- Wind movement

Climate in Lebanon is characterized by the existence of a cold winter season, a hot summer season and two mild mid-seasons:

The summer season extends from July till September with August being the hottest month.

The winter season varies according to the region, whether coastal or inland, but January remains the coldest month.<sup>1</sup> This season extends from January till March.

The mid-seasons are characterized by their mild weather, and extend from April till June and from October till December.

Lebanon is divided into four regions based on temperature, relative humidity and solar radiation. These climatic parameters affect the heating and cooling requirements in buildings.

- A coastal region which is defined as having less than 1000 degree days;<sup>1</sup>
- A mid-mountain region which is defined as having between 1000 and 2000 degree days;
- A high-mountain region which is defined as having more than 2000 degree days;
- An inland region which is also defined as having between 1000 and 2000 degree days.

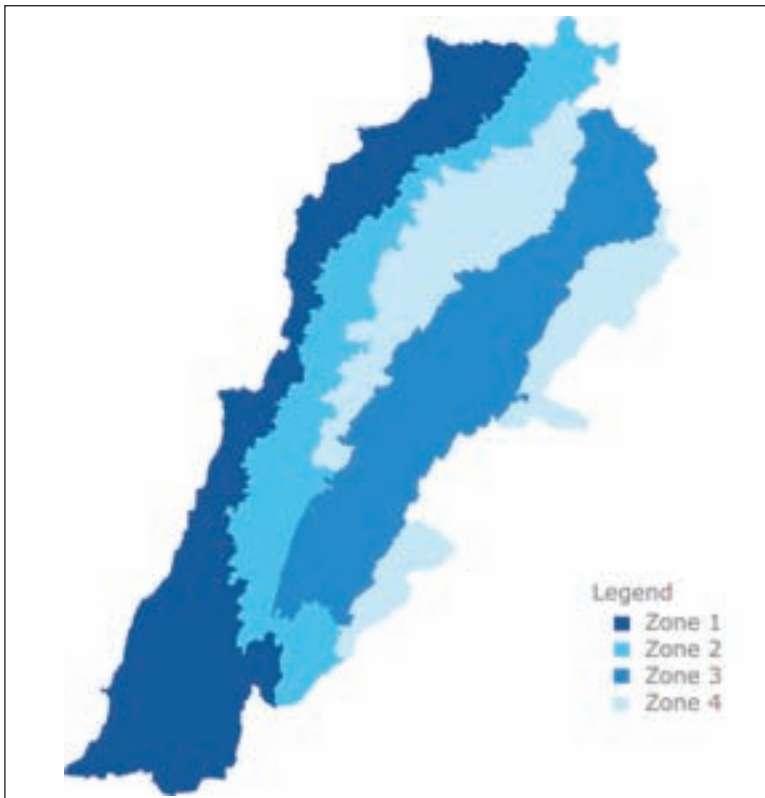


Figure 1.1: Lebanon: Climate regions

<sup>1</sup> Refer to Chapter 2 of the Climate Zoning Study for buildings in Lebanon

The diverse topographic characteristics of these regions result in different site-specific situations.<sup>1</sup>

The configuration of hills and valleys affects the orientation\* of the sites with respect to the sun, the degree of relative humidity\* as well as the wind direction. In these configurations, the wind direction flows from the coast into the valley in the daytime and does the reverse at night. Consequently, all the sites flanking the valley have particular wind flow patterns depending on location, altitude\*, and time of day.

Therefore, it is important to analyze each site individually in terms of climatic parameters in order to improve the impact of passive design strategies.

The gradual increase in altitude produces colder winters with more precipitation\* and snow. The higher the altitude, the less the atmospheric pressure is and therefore the lower the temperature\*.

In general, the influence of the Mediterranean Sea is abated by the increasing altitude. With higher precipitation than that along the coast; fluctuations of temperatures are wider and winters are colder.

### **Climatic characteristics**

The following is a selection of climatic charts representing overall climatic trends in the different climatic regions.

<sup>1</sup> Goulding, J., Owen Louis, J., Steemers, T. (1993), Energy Conscious Design. Batsford, UK

# Coastal region

Figure 1.2 shows the yearly variations of the maximum, minimum and mean temperatures\* in °C.

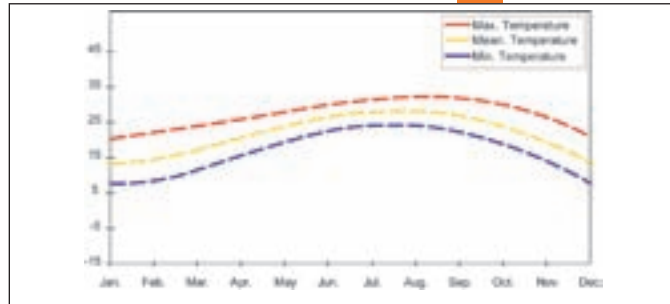


Figure 1.2: Coastal region: temperature

Figure 1.3 shows the yearly diurnal range\* fluctuations in °C.



Figure 1.3: Coastal region: diurnal range

Figure 1.4 illustrates the yearly variation of solar radiation\* intensity in Whr/m<sup>2</sup>.

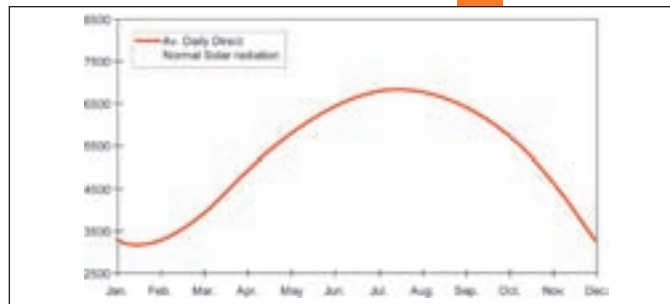


Figure 1.4: Coastal region: solar radiation

Figure 1.5 illustrates the yearly variation of relative humidity\* in %.



Figure 1.5: Coastal region: relative humidity

Figure 1.6 illustrates the yearly average wind speed in km/hr.

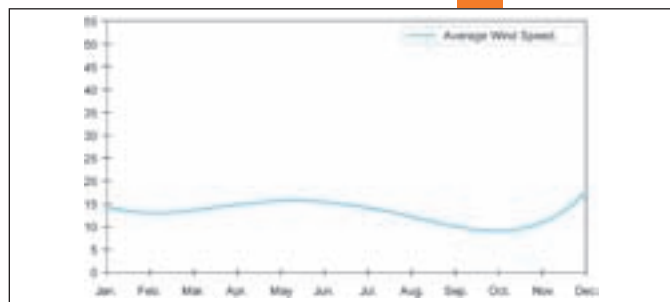


Figure 1.6: Coastal region: wind speed

# Mid-mountain region

Figure 1.7 shows the yearly variations of the maximum, minimum and mean temperatures\* in °C.

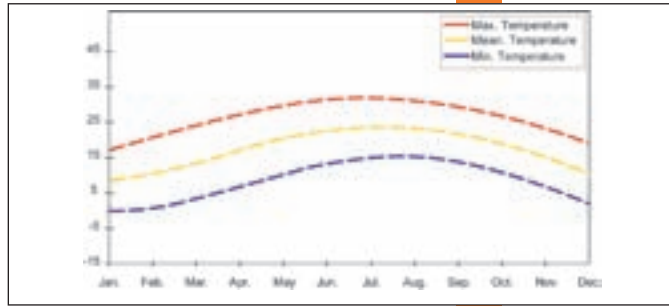


Figure 1.7: Mid-mountain region: temperature

Figure 1.8 shows the yearly diurnal range\* fluctuations in °C.



Figure 1.8: Mid-mountain region: diurnal range

Figure 1.9 illustrates the yearly variation of solar radiation\* intensity in Whr/m<sup>2</sup>.

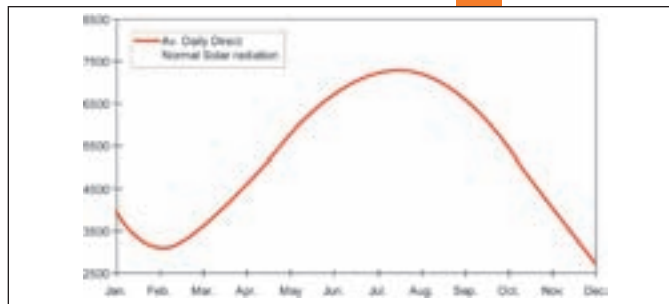


Figure 1.9: Mid-mountain region: solar radiation

Figure 1.10 illustrates the yearly variation of relative humidity\* in %.

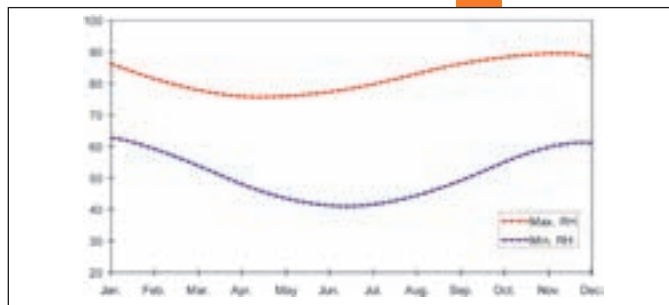


Figure 1.10: Mid-mountain region: relative humidity

Figure 1.11 illustrates the yearly average wind speed in km/hr.

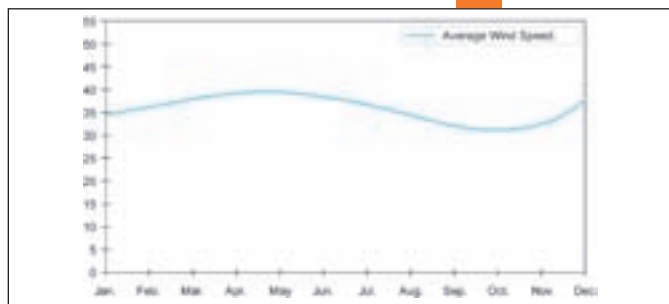


Figure 1.11: Mid-mountain region: wind speed

# High-mountain region

Figure 1.12 shows the yearly variations of the maximum, minimum and mean temperatures\* in °C.

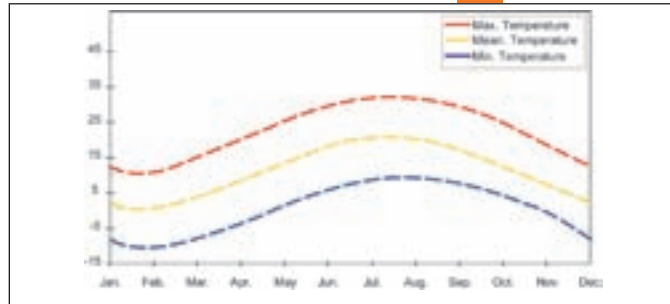


Figure 1.12: High-mountain region: temperature

Figure 1.13 shows the yearly diurnal range\* fluctuations in °C.



Figure 1.13: High-mountain region: diurnal range

Figure 1.14 illustrates the yearly variation of solar radiation\* intensity in Whr/m<sup>2</sup>.

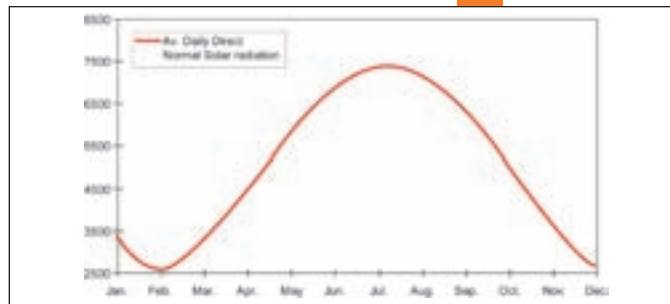


Figure 1.14: High-mountain region: solar radiation

Figure 1.15 illustrates the yearly variation of relative humidity\* in %.

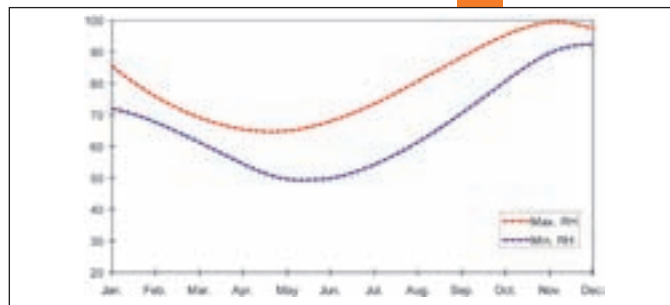


Figure 1.15: High-mountain region: relative humidity

Figure 1.16 illustrates the yearly average wind speed in km/hr.

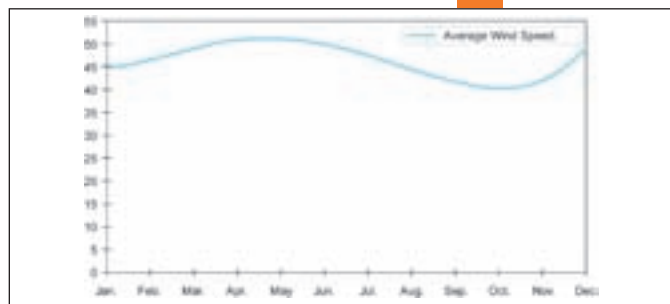


Figure 1.16: High-mountain region: wind speed

# Inland region

Figure 1.17 shows the yearly variations of the maximum, minimum and mean temperatures\* in °C.

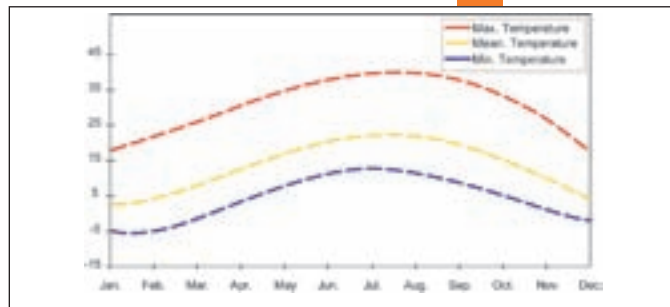


Figure 1.17: Inland region: temperature

Figure 1.18 shows the yearly diurnal range\* fluctuations in °C.



Figure 1.18: Inland region: diurnal range

Figure 1.19 illustrates the yearly variation of solar radiation\* intensity in Whr/m<sup>2</sup>.

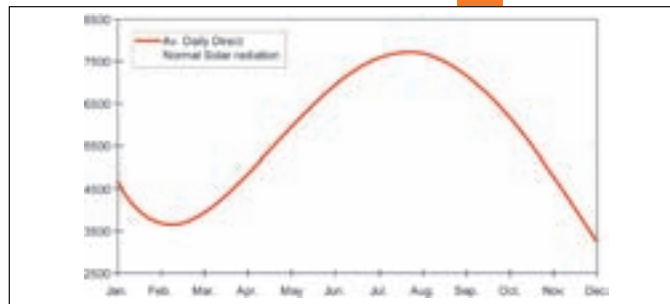


Figure 1.19: Inland region: solar radiation

Figure 1.20 illustrates the yearly variation of relative humidity\* in %.

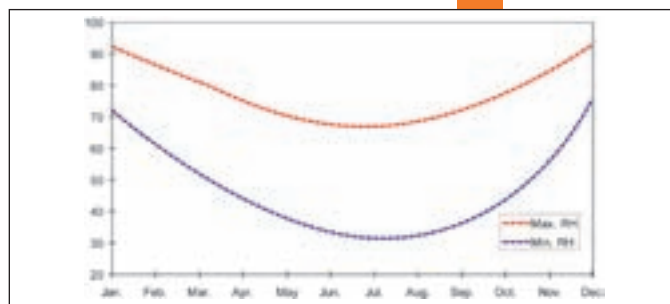


Figure 1.20: Inland region: relative humidity

Figure 1.21 illustrates the yearly average wind speed in km/hr.

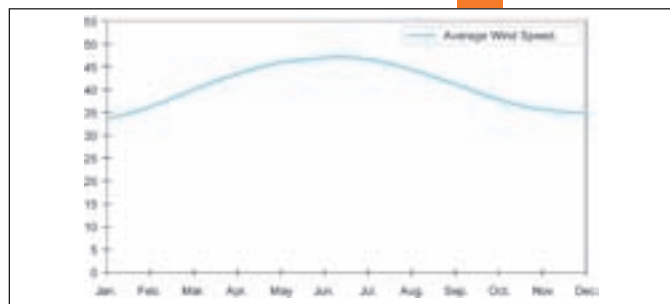


Figure 1.21: Inland region: wind speed

### Key issues

Dry bulb temperature\* and relative humidity\* are the climatic characteristics that will be considered in the analysis of the comfort zones on the psychrometric charts.



# Definition

Thermal comfort is, to a large extent, dependant on the balance between the heat\* produced by the body, heat and radiation\* received by the body and heat lost from the body to the surrounding environment through radiation, convection\*, evaporation and sometimes conduction\*.

This balance is a necessary condition for thermal comfort.

Activities, age, clothing, culture and human acclimatization play an important role in the perception of thermal comfort.

People perceive thermal comfort differently depending on their particular adaptive strategies and circumstances.

The parameters affecting thermal balance are divided into environmental and personal determinants:<sup>1</sup>

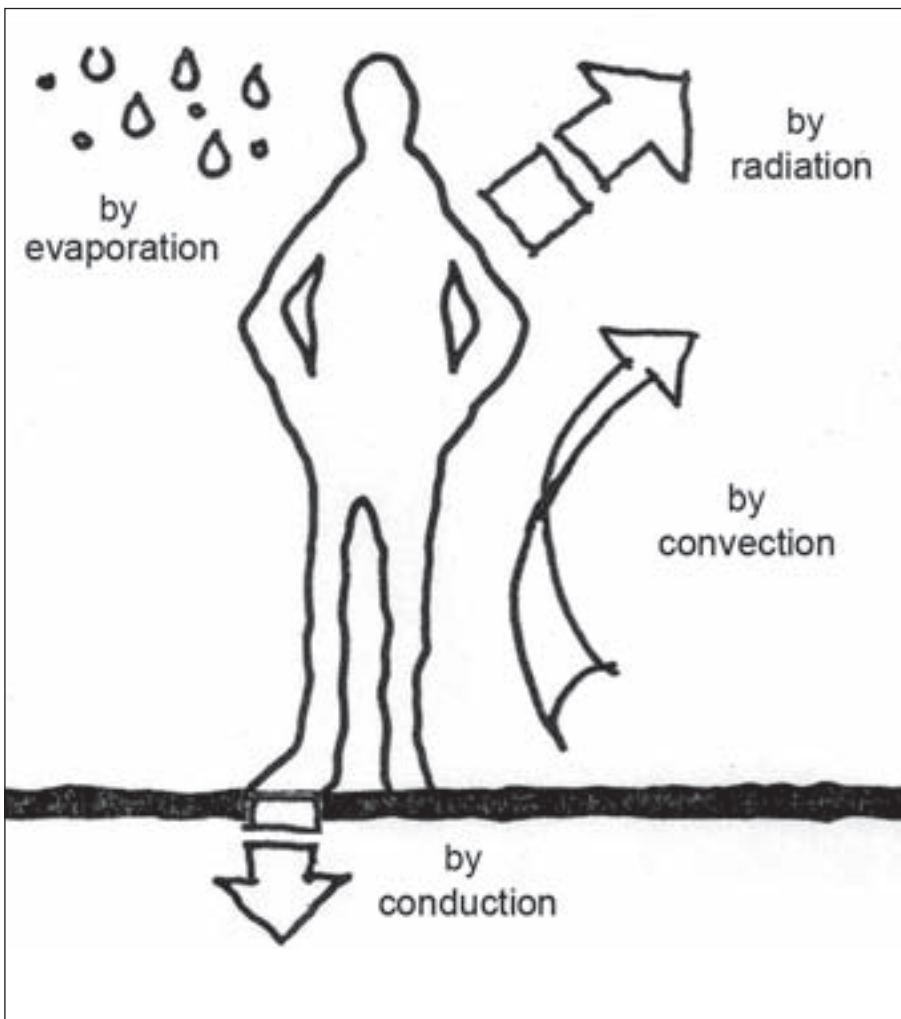


Figure 2.1: Heat loss from body



Figure 2.2: Radiation

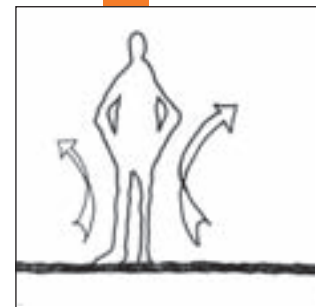


Figure 2.3: Convection\*

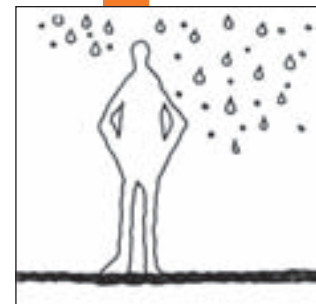


Figure 2.4: Evaporation



Figure 2.5: Conduction\*

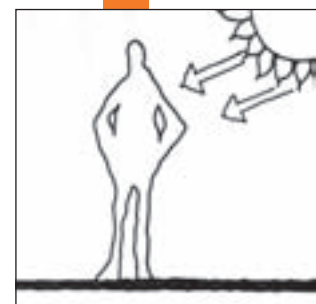


Figure 2.6: Heat gain

<sup>1</sup> Goulding, J., Owen Louis, J., Steemers, T. (1993), Energy Conscious Design. Batsford, United Kingdom.

# Environmental Determinants

**Dry bulb temperature\* (DBT)** is a dominant environmental factor as it determines convective heat\* dissipation due to the difference in temperature\* between the skin and the surrounding air.

**Relative Humidity\* (RH)** determines the rate of evaporation. Very low and very high relative humidities\* cause discomfort.

The comfort zone is a situation whereby a person needs to make as little effort as possible to adjust to the environment he is in.<sup>2</sup>

In each region, the approximate range for the comfort zone is as follows:

- Coastal region: between 18°C-19°C and 30°C-31°C dry bulb temperature with the corresponding 20% to 90% relative humidity.
- Mid-mountain region: between 17°C-18°C and 29°C-30°C dry bulb temperature with the corresponding 20% to 90% relative humidity.
- High-mountain region: between 14°C-15°C and 28°C-29°C dry bulb temperature with the corresponding 15% to 90% relative humidity.
- Inland region: between 15°C-16°C and 30°C-31°C dry bulb temperature with the corresponding 15% to 90% relative humidity.

**Air movement** accelerates convection\* and helps evaporation from the skin, thus producing a cooling effect.

The way air velocity affects comfort varies depending on the surface temperature and wind speed. For example, a surface temperature\* of 25°C would feel the same for air temperature\* 30°C at 0.8 m/s and air temperature\* of 26°C at 0.25 m/s.

**Mean radiant temperature\* (MRT)** affects the heat lost or gained by the body through radiation\* and conduction\*.

# Personal Determinants

**Activity** determines the rate at which the body converts food into heat\* (metabolic rate). This process is a function of a person's activity level. The "met" quantifies the metabolic rate and varies from 7.6 for playing basketball to 0.7 for sleeping.

These values can be found in Appendix A of ASHRAE 55.

**Clothing** is a thermal insulator for the body. It is an adjustment mechanism that allows adaptation to cooler or warmer air temperatures.

The "clo" quantifies the level of clothing insulation. It varies from 0.1 for shorts, to between 3 and 4 for a polar weather suit.

These values can be found in Appendix B of ASHRAE 55.

## Key issues

The dry bulb temperature and the relative humidity are the main determinants that define the comfort zones which lead to the definition of passive strategies.

Air movement, mean radiant temperature\*, and clothing factors are addressed punctually in this document when carrying out simulations relating to the sensation of comfort.

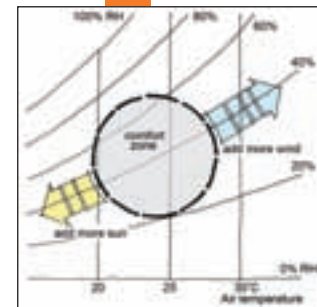


Figure 2.7: Comfort zone defined by relative humidity and air temperature.<sup>1</sup>

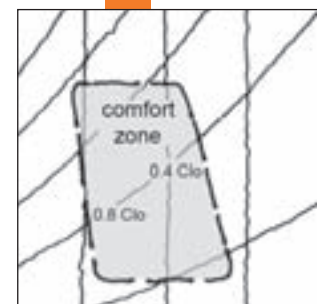


Figure 2.8: Relationship of air movement and CLO with the comfort zone.<sup>3</sup>

<sup>1</sup> Adaptation from Stein / Reynolds / Mc Guinness 7th edition V1

<sup>2</sup> Olgyay, V. (1973), Design with Climate. Princeton University Press, Princeton.

<sup>3</sup> Adaptation from Arens, et al. (1980), (Stein / Reynolds / McGuinness 7th edition V1)



# Approach and limitations

The comfort of the occupants of a building is the combination of thermal comfort, visual comfort, acoustic comfort, etc. This document addresses and elaborates on the issues relating to thermal comfort.

## The approach

The psychrometric chart<sup>1</sup> is adopted as a tool to analyze climate and comfort.

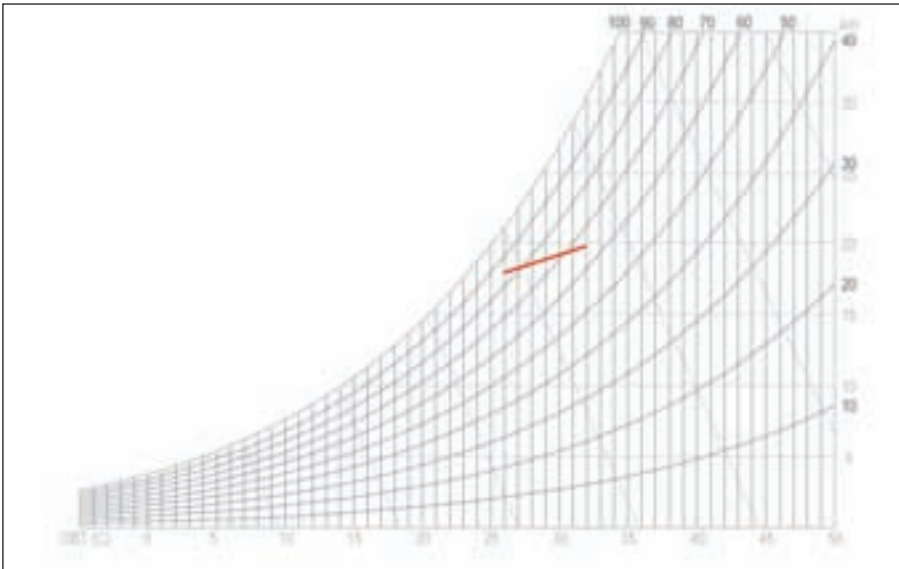


Figure 3.1: Psychrometric chart

This chart graphically illustrates the relationship between the outdoor dry bulb temperature\* and the water vapor present in the air. Climatic data consisting of temperatures\* and relative humidities\*, which belong to each season in a particular region, are plotted on the chart. The location of the climatic data on the chart is analyzed in relation to a 'comfort zone' discussed on the next page. If the actual temperature\* and relative humidity are within the comfort zone, then a person experiencing that condition would be comfortable.

The psychrometric chart is a tool that helps understand the relationship between dry bulb temperature and relative humidity, and relates them to the sensation of comfort. However, the thorough analysis of the information on this chart should be carried out taking into account the particular climatic characteristics of a project's site.

<sup>1</sup> The psychrometric chart is explained in Appendix 2.

# Comfort zone delineation

Several methods can be used to define the comfort zone<sup>1</sup>.

The Givoni method<sup>2</sup>, adopted here and explained below, consists of defining a comfort zone on the psychrometric chart.

This comfort zone represents the range of outdoor climatic conditions wherein a person would feel comfortable. It delineates where the acceptable ranges of dry bulb temperature\* and relative humidity\* are for each zone. The climatic characteristics of uncomfortable outdoor climatic conditions are also shown on the chart.

The figure below is a graphic example of a comfort zone on the psychrometric chart. The values listed at the bottom are the dry bulb temperatures.

The curved lines represent the percentages of relative humidity.

Example: A combination of 24°C dry bulb temperature and 45 % relative humidity would lie within the comfort zone. Hence a person experiencing that condition would be comfortable.

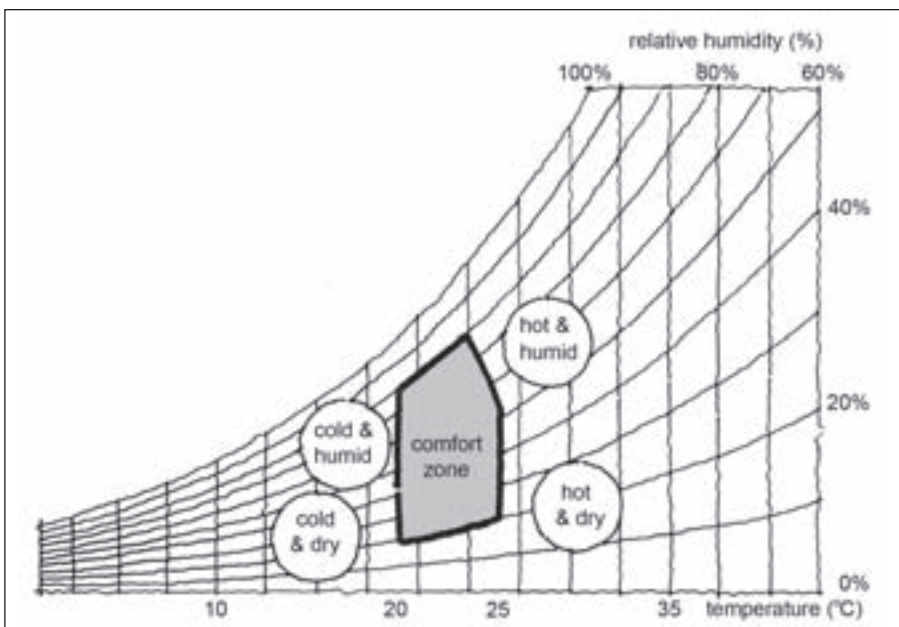


Figure 3.2: Climate situations and comfort zone<sup>3</sup>

There is a difference between summer and winter comfort zones due to seasonal acclimatization relating to climate, clothing, activity and changes in metabolism.

For Lebanon, three comfort zones are defined for each climatic region:

- One for the winter season, from January till March;
- One for the two mid-seasons, from April till June and from October till December;
- One for the summer season, from July till September.

<sup>1</sup> These methods are described in Appendix 3

<sup>2</sup> Szokolay, S (2004), Introduction to Architectural Science. Elsevier & Architectural Press. Amsterdam

<sup>3</sup> Adaptation from Milne and Givoni in Energy Conservation through Building Design (Dr. Marsh / Square One)

# Application to the 4 climatic regions

## Coastal region

The average daily minimum temperature\* and the average relative humidity\* at 4 am, as well as the average daily maximum temperature and the average relative humidity at 4 pm are plotted on the psychrometric chart (Figure 3.3) and are numbered from 1 to 12 representing the months from January to December respectively.<sup>1</sup>

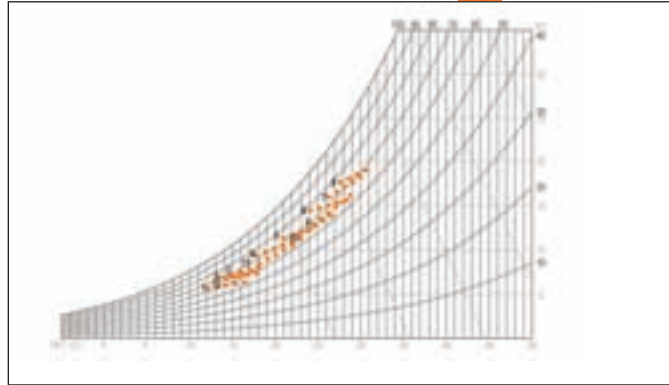


Figure 3.3: Coastal region : climatic characteristics

### Comfort zones

Figure 3.4 illustrates the comfort zone for the **winter season**. The chart shows that temperatures below 19°C lie outside the comfort zone. All of the monthly temperatures and relative humidities fall outside the comfort zone. This indicates that there is a necessity to introduce passive strategies to improve this condition for comfort.

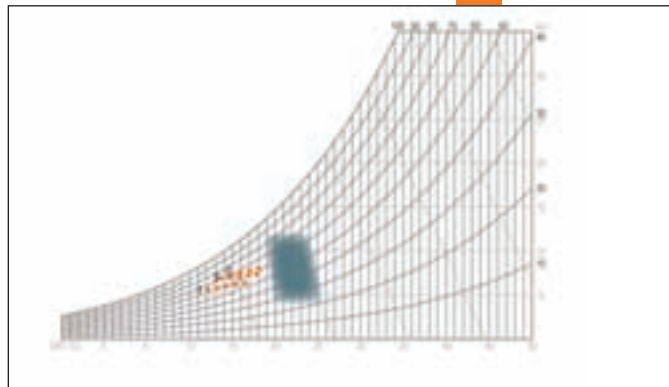


Figure 3.4: Coastal region : winter season comfort zone

Figure 3.5 illustrates the comfort zone for the **mid-seasons**. The chart shows that, temperatures below 21 °C that have a corresponding relative humidity of up to 100%, as well as some temperatures above 19 °C that have a corresponding relative humidity above 65%, fall outside the comfort zone.

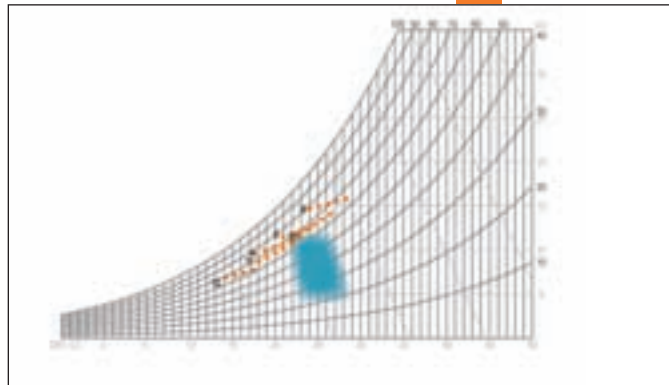


Figure 3.5: Coastal region : mid-season comfort zone

Figure 3.6 illustrates the comfort zone for the **summer season**. As shown, all of the temperatures and relative humidities corresponding to this season fall outside the comfort zone, hence the need for passive strategies to improve the conditions for comfort.

Therefore, these charts indicate that in all three seasons there is a necessity to introduce passive strategies to improve conditions for comfort.

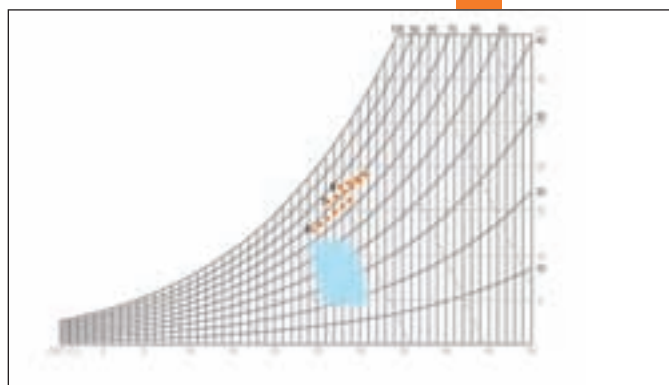


Figure 3.6: Coastal region : summer season comfort zone

<sup>1</sup> Szokolay, S. (2004), Introduction to Architectural Science - Elsevier and Architectural Press. Amsterdam.

## Mid-mountain region

The average daily minimum temperature\* and the average relative humidity\* at 4 am, as well as the average daily maximum temperature and the average relative humidity at 4 pm are plotted on the psychrometric chart (Figure 3.7) and are numbered from 1 to 12 representing the months from January to December respectively.

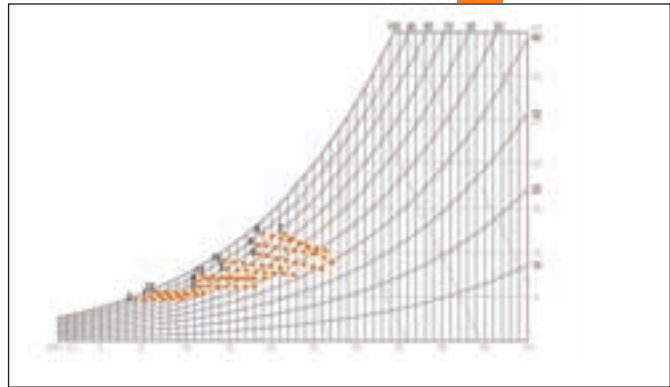


Figure 3.7: Mid-mountain region : climatic characteristics

### Comfort zones

Figure 3.8 illustrates the comfort zone for the **winter season**. The monthly temperatures and relative humidities fall outside the comfort zone for all the months. This indicates that there is a necessity to integrate passive strategies into a design.

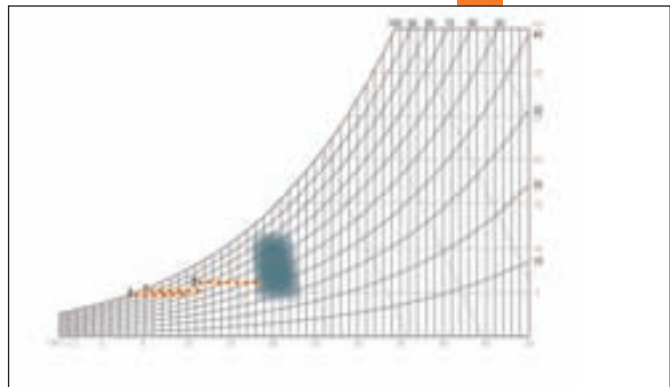


Figure 3.8: Mid-mountain region : winter season comfort zone

Figure 3.9 illustrates the comfort zone for the **mid-seasons**.

The chart shows that temperatures below 20°C as well as temperatures above 27°C are not comfortable. Temperatures between 20°C and 27°C that have a very low corresponding relative humidity are also considered uncomfortable.

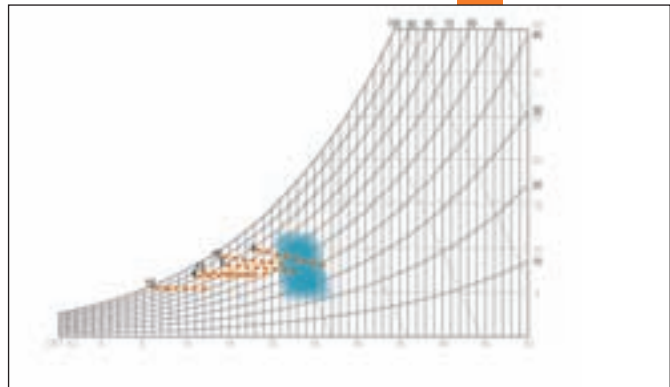


Figure 3.9: Mid-mountain region : mid-season comfort zone

Figure 3.10 illustrates the comfort zone for the **summer season**. The months are from July till September.

The chart shows that temperatures below 22°C and above 28°C having different relative humidities fall outside the comfort zone.

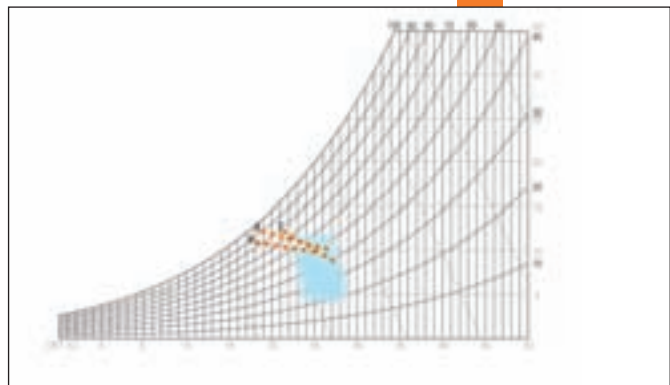


Figure 3.10: Mid-mountain region : summer season comfort zone

## High-mountain region

The average daily minimum temperature\* and the average relative humidity\* at 4 am, as well as the average daily maximum temperature and the average relative humidity at 4 pm are plotted on the psychrometric chart (Figure 3.11) and are numbered from 1 to 12 representing, respectively, the months from January to December.

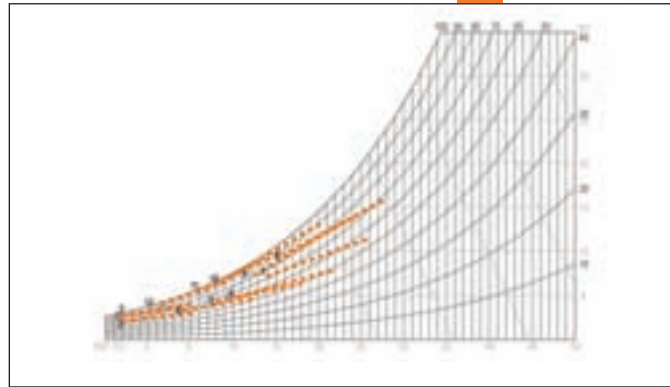


Figure 3.11: High-mountain region : climatic characteristics

### Comfort zones

Figure 3.12 illustrates the comfort zone for the **winter season**. The chart shows that temperatures below 15°C are not comfortable. The monthly temperatures and relative humidities fall outside the comfort zone for all the months. This means that introducing passive strategies to improve comfort conditions is necessary.

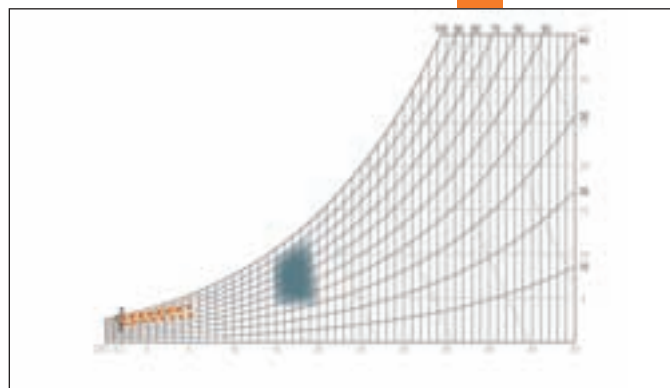


Figure 3.12: High-mountain region : winter season comfort zone

Figure 3.13 illustrates the comfort zone for the **mid-seasons**. The chart shows that temperatures below 18°C or above 25°C as well as temperatures between 18°C and 25°C that have a corresponding relative humidity\* lower than 25% are not comfortable.

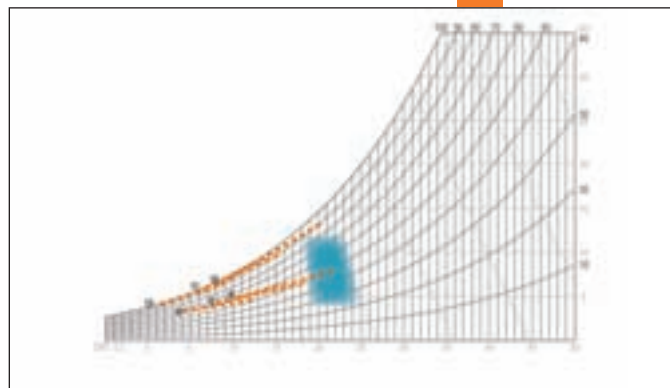


Figure 3.13: High-mountain region : mid-season comfort zone

Figure 3.14 illustrates the comfort zone for the **summer season**. The months are from July till September. The chart shows that temperatures below 22°C fall outside the comfort zone.

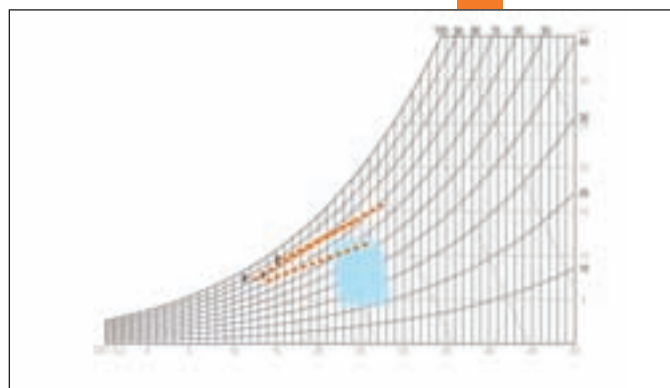


Figure 3.14: High-mountain region : summer season comfort zone

## Inland region

The average daily minimum temperature\* and the average relative humidity\* at 4 am, as well as the average daily maximum temperature and the average relative humidity at 4 pm are plotted on the psychrometric chart (Figure 3.15) and are numbered from 1 to 12 representing the months from January to December respectively.

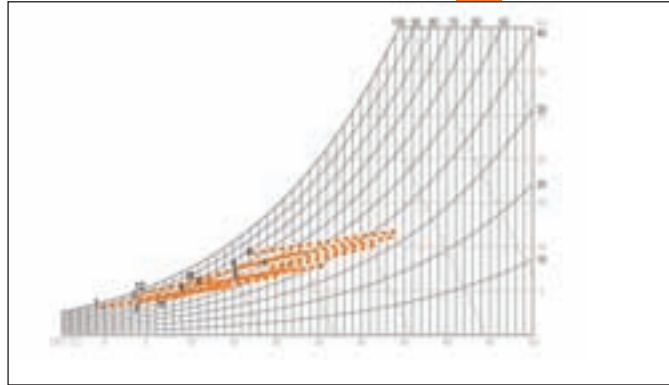


Figure 3.15: Inland region : climatic characteristics

### Comfort zones

Figure 3.16 illustrates the comfort zone for the **winter season**. The chart shows that temperatures below 16°C are not comfortable. The monthly temperatures and relative humidities fall outside the comfort zone for all of the months.

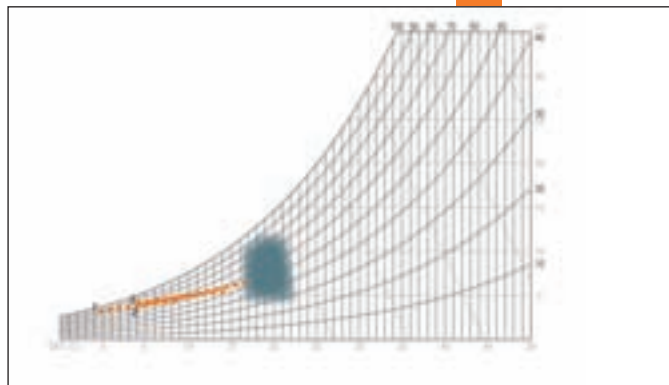


Figure 3.16: Inland region : winter season comfort zone

Figure 3.17 illustrates the comfort zone for the **mid-seasons**. The chart shows that temperatures below 20°C or above 25°C are not comfortable.

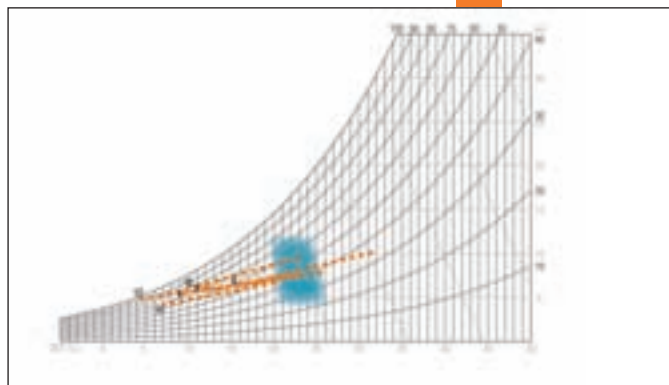


Figure 3.17: Inland region : mid-season comfort zone

Figure 3.18 illustrates the comfort zone for the **summer season**. The chart shows that temperatures below 23°C and relative humidities above 60% as well as temperatures above 29°C fall outside the comfort zone. This indicates that there is a necessity to introduce passive strategies to improve the situation.

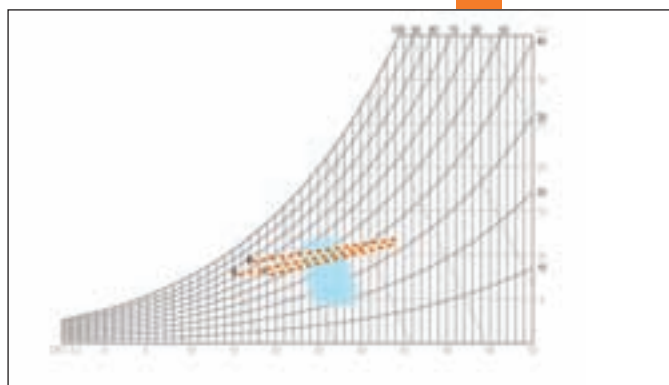


Figure 3.18: Inland region : summer season comfort zone

# Outdoor and indoor comfort

When the monthly outdoor temperatures\* and their corresponding relative humidities\* fall outside the comfort zone, the introduction of passive strategies helps in maintaining a comfortable indoor environment.<sup>1</sup>

The adjacent sketches illustrate the relationship between outdoor and indoor comfort situations.

Figure 3.19 : If the outdoor temperature and relative humidity combination is within the comfort zone, then a person would feel comfortable outdoors, as well as in an indoor space open to the outside.

Figure 3.20 : If the outdoor temperature and relative humidity combination is not within the comfort zone (e.g. the temperature\* is too high), then a person would feel uncomfortable outdoors, as well as in an indoor environment open to the outside.

Figure 3.21 : Consequently, if the outdoor temperature and relative humidity combination falls outside the comfort zone, then a person inside a building designed with passive strategies would feel more comfortable than a person outdoors.

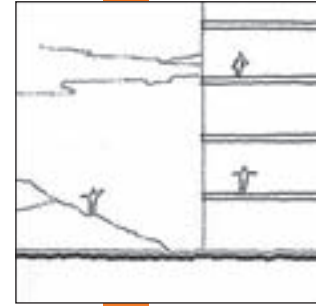


Figure 3.19: Outdoor - Indoor conditions 1

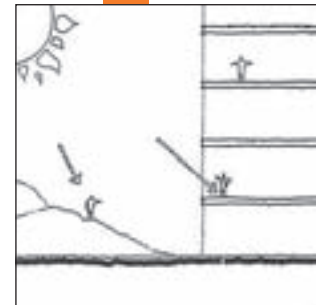


Figure 3.20: Outdoor - Indoor conditions 2

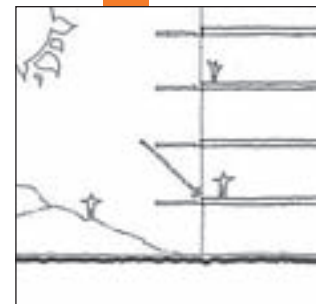


Figure 3.21: Outdoor - Indoor conditions 3

## Key issues

The location and extent of the comfort zone discussed in this chapter can be manipulated by parameters related to building massing and skin.

<sup>1</sup> Discussed in Chapter 8: Principles of Passive Concepts in the Different Climate Regions



The resultant temperature\* that affects a person's perception of comfort is a function of numerous varying parameters that interact dynamically throughout the day, week, month, and year. These parameters<sup>1</sup> include:

- 1- Internal heat\* gains
- 2- Solar gain
- 3- Relative humidity\*
- 4- Ventilation
- 5- Infiltration
- 6- Occupants
- 7- Thermal transmittance (U-value)
- 8- Area and quality of glazing
- 9- Internal surface temperature
- 10- Admittance (thermal mass\*)
- 11- External temperature
- 12- Internal temperature



Figure 4.1: Multi-level buildings

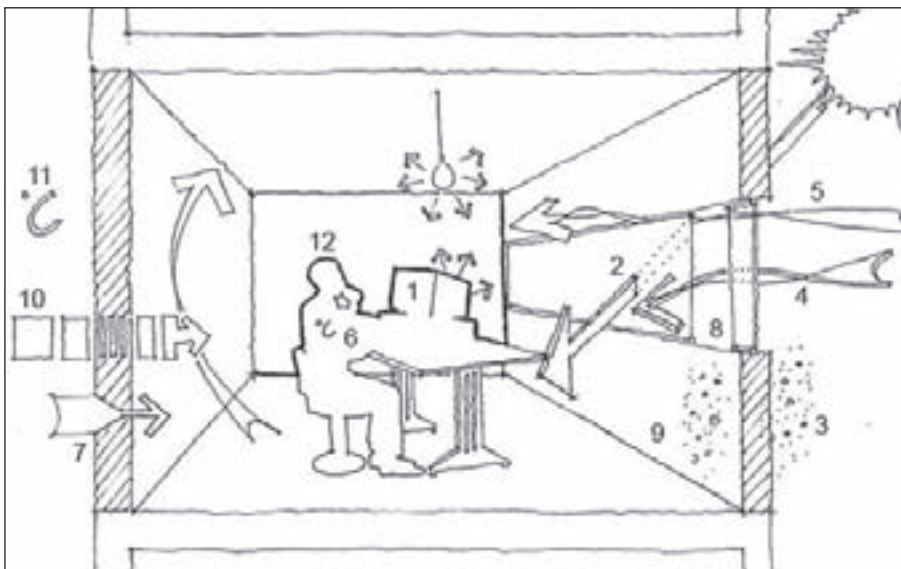


Figure 4.2: Parameters affecting comfort

<sup>1</sup> Allard, F. (1998). Natural Ventilation in Buildings. James & James. London

# Approach and limitations

## The Approach

Mean radiant temperature\* (Tmrt) is the average temperature\* of the walls and slabs of the room.

$$T_{mrt} = (\sum T_i \times A_i) / AT$$

Tmrt: mean radiant temperature (°C)  
 Ti: wall temperature (°C)  
 Ai: wall area (m<sup>2</sup>)  
 AT: total wall area (m<sup>2</sup>)

Effective operative temperature (Te) is a function of the Tmrt as well as the direct and diffuse radiation\*.

$$T_e = (hr \times T_{mrt} + hc \times T_{ai} + \alpha_s (q_d + q_b/4)) / (hr + hc)$$

Te: effective operative temperature\* (°C)  
 Tmrt: mean radiant temperature (°C)  
 hr: radiative heat transfer coefficient (W/m<sup>2</sup>K)  
 hc: convective heat transfer coefficient (W/m<sup>2</sup>K)  
 Tai: Outdoor temperature (°C)  
 αs: skin/clothing absorbance  
 qd: diffused radiation (W)  
 qb: beam radiation (W)

Resultant temperature (Tres) is a function of the Tmrt, Tair, and the air velocity.

$$T_{res} = (T_{mrt} + T_{air} \times \sqrt{(10V)} / (1 + \sqrt{(10V)}))$$

Tres: resultant temperature (°C)  
 Tmrt: mean radiant temperature (°C)  
 Tair: air temperature (°C)  
 V: velocity of the air (m/sec)

## Limitations

In the simulations carried out in this document, the internal temperature is always considered lower than the external temperature in summer and higher than the external temperature in winter, although this is not necessarily always the case.

## Key issues

These equations are used to simulate the impact that different parameters have on internal temperature. Since they are steady state equations, the results only give an indication of how temperatures are modified. Depending on the information needed, more comprehensive simulations that integrate numerous parameters necessitate the use of specialized software.



# Building sections and components

In general, the local residential and office building typologies are divided into 5 sections depending on the different rates of heat\* gain and loss.

1. Roof floor: residential or office spaces having the peripheral walls and roof as an external envelope.
2. Typical floors: residential or office spaces having the walls as an external envelope.
3. Ground floor: residential or office spaces having walls (including those of the entrance space) as an external envelope. This floor could also consist of pilotis.
4. Basements: spaces having for external envelope walls and floor slabs in contact with the soil.
5. Building core: a vertical element that contains the lifts, stairs and electrical / mechanical shafts. The core can be seen as being the backbone of the building.
6. Atriums or courtyards: an open space that can be located in the center of the building or at its periphery.<sup>1</sup>

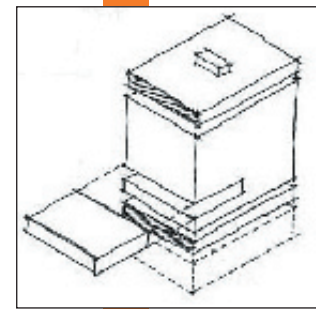


Figure 5.1: Building sections

The choice and position of the layers of building materials influence the heat flow\* through the components mentioned below.

## Roof

A construction method widely used for roofs is shown in figure 5.2.

## Slab on grade

Slabs that are placed directly on grade are usually cast in-situ reinforced concrete.

## Walls

Some of the building methods widely used for the wall construction are illustrated in figures 5.3 and 5.4.

## Openings

Materials used for window frames are aluminum, wood, steel and PVC. The shutter can be designed in a number of ways including folding, rolling or sliding. It could either be integrated in the window frame or may be a separate component. The specifications of the glass used can vary from a single layer float glass to a more sophisticated double glazed panel.

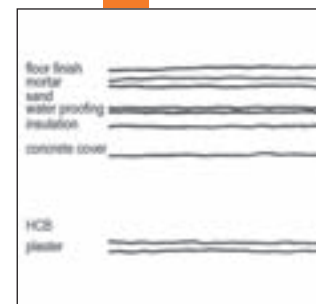


Figure 5.2: Roof slab section

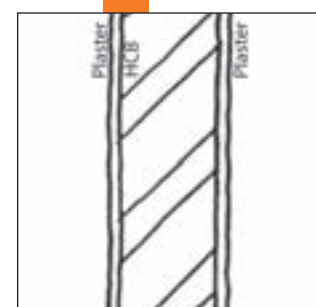


Figure 5.3: Single wall section

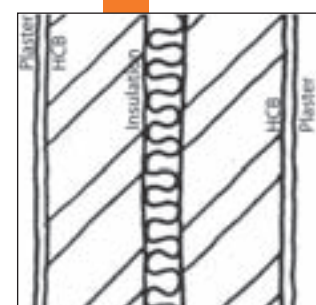


Figure 5.4: Double wall section

<sup>1</sup> Baker, N., Steemers, K. (2000) Energy and Environment in Architecture. E & FN SPON. London.

# Thermal transmittance

The approaches used to simulate and understand heat flow\* through building components are related to thermal transmittance\* and effective fenestration ratio<sup>1</sup>.

**The thermal transmittance (U-value)** of the building envelope is a function of the thermal performance of its various building components. It is expressed by the equation:

$$U = (\sum U_i \times A_i + \sum \Psi_i \times L_i) / \sum A$$

**U<sub>i</sub>** : Thermal transmittance of a building material (W/m<sup>2</sup>·K)

**A<sub>i</sub>** : Area of the building material (m<sup>2</sup>)

**Ψ<sub>i</sub>** : Thermal transmittance of a joint in the building component (W/m<sup>2</sup>·K)

**L<sub>i</sub>** : Linear distance of the joint in the building component (m)

**A** : Area of the overall component (m<sup>2</sup>)

Thermal transmittance

## Opaque elements

Each component of a wall, roof or floor assembly resists the passage of heat\* through it in a different manner. Therefore after each component is addressed individually, the overall performance is analyzed in order to evaluate the performance of the wall and its compliance with the requirements<sup>2</sup>. Insulation regulates the variations of heat flow and consequently affects the internal temperatures\*.

Figure 5.5: In general, decreasing the U-value by 1 W/m<sup>2</sup>K improves the internal temperature\* by about 5%.

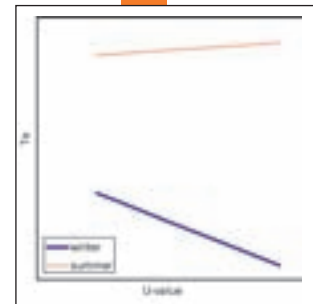


Figure 5.5: U-value and operative temperature.

## Openings

The materials used for external window and/or door frames directly affect the heat flow between the external and internal environments. Properties of single, double, or low-emissivity glass are analyzed in order to avoid excess solar gain and condensation.

description	U-value (W/m <sup>2</sup> ·K)
cement mortar	0.73
sand and gravel or stone aggregate	1.75
lightweight concrete block (10 cm)	0.08
hollow concrete block (hourdi = 20 cm)	0.20
glass-single pane	5.80
glass-double pane+6 mm air space	3.80

Examples of U-values

## Joints

Joints between the opaque and the transparent elements of the wall as well as joints between solid components and corners of walls are, if improperly designed, the source of problems that result in uncomfortable interiors.

## Limitations

The values for the thermal transmittance (U-value) of materials are the generic values presented in the Thermal Standards and are not values calculated on local materials.

The value for the transmittance through joints is considered to be the same, irrespective of the building components that constitute the wall assembly.

<sup>1</sup> These two parameters are addressed in the Thermal Standards document

<sup>2</sup> Thermal Standards document

## Effective Fenestration ratio

The **effective fenestration ratio (FR)**, which depends on the ratio of window to wall area, ratio of skylight to roof, shading coefficient for the glazing used and the architectural shading factor, affects the total solar radiation\* that enters the building divided by the total incident radiation.

$$FR = [ \sum (A_{wi} \times SC_{wi} \times ASF_{wi}) / \sum A_v ] + [ 2 \sum (A_{si} \times SC_{si}) / \sum A_h ]$$

**A<sub>wi</sub>** : Area of individual window (m<sup>2</sup>)

**SC<sub>wi</sub>** : Shading coefficient of the individual window (m<sup>2</sup>)

**ASF<sub>wi</sub>** : Architectural shading\* factor of the individual window

**A<sub>v</sub>** : Area of all vertical surfaces (opaque walls + windows) (m<sup>2</sup>)

**A<sub>si</sub>** : Area of individual skylight (m<sup>2</sup>)

**SC<sub>si</sub>** : Shading coefficient of the individual skylight

**A<sub>h</sub>** : Area of all horizontal surfaces (roofs + skylights) (m<sup>2</sup>)

effective fenestration ratio

### Limitations

Incompatibility of the fenestration ratio with current building practice.

### Thermal Time Constant (TTC)

Another element that defines the characteristics of a wall is the thermal mass which is the heat\* storage value of a structure.

Thermal mass\* is not a substitute for insulation. It stores and re-radiates heat\* while insulation stops heat flow\* into or out of the building.

The denser the material (less trapped air), the higher its thermal mass.

For example, concrete has high thermal mass, hollow concrete blocks have a lower thermal mass, and insulation has none.

The most important mathematical construct that enables us to understand the behavior of thermal mass is the thermal time constant of a building envelope. The thermal time constant represents the effective thermal capacity of the building and is defined by:

$$TTC = Q \times R$$

**Q**: Heat capacity (W) = thickness x specific heat x density

**R**: Resistance (°C/W·hr)

Thermal time constant

### Key issues

The thermal transmittance and the effective fenestration ratio are methods that quantify the impact that these building components and materials have on internal comfort conditions. They are thoroughly addressed in the Thermal Standards document. Moreover, their results are integrated in the simulations for comfort.

The thermal time constant is an additional parameter that is used to evaluate the thermal capacity of walls.



# Building Massing

Climatic characteristics are important to take into consideration when designing a building that relates to its context.

Two important architectural issues are: a building's mass and its skin. This chapter starts by highlighting the interaction between the building's massing and the two climatic parameters: solar radiation\* and air movement. Then the relationship of these two climatic parameters with the building skin is addressed.

## Form and solar radiation

The three dimensional aspect of the building has different repercussions on its behavior when examined with respect to solar radiation and wind movement.<sup>1</sup>

The compact rectangular solid (figure 6.3) is the basis for comparison of solid forms that have the same floor area ( $A$ ) but different envelope areas ( $EA$ ).

Analysis shows that although the cone has a smaller roof area, the total direct solar radiation reaching it is more than that reaching the other shapes due to the inclination of its vertical surfaces. The inclination of the roof and the walls with respect to the angle of the incident sun rays (figure 6.4) determines the quantity of solar radiation reaching the building. These considerations have a direct effect on the shape of a building depending on its context and the passive strategies that are considered.

Figure 6.5 illustrates how buildings relate to incident solar radiation in terms of orientation\*.<sup>2</sup>

The cosine law states that the amount of radiation received by a surface decreases as the angle with the normal increases.

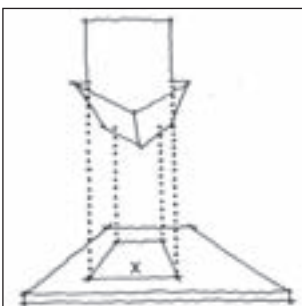


Figure 6.1: Cosine law 1

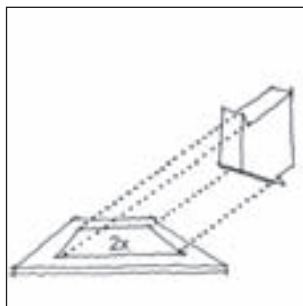


Figure 6.2: Cosine law 2<sup>3</sup>

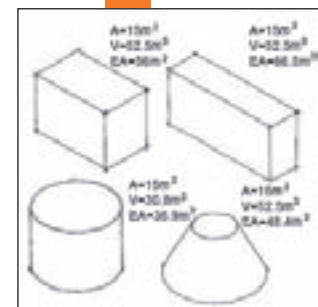


Figure 6.3: Envelope/volume ratio

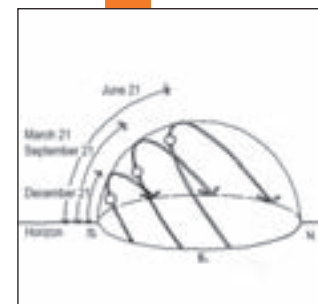


Figure 6.4: Seasonal sun path

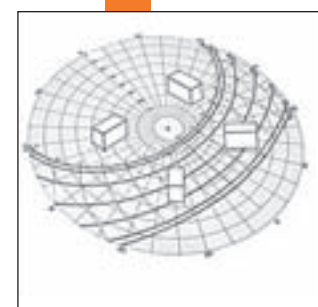


Figure 6.5: Orientation

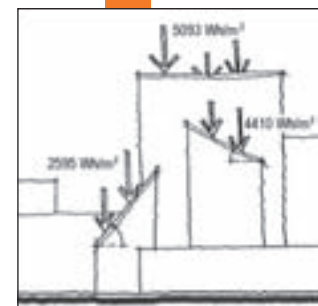


Figure 6.6: Solar radiation and slope

In Beirut<sup>4</sup>, the yearly average daily direct normal solar radiation is 5093 Whr/m<sup>2</sup>. Consequently, the amount of solar radiation received on a building depends on the angle of the plane receiving the radiation\*. (Figure 6.6)

Depending on the climate region, this free source of energy can be useful in winter, while its effect can be reduced in summer.

The question of what quantity of solar heat\* gain is to be absorbed or rejected, depends on the degree of heating and/or cooling strategies needed and studied during the design process.

<sup>1</sup> Markus, T., Morris, E., (1980) Buildings, Climate and Energy. Pitman. London

<sup>2</sup> Daniels, K. (1994) The Technology of Ecological Building. Birkhauser Basel

<sup>3</sup> Adaptation from Szokolý, S. (2004) Introduction to Architectural Science. Elsevier and Architectural Press. Amsterdam

<sup>4</sup> Climatic Zoning Study

The following figures<sup>1</sup> illustrate the sunpath diagrams for Lebanon.

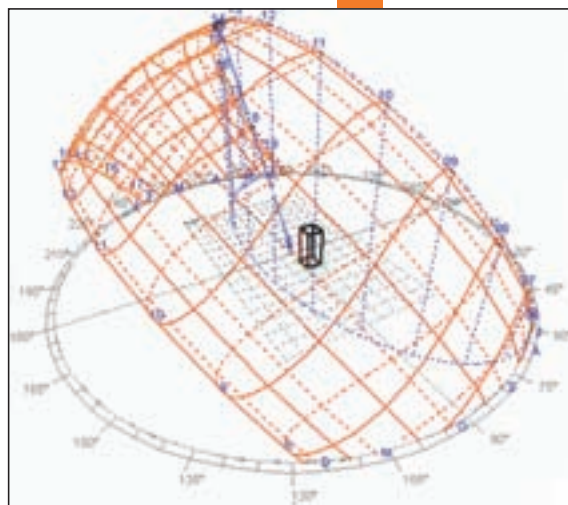


Figure 6.7: Summer season sun path

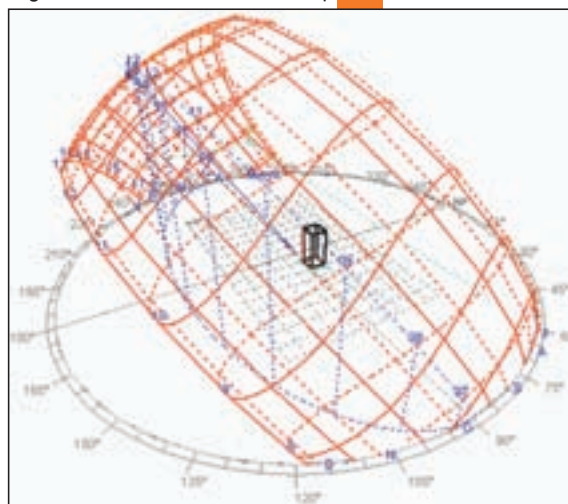


Figure 6.8: Mid-season sun path

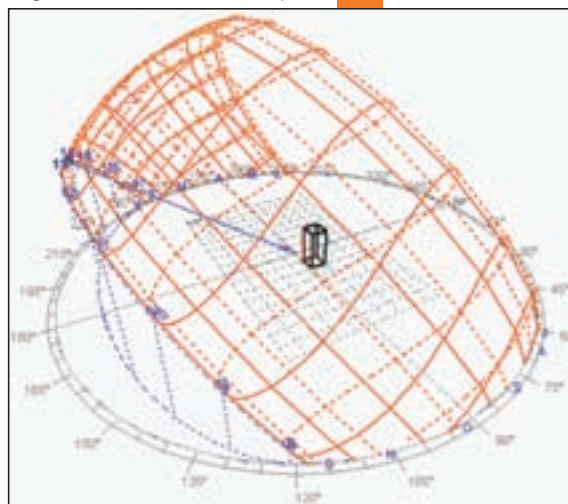


Figure 6.9: Winter season sun path<sup>1</sup>

The positions of buildings or other obstructions\* adjacent to a site result in overshadowing\*. This affects the amount and quality of sun reaching the site during different times of the day and year.

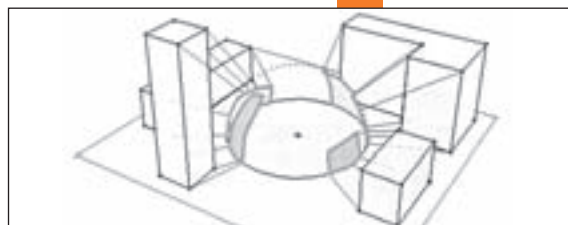


Figure 6.10: Overshadowing\*<sup>2</sup>

<sup>1</sup> Sunpath diagrams adapted from the Ecotect software  
<sup>2</sup> Dr. A. Marsh, Square One. www.squ1.com

### Form and air movement

Management of air movement can be an important tool for modifying site micro-climates. Vegetation, landscaping and massing of buildings, can control and modify the pattern of air movement. This helps in approaching comfortable temperatures\* in cold regions and making use of cooling breezes in warm and humid regions.

The shape, position and relation of the building to the prevailing wind directions can enhance natural ventilation during summer and mid-seasons by modifying the wind movement in the vicinity of the building.<sup>1</sup>

Figures 6.11, 6.12, and 6.13 show some examples of how the relationship between building form and wind direction can result in the redirection of air movement. This can influence wind movement within the building and consequently enhance natural ventilation, as shown in figures 6.14 and 6.15.

### Local context

The following brief description presents a general overview of the wind patterns in the different climatic regions.<sup>2</sup>

In the coastal region, the prevailing winds are from the south-west direction and are mostly moderate winds (6-10m/sec). Some mild winds (2-5m/sec) also arrive from the east.

In the mid-mountain region, the majority of the winds are from the west. Most of the time the moderate wind speed is about 6-10m/sec and can sometimes reach a velocity of 11-15m/sec.

In the high-mountain regions, the mild winds (2-5m/sec) come from the north-west. They can achieve a moderate speed of 6-10m/sec and can reach the speed of 11-15m/sec on some occasions.

In the inland regions, the main wind direction is from the south-west or north-east. The wind speed varies from mild to strong (11-15m/sec).

Very strong winds (above 16m/sec) occur in all regions but for rare time intervals.

Forms and shapes of roofs and openings of buildings can create more aerodynamic effects by increasing the airspeed and creating pressure difference. This pressure difference between opposite facades is an effective way to enhance natural ventilation and increase the thermal comfort in summer.<sup>3</sup>

The topology of the site has an impact on the wind speed. If the building is situated on the windward side of a slope, the wind velocity over the building will be greater. If the building is situated on the leeward side of a slope, a wind shadow will be created, resulting in reduced wind velocity.

Concerning the internal spaces of the buildings, ASHRAE guidelines recommend a maximal airspeed of 0.8m/sec in residential buildings, where no papers fly from desks, and the airspeed can be increased up to around 2m/sec.

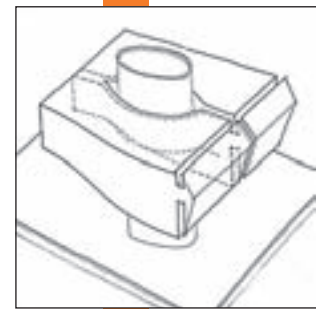


Figure 6.11: Wind movement and massing 1

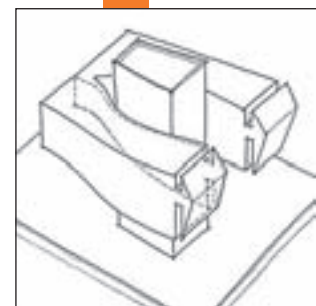


Figure 6.12: Wind movement and massing 2

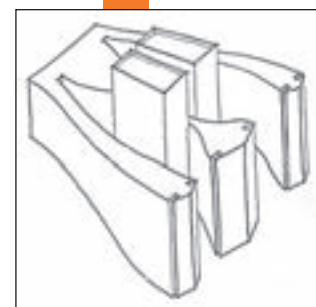


Figure 6.13 : Wind movement and massing 3

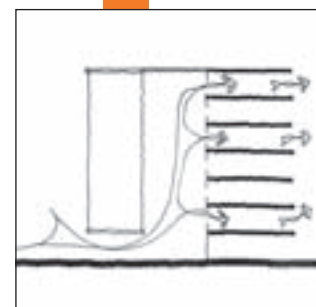


Figure 6.14: Wind movement and building 1

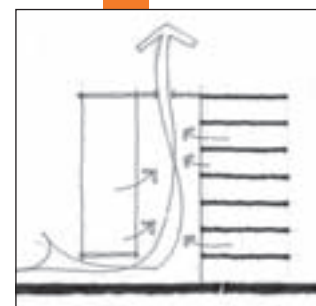


Figure 6.15: Wind movement and building 2

<sup>1</sup> Olgyay, V. (1963) Design with Climate. Princeton University Press. Princeton

<sup>2</sup> Atlas Climatique du Liban. (1969) Service Meteorologique du Liban.

<sup>3</sup> Moore, F. (1993) Environmental Control Systems. Mc Graw Hill. New York.

# Building Skin

## Skin and Solar Radiation\*

The function of the skin of a building is to improve comfort conditions in the interior environment by protecting from heat\* and controlling, light, sound, ventilation and air quality.<sup>1</sup>

The building skin regulates the flow of heat\* into the building; it consists of the roof, the external walls, the window openings as well as the slab on the ground and the walls in contact with the earth backfill. In buildings with pilotis, the slabs above and below pilotis are considered as additional components of the envelope.<sup>2</sup>

There are two ways in which buildings are subjected to heat\* gains due to solar radiation:

- The openings allow solar radiation to enter directly into a space. The heat gain effect is achieved when the internal surfaces absorb the radiation.
- The external building skin absorbs solar radiation and transfers it to its internal surface.

Buildings are also subjected to heat loss as follows:

Solar radiation gained and stored in a building may be released back to the atmosphere. This happens when the external temperature\* is cooler than that of the building surfaces. This can occur at any time but is more likely to occur during the night.

## Roof

The roof is the component that is the most exposed to solar radiation. Therefore, its protection from sun rays during summer to minimize heat gain, and its exposure to the sun rays in winter to maximize heat gain, are issues to be addressed during the successive design stages.

The main parameters that affect the heat flow\* through a roof are:

- Roof forms: flat, arched, domed or pitched;<sup>3</sup>
- Composite construction with light weight roof and dense ceiling separated with air space;
- Heavy weight construction;
- Air movement over roof surface;
- Orientation\* of slope towards prevailing winds;
- Insulation;
- Roof color and reflectivity.

## Walls

Walls provide protection from climatic elements such as heat, rain, wind, and dust. Depending on the orientation\* of the wall, the exposure to solar radiation varies considerably. North-facing walls do not receive direct solar radiation whereas south-facing walls receive a high intensity of solar radiation. East and west-facing walls receive direct solar radiation only for part of the day. The form of the building can be designed to reduce or increase the surfaces of walls that are subject to the incidence of solar radiation.

Measures for architectural shading\* of walls include:

- Louvers;
- Double skin\* wall with a gap between skins ventilated by the stack effect through openings at the bottom and top. The top opening is regulated to control air flow as required in different seasons; The gap between the two wall layers can be controlled to allow for different ventilation requirements
- Vegetation.



Figure 6.16: Solar radiation on a building 1

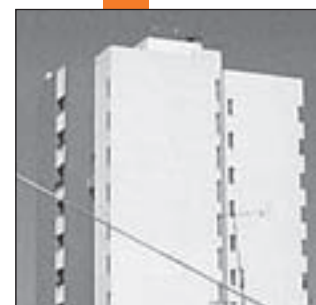


Figure 6.17: Solar radiation on a building 2



Figure 6.18: Solar radiation on a building 3



Figure 6.19: Solar radiation on a building 4

<sup>1</sup> Wigginton, M., Harris, J. (2002) Intelligent Skins. Butterworth. Oxford.

<sup>2</sup> Koch-Nielsen, H. (2002) Stay Cool. James & James, London.

<sup>3</sup> Konya, A. (1980) Design Primer for Hot Climates. The Architectural Press Ltd. London

### The openings

In general, heat\* is transmitted through windows at a higher rate than through opaque wall components.<sup>1</sup> This depends on the quality of glazing and the infiltration through the joints. The window size, glazing (with appropriate U-value), shading coefficient\*, and adequate shading devices affect heat transmission and air infiltration. Proper detailing, construction methods and installation of window frames also influence their performance.

### Skin and Wind Movement

Natural air movement in buildings relies substantially on the building skin. Some key issues considered when addressing this point are internal air hygiene and the correct amount of ventilation needed per season.

In general, natural ventilation can be achieved in spaces with depths not exceeding 6m (Figure 6.20). If a space is deeper (up to 10m), then cross ventilation can provide for natural air movement (Figure 6.21). This would require openings on opposite sides of a space. The effectiveness of natural ventilation can be increased to provide for the occupants' comfort when operable elements are placed in the building skin.<sup>2</sup>

### Double skin\*

The system of double skin\* is referred to when a second envelope is added to the building skin. In general, this results in having two independent skins with a space in between. The dimension of this space varies in order to account for different shading devices, maintenance walkways, or environmental air spaces.<sup>3</sup>

### Key issues

The main parameters of massing and skin can have a strong influence on building design. When these parameters are integrated in the early stages of the design process, they can result in improvements in thermal comfort.

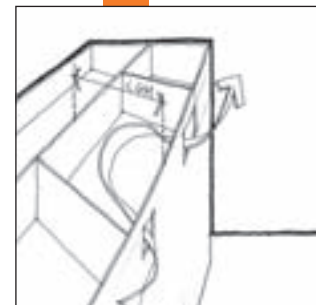


Figure 6.20: Single sided natural ventilation

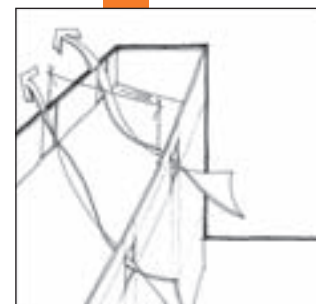


Figure 6.21: Natural cross ventilation

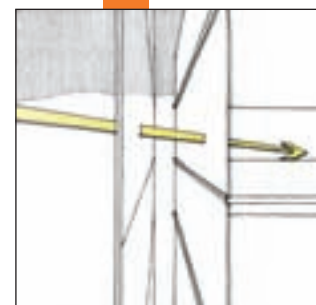


Figure 6.22: Double skin\*: winter

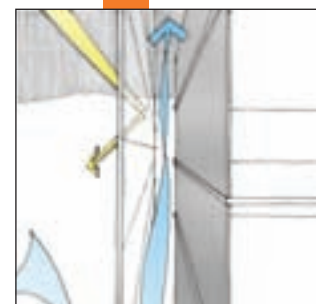


Figure 6.23: Double skin\*: summer

<sup>1</sup> Evans, M. (1980) Housing, Climate and Comfort. The Architectural Press, London.

<sup>2</sup> Schittich, C. (2001), Building Skins, Birkhauser, Munich.

<sup>3</sup> Wigginton, M., Harris, J. (2002), Intelligent Skins. Architectural Press, Oxford.



# General factors

Several factors that influence the perception of comfort in a building by controlling the energy balance through its envelope are:

## Heat flow\*

The amount of heat\* flowing through a building depends mainly on the skin's thermal mass\* and thermal transmittance\*. Insulating materials have a direct impact on transmittance and are used on roofs, external walls and ground floor slabs of buildings to ensure protection against outdoor conditions.<sup>1</sup> Possible configurations are:

a- Building with external mass, insulated internally.

The diagrams illustrate how insulation behaves in different seasons.

Figure 7.1 *Summer season*: The heat from the sun penetrates through the external wall and is strongly resisted by the insulation.

This results in reduced fluctuations of the internal temperatures\*.

On the other hand, any heat\* generated indoors will not be dissipated out through the wall.

Figure 7.2 *Winter season*: The internal temperature remains stable because the space is surrounded by insulation. This maintains a comfortable environment and reduces energy consumption.

Here the thermal time constant is low. The mass will store energy and release it mostly to the exterior. This is suitable for buildings in summer where natural ventilation is possible and diurnal range\* is not high.

b- Building with internal exposed mass, insulated externally.

Figure 7.3 *Summer season*: This situation prevents the heat from reaching the wall or roof components. On the other hand, excess heat generated indoors can be absorbed into the wall.

Figure 7.4 *Winter season*: In this case, achieving the internal temperature of comfort (by using heating devices) would take more time since some generated heat would be absorbed by the wall. The effect is that once the heating mode is turned off, the heat\* radiated back from the walls to the space will provide some warmth.

When the building is ventilated at night and closed during the day, it can absorb the heat in the mass with a relatively small rise in temperature. This type is suitable for dry hot weather.

c- Figure 7.5: Building with insulation between two layers of thermal mass. In local methods of construction insulation is normally placed in a cavity between two walls. Therefore, the composition of the wall, the choice of the material and the dimension of its individual components can be defined to improve the performance of the envelope during the different seasons. The thermal time constant is mostly a function of the interior mass and the amount of insulation.

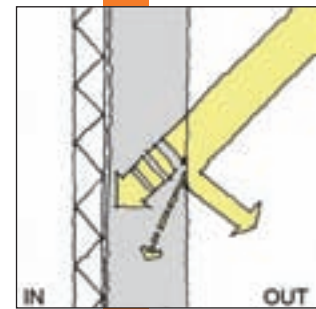


Figure 7.1: Internal insulation: summer

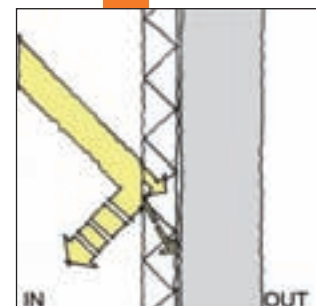


Figure 7.2: Internal insulation: winter

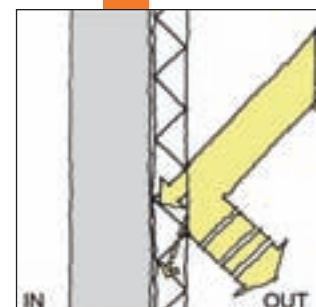


Figure 7.3: External insulation: summer

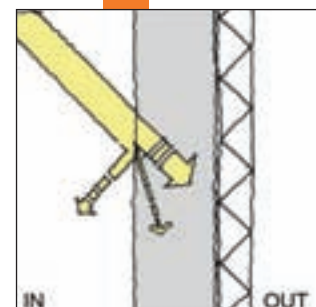


Figure 7.4: External insulation: winter

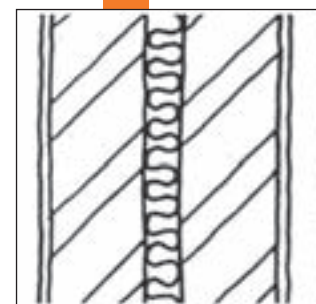


Figure 7.5: Core insulation

<sup>1</sup> Thomas, R., Fordham, M. (1996) Environmental Design. E & FN SPON. London

### Envelope to area ratio

This is the ratio of the total envelope area to the total floor area.

The higher the ratio, the more contact between the building and the outside, resulting in higher heat\* loss/gain. The more compact the building, the lower the ratio.<sup>1</sup>

Reducing the external surface area through which heat is exchanged also reduces heating or cooling energy. For example, external heat gains and losses are less for spherical buildings than for other shapes of equal volume. However, a low ratio may result in the decrease of the window to wall ratio. This may increase the need for artificial lighting and hence energy consumption and internal heat\* gain.

### Thermal mass\*

Higher thermal mass\* improves the characteristics of a wall by lowering the propagation of heat through it.<sup>2</sup>

With higher thermal mass, the comfort zone extends to include lower outdoor temperatures\* in winter and higher outdoor temperatures in summer.

A high thermal time constant indicates a high thermal inertia of the building and results in a substantial decrease of the interior temperature swings.

### Window - wall ratio

This defines the proportion of openings as compared to the overall opaque wall area. Other than the size of the window, the following parameters affect the condition of internal comfort:

- 1- The shading coefficient\* of the glass
- 2- The shading device (architectural shading\* factor)

Figures 7.7, 7.8 and 7.9 illustrate the relationships that exist between these parameters.

### Surface condensation

In general, the cold winter external temperatures result in cold indoor surface temperatures.<sup>3</sup> As a result, the moisture generated by the indoor activities of the occupants (breathing, smoking, and cooking) condenses on these cold surfaces at the corners of rooms and around window frames. Such condensation causes mould growth on the wall which is both unsightly and unhealthy.

The location of vapor barriers and the provision of natural ventilation (backed up with mechanical ventilation) should be studied in order to eliminate the problem of moisture migration and condensation.

### Interstitial condensation

This happens when moisture within a double wall condenses. The fact that it is not visible makes it particularly harmful. Consequently, a wall should be studied to totally avoid this kind of condensation.

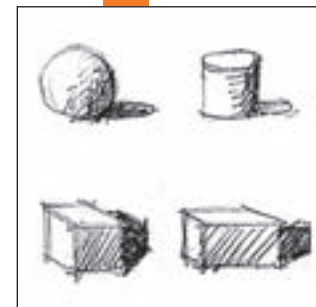


Figure 7.6: Envelope areas to floor area ratio

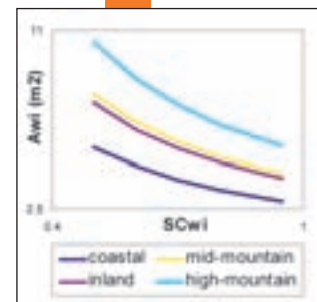


Figure 7.7: Shading coefficient and window area

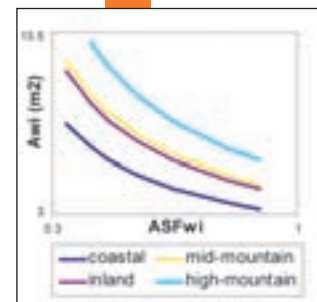


Figure 7.8: Shading coefficient and window area

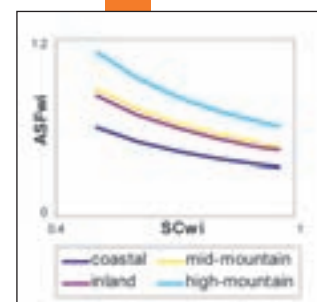


Figure 7.9: Architectural shading factor and shading coefficient

<sup>1</sup> Daniels, K. (1994) The Technology of Ecological Building. Birkhauser. Basel.

<sup>2</sup> Daniels, K. (1994) The Technology of Ecological Building. Birkhauser. Basel.

<sup>3</sup> Evans, M. (1980) Housing, Climate and Comfort. The Architectural Press. London.

### Thermal bridges

Thermal bridges are areas in building components where the heat flow\* is higher than in adjacent areas due to the presence of high conductivity materials (such as metals).<sup>1</sup> Higher heat flow through thermal bridges reduces internal surface temperatures\*,<sup>2</sup> thus creating discomfort and encouraging mould growth due to condensation.

### Infiltration

Infiltration is uncontrolled air movement through cracks and openings in the building skin. When excessive, it is called air-leakage which can become a serious problem accounting for up to 50% of heat\* loss or gain in a building. If not controlled, especially in winter, the air temperature\* drops to uncomfortable levels.<sup>3</sup>

## General passive strategies

The manipulation of the items discussed before independently or in combination helps in devising strategies which modify the comfort zone.

The following illustrations show the extent to which a particular comfort zone can be modified by using passive strategies<sup>4</sup>. Since these strategies are interventions on an architectural level, they affect the perception of comfort inside a space.

Figure 7.10: If the natural ventilation strategy is integrated in the design scheme, then the comfort zone would include areas of higher temperature\*. In other words, a person would still be comfortable at higher temperatures (i.e. 28°C) if the space he is in is ventilated.

In Lebanon, during the summer, a good naturally ventilated building can push the comfort zone up to a temperature of 32°C and a relative humidity\* of 90%. For example, an extra 4-5°C in dry bulb temperature and an increase of 10%-20% in relative humidity\* can become bearable. In the coastal region of Lebanon, a dry bulb temperature\* of 32°C and a relative humidity of 55%-60% can be felt as pleasant and comfortable if brushed by an air velocity of around 0.5m/sec. With well designed natural ventilation, the comfort zone can be enlarged in humid and hot weather by increasing the wind velocity.

Figure 7.11: The use of the thermal mass\* strategy in summer considerably improves comfort.

Figure 7.12: The use of the thermal mass\* strategy in winter also improves indoor comfort condition.<sup>5</sup>

Figure 7.13: Passive solar heating during the winter season is another strategy that, if accounted for during the design stages, can result in more comfortable spaces.

### Key issues

The passive design strategies mentioned above define the basic approaches that can be adopted when designing a climate responsive building.

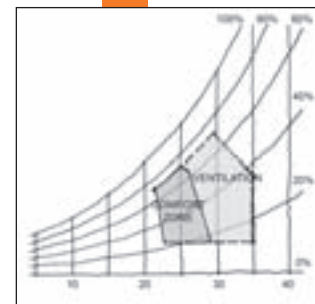


Figure 7.10: Natural ventilation strategies

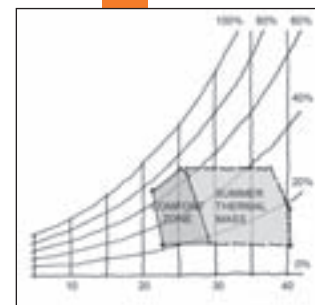


Figure 7.11: Summer thermal mass strategy

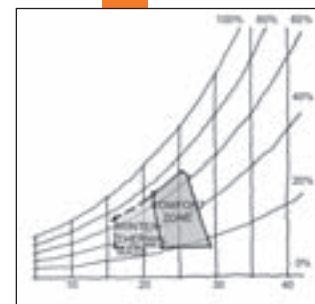


Figure 7.12: Winter thermal mass strategy

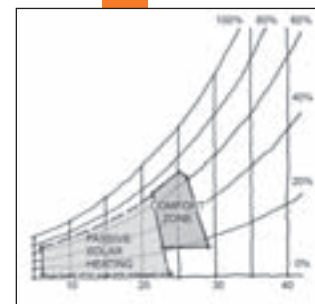


Figure 7.13: Passive solar heating strategy

<sup>1</sup> Gauson - Muller, D. (2002) Sustainable Architecture and Urbanism. Birkhauser. Basel.

<sup>2</sup> Givoni, B., (1976) Man, Climate and Architecture. Applied Sciences Publishers Ltd. London

<sup>3</sup> Borer, P., Harris, C. (1998) The Whole House Book. The Centre for Alternative Technology Publications. UK

<sup>4</sup> Givoni, B. (1998), Climate Considerations in Building and Urban Design. Van Nostrand Reinhold. New York

<sup>5</sup> Discussed in Chapter 8: Principles of Passive Concepts in the Different Climate Regions.

<sup>6</sup> Figures 7.10 to 7.13 are adapted from Givoni

**8**

## **Principles of passive concepts in the different climate regions**

### Thermal mass\*

During a building's design process, thermal mass is studied in conjunction with several building parameters including function, occupancy patterns, typology and materials.<sup>1</sup>

Figures 8.2 to 8.5 show the effect that thermal mass (Figure 8.3) and insulation (Figure 8.4) have on a hypothetical wall that has no thermal capacity (Figure 8.2).

The combined effect is illustrated in Figure 8.5.

### Multi-level residential buildings

Residential buildings are inhabited day and night, and most often, are built with concrete and masonry.

In summer, during the day, the thermal mass of the external walls absorbs heat\* from the sun, keeping the interior spaces comfortable.

At night, the heat\* in the external walls will dissipate to the cooler outside environment. The same cycle is repeated on a daily basis.

Figure 8.1 illustrates the internal temperature\* fluctuations resulting from the thermal mass of a wall.

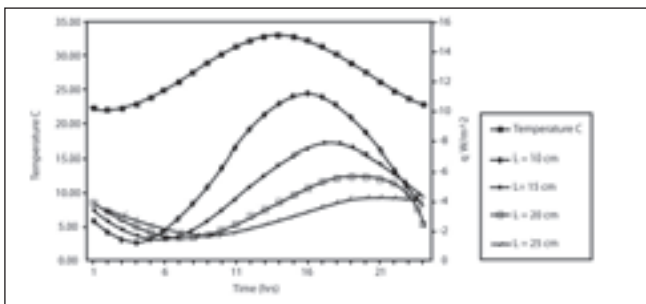


Figure 8.1: Hourly thermal gains through a wall versus selected concrete wall thicknesses on a typical day in July<sup>2</sup>

In winter, due to the low sun angle, the internal thermal mass\* stores the heat from the sun during daytime and releases it to the interiors at night when the inhabitants are occupying the space. This results in more comfortable interiors and helps reduce energy consumption resulting from the use of artificial heating devices.

### Multi level office buildings

Office buildings are usually occupied for a part of the day and their methods of construction vary from masonry to glass curtain wall systems.

In summer, the masonry building behaves similarly to the residential building. An important factor to consider here is that the thermal mass also helps by absorbing the heat generated from the appliances used inside, such as computer monitors, hard drives, artificial lighting systems and others. In the afternoon and evening, when the occupants leave the building, ventilating the high mass masonry components can help purge out the heat.

In summer, the protection of the thermal mass from the summer sun by shading and insulation is necessary.

Lightweight construction, on the other hand, responds quickly to cooling breezes.

In winter, the heat stored in the thermal mass during the day will be released at night to preheat the interiors. Consequently, when the occupants arrive in the morning, they may have to heat less in order to achieve comfort.



Figure 8.2: Wall and heat flow

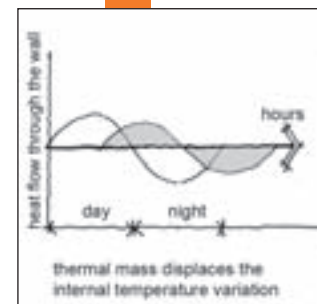


Figure 8.3: Thermal mass and heat flow

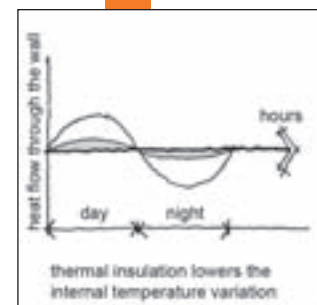


Figure 8.4: Thermal insulation and heat flow

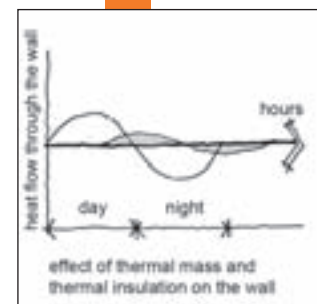


Figure 8.5: Combined heat flow effect<sup>3</sup>

<sup>1</sup> Baker, N., Steemers, K. (2000) Energy and Environment in Architecture. E & FN SPON. London.

<sup>2</sup> Ghaddar, N., Bsat, A. International Journal of Energy Research 22, 523-546 (1998)

<sup>3</sup> Figures 8.2 to 8.5 are adapted from Goulding, J., Owen Lewis, J., Steemers, T. (1993) Energy Conscious Design. Batsford. UK.

### Passive solar heat\* gain

Passive solar heat gain is achieved when thermal energy flows by natural radiation\*, conduction\*, and convection\*. The integration of these methods of heat flow\* into a building is essential to ensure the efficiency of this strategy.

With passive solar heating, the comfort zone extends to include lower temperatures\*. This strategy becomes more applicable as the altitude\* increases. In the high-mountain region, making use of the sun energy in the cold season helps achieve thermal comfort for most months of the year. In the coastal region, this strategy could be used for the fewer cold winter months.

Figure 8.7: Increasing the direct radiation transmitted through a window and incident on a person by about 100W would cause an apparent increase in the operative temperature\* of approximately 2°C.

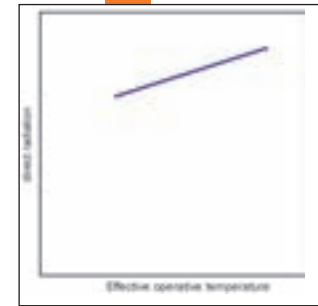


Figure 8.7: Direct radiation and effective operative temperature

### Ventilation and air movement

Air movement resulting from natural ventilation is due to air pressure differences generated by temperature or wind. Air movement improves the comfort conditions for higher temperatures and higher relative humidities\*. This strategy can affect buildings in several ways:

Outside the buildings: A thorough study of a particular site usually results in defining interesting options for this strategy. For example, sites located on valley flanks can benefit from wind flow patterns to enhance potential cooling effects.

Inside the buildings: In the summer season, a natural breeze passing through a living room can create a comfortable sensation without relying on artificial cooling systems.

In the winter season, air movement reduces the risk of condensation when there is an increase in indoor humidity\* due to cooking, having a bath, etc. The lack of proper ventilation results in the formation of mould which is unhealthy and can harm building materials.

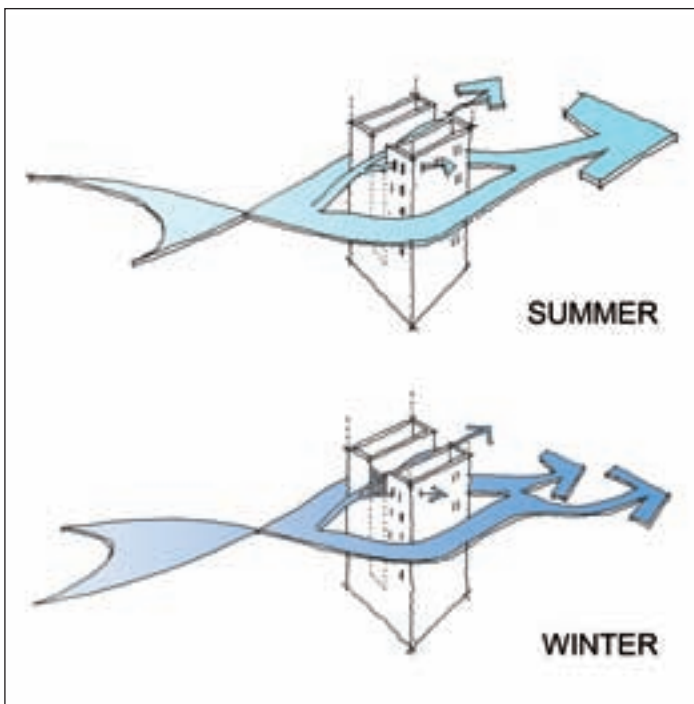


Figure 8.6: Natural ventilation and seasons

## Shading

Shading of walls and roofs minimizes direct solar incidence on them. Although shading devices are mostly needed in summer, they can allow sun rays through during winter. Shading by vegetation (vines) could reduce the amount of heat\* gain during summer while achieving sun exposure during winter.<sup>1</sup> Some parameters that help reduce heat impact are:

- Inclined roof tile covers, especially if the area under the slope is ventilated;
- Insulation of the roof slab (that complies with the recommended values suggested in the Thermal Standards) helps decrease heat gain in summer and heat loss in winter;
- Color of the roof strongly affects the amount of reflected and absorbed heat. Dark, matt or textured surfaces absorb and re-radiate more energy than light, smooth, and reflective surfaces.

### Designing a shading device

The sunpath diagram<sup>2</sup> is a helpful tool when designing a shading device. It allows the understanding of how the sun moves on a daily, monthly and yearly basis. Sun path diagrams exist for each latitude.

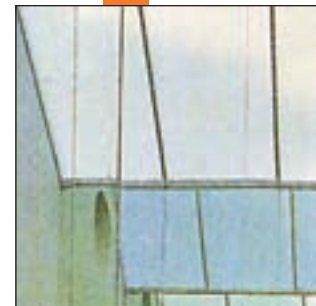


Figure 8.8: Shading device 1

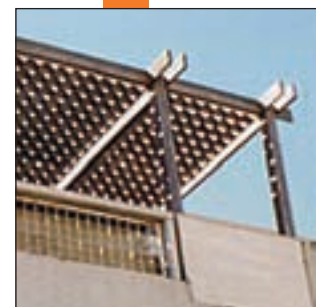


Figure 8.9: Shading device 2



Figure 8.10: Shading device 3<sup>3</sup>

<sup>1</sup> Givoni, B. (1976) Man, Climate and Architecture. Applied Science Publishers. London.

<sup>2</sup> The use of a sunpath diagram is explained in Appendix 1

<sup>3</sup> Saliba, R. (1998) Beirut 1920-1940 Domestic Architecture Between Tradition and Modernity. The Order of Engineers and Architects. Beirut.

## Coastal region

The following charts illustrate the winter, mid-season and summer comfort zones as well as the passive design strategies that can be developed for each season.

The issues of thermal transmittance\* and effective fenestration ratio are further elaborated later.

### Winter season

With higher thermal mass\*, temperatures\* as low as 18-19°C can be included in the comfort zone.

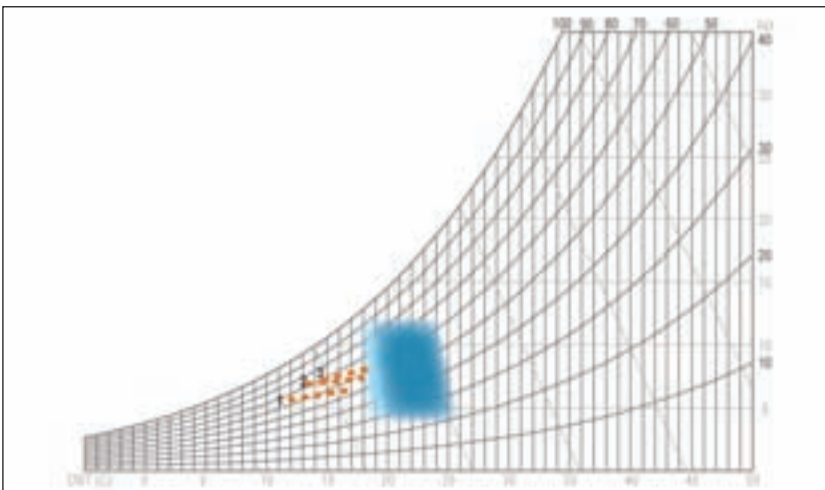


Figure 8.11: Coastal region: winter season thermal mass

Solar heat\* gain can provide comfort for temperatures as low as 8-9°C.

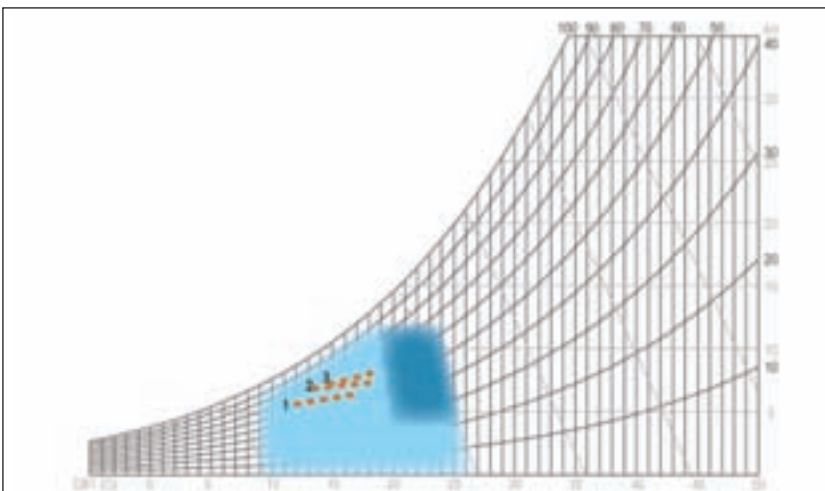


Figure 8.12: Coastal region: winter season solar heat gain

*Mid-season*

Air movement improves the comfort conditions when the temperature\* ranges from around 23°C to 35°C.

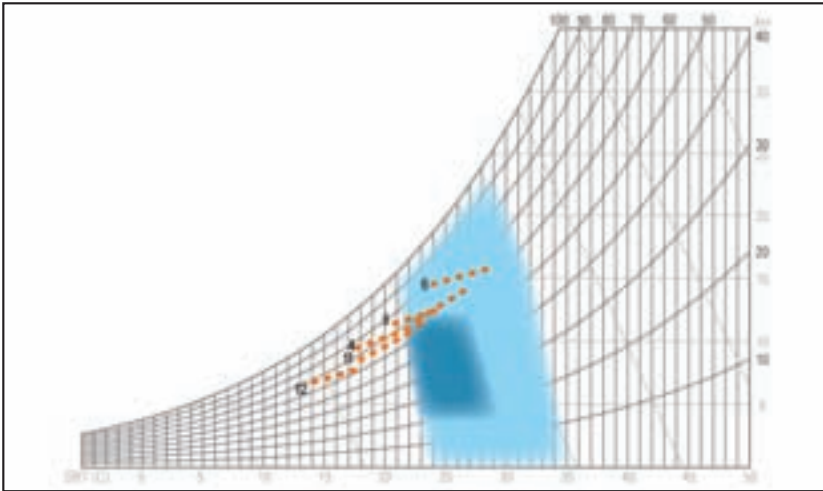


Figure 8.13: Coastal region: mid season air movement

*Summer season*

Thermal mass\* can improve the comfort conditions for the summer season except for temperatures above 33-34°C.

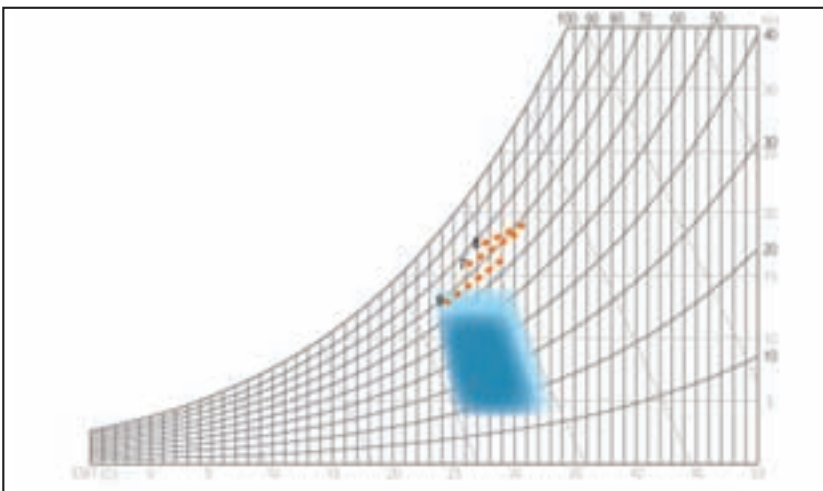


Figure 8.14: Coastal region: summer season thermal mass

Air movement improves the comfort conditions when the temperature ranges from around 25°C to 38°C.

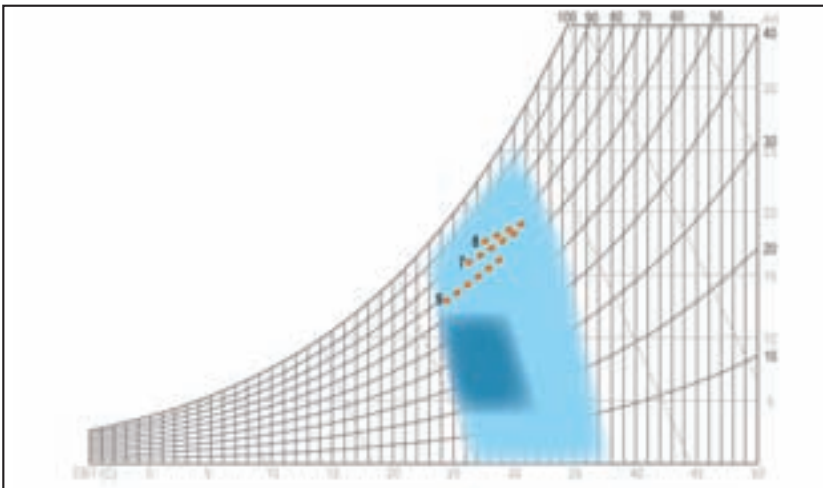


Figure 8.15: Coastal region:summer season air movement

**Thermal transmittance\***

Figures 8.18 and 8.19 illustrate the relation between the U-value of a wall and its internal surface temperature\*, in residential and office buildings, respectively. In the summer season, as the U-value increases (has less resistance to heat flow\*), the internal surface temperature tends to increase resulting in a less comfortable sensation.

Figures 8.20 and 8.21 show the relation between the U-value of a roof and its internal surface temperature, in residential and office buildings, respectively.

The trends shown in the figures, and the information provided in the Thermal Standards, propose U-values ranging from 0.6 W/m<sup>2</sup>°C to 1.6 W/m<sup>2</sup>°C that are applicable in this region. Obtaining a wall's U-value within that range can be achieved by using different layers of building materials. Walls with the same U-value will have different thermal performances depending on their thermal time constants. A simulation in this region is based on a wall that is built with the following materials (Figures 8.16 and 8.17):

- 2 cm plaster: R=0.025 m<sup>2</sup>K/W
- 15 cm concrete masonry unit: R=0.08 m<sup>2</sup>K/W
- 4 cm rigid insulation: R=0.71 m<sup>2</sup>K/W
- 2 cm internal plaster and paint: R=0.025 m<sup>2</sup>K/W

The analysis of the temperature fluctuations and the moisture migration within the wall shows that there is a problem of condensation within the wall. Hence, this wall does not represent an appropriate solution for this region. Its design should be reconsidered by modifying the dimensions and properties of the materials to avoid this problem.

This wall has a thermal time constant of 12.38.<sup>1</sup>

This value is indicative and may be modified depending on the impact that the thermal mass strategy has with respect to other passive strategies.

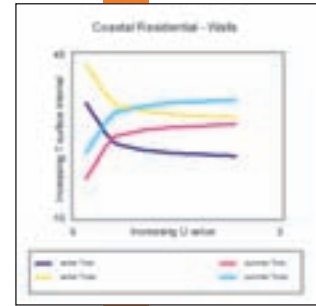


Figure 8.18: Coastal region: residential wall

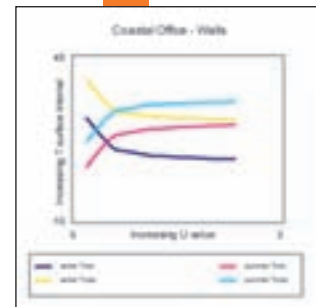


Figure 8.19: Coastal region: office wall

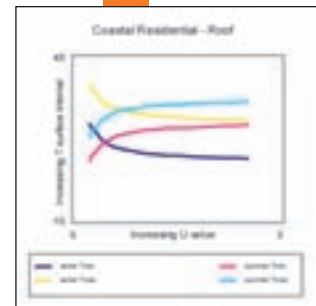


Figure 8.20: Coastal region: residential roof

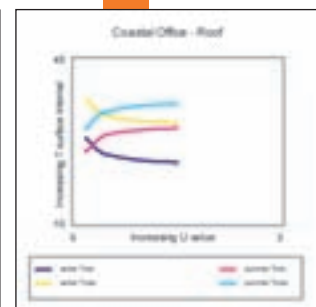


Figure 8.21: Coastal region: office roof

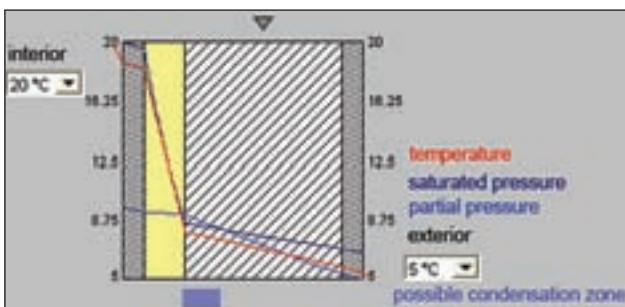


Figure 8.16: Coastal region: temperature fluctuations and moisture migration

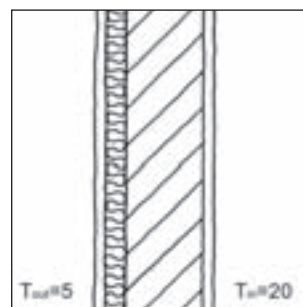


Figure 8.17: Coastal region: simulated wall

**Effective fenestration ratio**

A simulation in this region is based on a window that has the following characteristics: SC = 0.7

ASF<sub>w</sub> = 0.72

FR = 0.13

The interaction of these parameters is illustrated in Figure 8.22.

**Case study**

In the following case study, two of the three parameters, namely the shading coefficient\* (SC) and the architectural shading\* factor (ASF) are given a constant value of 0.7 and 0.72 respectively. The third parameter, the opening size, differs according to the climatic region. The SC of 0.7 is a characteristic of the glass panel. The ASF of 0.72 is the value for an overhang having a depth of 90 cm. In order to conform with the values required in the Thermal Standards for the effective fenestration ratio, the opening would have a width of 1.76 m for a constant height of 2.2 m.

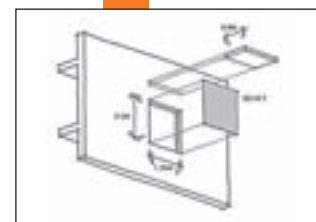


Figure 8.22: Case study: window opening in the coastal region

<sup>1</sup> Application of TTC= Q x R (refer to page 32)

The wall and window parameters considered on the previous page, are accounted for to yield the mean radiant temperature\* ( $T_{mrt} = (\sum T_i A_i) / A_T$ ). Then, the  $T_{mrt}$  and other parameters are defined in order to simulate the internal operative temperature\*.

$$T_e = (h_r \times T_{mrt} + h_c T_{ai} + \alpha_s (q_d + q_b/4)) / (h_r + h_c)$$

The simulation illustrates the different temperatures\* experienced depending on whether a person is exposed to the sunrays or standing in the shade. Figure 8.23 shows these temperatures with respect to the external temperature.

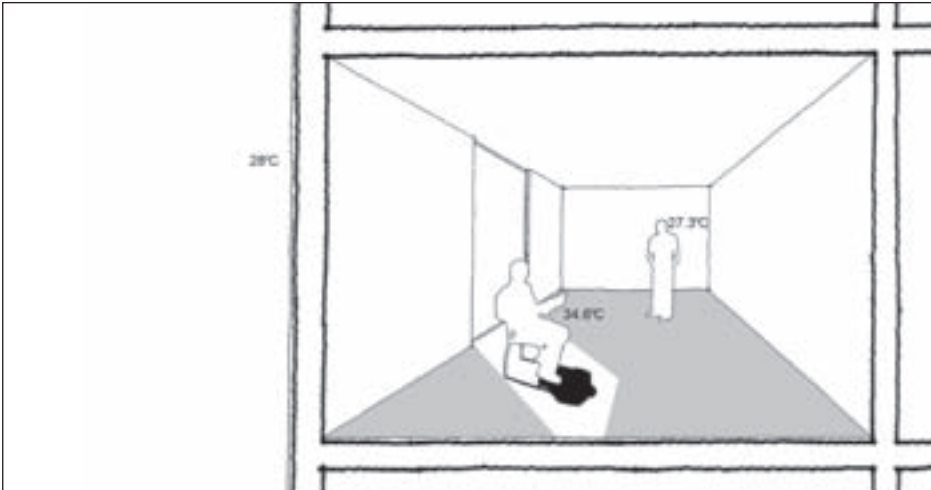


Figure 8.23: Coastal region: internal operative temperature

The introduction of natural ventilation improves the internal temperature as shown in Figure 8.24. Depending on its speed, wind movement can affect the sensation of comfort inside a space.

$$T_{res} = (T_{mrt} + T_{air} \times \sqrt{(10V)}) / (1 + \sqrt{(10V)})$$

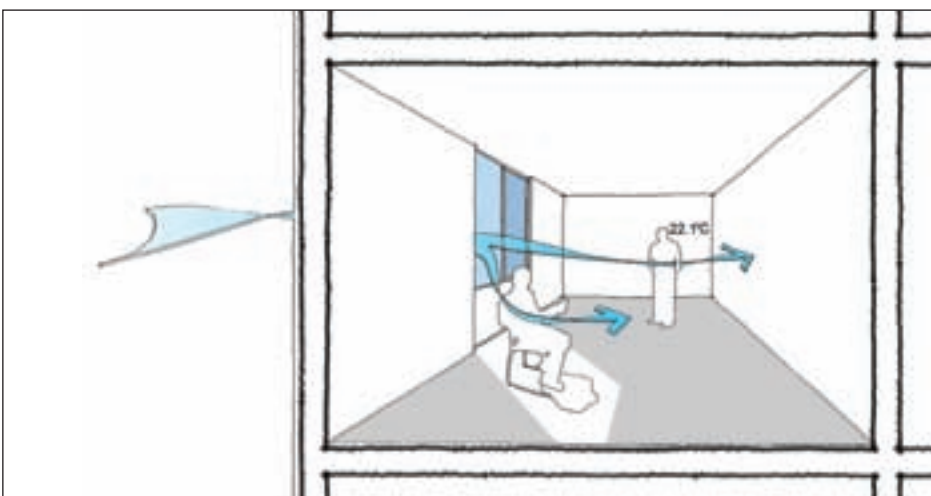


Figure 8.24: Coastal region: internal temperature with natural ventilation

Introducing a deep shading device on the previously simulated wall significantly reduces the heat\* entering the space and results in decreasing the internal temperature\* from about 34.6°C to 29.1°C as shown in Figures 8.25 and 8.26.

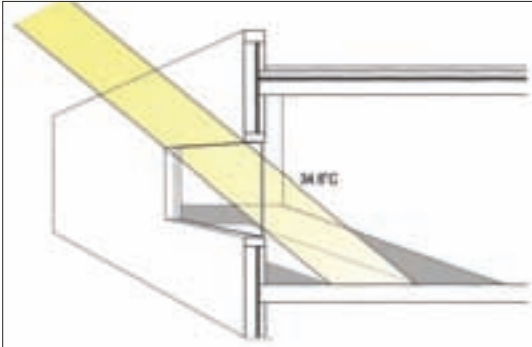


Figure 8.25: Coastal region: simulation

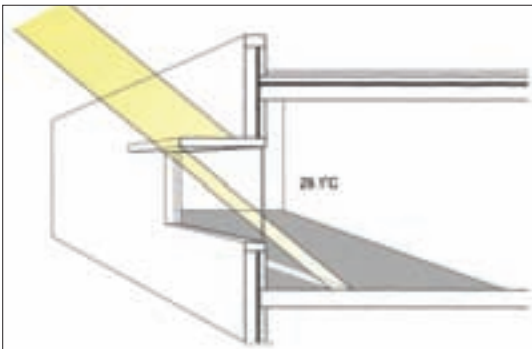


Figure 8.26: Coastal region: effect of a shading device

The majority of buildings in this coastal region accommodate residential or office functions. This section discusses several strategies applicable to the office typology while the residential typology is elaborated on in the mid-mountain region (pages 57-58).

The main concern in this region is to minimize artificial cooling requirements during a considerable part of the year. Consequently, integrating the following strategies may enhance the building's response to climate and improve thermal comfort. Issues to be considered are:

#### **Layout, orientation and shading**

Building orientation may reduce exposure to the low sun angles on the east and west facing elevations. Due to the users' occupancy patterns in an office building (early morning to early or mid afternoon) the east sun may have more impact on internal space than the west sun. In summer, this results in overheating. In winter, this may provide solar gain that can be used to heat the space.

Elongating the building along the east-west axis maximizes the south-facing elevation. When the sun is at the south, its angle is high, therefore, depending on the season, the interior spaces can be easily protected from the sun rays by using horizontal shading devices.

The integration of these shading devices is a strategy that can help achieve more comfort in the interior space while relying less on artificial cooling.

There are numerous ways of designing shading devices to fit within an architectural concept. Figure 8.26 illustrates how adding a horizontal overhang can cause internal temperature\* variations.

Moreover, other devices such as trellises or deciduous trees can be used for shading in summer.

**Air movement**

Heat\* is generated in office buildings due to computers, interior lighting fixtures, and other appliances. Consequently, natural wind movement can be used to dissipate the heat given off by these systems and by the occupants.

Buildings may be positioned to benefit from the summer prevailing wind directions. Narrow building shapes allow for increased natural ventilation as opposed to deep buildings. Operable windows allow for natural ventilation and ceiling fans offer additional air movement.

Location and distances between openings may enhance single sided or cross natural ventilation. In winter, protecting the openings from prevailing northern cold winds helps reduce heat loss from the interior space to the outdoors.

**Building skin****Opaque Components**

External walls may have a low thermal time constant due to the low diurnal range\* in this region. Defining the proper thermal mass\* requirements results from studying numerous parameters including external temperature\* swings, the materials used, the occupancy patterns of the users and the comfort level required. On the other hand, internal walls and slabs with a high thermal time constant may reduce internal temperature\* variations by absorbing the heat gain resulting from the incoming sun rays, the appliances, and the users inside the space.

**Transparent Components**

Although smaller opening sizes minimize solar heat gain, day-lighting considerations for office use may require otherwise.

The designer maintains design flexibility if opening size is studied in conjunction with the physical properties of the window materials (U-value, shading coefficient\*, shading device, etc.).

**Atria**

Integrating this element can be beneficial to enhance comfort and provide better day-lighting.

The position of the atrium (central or peripheral) in a building affects its efficiency for cooling or heating. In summer a shaded and naturally ventilated atrium may enhance air movement in the spaces surrounding it. In winter, heating the space of the atrium may serve to dissipate warm air to the surrounding indoor spaces.

**Skylights**

Properly oriented glazed skylights may improve day-lighting. Their shading is necessary to prevent overheating.

## Mid-mountain region

The charts show the winter, mid-season, and summer comfort zones as well as the passive design strategies that can be developed for each season.

The issues of thermal transmittance\* and effective fenestration ratio are further elaborated later.

### Winter season

With higher thermal mass\*, temperatures\* as low as 12-13°C can be included in the comfort zone.

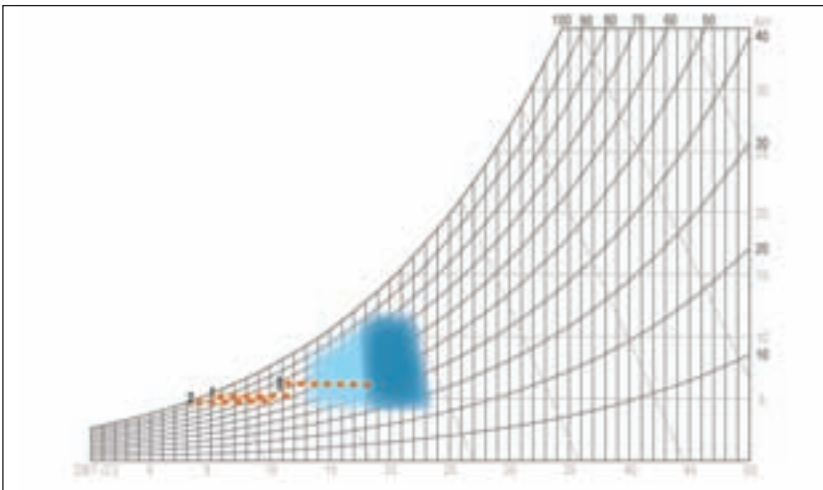


Figure 8.27: Mid-mountain region: winter season thermal mass

Solar heat\* gain can improve the comfort for temperatures as low as 6-7°C.

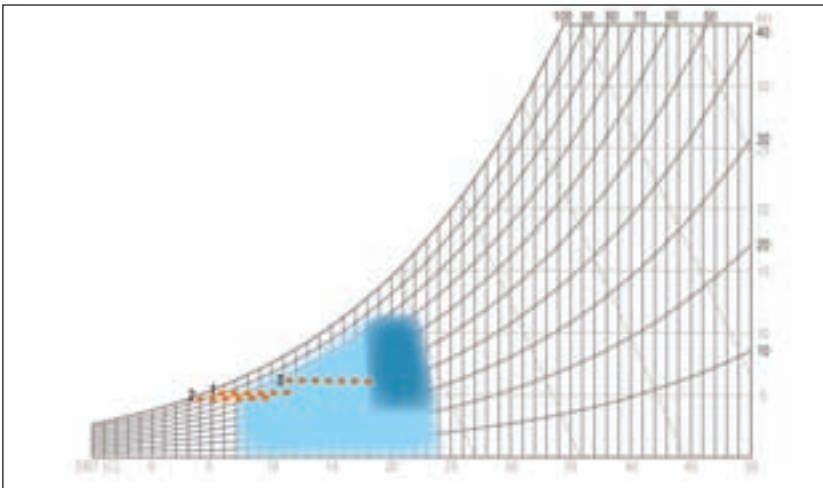


Figure 8.28: Mid-mountain region: winter season solar heat gain

*Mid-season*

Air movement improves the comfort conditions when the temperature\* is between 24°C and 33°C.

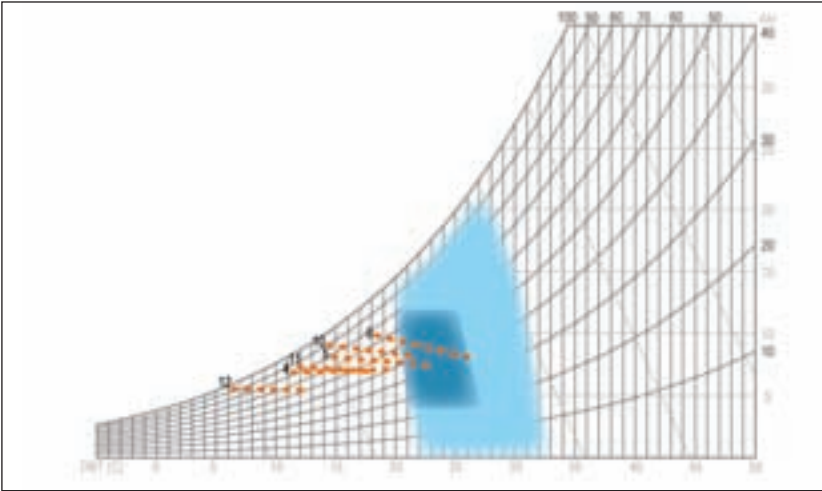


Figure 8.29: Mid-mountain region: mid season air movement

*Summer season*

Thermal mass\* can improve the comfort conditions during the summer season for temperatures of 36-37°C.

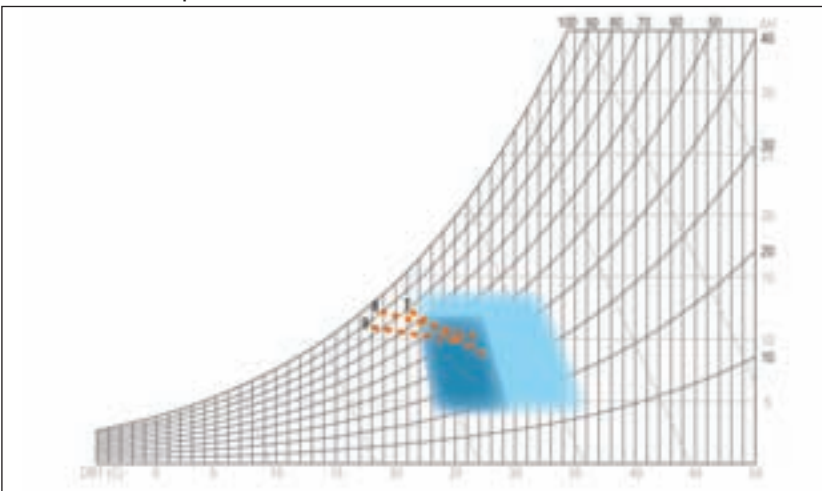


Figure 8.30: Mid-mountain region: summer season thermal mass

Air movement improves the comfort conditions when the temperature is below 35-36°C.

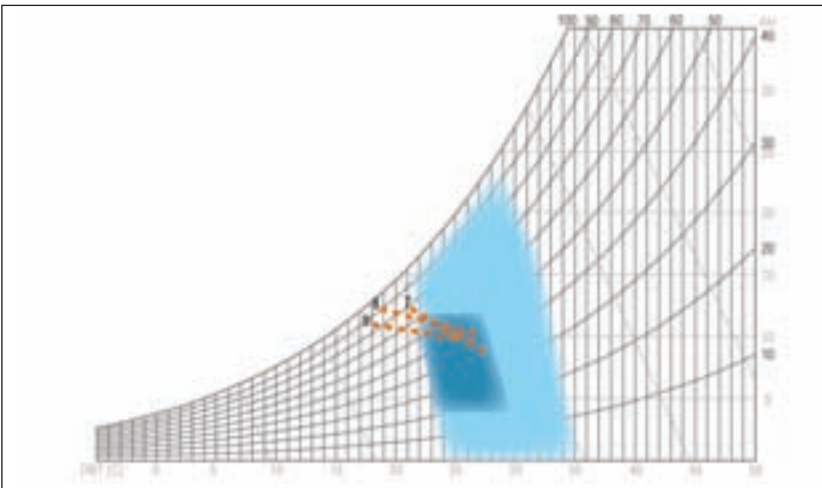


Figure 8.31: Mid-mountain region:summer season air movement

**Thermal transmittance\***

Figure 8.34 illustrates the association that exists between the U-value of a wall and its internal surface temperature\*, in a residential building. In the summer season, as the U-value increases, the internal surface temperature tends to increase.

Figure 8.35 shows the association that exists between the U-value of a roof and its internal surface temperature, in a residential building.

The trends shown in the figures, and the information provided in the Thermal Standards, result in applicable U-values ranging from 0.5 W/m<sup>2</sup>°C to 1 W/m<sup>2</sup>°C. Obtaining a wall's U-value within this range can be achieved by manipulating the different layers of building materials. Walls with the same U-value have different thermal performances according to their thermal time constants.

A simulation in this region\* is based on a wall that is built with the following materials:

- 2 cm plaster: R=0.025 m<sup>2</sup>K/W
- 15 cm concrete masonry unit: R=0.08 m<sup>2</sup>K/W
- 3 cm rigid insulation: R=0.71 m<sup>2</sup>K/W
- 10 cm concrete masonry unit: R=0.08 m<sup>2</sup>K/W
- 2 cm internal plaster and paint: R=0.025 m<sup>2</sup>K/W

Analysis of the temperature fluctuation and the moisture migration within the wall shows that there is no problem of condensation within the wall. This wall has a thermal time constant of 41.51.<sup>1</sup>

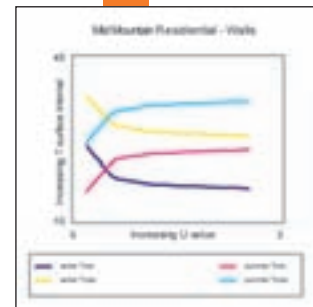


Figure 8.34: Mid-mountain region: residential wall

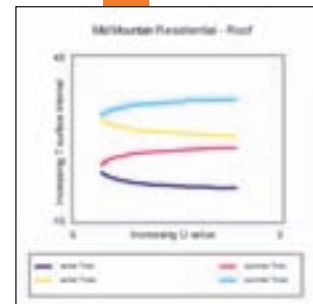


Figure 8.35: Mid-mountain region: residential roof

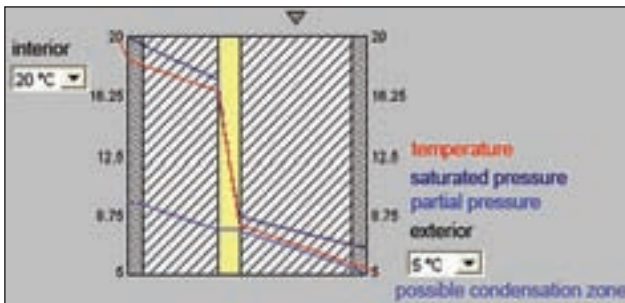


Figure 8.32: Mid-mountain region: temperature fluctuation and moisture migration

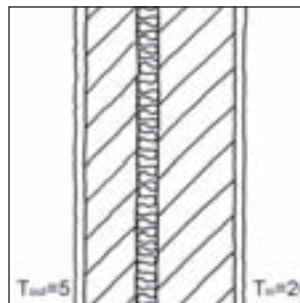


Figure 8.33: Mid-mountain region: simulated wall

**Effective fenestration ratio**

The simulation for this region is based on a window that has the following characteristics: SC = 0.95

ASF<sub>w</sub> = 0.72

FR = 0.19

The interaction of these parameters is illustrated in Figure 8.36.

**Case study**  
 For a similar case study as the one carried out for the coastal region, and in order to conform with the values required in the Thermal Standards for the effective fenestration ratio, the opening would have a width of 2.44 m for a constant height of 2.2 m in the mid-mountain region.

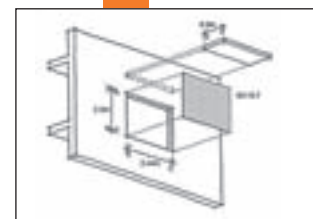


Figure 8.36: Case study: window opening in the mid-mountain region

<sup>1</sup> Application of TTC= Q x R (refer to page 32)

Taking into account the factors that affect the internal operative temperature\* results in decreasing these temperatures as shown in Figure 8.37.

$$T_e = (h_r \times T_{mrt} + h_c T_{ai} + \alpha_s (q_d + q_b/4)) / (h_r + h_c)$$

whereby  $T_{mrt} = (\sum T_i A_i) / A_T$

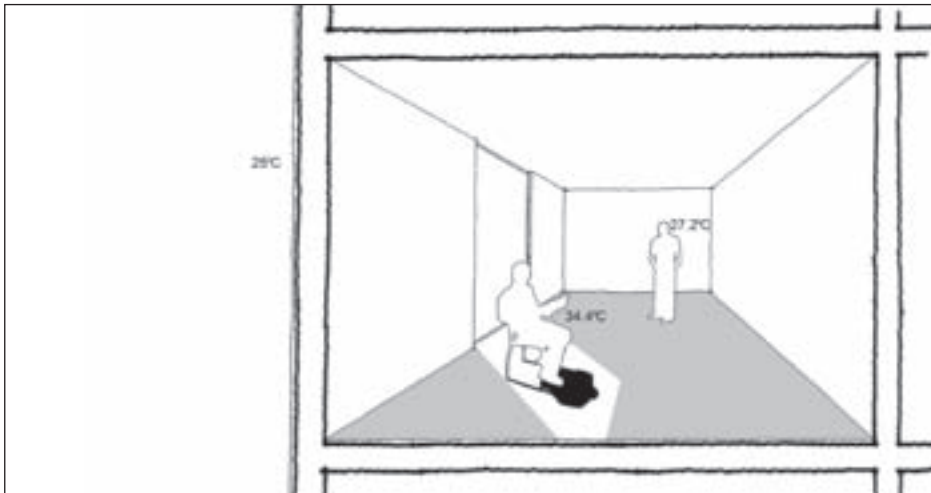


Figure 8.37: Mid-mountain region: internal operative temperature

Moreover, the introduction of natural ventilation improves the situation as shown in Figure 8.38.

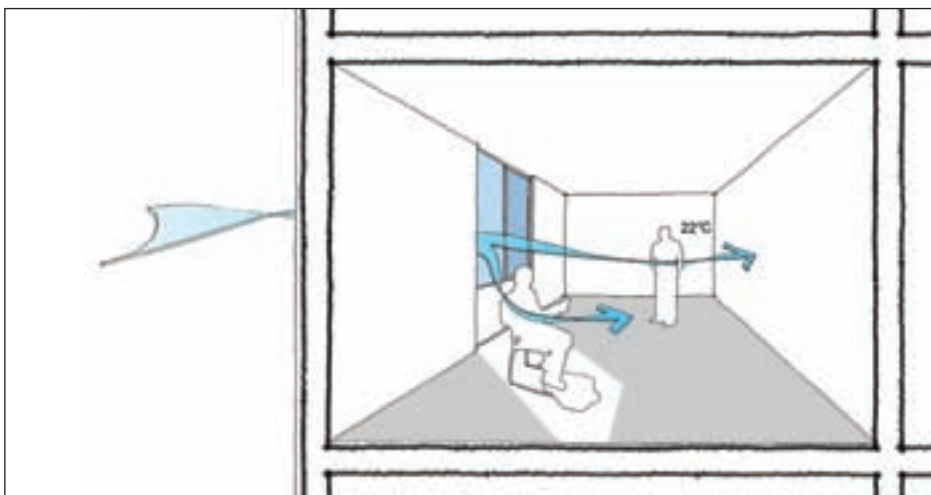


Figure 8.38: Mid-mountain region: internal temperature with natural ventilation

$$T_{res} = (T_{mrt} + T_{air} \times \sqrt{(10V)}) / (1 + \sqrt{(10V)})$$

Introducing a shading device which reduces the heat\* entering the space results in decreasing the internal temperature\* from about 34.4°C to about 30.8°C as shown in Figures 8.39 and 8.40.

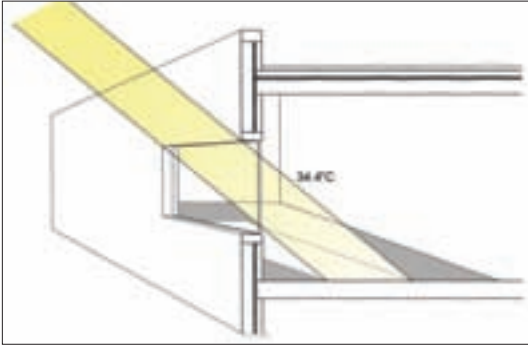


Figure 8.39: Mid-mountain region: simulation

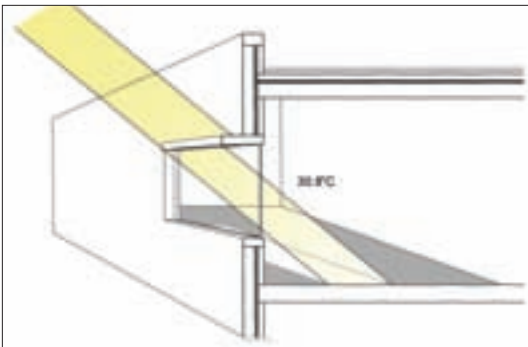


Figure 8.40: Mid-mountain region: effect of a shading device

Numerous inhabitants of the coastal cities, as well as visitors, seek refuge from the excessive heat and humidity\* of the coast by spending much of the summer season in the mountains. The population of this region tends to be denser during the summer than during the winter.

This section discusses several heating and cooling strategies applicable to the residential typology in the mid-mountain region. These strategies may also be valid for the coastal region, and can be achieved by considering the following issues:

#### **Layout, orientation and shading**

Several factors such as solar incidence, view, and residential zoning requirements affect the massing and location of the building. In general, bedrooms are oriented towards the east morning light, reception areas towards the view, and kitchen and other services occupy a space adjacent to both. Shading devices may be beneficial in controlling the amount of sun entering the different spaces.

#### **Air movement**

Depending on the season, air movement may have an important role in creating comfortable residential spaces.

In summer, regulated air movement in residential interiors may provide comfort ventilation. This is sometimes particularly beneficial in this region due to the high moisture content in the air.

In winter, natural ventilation helps avoiding condensation problems that result from the increase of internal humidity\* usually generated from cooking, bathing, and latent heat\* produced by people.

The verticality of the core in a building can be used to enhance stack ventilation. The rising air due to the stack effect produces negative pressure in the core. This induces air movement in the private residential spaces.

### **Building skin**

#### Opaque Components

Thermal mass\* in the residential buildings helps in achieving comfort.

In winter, the heat\* from the sun is stored in the thermal mass of the floor and interior walls, and is released back inside during the night when the building is occupied.

Problems of glare or fading of fabrics are likely to occur when solar radiation\* is admitted into a space. Consequently, a thorough analysis of the sun's position is required in order to reduce its negative impact. This analysis helps to define the location, size and properties of openings and shading devices.

#### Transparent Components

Architectural flexibility demands the manipulation of window size, position, and view. To properly design a window, the parameters that should be accounted for include amount of daylight, ventilation requirements, operability of windows, shading coefficient\*, shading devices and U-value.

# High-mountain region

The following charts illustrate the comfort zones for all seasons as well as the passive design strategies that can be developed for each season.

The issues of thermal transmittance\* and effective fenestration ratio are further elaborated later.

## Winter season

With higher thermal mass\*, temperatures\* as low as 8-9°C can be included in the comfort zone.

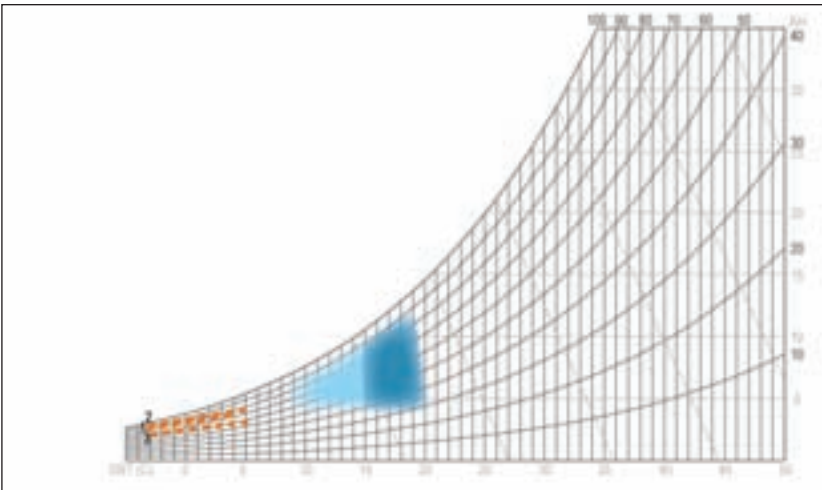


Figure 8.41: High-mountain region: winter season thermal mass

Solar heat\* gain can improve the comfort for temperatures as low as 4-5°C.

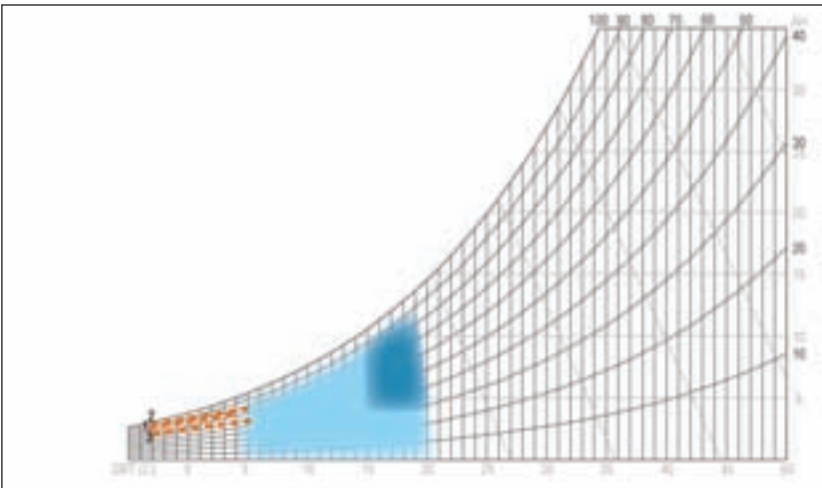


Figure 8.42: High-mountain region: winter season solar heat gain

*Mid-season*

Air movement improves the comfort conditions when the temperature\* is between 19-20°C and 30-31°C.

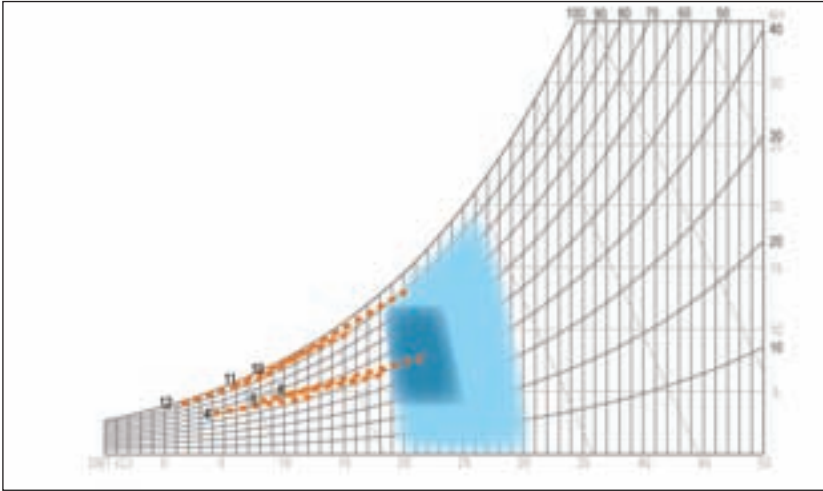


Figure 8.43: High-mountain region: mid season air movement

*Summer season*

Thermal mass\* can improve the comfort conditions for the summer season until the temperatures exceed 37-38°C.

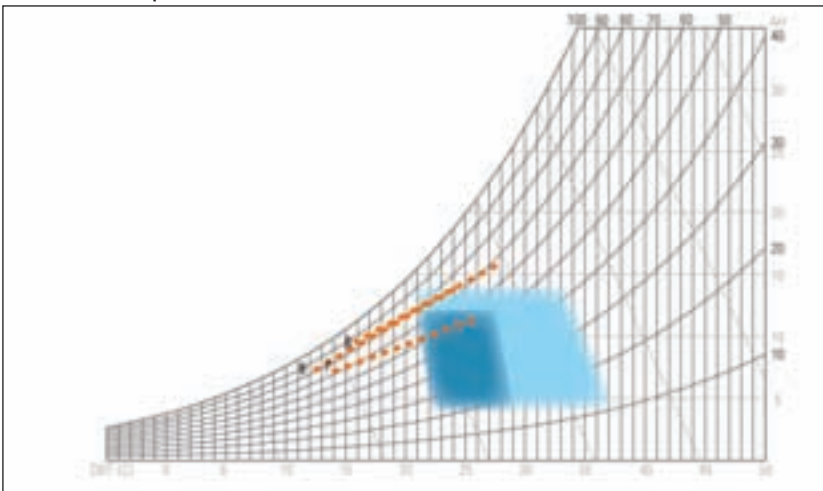


Figure 8.44: High-mountain region: summer season thermal mass

Air movement improves the comfort conditions when the temperature is between 22-23°C and 34-35°C.

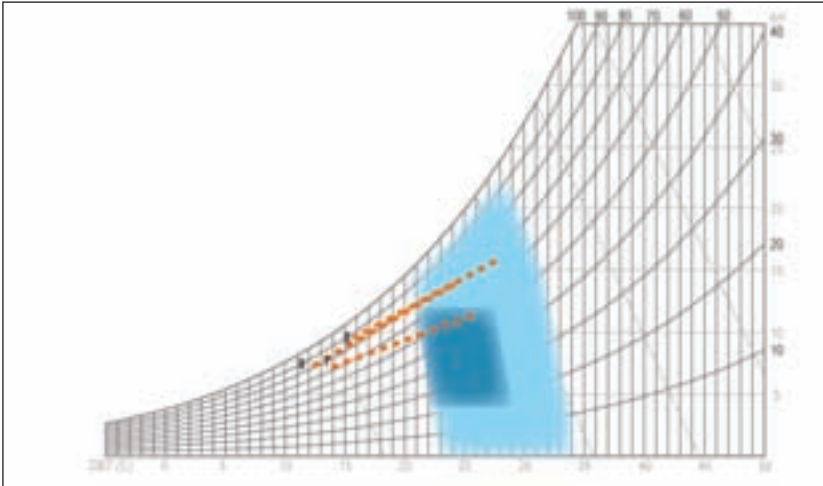


Figure 8.45: High-mountain region:summer season air movement

**Thermal transmittance\***

Figure 8.48 illustrates the trend that exists between the U-value of a wall and its internal surface temperature\* in a residential building. In the summer season, as the U-value of the wall increases, the internal surface temperature tends to rise.

Figure 8.49 shows the trend that exists between the U-value of a roof and its internal surface temperature in a residential building.

The trends obtained from these simulations, and the information provided in the Thermal Standards, yield applicable U-values ranging from 0.5 W/m<sup>2</sup>°C to 0.8 W/m<sup>2</sup>°C.

Obtaining a wall's U-value that lies in that range can be achieved by differently combining building materials. Walls with the same U-value may have different thermal time constants depending on how the materials are layered.

A simulation in this region is based on a wall that is built with the following materials:

- 3 cm cladding: R=0.02 m<sup>2</sup>K/W
- 2 cm mortar: R=0.025 m<sup>2</sup>K/W
- 15 cm concrete masonry unit: R=0.08 m<sup>2</sup>K/W
- 5 cm rigid insulation: R=0.71 m<sup>2</sup>K/W
- 10 cm concrete masonry unit: R=0.08 m<sup>2</sup>K/W
- 2 cm internal plaster and paint: R=0.025 m<sup>2</sup>K/W

Analysis of the temperature fluctuation and the moisture migration within the wall shows that there is a problem of condensation within the wall. Hence, this wall does not represent an appropriate solution for this region. Its design should be reconsidered by modifying the dimensions and properties of the materials to avoid this problem. This wall has a thermal time constant of 44.34.<sup>1</sup>

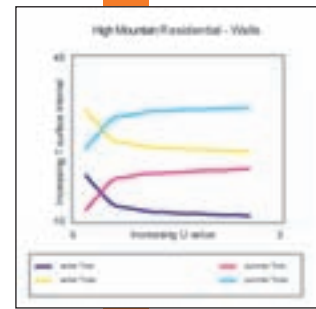


Figure 8.48: High-mountain region: residential wall

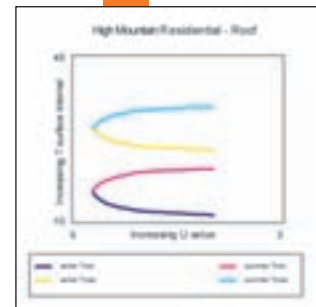


Figure 8.49: High-mountain region: residential roof

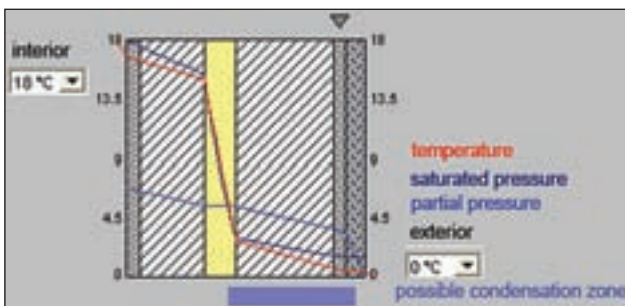


Figure 8.46: High-mountain region: temperature fluctuation and moisture migration

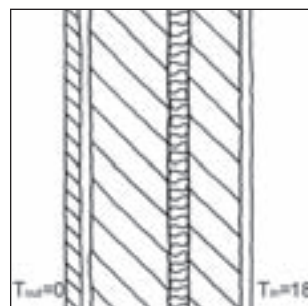


Figure 8.47: High-mountain region: simulated wall

**Effective fenestration ratio**

A simulation in this region is based on a window that has the following characteristics: SC = 0.95

ASFW = 0.89

FR = 0.25

The interaction of these parameters is illustrated in Figure 8.50.

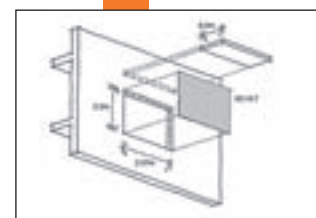


Figure 8.50: Case study: window opening in the high-mountain region

**Case study**  
For a similar case study as the one carried out for the coastal region, and in order to conform with the values required in the Thermal Standards for the effective fenestration ratio, the opening would have a width of 2.57 m for a constant height of 2.2 m in the high-mountain region.

<sup>1</sup> Application of TTC= Q x R (refer to page 32)

The simulation done for the wall and window as defined before results in the following:

The internal operative temperature\* is modified as shown in Figure 8.51.

$$T_e = (h_r \times T_{mrt} + h_c T_{ai} + \alpha_s (q_d + q_b/4)) / (h_r + h_c)$$

whereby  $T_{mrt} = (\sum T_i A_i) / A_T$

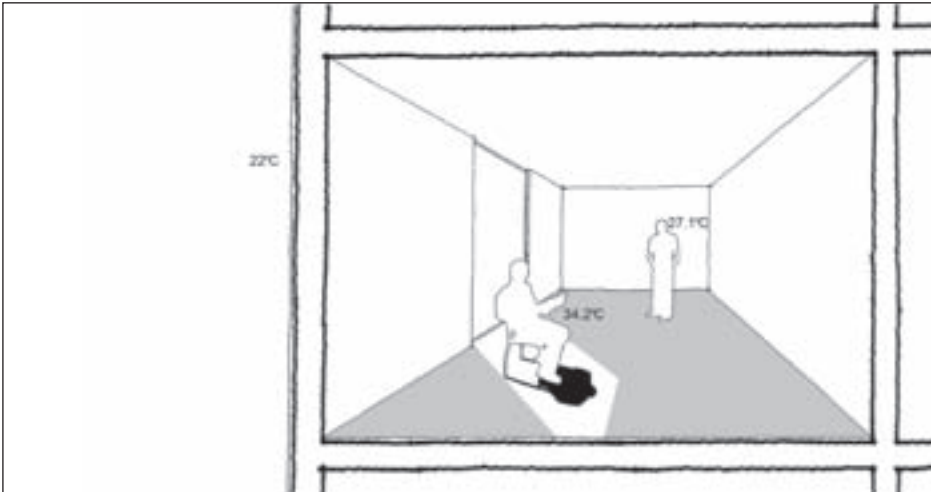


Figure 8.51: High-mountain region internal operative temperature

The introduction of natural ventilation further improves the situation of internal temperature as shown in Figure 8.52.

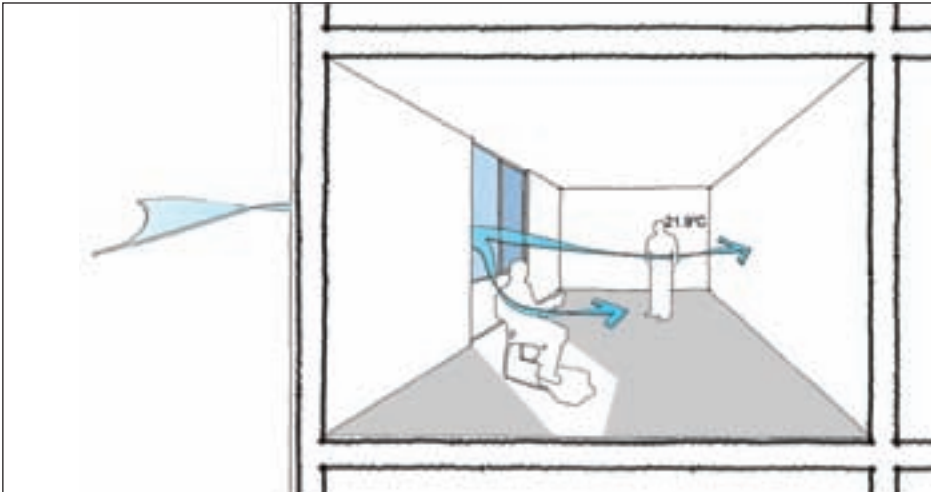


Figure 8.52: High-mountain region internal temperature with natural ventilation

$$T_{res} = (T_{mrt} + T_{air} \times \sqrt{(10V)}) / (1 + \sqrt{(10V)})$$

Introducing a relatively small shading device which reduces the heat\* entering the space results in decreasing the internal temperature\* from about 34.2°C to about 32.6°C as shown in Figures 8.53 and 8.54. The small shading device is considered since the solar radiation\* is needed most of the time. Therefore this shading device will keep the sun out at the peak time of the day in summer when there is the highest solar load.

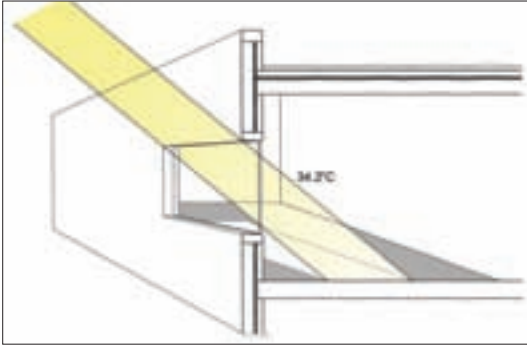


Figure 8.53: High-mountain region: simulation

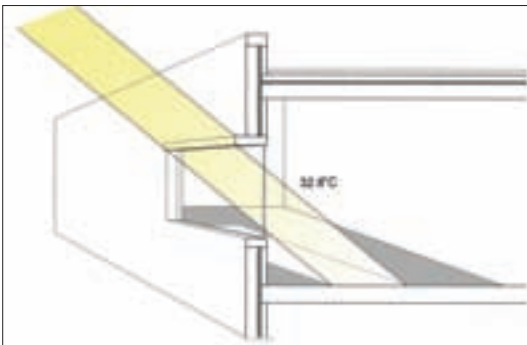


Figure 8.54: High-mountain region: effect of a shading device

In this region, the main concerns are orientation towards the sun and minimizing winter shade areas. Issues to be considered:

### Layout, orientation and shading

Compact building configurations help reduce envelope exposure to the climatic elements of temperature, wind, humidity\*, etc. This reduces the amount of heat lost through the building skin. It is recommended that the layout of residential spaces take advantage of morning sunlight for the kitchen and the bedrooms. Buffer spaces such as garages and storage areas may help shield the building from the northern winds.

### Air movement

At these altitudes\*, low temperatures characterize a significant part of the year.

Therefore, reducing exposure to cold winds minimizes heat loss from internal spaces.

In the winter season, some controlled natural ventilation may help relieve the interior spaces from the problems of condensation due to moisture build-up.

### **Building envelope**

#### Opaque Components

In general, the glass area that allows the direct gain should represent a small fraction of the thermal mass\* area of an elevation.

This proportion varies depending on the properties of the opaque and transparent materials used.

Adequate insulation of the envelope helps reduce internal temperature\* fluctuations.

Storing the heat\* that enters a space helps keep the spaces warm when there is no direct sunlight entering the space.

When sunlit portions of the floor are dark colored, heat\* is stored due to increased absorption.

Low air leakage also helps enhance the sensation of comfort within a space.

#### Transparent Components

When integrating passive heating strategies in a project, the proper size and orientation\* of openings help benefit from available solar radiation\* by providing heat\* gain.

In this cold region, large south-facing windows are helpful as they have the most exposure to the sun in all seasons.

## Inland region

The following psychrometric charts illustrate the winter, mid-season and summer comfort zones as well as the passive design strategies that may be developed for each season.

The issues of thermal transmittance\* and effective fenestration ratio are further elaborated later.

### Winter season

With higher thermal mass\*, temperatures\* as low as 13-14°C can be included in the comfort zone.

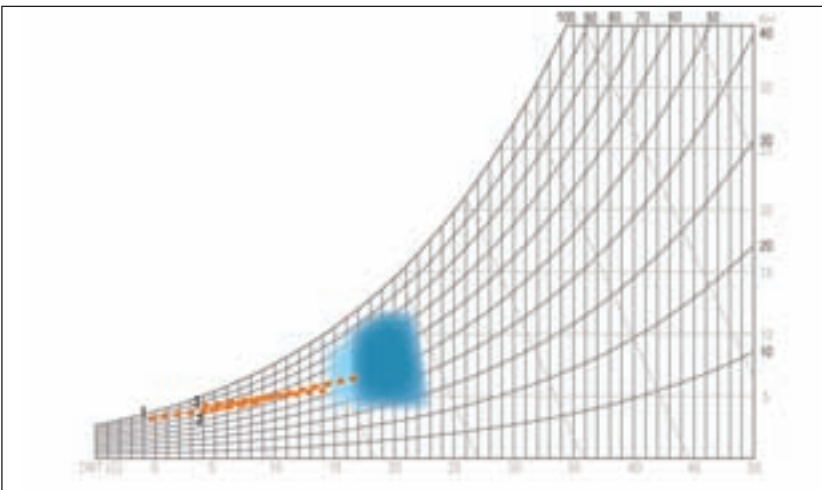


Figure 8.55: Inland region: winter season thermal mass

Solar heat\* gain can improve the comfort for temperatures as low as 1-2°C.

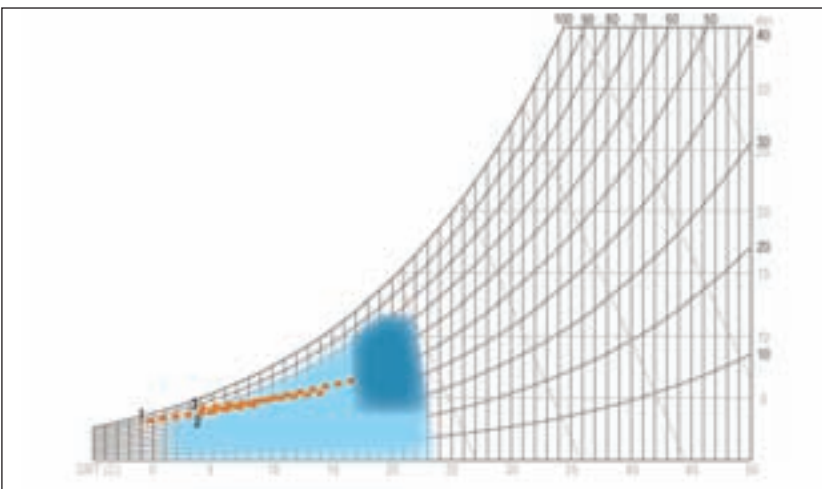


Figure 8.56: Inland region: winter season solar heat gain

*Mid-season*

Air movement improves the comfort conditions when the temperature\* is between 20-21°C and 32-33°C.

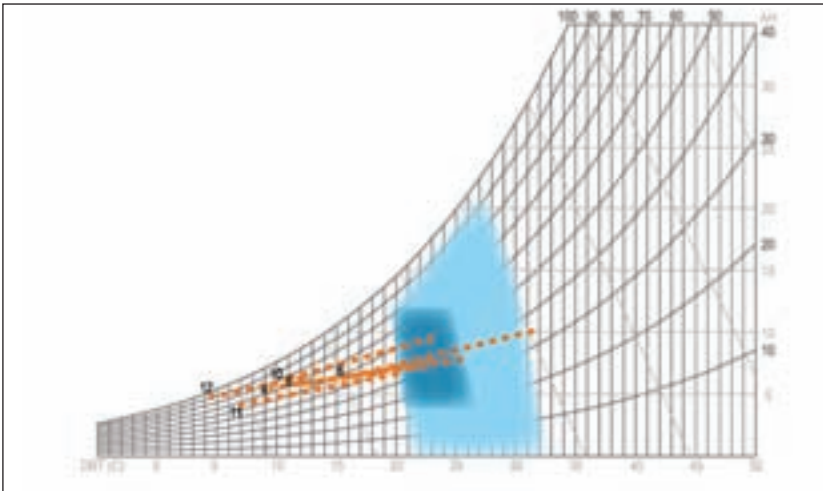


Figure 8.57: Inland region: mid season air movement

*Summer season*

Thermal mass\* can improve the comfort conditions for the summer season for temperatures below 37-38°C.

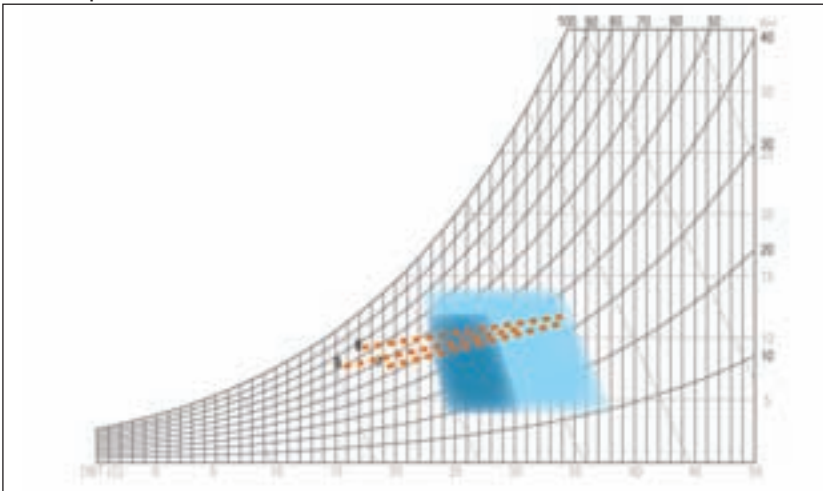


Figure 8.58: Inland region: summer season thermal mass

Air movement improves the comfort conditions when the temperature is between 24-25°C and 36-37°C.

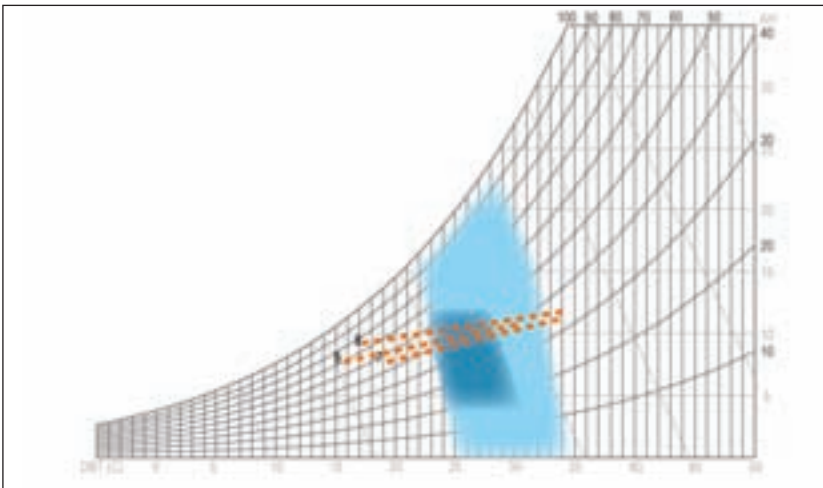


Figure 8.59: Inland region:summer season air movement

**Thermal transmittance\***

Figure 8.62 illustrates the association that exists between the U-value of a wall and its internal surface temperature\* in a residential building.

Figure 8.63 shows the association that exists between the U-value of a roof and its internal surface temperature in a residential building.

The trends shown in the figures, and the information provided by the Thermal Standards, propose applicable U-values ranging from 0.5 W/m<sup>2</sup>°C to 0.8 W/m<sup>2</sup>°C.

Obtaining a wall's U-value within that range can be achieved by using different layers of building materials.

A simulation in this region is based on a wall that is built with the following materials:

- 2 cm plaster: R=0.025 m<sup>2</sup>K/W
- 15 cm concrete masonry unit: R=0.08 m<sup>2</sup>K/W
- 2 cm air cavity
- 15 cm concrete masonry unit: R=0.08 m<sup>2</sup>K/W
- 2 cm internal plaster and paint: R=0.025 m<sup>2</sup>K/W

Analysis of the temperature fluctuation and the moisture migration within the wall shows that there is no problem of condensation within the wall. This wall has a thermal time constant of 16.99.<sup>1</sup>

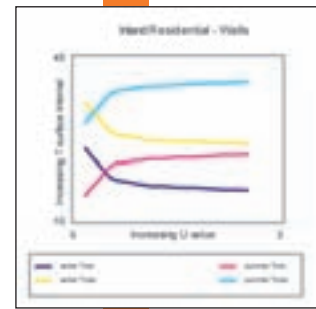


Figure 8.62: Inland region: residential wall

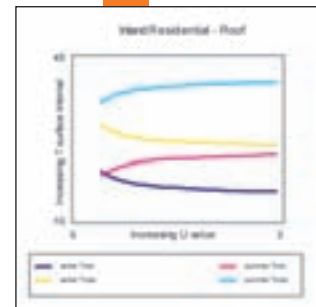


Figure 8.63: Inland region: residential roof

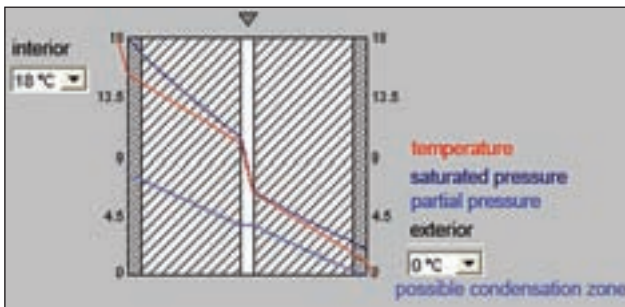


Figure 8.60: Inland region: temperature fluctuation and moisture migration

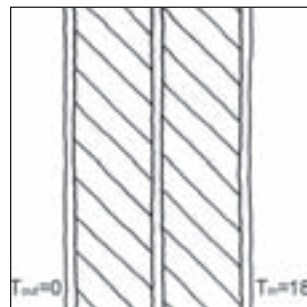


Figure 8.61: Inland region: simulated wall

**Effective fenestration ratio**

A simulation in this region is based on a window that has the following characteristics: SC = 0.9

ASF<sub>w</sub> = 0.72

FR = 0.18

The interaction of these parameters is illustrated in Figure 8.64.

**Case study**

For a similar case study as the one carried out for the coastal region, and in order to conform with the values required in the Thermal Standards for the effective fenestration ratio, this opening in the inland region would have a width of 3.38 m for a constant height of 2.2 m.

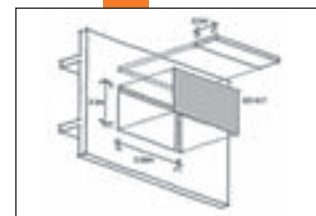


Figure 8.64: Case study: window opening in the inland region

<sup>1</sup> Application of TTC= Q x R (refer to page 32)

The simulation accounting for the wall and window parameters considered here, results in the situation illustrated below.

The parameters adopted in this approach affect the internal operative temperature\* as shown in Figure 8.65.

$$T_e = (h_r \times T_{mrt} + h_c T_{ai} + \alpha_s (q_d + q_b/4)) / (h_r + h_c)$$

whereby  $T_{mrt} = (\sum T_i A_i) / A_T$

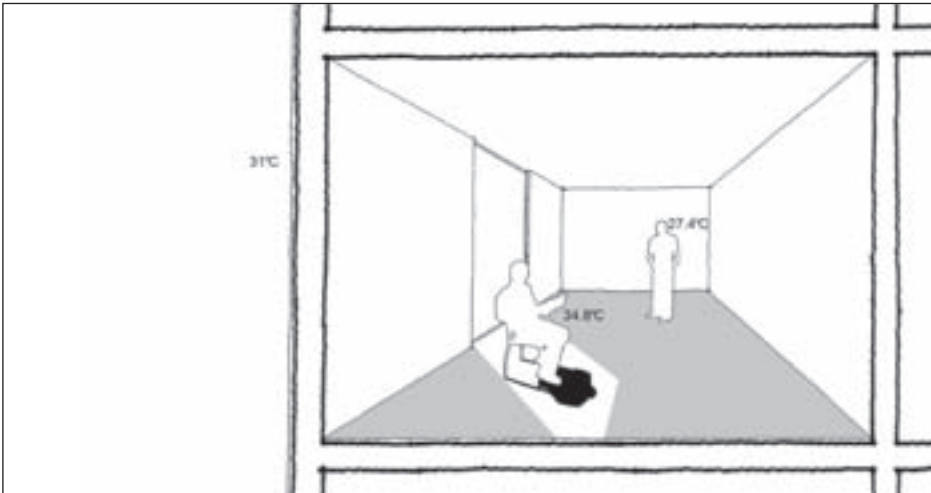


Figure 8.65: Inland region internal operative temperature

The introduction of natural ventilation further improves the situation as shown in Figure 8.66.

$$T_{res} = (T_{mrt} + T_{air} \times \sqrt{(10V)}) / (1 + \sqrt{(10V)})$$

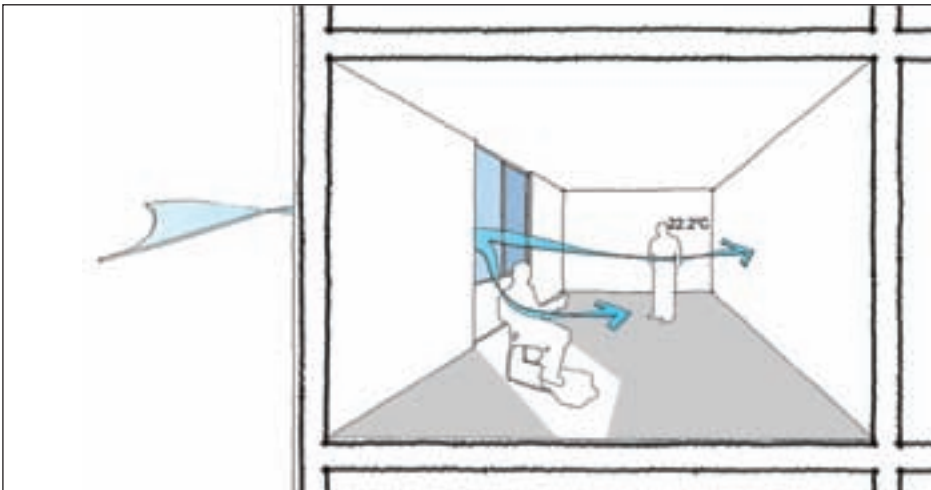


Figure 8.66: Inland region internal temperature with natural ventilation

Increasing the thermal time constant of the external wall and roof by placing the insulation closer to the exterior skin results in a lower internal temperature\* as shown in Figure 8.67.

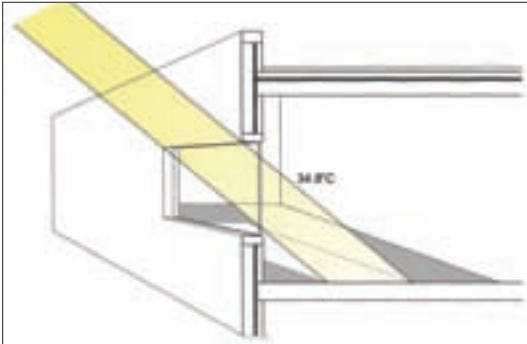


Figure 8.67: Inland region: simulation

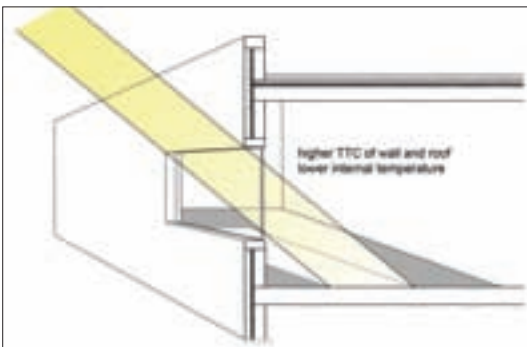


Figure 8.68: Inland region: effect of thermal time constant

In this region, in addition to the principles already discussed for the other regions, thermal mass\* is important to consider due to the high diurnal temperature range. Issues to be considered:

#### **Layout, orientation and shading**

The massing of a climate responsive building accounts for solar radiation\* and wind movement. Moreover, in areas where the daily or seasonal temperature difference is large, using the thermal mass strategy can prove effective in controlling internal temperature variations. The diurnal temperature fluctuations can be managed by absorbing the heat\* of the summer sun during the day and releasing it at night.

#### **Air movement**

Depending on the seasons, ventilation can have several advantages as discussed in the other climate regions.

In addition to comfort ventilation and moisture dissipation, air movement can act as a complementary strategy to thermal mass. On summer evenings, natural ventilation helps relieve the thermal mass\* of the heat it has stored during the day.

### **Building skin**

#### Opaque Components

It is beneficial to incorporate adequate thermal mass\* in buildings that attempt to achieve a high level of passive cooling and heating.

Thermal storage may be incorporated in floors or walls consisting of concrete, masonry, or tile. The choice of materials is important so that thermal mass is effective. Among the common building materials, steel and glass do not provide good thermal mass. On the other hand, concrete and other masonry products provide for substantial thermal mass because they have a high capacity to store heat\*, they allow heat to transfer into the material and be stored within it, and radiation\* absorbed within them is more than the radiation that is reflected.

In the summer, walls and floors that store heat from the sun release it slowly at night to the outdoor space.

#### Transparent Components

As stated in the other climate regions, the thorough study of openings is important to allow for the most appropriate functional and technical givens. Moreover, the physical characteristics of openings can improve the performance of thermal mass\*. For an internal thermal mass\* to be efficient, it must be exposed to, and absorb, a substantial amount of solar energy entering the space.

### **Courtyards**

Externally used thermal mass can be significant in providing comfort.

The thermally massive floor of a courtyard may improve comfort in different ways:

First, the nighttime radiation that cools the floor results in warm air rising. This rising air takes with it the warm air in the internal spaces surrounding the courtyard. Consequently, cool comfortable air replaces the warm air.

Second, during the day, the courtyard floor is cool since all the heat is removed from it during the night.



**Day-lighting**

The following factors, when taken into consideration during the early design stages, improve the quality of daylight inside a space:<sup>1</sup>

- Orientation\*, organization and geometry of spaces;
- Location, form, and dimensions of openings;
- Location, form, and dimensions of movable and permanent shading devices;
- Location and surface properties of internal partitions (reflect daylight)
- Reflective shading coefficient\* characteristics of the glazing materials.

Proper design for day-lighting is recommended for the following reasons:

- Visually comfortable interiors avoid excessive contrast and glare;
- Reduction in energy consumption by minimizing the overheating caused by lighting appliances.

Artificial lighting is seen as a system that supplements natural lighting when necessary. Therefore, the less it is used the better.

**Landscaping**

Trees and shrubs protect parts of the buildings from solar radiation\* by casting shadows.<sup>2</sup> The amount of shade depends on the position of the trees with respect to the sun, their proximity to the building, their shape, their height, and the density of their leaves.

Evergreen trees provide shade throughout the year. Deciduous trees have the advantage of not cutting out the winter sunshine while preventing the summer sun rays from entering the building (Figure 9.2). Vines reduce the heat\* transmission through the wall or roof exposed to the sun by shading it.

Trees also provide protection from wind as evergreens play the role of effective wind breakers during winter and reduce the building's heat\* losses.

Moreover, through the evapotranspiration of their leaves, trees cool the surrounding air and increase its humidity\*.

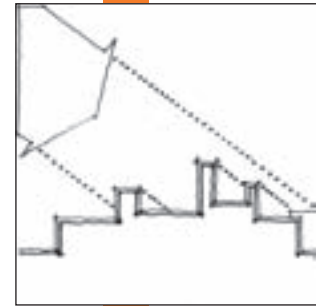


Figure 9.1: Urban overshadowing\*



Figure 9.2: Deciduous and evergreen vegetation

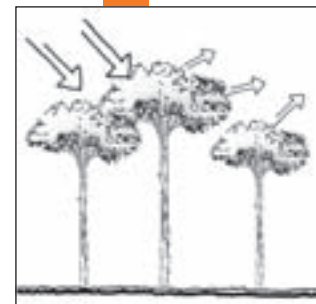


Figure 9.3: Deciduous and evergreen vegetation

<sup>1</sup> Bell, J., Burt, W. (1995) Designing Buildings for Daylight. BRE. London.

<sup>2</sup> Konya, A. (1980) Design Primer for Hot Climate. The Architectural Press Ltd. London

### Occupants' behavior

The occupants of the building play an important role in its successful operation which leads to maintaining thermal comfort. For example, raising and lowering the shading devices at the proper times of the day helps achieve the required comfort.

### Ground cover

The type of ground cover of the site has a prominent effect on temperature\*. Ground covers surrounding a building could consist of grass, trees, soil, and built-up areas covered with concrete or asphalt each having a different rate of heat\* absorption and transmission. Natural vegetation tends to moderate extreme temperatures. Planted grounds reduce temperatures by absorption of insolation\* and evaporative cooling. Asphalt paving also elevates the temperature thus heating up the air entering the building. In general, hard surfaces should be kept far from the building's envelope.<sup>1</sup>

### Surrounding buildings

Buildings are solid screens that influence air movement and cast shadows. Because of their distinct impact on surrounding micro climate, careful consideration should be given to their layout and grouping in order to minimize funneling which can cause uncomfortable turbulences. The relationship between buildings, topography\* and vegetation may enhance the external environment.<sup>2</sup>

### Water bodies

Water bodies such as the sea, lakes, rivers, ponds, pools and fountains influence the micro climate in moderating variations in ambient temperature. In addition, courtyard ponds, fountains, moving waters, and waterfalls blended into the landscape create breezes between water and land. The larger the water bodies, the more their micro climatic impact. Water is a very efficient heat storage medium because of its high specific heat\*.<sup>3</sup> Stagnant water ponds on roofs can be used to provide cooling for buildings.

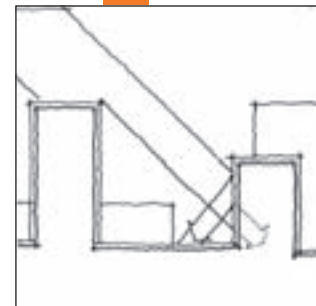


Figure 9.4: Effect of surrounding surfaces

<sup>1</sup> Givoni, B. (1998) Climate Considerations in Building and Urban Design. Van Nostrand Reinhold. New York.

<sup>2</sup> The European Commission. A Green Vitruvius.

<sup>3</sup> Goulding, J., Owen Lewis, J., Steemers, T. (1993) Energy Conscious Design. Bratsford. London.



**Airflow** is caused by pressure difference: In external environments, pressure difference occurs when warm (low-pressure) air is replaced by cool (high-pressure) air. Shapes of buildings also influence air pressure whereby positive pressure is created on its windward side and negative pressure on its leeward side.

**Altitude** is the elevation of a terrain above sea level. Altitude influences temperature, humidity, wind and precipitation.

**Architectural shading:** the impact of solar radiation on buildings is controlled not only by effective design of the massing, envelope, and orientation, but also by adequate shading. Architectural shading will serve the dual function of excluding sun during summer and of admitting it during winter. Roof overhangs, balconies, and projecting slabs are forms of horizontal shading. Shading of transparent elements can be provided by horizontal and vertical screening, or a combination of both. Solar azimuth angle, wall solar azimuth angle, solar altitude angle and angle of incidence determine the design of the shading device.

**Conduction:** heat flow by conduction occurs within a body or between bodies in physical contact by the spread of molecular movement. An example of heat transfer by conduction is a metal spoon in a cup of hot coffee.

**Convection:** heat flow by convection flows from a solid body to a fluid (liquid or gas) and vice-versa. An example is warm air that rises.

**Diffused solar energy** is the heat energy scattered by the atmosphere, thus arriving at the earth's surface from the whole of the sky vault.

**Direct solar energy** or **beam component** is the amount of heat energy reaching the earth's surface from the sun directly.

**Diurnal range** is the temperature difference between day and night. It may also portray seasonal temperature variations.

**Double skin** facades consisting of two distinct skins separated with air space. The space in between acts as a climate buffer zone and reduces stress on the internal skin.

**Dry bulb temperature (DBT)** is the air temperature taken with an ordinary wall thermometer.

**Heat** is a form of energy contained in substances as molecular motion, and in space as electro-magnetic radiation.

**Heat flow:** heat flows from a higher temperature zone to a lower temperature zone. It flows by: conduction, convection, and radiation.

**Humidity** is the moisture content of air gained as a result of evaporation from exposed water surfaces, moist or wet ground and from plant transpiration. The capacity of air to hold water vapor increases progressively with its temperature.

**Insolation** is the total amount of solar energy (direct, diffused and reflected) that reaches a surface.

**Irradiance** is the instantaneous energy flow density measured in  $W/m^2$ . Global irradiance on a particular surface consists of three components: direct, diffused, and reflected energy.

**Irradiation** is the energy quantity accumulated over a period of time measured in  $W/m^2 \cdot C$

**Mean radiant temperature (MRT)** is the average temperature of surrounding surfaces calculated in function of the angle the surface has with the measuring point.

**Obstructions** include surrounding buildings, hills, and trees. These features can modify wind movement and the incidence of solar radiation.

**Operative temperature (Te)** accounts for the mean radiant temperature as well as direct and diffuse radiation.

**Orientation** of a building is determined by the climatic factors of wind and solar radiation, as well as by considerations of view, noise and requirements of privacy. Orientation may reduce radiation in overheated periods, while simultaneously allowing some radiation during the under heated period.

**Overshadowing** is caused by surrounding buildings, vegetation and raised topographic features. In the heating season it is necessary to devise means to prevent overshadowing solar collection areas. During the cooling season existing shade can be exploited.

**Precipitation** is the total amount of rain, hail, snow or dew expressed in mm per unit of time. Precipitation occurs when the moisture-holding capacity of air is reduced by cooling until it reaches the saturation point.

**Radiation:** heat by radiation flows from a body with a warmer surface to a body with a cooler surface.

**Reflected solar energy** is the heat energy received on any surface other than the horizontal by reflection from the ground or surrounding surfaces of buildings.

**Relative humidity** is the ratio of the moisture content in the air to the maximum content that the air can contain at that same dry bulb temperature.

**Shading coefficient** represents the ratio of energy transmittance of a glazing unit to the energy transmittance of a standard double-glazed unit.

**Specific heat** is the quantity of heat required to raise the temperature of one unit of mass by one degree.

**Specific humidity** or humidity ratio is the weight of water vapor per unit weight of dry air expressed in gram per kilogram.

**Stack-effect:** air movement resulting from decreasing air density as temperature increases.

**Temperature** indicates the pressure of heat and is expressed in degrees.

**Thermal mass** is the heat storage value of a material. The larger the thermal mass, the slower the propagation of heat through the material.

**Thermal transmittance** also referred to as the U-value of the wall is an indicator of the amount of the heat that is gained or lost through it. The U-value is inversely proportional to the resistance of the material to heat flow and hence has better thermal characteristics. The U-value is measured in  $W/m^2\text{°C}$ .

**Topography** relates to valleys and hills, creates overshadowing and influences wind exposure and airflow.

**Wet bulb temperature (WBT)** is the air temperature measured with a thermometer with its bulb wrapped in moist gauze. The readings are affected by the moisture content of the air: the drier the air, the higher the wet-bulb reading.

**Wind exposure:** the principal determinants of wind distribution and characteristics are differences in atmospheric pressure due to the daily variations in heating and cooling of land and water masses and topography. Because wind affects ventilation, its direction, speed and daily and seasonal shifts should be analyzed in order to best utilize its positive aspects and bar the negative ones.

**Wind scoop:** wind catching opening on the windward side of a structure.

**Wind tower:** airflow resulting from incoming air-pressure on the windward side and suction created on the leeward side.

**Window to wall ratio** is the ratio of the size of an opening to the size of the overall wall. It is an important factor affecting solar heat gain and day-lighting. Adequate measures are to be adopted to reconcile the requirements of heat gain and day-lighting.



# Appendix 1

## Sun path diagram <sup>1</sup>

The sun path diagram shows the path of the sun in the sky as projected onto a horizontal plane. The horizon is represented as a circle with the observation point in the center. The sun's position at any date and hour can be determined from the diagram in terms of its altitude\* and azimuth ( $\alpha$ ). The altitude\* angles are represented at 10° intervals by equally spaced concentric circles; they range from 0° at the outer circle (horizon) to 90° at the center point. Azimuth is represented at 10° intervals by equally spaced radii; they range from 0° at the south meridian to 180° at the north meridian. These intervals are graduated along the periphery. The elliptical curves in the diagram represent the horizontal projections of the sun's path. They are given on the 21st day of each month. The longest sunpath line is in June. The shortest is in December. The numbers on these curved lines indicate the hour of the day.

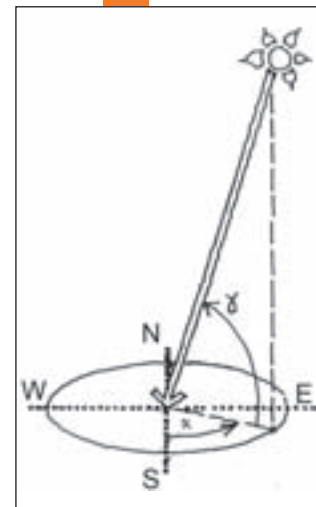


Figure A 1.1: Azimuth and altitude

### Example

To find the sun's position in Lebanon on February 21 at 2pm:

- 1- On the sun path diagram select the February path, and locate the 2hr line. Where the two lines intersect is the position of the sun.
- 2- Read the altitude\* on the concentric circles, 34°, and the azimuth along the outer circle, 37° west of south.

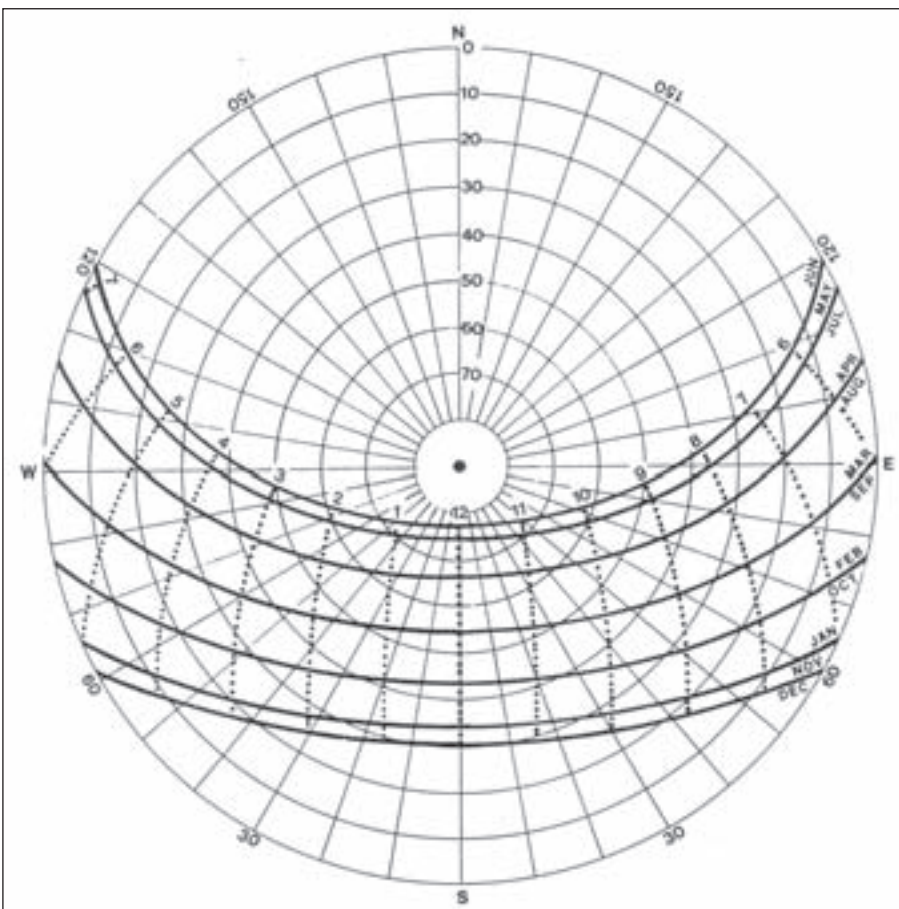


Figure A 1.2: Sun path – 36°N latitude

<sup>1</sup> Ramsey, C., Sleeper, H. (1963) Architectural Graphic Standards. John Wiley and sons. New York

# Appendix 2

## Psychrometric chart

The relationship between the dry bulb temperature\* and the relative humidity\* present in the air can be described graphically on a psychrometric chart.<sup>1</sup>

The values listed at the bottom are the dry bulb temperatures. The curved lines represent the percentage of relative humidity.

For each month, the hourly temperature\* and its corresponding relative humidity are plotted on the chart (Figure A 2.2). The group of points determines a zone which represents the range of temperatures and relative humidities of the month (Figure A 2.3).

When all the hourly points for a whole year are plotted on the chart, the result is as shown in Figure A 2.4.

For the purpose of this guide, the monthly hourly temperatures and relative humidities are replaced by the monthly mean maximum and mean minimum temperatures plotted with the mean minimum and mean maximum relative humidities respectively (Figure A 2.5).

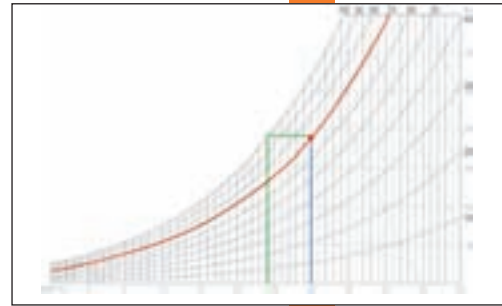


Figure A 2.1: Psychrometric chart and climate information 1

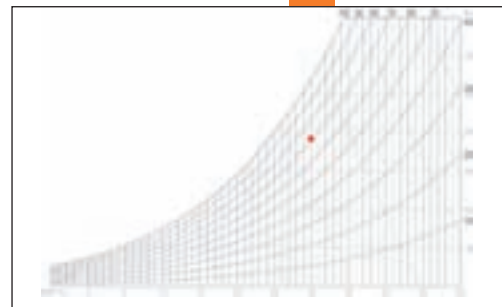


Figure A 2.2: Psychrometric chart and climate information 2

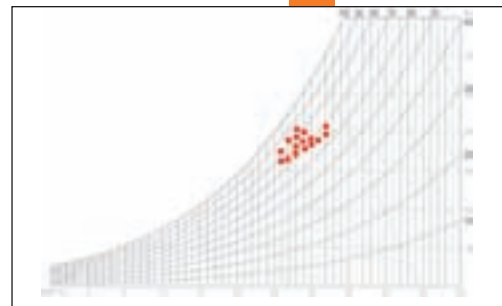


Figure A 2.3: Psychrometric chart and climate information 3

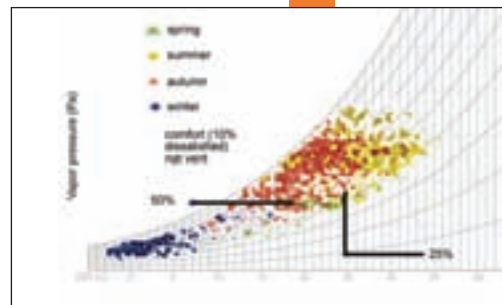


Figure A 2.4: Psychrometric chart and climate information 4

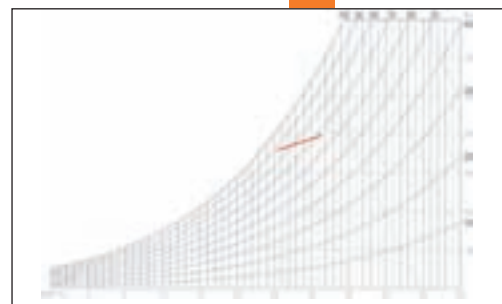


Figure A 2.5: Psychrometric chart and climate information 5

<sup>1</sup> Moore, F. (1953) Environmental Control Systems. Mc Graw Hill. New York.

# Appendix 3

**Mahoney tables** provide a guide to design in relation to climate using the minimum and maximum temperatures\* and relative humidities\*. The procedure leads the designer from the climatic information to specifications for optimal conditions of layout, orientation, shape, and structure needed at the sketch design stage.



Figure A 3.1: Mahoney tables

**Fergus Nicol - Adaptive effect:** The Nicol graph gives building designers a guide to the optimum temperature based on the idea that the people's comfort temperature changes from time to time, thus the graph suggests the average value for the temperature in a particular climate<sup>1</sup>.

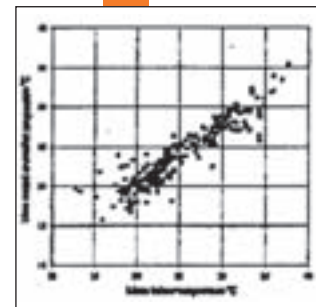


Figure A 3.2: The Nicol graph

**ANSI-ASHRAE standard 55** provides alternative methods for determining operative temperature (the weighted average of the air temperature and the mean radiant temperature) limits for the comfort zone, which are: The graphical method (Figures A 3.3, A 3.4 and A 3.5) The computer model (PMV/PPD). An optional method for naturally conditioned spaces.

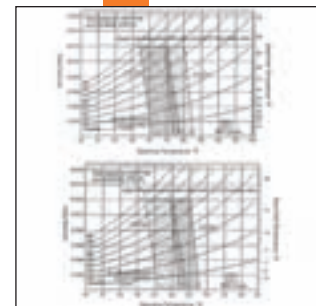


Figure A 3.3: ASHRAE 1

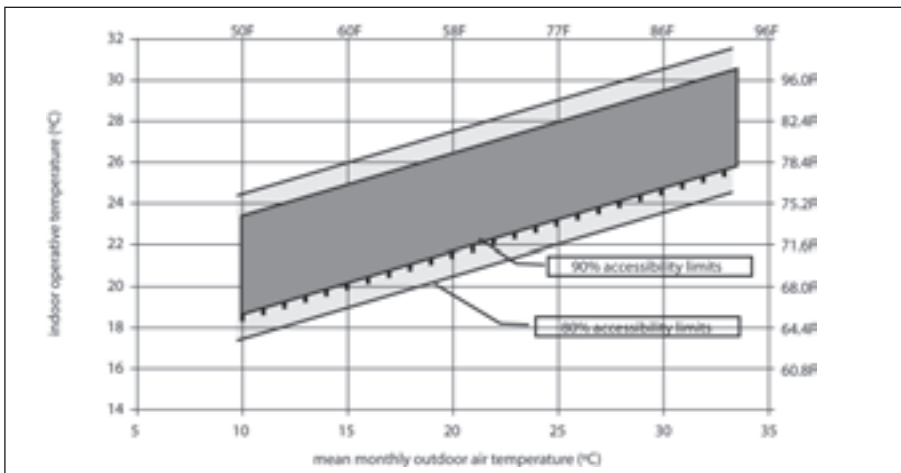


Figure A 3.5: ASHRAE 3

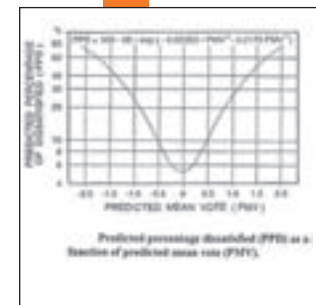


Figure A 3.4: ASHRAE 2

<sup>1</sup> Roaf, S. (2004). Closing the Loop. RIBA Enterprises Ltd. London.



Heat capacity	$\text{kJ/m}^3\text{°C}$ or $\text{kWh/m}^3\text{°C}$
Air velocity	$\text{m/s}$
Angle	$^\circ$
Area	$\text{m}^2$
Density	$\text{kg/m}^3$
Heat flow	$\text{W/m}^2$
Heat quantity	$\text{kJ}$ or $\text{kWh}$
Heat transmission	$\text{W/m}^2\text{°C}$
Metabolism	$\text{W/m}^2$ or met
Solar gain	$\text{MJ/m}^2$ or $\text{kWh/m}^2$
Temperature	$^\circ\text{K}$ or $^\circ\text{C}$
Thermal conductance	$\text{W/m}^2\text{°C}$
Thermal conductivity	$\text{W/m}^\circ\text{C}$
Thermal resistance	$\text{m}^2\text{°C/W}$
Thermal resistivity	$\text{m}^\circ\text{C/W}$
Volume	$\text{m}^3$



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