Building Problems in Hot Climates

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ABSTRACT

Nowadays, because of lack of traditional sources of energy and high maintenance cost, building as a one of the major energy consumer and its problems in hot regions become one of the main concerns of architects and designers. Also, there is a growing global interest in the impact of human activities on the environment in respect to global warming. The increment of energy demand in the developing world and global warming issues define the need for buildings with less problems.

With regards to built environment, the primary concern is sustainability in the developments of the building industry and building energy consumption. This implies consideration of the impact of the climate and environment on the building and ultimately the effect of the building's condition on the occupants. This awareness has initiated many studies related to climatic design to maximize indoor comfort with minimum and efficient use of the energy.

Therefore, this study tried to collect building problems by focus on hot regions and provide some precautions related to those problems for planners, architects and others who working with planning and design of the built environment in hot climate zones. In this case building problems in different terms for hot climate areas have been considered. Following research contains three chapters. First chapter is the introduction to building problems in terms of thermal comfort, construction and building services systems in hot climates. In second chapter those problems, which have been discussed in chapter 1 evaluated. Finally chapter 3, which is conclusion for this study, tried to show the possible areas for further studies.

Keywords: Building problems, hot climate, Thermal Comfort,

ÖZ

Günümüzede, enerjinin azalması ve bakım maliyetlerinin yüksek olması nedeniyle, sıcak iklim bölgelerinde yer alan ve enerji tüketicilerinden biri olan binaların yapı problemleri, tasarımcı ve mimarların ilgilendiği temel sorunlardan biri haline gelmiştir. Bununla birlikte, insan aktivitelerinin Dünya üzerindeki olumsuz çevresel etkilerileri konusunda ilgi artmıştır. Bu bağlamda inşaat sektöründeki gelişmeler, çevresel sürdürülebilirliğin sağlanmasını hedeflemeya başlamıştır. İklim ve çevre üzerinde oluşan olumsuz etkiler, binalar ve bina kullanıcılarını da etkilenmektedir. Bu nedenle kullanıcıların ısıl açıdan kendilarini konforlu hissetmeleri, iklimlendirme için harcanacak enerjinin etkin kullanımı ve yapı hasarları konusunda birçok çalışma yapılmaya başlanmıştır.

Yapılan bu çalşmada sıcak iklim bölgelerinde bina problemleri hakkında bilgi toplamak, bu problmlerle ilgili önerilen önlemleri, bu bölgelerde çalışacak olan tasarımcı ve mimarlara bilgi olarak sunmaktır. Üç bölümden oluşan bu çalışmada, sıcak iklim bölgelerinde bina problemleri farklı açılardan değerlendirilmiştir. Birinci bölümde yapılan çalışmanın girişi, sıcak iklimlerde binalarda ısıl konfor problemleri, yapım ve yapı problemleri ve bina servis sistemleri problemleri incelenmiştir. Ikinci bölümde, birinci bölümde araştırılan problemler değerlendirilmiş, ve sonuç bölümü olan bölüm dörtte ise, araştırmada elde edilen sonuçlar ve daha ileri çalışmalar yapılması gereken alanlar belirtilmiştir.

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INTRODUCTION

There is growing worldwide interest in the impact of human activities on the environment. With regards to built environment, the primary concern is sustainability in the developments of the building industry and building energy consumption. This implies consideration of the impact of the climate and environment on the building and ultimately the effect of the building's condition on the occupants. This awareness has initiated many studies related to climatic design to maximize indoor comfort with minimum and efficient use of the energy. [1]

As we know, the baseline heat load is governed by the owner's functional and decisions about building orientation, solar shading of the windows and their total glazing area. After those decisions have been made, the architectural designer controls the percent of those baseline loads, which enter the building and then HVAC designer figures out how to remove the remaining loads as smoothly as possible. [2]

So, in order to gain successful result in architectural design steps, some aspects as like as following points has to be strongly considered:

- Shaded windows improve comfort and reduce glare
- Less glass on east and west faces provide better comfort level
- Tight, well-insulated exterior wall avoid sharp changes
- High ceilings and personal fans allow low cost comfort
- One fan per room prepare better comfort and simple systems

This study tries to answer to this question that how we can define those aspects. In this thesis, general problems of buildings in hot climates will take into consideration to finally provide some checkpoints for architects to have appropriate evaluation of their design with maximum thermal comfort level for the building occupants. In order to reach to this aim, first of all factors which effect building design on thermal comfort as like as building layout, building orientation and building envelope will be reviewed. After this revision, those problems, which rise up will be categorized into two sections as following:

- Building construction problems
- Building service system problems

In order to find out building construction problems, factors which effect building construction during two different stage, construction stage and after construction stage will be taken into consideration, which in first stage, problems of different structure systems will be mentioned. Those structural systems will be Reinforced Concrete, Steel, Timber structure. In the second stage of building construction problems, problems appeared in non-structural components, as like as external walls, wall openings, roofs and internal components will be analyzed. Finally, building services system problems, which include air conditioning system, electric supply system, domestic water supply system and water waste system will be mentioned.

1.1 Aim and objective

The aim of this investigation is to minimize the unfavorable impact of the outdoor climate on the building and consequently the condition of the indoor climate. So simply stated, the goal is to introduce a collection of successful applied methods to maximize indoor comfort by minimizing the adverse climatic effect with minimum energy consumption.

In this case, for optimum thermal performance of the building, different climates call for different design strategies. In design strategies, which normally apply by architects in those region different types of problems reported frequently. Those important problems, which are structural and non-structural problems, will be categorized as following:

Construction Problems of Building Structure

1. Construction Problems of Reinforced Concrete (RC) Structure Systems
2. Construction Problems of Steel Structures
3. Construction Problems of Timber Structures

Construction Problems of Building Non-Structural Components

1. Construction Problems of External Walls
2. Construction Problems of Wall Openings (windows, doors, openings)
3. Construction Problems of Roofs
4. Construction Problems of Internal Non-Structural Building Components (stairs, partition walls, suspended ceiling, etc).

Building Services Systems Problem

1. Building Air Conditioning Systems
2. Electric Supply Systems
3. Domestic Water Supply Systems
4. Waste Water Systems

This research, reviewed all problems mentioned above and tried to suggest appropriate solution for them with respect to specific hot climates chosen before. It tried to be a reference for architects who need to be aware of constructional or non-constructional problems in hot climates.

1.2 Methodology of research

Methodology used in this study is literature review in combination with empirical investigation in order to collect data. Those data has been collected from books, articles and scientific journals in this specific topic. After data collection stage, data analysis had been done in order to find out the problems of buildings in hot climates in compare to other type of climates.

In other words, important aspect of architectural planning like site selection, layout, shape, spacing, orientation reviewed and different type of technologies applied to elements of building envelope as like as walls, windows, roof, underground slab and foundation compared in order to find out the best technology and highest building performance to solve or at least decrease any type of problems usually observed in Hot climates.

1.3 Scope of the study

In this study, general problems of buildings in hot climates will take into consideration. In order to reach to this aim, first of all factors which effect building design to reach to thermal comfort as like as building layout, orientation and building envelope, etc. will be reviewed. After this phase building problems will be categorized as following:

- Building construction problems
- Building service system problems

In order to find out building construction problems, factors which effect building construction during two different stage, construction stage and after construction stage will be taken into consideration, which in first stage, problems of different structure systems will be mentioned. Those structural systems are Reinforced Concrete, Steel, Timber and Composite structural system. After analyzing the constructional problems, problems appeared in non-structural components, as like as external walls, wall openings, roofs and internal components will be analyzed. At the end building services system problems, which include air conditioning system, electric supply system, domestic water supply system and water waste system will be mentioned.

1.4 Background Information

It will be essential for any readers to be familiar with the key terms of this study. In following a quick review on some of those terms has been done:

Thermal comfort: Thermal comfort is defined as the situation in which the body adopts itself to the environment by consuming the minimum amount of energy. [3]

Climate: Weather is the set of atmospheric conditions prevailing at a given place and time. The change in time of weather conditions in a certain geographical location can be defined as Climate. The differentiation in solar heat input and the uniform heat emission over the earth's surface will create global level of climates. [4]

Hot-humid Climate: If a region has share of annual precipitation greater than 50 cm and has 3000 or more hours of 19.5° C temperature or 1,500 or more hours of 23° C temperature during the warmest six months of the year (Building Science Corporation), region has hot-humid climate. The function of the buildings in such a climate is to simply moderate the daytime heating effects of the external air. [4]

Thermal convection: Natural or free convection is the process whereby a fluid moves because of differences in its density resulting from temperature changes. [5]

Thermal conduction: The concepts of thermal conduction and resistance are important in attempting to provide a comfortable environment for the inhabitants of hot, arid regions. These heat-flow concepts are based on the movement of a quantity of heat. [5]

Thermal radiation: All matter emits electromagnetic waves, which are generated by the thermal motion of molecules composing the material. Such radiation is called thermal radiation. [5]

Insulation: Insulation is essential to keep building warm in winter and cool in summer. A well-insulated building will provide year-round comfort, and cost less to cool and heat. Insulation also helps to reduce noise levels and condensation. [6]

R-value: The ‘R value’ measures how good the insulation material is at containing heat. The higher the R-value, the better the insulation will be. The insulation needs to be properly installed to reach the R-value. [6]

Reinforced concrete: is one of the most widely used modern building materials. Concrete is artificial stone obtained by mixing cement, sand, and aggregates with water. Fresh concrete can be molded into almost any shape, which is an inherent advantage over other materials. [7]

Buildings with Steel structure systems: A steel building is a metal structure fabricated with steel for the internal support and, commonly but not exclusively, for exterior cladding. Such buildings are used for a variety of purposes including storage, office space and living space. They have evolved into specific types depending on how they are used. [8]

Timber-framed structure: Timber-framed structures differ from conventional wood framed buildings in several ways. Timber framing uses fewer, larger wooden members, commonly timbers in the range of 15 to 30 cm, while common wood framing uses many more timbers with dimensions usually in the 5 to 25 cm range. [9]

1.5 Introduction to building problems in hot climates

"The primary purpose of a building is to shelter the occupants from unfavorable outdoor conditions such as heat, cold, wind and rain. Thus, the building should be designed to provide a desirable indoor climate." [1] By worldwide concern on sources of energy and environmental issues, many factors should be considered altered at the design stage of buildings. Through those issues to be considered at is the suitability of the building design and materials in terms of climate properties. [1]

According to a large number of research works [2], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], in order to indicate the climatic suitability of the building design and building materials, designers and/or architects have to be aware of the climatic characteristics of their working environment. Moreover, based on the related climatic elements, they will be able to categorize the building problems and apply or suggest their solutions to avoid them. This progress is defined as climatic design, having taken into consideration the climatic parameters of the area.

In order to have successful climatic design in hot climates, which is the main focus in this study, first of all, the resources of the building problems have to be known in advance. Five factors have been commonly referenced in many studies [1], [2], [15], [17], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33].

These resources include:

- High temperature,
- High solar radiation or high UV level,
- Moisture or high RH level,
- Excessive heat gain in summer
- Heat loss during winter

Considering the said factors, different types of building problems, classified in three different categories are listed below:

- Thermal comfort problems
- Constructional (structural and non-structural) problems
- Building service systems problems

In this chapter, a brief description regarding the climatic design, classification of climates and climatic elements is given in order to provide some basic information and then the three groups of problems mentioned above will be reviewed deeply. In order to reach the maximum building performance with less energy consumption, building designers have to pay attention to regional climate. The process of identifying, understanding and controlling climatic influences on the building site is perhaps the most critical part of the building design. The key objectives of climatic design include: [24]

- To reduce building energy consumption
- To use natural and renewable energy resources
- To reach the maximum level of thermal comfort

1.5.1 Thermal comfort problems in hot climates

In the previous section, it was clarified that the type of climate and the concept of climatic design play the main role in building design strategies. In hot climates, as mentioned in different studies [1], [2], [4], [5], [15], [17], [18], [24], [25], [26], [29], [31], [32], [35], [36], [37], [38], high heat gain during the summer and high heat loss during the winter period is the main issue, which affects the thermal comfort level of occupants. In this section, the following subjects are the main focus:

- How hot climates affects thermal comfort,
- How building should be designed to be comfortable in thermal terms
- And finally how we can design energy efficient buildings with air-conditioning facilities.

Human body is faced with three common types of heat transfer methods and as their consequences during summer time body temperature will increase while in winter time it will be in reverse. Therefore, in order to provide comfortable situation for human in terms of temperature, an important concept introduced as Thermal Comfort. Thermal comfort is defined as the situation in which the body adopts itself to the environment by consuming the minimum amount of energy and its factors generally are divided into two major groups, objective and subjective. For instance, air temperature and relative humidity are objective factors, while thermal insulation clothing and shape of the body are taken into account as the subjective factors [2], [3]. Thus, in order to provide thermal comfort situation for those who live specially in hot regions, recognition of its problems and related solutions will be mandatory.

In hot regions, buildings normally face three main issues with respect to the thermal comfort principles:

- Excessive heat gain in summer
- Excessive heat loss in winter
- High relative humidity level

Therefore in order to reach an acceptable thermal comfort level, building as subject, should be designed in a way to reduce the above-mentioned defects. For instance, many studies have been performed on the properties of building envelope, building layout and orientation of building in order to eliminate the negative effects of hot climates on occupants' thermal comfort [4], [24], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56]. These researches mention that building has to be designed appropriately by taking some major factors into consideration. These factors include, but are not limited to orientation, layout, form and materials. On the other hand, in a building that takes advantage of air conditioning system, in order to have efficient use of energy resources, the building has to be able to conserve energy generated in the field with use of sufficient insulation material. Thus, thickness, type and installation location of those materials in building envelope have to be well defined [4], [25], [51], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72].

Furthermore, a combination of passive solar systems with these mechanical systems will provide additional control on the amount of energy, which consumes to provide the desired thermal comfort for the occupant [1], [16], [26], [31], [32], [36], [38], [73], [74], [75], [76], [77].

In this section, a number of studies on thermal comfort principles and its problems in hot climates were taken into account in order to clarify the following subjects:

- The effect of hot climates on thermal comfort
- Find out problems in hot climates in thermal comfort terms
- Suggest relative design strategies to avoid those problems

Effect of Hot Climates on Thermal Comfort

As mentioned before, thermal comfort is defined as the condition of mind, which expresses satisfaction with the thermal environment [11]. Different types of analyses indicate that a variety of factors can be involved in situations of human comfort [2], [3], [78]. For example, merely temperature could not measure discomfort. In hot and dry climate, 32 °C is quite bearable, but it is generally intolerable in hot and humid climate. The difference completely belongs to the relative humidity of the atmosphere.

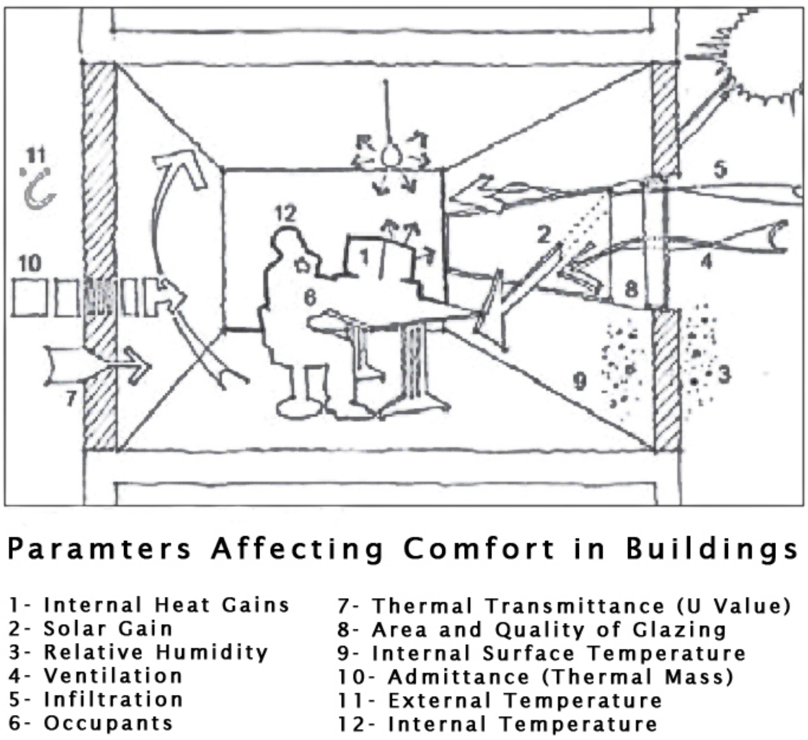


Figure 1.1: Parameters affecting comfort in buildings
(Source: Allard F., *Natural ventilation in buildings*, James & James, London, 1988)

In building industry, factors that have been identified as standard for thermal comfort are: air temperature, air humidity, rate of air movement, level of radiation, and rate of heat production by the bodies of people in the building. Some parameters affecting comfort in buildings are depicted in figure 1.1. [79]

In hot climates areas as described before, heat gains during cooling season and heat loss in the heating season are the major defects engaged in hot climates. These problems, which affect thermal comfort level of the building occupants, can be accompanied by excessive moisture content (Relative humidity), which is another important factor to create an uncomfortable thermal environment. During summer, due to different parameters such as angle of solar radiation, high temperature and relative humidity, large amount of heat gain from building envelope and roof will bring uncomfortable feeling including large amount of energy consumption.

On the other side, in winter heat loss will appear because of incorrect insulation progress. This amount of loss is directly in relation with thickness, position and type of building insulation materials. Now thermal comfort problems caused by factors mentioned above will be reviewed and analyzed accordingly.

Thermal Comfort Problems in Hot Climates

The first consequence of thermal comfort problems as described in some studies is reduction in energy efficiency level of buildings [1], [16], [26], [36], [73], [74], [75], [80], [81]. Energy efficiency can be described as reaching the highest quantity of goods and services out of each unit of energy consumed. Successfully designed energy efficient building will reduce a building's operating costs, because of less consumption of energy and therefore its maintenance costs. In technical terms, energy efficiency is expressed in terms of the ratio in percentage shown by η:

$$\eta = \text{Output}/\text{input} \quad [6]$$

Note that, unfortunately, due to loss of energy when one form of energy transforms into another, there is no optimal performance in the real world.

In general, buildings are significant users of energy and building energy efficiency is a high priority in many countries. In hot climates regions, huge amount of energy is usually used in order to provide thermal comfort conditions for the occupants and large amount of money is spent due to maintenance costs arising from inappropriate design or put another way thermal comfort problems. [6] These inappropriate designs resulting in heat loss due to building envelope in winter and heat gain from roof and walls in summer could be avoided by applying techniques such as heat gain reduction in overheated periods and under heated periods. In addition to excessive heat gains and losses, controlling air moisture content is another important issue, which has to be considered by providing proper air ventilation.

Therefore, to achieve the mentioned goal, architects as building designers have to examine some aspects in the design stage namely building layout, orientation and envelope details (shape, insulation, solar control) to control thermal performance and sustainability of buildings. In following sections heat gain reduction methods in overheated periods, heat gain methods in under-heated period and reduction relative humidity will be discussed in more details.

1.5.1.1 Building problems in Overheated Periods

In summer season of hot climates regions, building should be designed in a way to reduce the amount of heat gain. To consider this issue, different components of the building should be analyzed accordingly with respect to two main factors: solar control and thermal insulation. For instance, for the purpose of controlling the solar radiation, taking into consideration an appropriate building layout, orientation and form will be beneficial and will in turn makes it feasible to take advantage of methods such as shading, envelope reflective texture and transparent envelope. In the meantime, making use of thermal insulation will provide a type of barrier to isolate the interior from exterior and therefore control the consumption of energy and cost.

As mentioned above, solar control is one of the main strategies in building design in hot climates. In order to have successful control on solar radiation following parameters have to be taken into account precisely:

- Building layout, form and orientation
- Building envelope
- Opaque envelope (including walls and roofs)
- Transparent envelope (including walls and roofs)

Building Layout, Form and Orientation

In hot climates, architectural and landscape designs should be closely integrated. If possible, windbreaks must be provided in cold winter and access must be made feasible to cooling breezes in the summer. Noted that, proper windbreaks will add advantage of low relative humidity by using natural air ventilation.

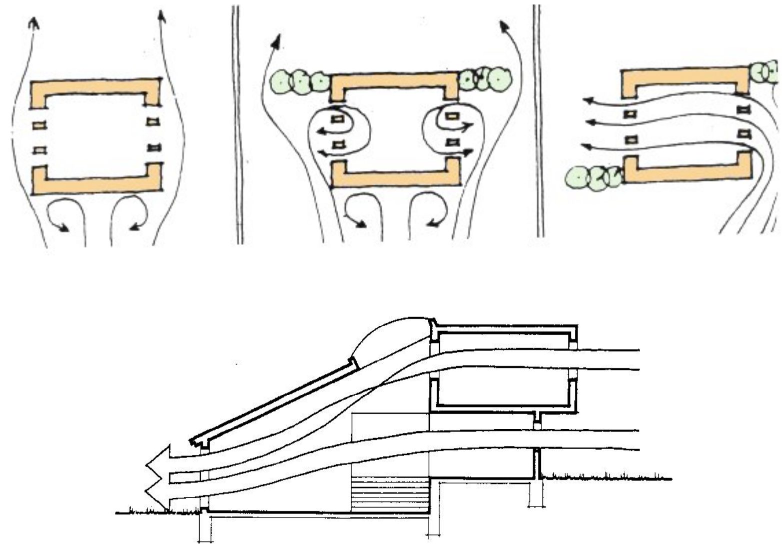


Figure 1.2: wind control in site analysis
(Source: Watson D., Kenneth Labs, *Climatic building design – energy efficient building principles and practice*, McGrow Hill, USA, 1983)

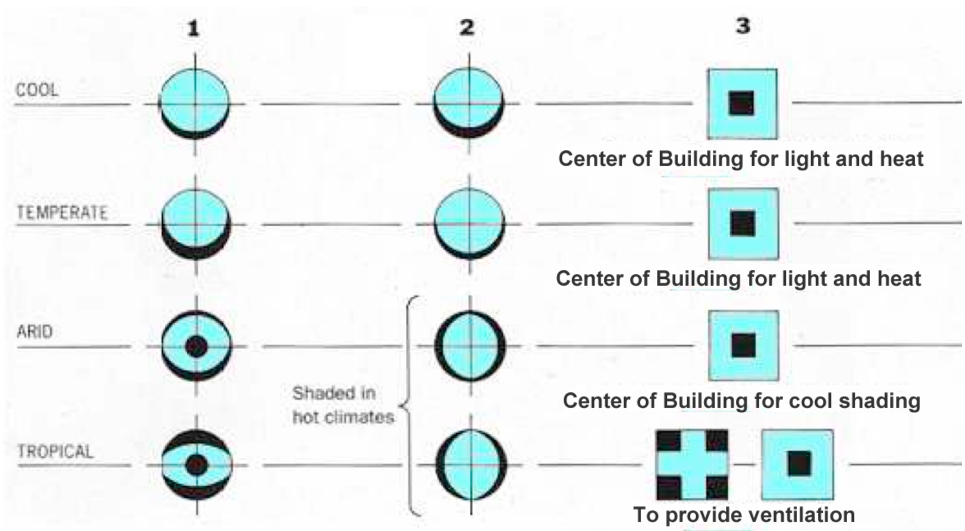


Figure 1.3: different areas of building in different climates
(Source: URL www.arch.hku.hk)

In order to get an idea about building orientation and layout, group of engineers and professors at the University of Hong Kong have performed an analysis, which is summarized in figure 1.3. As depicted in this figure, there are 3 different columns, which analyze different areas of building form in 4 different climates. In the first column, the black areas represent the traditional spaces used for lobbies, stairs, utility spaces, circulation, balconies and any other areas where movement take place. These areas do not require total climatic control, because natural ventilation is sufficient. For hot climates areas, the transitional spaces are located on the north and south sides of the building where the sun's penetration is not as great as the other sides. In temperate and cool areas the transitional spaces should be located on the southern side of the building to maximize solar gain. In the second column, the black areas are spaces that can be used for solar heat gain, which will be the eastern and western sides in hot climates areas. The third column indicates that in the hot climates area, atrium should be located at the centre of the building for cooling and shading purposes. [24]

In the case of the orientation of building in hot climates, different studies carried on by some group of researchers show that it should be directed to southeast. This result is also confirmed by Lewis G.Harriman, Joseph W. Lstiburek in ASHRAE guide for buildings in hot and humid climate.

Table 1.1: Potential building orientation in different climates [23]

Zone	Building's main orientations	Directional emphasis
Tropical	On an axis 5^{o} north of east	north-south
Arid	On an axis 25^{o} north of east	south-east
Temperate	On an axis 18^{o} north of east	south-south-east
Cool	On an axis facing south	facing south

In case of building forms few studies have been done. [24], [82] The optimum building form in hot climates according to scientific statistics and research, is those forms which have 1:2 where the sides are of length x:y. In addition to ratio of width/length, the cores could be located on the east and west sides, but primarily on the south side because of high sun depth in those location. It has to be noted that in hot climates major shading is only needed during the summer.

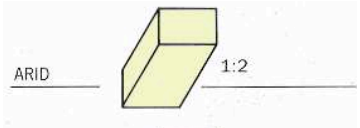


Figure 1.4: building forms in hot climates
(Source: URL www.arch.hku.hk)

Building Envelope

Building envelope can be opaque or transparent. In any of these cases, different methods will be applied to have successful solar control method on building. For example in transparent surfaces (glass or plastic base materials), we use solar shading devices, reflective glasses, low-emission glasses or double skin facades. But in opaque surfaces, we usually use painting, which has reflective properties. In addition to that, in opaque envelope, thermal insulation materials, placed near the inner surfaces, will provide sufficient level of comfort ability. In this section these issues will be discussed in more detail.

A. Opaque Envelope

Roof and wall are two important components of any envelope. Therefore, to have review on problems cause in opaque envelope and their precautions, in following sections first opaque walls and then opaque roofs will be taken into consideration.

Opaque walls

In opaque wall, also referred to as masonry walls, two factors are mentioned in researches [2], [37], [44], [57], [58], [62], [64], [72], [83], which will avoid excessive heat gain in hot climates, reflective surface and thermal insulation.

Because of high absorption of solar radiation by opaque walls, it would be possible to use reflective surfaces on opaque walls in order to reduce heat gain by this component of building envelope. Note that, related to reflective opaque wall there is no enough scientific research and the main focus of researchers was in reflective opaque roofs and their behaviors. But the same result of roofs could be applied to opaque walls color. In this form, it will be feasible that light colors as like as white or grey will work as reflective surface on opaque walls.

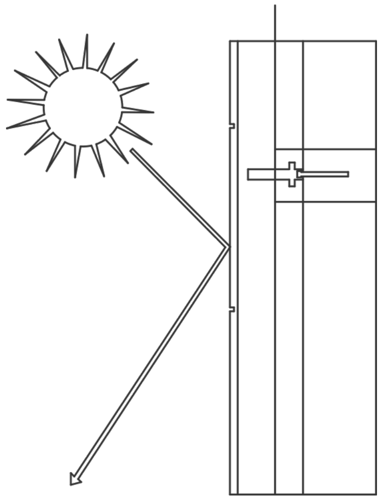


Figure 1.5: Reflective surface in order to reduce heat gain

As discussed above, in order to provide appropriate thermal comfort level for building's occupants and also reduce defects of structural and non-structural building components, in hot climates regions, designers have to use some techniques to reduce heat loss/gain level in winter/summer. The most well known technique is called thermal insulation. Most insulation installed in buildings is installed at the time of the original construction. For this reason the insulation used are part of system of construction of the building. The number of construction materials and combinations used are quite numerous. They generally divided into to groups:

- Organic insulation materials
- Non-organic insulation materials

A comprehensive list of famous insulation materials used nowadays in construction progress is explained in table 1.2.

Table 1.2: List of insulation materials

Insulation Type	Insulation materials
Inorganic, made from synthetic materials	Calcium silicate
	Glass wool/rock wool
	Cellular glass (CG)
Inorganic, made from natural materials	Expanded perlite (EPB)
	Expanded clay
	Vermiculite
Organic, made from synthetic materials	Polyester fibers
	Expanded polystyrene foam (EPS)
	Extruded polystyrene foam (XPS)
	Expanded polyurethane foam (PUR)
Organic, made from synthetic materials	Cotton
	Flax
	Granulated cereals
	Hemp fibers
	Wood fiber insulating board (WF)
	Wood-wool slab (WW)
	Wood-wool multi-ply board (WW-C)
	Coconut fibers
	Insulation cork board (ICB)
	Sheep's wool
	Cellulose fibers
Innovative insulating materials (organic/inorganic)	IR absorber modified EPS
	Transparent thermal insulation
	Vaccum insulation panel (VIP)

(Source: Auch-schwelk H., Rosenkranz F., *Construction materials manual,* Birkhauser edition detail, Munich, 2006)

There are legal minimum requirements for insulation in new buildings and additions to existing buildings, defined by different institutions and the standard organization. To consider the relative efficiency of insulating materials, some parameters of the insulation materials can be taken into consideration.

In thermal insulation materials, two main specifications are:

- **R value**
  - R-value measures the heat absorption capacity of insulation material. The higher the R-value, the better the insulation will be. The Building Code specifies minimum R-values for floor, wall and ceilings. [84]
- **Labeling**
  - Insulations materials normally labeled to provide the following information:
    - Description of contents
    - R value with the conditions under which the R value applies
    - Safety and handling instructions
    - Installation instructions
    - Fire safety. [84]

In order to have successful thermal insulation in hot climates, three main factors can be estimated and properly designed. These factors as found in number of studies [2], [4], [25], [26], [51], [59], [60], [61], [62], [63], [64], [65], [66], [70], [71], [72], [73], [83], are

- Type of insulation materials
- Location of the insulation materials
- Thickness of insulation materials

Although, it is better that some other parameters such as convection around insulation and heat bridging have to be evaluated.

Type of the insulation material

As mentioned before, nowadays there are different types of insulation materials with different prices for various purposes. According to these researches [57], [58], [59], [60], [61] on insulation materials and their usage in hot climates areas, there are four main insulated materials used the most. Those are foam polyurethane, mineral wool, extruded polystyrene and concrete block. The best solution by considering the cost as discussed by K.S. Al-Jabri, is use of concrete block as capacitive thermal insulation. K.S. Al-Jabri found out that development of concrete blocks with high thermal insulation properties becomes a necessity in hot climates regions. In addition to concrete blocks, the use of masonry walls with high thermal resistance has become of great importance in hot weather countries where temperature can reach high levels especially in summer, which can be achieved either by constructing double skin walls using ordinary blocks or manufacturing new blocks with low thermal conductivity [61].

But if the cost factor is eliminated, the Extruded polystyrene foam has the best performance for insulating houses in hot areas compared to foam polyurethane, mineral wool, since it has the lowest optimum thickness of insulation. This result is reported by Mohammed J. Al-Khawaja. Although it has the highest cost, it is still the preferable insulation for the hot climates. This is because of the optimum thickness of insulation which does not only account for the insulation cost but also for the thermal conductivity of the insulation, and Extruded polystyrene foam has the lowest thermal conductivity compared to others [35]. However, any other insulated material can be applied to building envelope in order to make it thermal insulated.

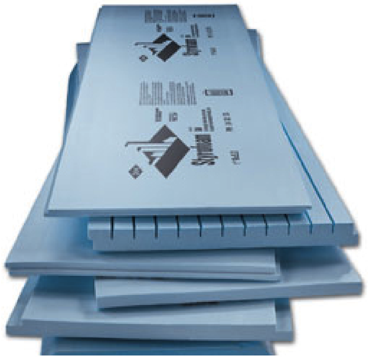


Figure 1.6: Styrofoam (extruded polystyrene foam) insulation materials
(Source: URL www.homeconstructionimprovement.com)

Location of the insulation material

Insulation in the buildings should reduce the heat loss in cold weather and heat gain in summer. If insulation were only required to control heat flow, it would not matter where the insulation is placed in the wall, but it can reduce thermal movement in the structure, at least. Movement due to temperature changes causes many of the stresses and cracks in buildings. Placing the insulation outside the structure can eliminate movements in the structure. Similarly, foundation walls can be kept warm by placing insulation in outer surfaces [63].

In order to check the influence of thermal insulation position in building envelope, M.Bojic and F.Yik, had a comprehensive investigation on yearly maximum cooling demand in different building envelops by adding insulation to external walls, varying the thickness of the insulation and concrete. The thermal insulation layer was located either at the inner, middle or outer part. They have found that the placement of the thermal insulation at the inner part of the wall structure lowers the yearly cooling load [25].

This result also reported by Sami A. Al-Sanea, indicates that in spaces where the air-conditioning system is switched on and off intermittently, the insulation should be placed indoors. However, the placement of the thermal insulation outside or at the middle may lower the yearly cooling load. On the other side, the yearly cooling load is mildly sensitive to the increase in the masonry thickness above 10 cm and to increase of the thermal insulation thickness above 5 cm [64], [66], [70].

In addition, architects should not forget these points that orientation of the building, size and occupancy patterns will affect the result coming from thermal insulation. As the final result of this investigation applying insulation indoor or outdoor can reduce the yearly cooling demand by considering whether indoor space is acclimatized or not [64].

To summarize the above discussion, and according to the investigations performed by researchers namely M. A. Eben Saleh in hot climatic regions [67], [69], in hot climates the position of insulation materials within the walls and roof will provide positive effect on the thermal performance of the buildings. But in buildings, which use air-conditioning systems, the suggestion is to place thermal insulation material in inner face of the building envelope to provide fast thermal comfort level for occupants. Insulation located on the outer layers of the building, along with an airtight waterproof membrane will keep solar heat out of the building, and it will also keep out hot air. Plus, when the insulation is all on the outside of the structure, the large mass of the building is inboard, so it will act as a thermal storage buffer, absorbing some of the excess heat from the indoor air during peak loads.

It should be noted that by placing the insulation material in outer face of building envelope, building will face a negative effect in winter day time and summer night time; therefore making use of passive solar systems extremely suggest in addition to the appropriate insulating process [65], [66], [67], [72].

Thickness of insulation materials

As mentioned in above sections, thickness of the insulation materials also has an important role in satisfying energy efficient concept. The optimum insulation thickness depends on the cost of insulation material and cost of energy, as well as cooling and heating loads, efficiency of the heating system. A sophisticated way of selecting insulation thickness is to use computer programs designed to minimize the energy use [68].

In hot climates based on all the factors reviewed, it is recommended that a medium density, glass fiber cavity wall insulation be used in walls and that it be applied with mechanical fasteners that hold it tightly to the air/vapor barrier. 5-10 cm thickness of thermal insulation materials, placed on external face of the building envelope, comes up with best solution that even could exclude thermal bridging. On foundation walls, apply waterproof polystyrene foam outside the waterproof membrane. Where it is exposed above grade, use cement coated polystyrene foam to protect it against sunlight [35], [60], [61], [63], [65], [66], [83].

Opaque roofs

In order to have acceptable design for building envelope with efficiency in energy issue, roof has to select and design carefully. In hot climates, generally there are 2 common types of opaque roofs according to their slopes: low sloped and sloped roofs. The importance of roof comes from that point, where it is exposed with large amount of solar radiation, therefore it is very difficult to protect.

According to study done by Hancer P., 14 different types of roofs with different position of insulation, shown in figure 1.7, has tested and overall evaluation of the roofs shown that roofs number 9,2,4,8 and 12 in the case of thermal comfort and energy saving criteria will be the solution in compare to roofs 10, 13, 3, 5, 1 and 14. By the way, roofs number 7, 11 and 6 show the worst performance accordingly.

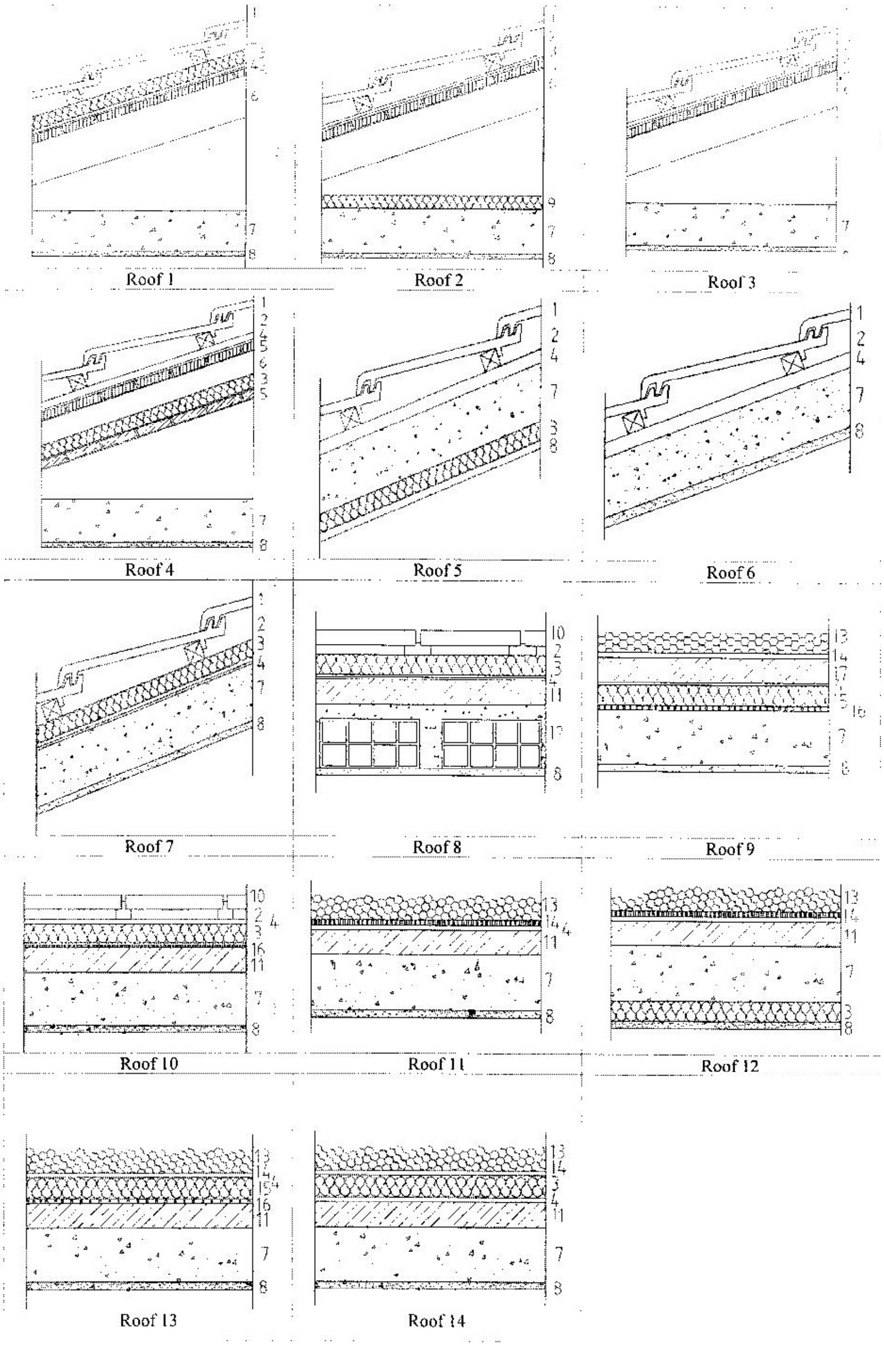


Figure 1.7: 14 roofs type with different insulation position

((1) roof tile, (2) timber lath 2.5cm (3) extruded polystyrene heat insulation 4cm (4) polymetric bituminous membrane water insulation (5) timber board 2.5cm (6) timber rafter 5/10xm (7) R.C. slab (8) Gypsum plaster 0.5cm (9) soft glass wool heat insulation4cm (10) terrazzo 4cm (11) leveling concrete 4-6cm (12) hollow clayblock floor 17cm (13) pebble 3cm (14) felt (15) hard glass wool 4cm (16) vapor retarder (17) protective concrete 8cm)

(Source: Polat Hancer, *Thermal insulation of roofs for warm climates*, PHD Thesis, Eastern Mediterranean University, North Cyprus, 2005)

So in hot climates, the low-slope roofs and inclined roofs with attic space, which are insulated closer to inner surface, and terrace roofs are the best-performed roofs. These are followed by, the inclined roofs without attic space insulated near the inner surface and low sloped roof insulated close to external surface. It should be noted that, all types of the roofs without insulation exhibited the worst performances compared to the other roofs.

The inclined roofs with attic space show higher performance in the overheated period. The roofs which benefit from the sun light during the under heated period like the low slope roofs, increase their performances compare to the performances in the under heated period.

Positioning of the thermal insulation in a roof section affects the performance. Therefore, placing the insulation towards the inner surface increases the thermal performance of all types of the roofs. The terrace roof showed the best performance when the thermal insulation is located close to the external surfaces of the roofs. The roofs insulated near the inner surfaces show higher performance than in the case of the thermal comfort criteria. Their extremely higher performances during the interrupted acclimatization, positively affect the total performances. [4]

Thus, by placing them towards the inner surfaces of roof, the thermal performance of all types of roof increases. This conclusion is valid whenever there is continuously acclimatized indoor space. In contrary, the positioning of the thermal insulation material to the close internal surface drops the roof performance, while there is not acclimatized indoor space. The same result from P. Hancer, confirms that for example the positioning of the thermal insulation materials in roof section affects the performance concerned in according to acclimatization. [4]

Moreover, In the case of insulating roof, as one of the most important building elements in hot climates, again massive thermal insulation will be the best solution in addition to reflective insulation concept. Australian engineers, Harry Suehrcke and Eric L. Peterson have done an analysis to measure the effect of color on the roof heat gain. Eventually in case of hot climatic location, architects can achieve to significant reduction of heat flow by using a light or reflective roof color instead of a dark one, which means a reduction in air-conditioning load or an increase in human comfort [62]. Unfortunately there seems to be few researches [4], [49], [22], [85] done on reflective roof and its advantages compared to non-reflective roof in hot climates.

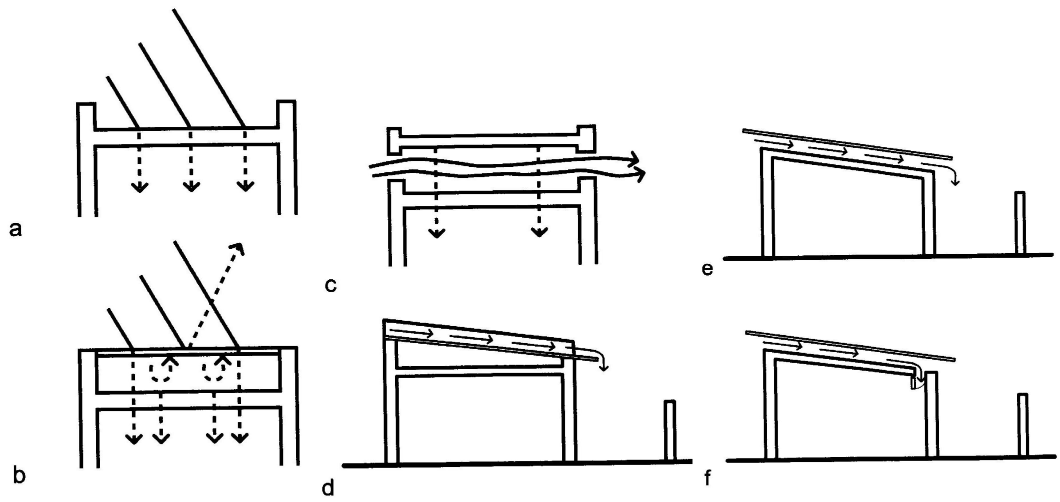


Figure 1.8: a) flat roof expose solar radiation during daytime b) reflectivity will reflect solar radiation partially c) remove trapped heat by roof ventilation d) sloped roof with control walls could be direct cool air into courtyards e & f) sloped roof could be separated to increase cooling process
(Source: *Stay Cool a design guide for the built environment in hot climates*, Holger Koch-Nielsen, Cromwell Press, UK , 2002)

At the end, It has to be mentioned that using rigid roofing type fiberglass as foundation insulation can be an appropriate solution, because in fact it makes drainage layer. On roofs, use waterproof extruded polystyrene foam in the protected membrane system. For conventionally insulated roofs, the special high-density glass fiber insulation made to be used as roof insulation [38], [61], [63], [65], [66], [83].

B. Transparent Envelope

For architectural designers, the most important decision concern glass. But more glass means heat getting into the building and less glass means less heat getting in. ASHRAE suggest that maximum 30% of the exterior wall as glass is a useful rule of thumb, but less is better from the perspective of excluding heat. The drama of large glass sheets, and the many exciting advancements in glass technology seem to have embedded the unhelpful misimpression that huge glass walls save energy and increase the building's sustainability. Such is not the case in an air-conditioned building in a hot and humid climate.

To keep heat out of the building, the glass decisions will need to be guided by the useful principle that less is more. Glass transmits far more heat from the hot outdoors that does an insulated wall. Their different heat transmission rates in respect to their U-value quantify this point. With glass, between 30 and 70% of solar radiation will enter the building, along with the heat moving through that glass by convection. Glass or any type of transparent building materials could be used in wall and roof to create transparent walls and roofs. Glass normally divided as following:

- Reflective and diffuse reflective glasses
- Solar control glass or low-E glasses
- Decorative glass and normal glass.

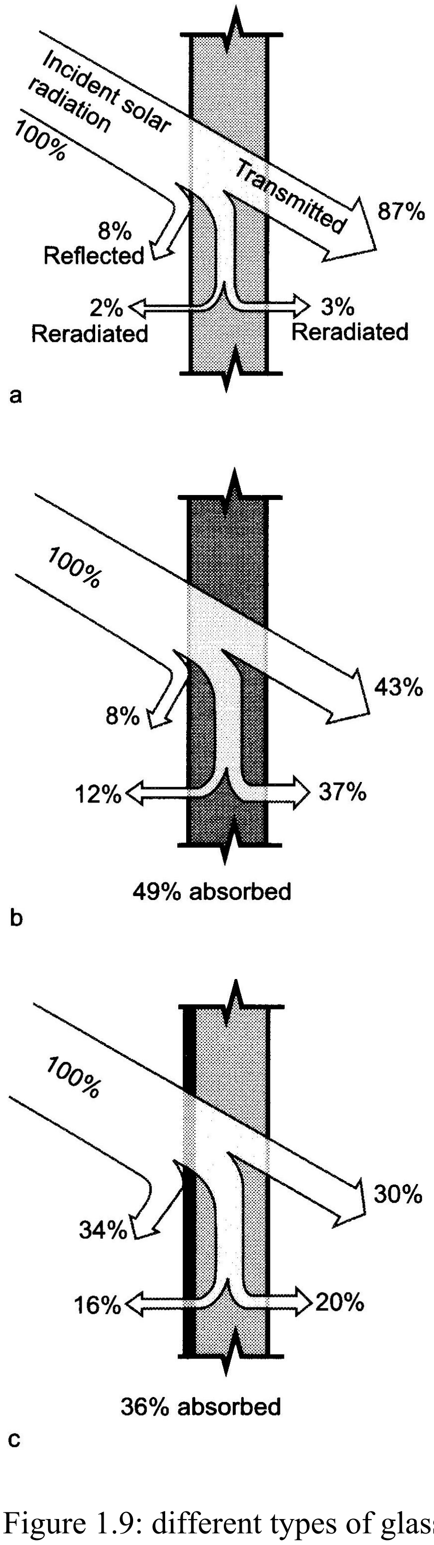


Figure 1.9: different types of glasses

a) Normal glass b) Reflective glass c) low-E glass

(Source: *Stay Cool a design guide for the built environment in hot climates*, Holger Koch-Nielsen, Cromwell Press, UK , 2002)

Reflective glass decreases the transmission of solar radiation, while blocks entering lights more than heat. Therefore, window's visible transmittance (VT) decreased dramatically. Meantime, it reduces a solar heat gain coefficient (SHGC). Reflective glasses usually include thin, metallic layers in various colors. They mostly used in hot regions where solar heat gain control becomes critical. A Low-E glass is a type of glass including microscopically thin, and somehow invisible, metal or metallic oxide layer applied directly to the surface of one or more of the glass panes. This Low-E cover declines the IR (infrared) radiation from a warm pane of glass to a cooler pane, thereby decreasing the U-factor of the window. To be noted here that U-factor is a rate, which any types of openings conducts non-solar heat flow. [99]

In hot climates, diffuse reflective glasses and solar control glasses are highly recommended, based on their heat gain reduction characteristics. Furthermore, if glasses powered by tinting or laminating techniques, total thermal performance of transparent envelope would increase tremendously.

Transparent walls

By considering above information related to glasses and their role in transparent walls, in particular should be stated that, west-facing glass increases the size and complexity of the cooling system more than glass on the other three faces. This is because the sun streams its heat through the west-facing glass at the end of the day, after the entire building has been heated up. ASHREA mentioned that west-facing glass passes about 2.7 times more heat during the peak summer months than does the same glass on the south or north faces of the building.

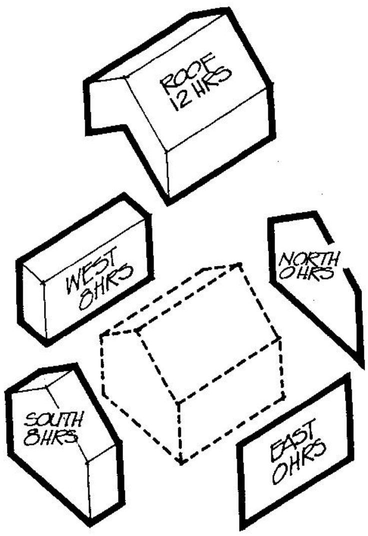


Figure 1.10: solar radiation duration on sides of buildings
(Source: Watson D., Kenneth Labs, *Climatic building design – energy efficient building principles and practice*, McGraw Hill, New York, USA, 1983)

As we know, transparent envelope will take the advantage of glasses [2]. Therefore, the importance of its two subsystems, double-glazing and double-façade needs more attention in their design stages. Double-glazing is a system where there is a space between two panes of glasses usually in few millimeters thickness. Therefore, dry air will be trapped between two panes and creates an insulation layer [97]. Meantime, use of reflective glass and low emissive glass, which have properties of reflecting solar radiation or insulating properties in order to reduce the heat loss from windows will reduce excessive heat gain or heat loss in buildings [2], [43].

Double façade is obtained by adding an extra layer of glazing outside the façade to provide the building with ventilation or additional soundproofing. This system may be realized in various ways, depending on the functions desired and the requirements made on the façade.

It could be in various types as following:

- Integrated façade
- Alternative façade
- Shaft-box façade
- Corridor façade
- Box-window façade
- Second skin façade

Integrated façade

"The idea of the double façade underwent consistent further development by integrating functions other than ventilation, such as air-conditioning or control of lighting levels, in the façade. The resulting system was then generally called a modular façade or hybrid façade." [88]

Alternative façade

"The double façades described above do not offer complete solutions to the problem of variable ventilation requirements. One approach to this problem was the development of alternating façades." [88] The aim here is to combine the advantage of the simplicity in single-skin façade with the buffering effect of the double façade.

Shaft-box façade

"The most effective version of the double façade, but that involving the greatest constructional and control-engineering effort, the shaft-box façade." Façade elements release their exhaust air into a shaft mounted on the façade and extending over several floors for greater thermal efficiency. [88]

Corridor façade

"To deal with the problem of interference between the ventilation systems at different levels, the corridor façade was developed. This used vertical baffles in the space between the two skins to prevent horizontal flow of air that could give rise to noise interference between neighboring rooms." [88]

Box-window façade

The advantage is the freedom provided by system to each occupant to control indoor environment. On the other side, its disadvantage is freedom given to one occupant may have a negative effect on the others experienced conditions. This problem can be avoided by staggering the ventilation inlets and outlets. [88]

Second skin façade

Second-skin façade is obtained by applying a second layer of glass over the whole outer surface of building. It has the advantage of simplicity in terms of technical-structural. Since it does not deal with a large number of moving parts ventilation mechanisms only have to be provided at the top and bottom zones of the façade. Few possibilities of controlling the indoor environment of the building are its disadvantage. Therefore, risk of overheating will be increase. [88]

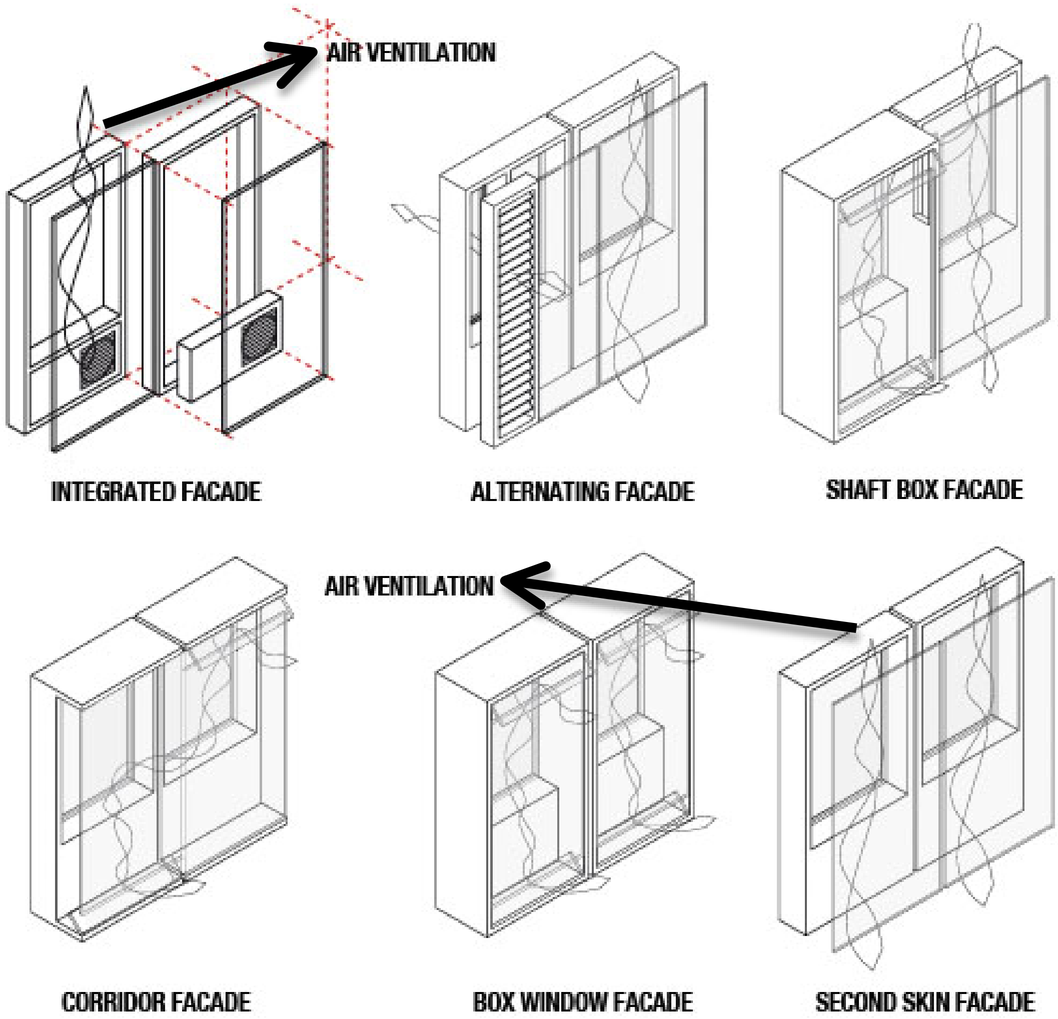


Figure 1.11: different types of transparent envelope
(Source: Knaack U., Klein T., Bilow M., Auer T., *Façades principles of construction,* Birkhäuser Verlag AG, Germany, 2007)

In the case of Double Skin Facades, unfortunately very limited research on their thermal performance in hot areas has been undertaken and these were only based on simulation [44], [45], [46]. Reviews of simulation studies mention that the exterior leaf would reduce direct solar heat gain in rooms; trapped heat in the gap is expected to induce natural buoyancy as a mean to reduce elevated air temperature away from the inner building skin, this may result in additional reduction of conductive heat gain through the inner façade layers into the occupied space. In the study which has been done by Neveen Hamza, a comparison between an optimized single façade and an optimized double skin façade in hot climates is carried out and simulation results indicate that with careful material choice, a reflective double skin façade can achieve better energy saving than using reflective glazing on windows in single skin [43].

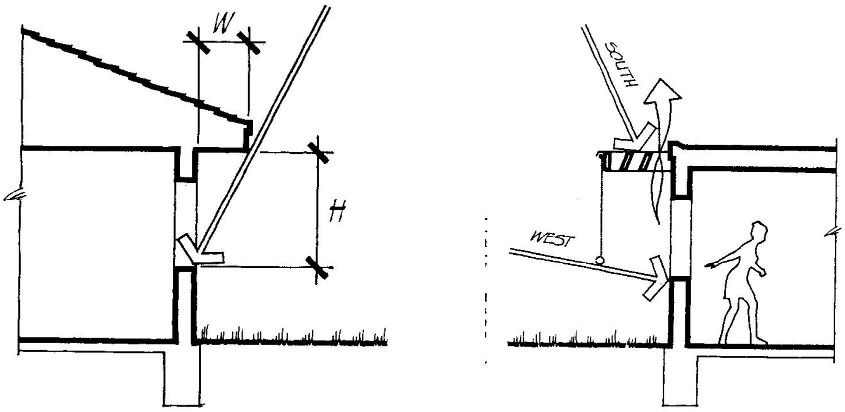


Figure 1.12: shading components in hot climates regions
(Source: Watson D., Kenneth Labs, *Climatic building design – energy efficient building principles and practice*, McGrow Hill, New York, USA, 1983)

As said before, it should be noted that shading devices should be mostly located on the west and south sides of the building in hot regions. So the most practical way to achieve reduction in solar heat gain is to shade transparent walls with horizontal projection over the whole window of about 1 meter [2].

Transparent roofs

As noted before, few resources are available related to transparent envelope and specifically related to its problems in hot climates. But by reviewing available buildings with transparent roofs in different regions as like as Reichstag in Berlin, Design Center in Linz, Kunsthaus in Bergenz, Crystal Palace in London, Railway station in Shanghai, Exhibition center of Milan, Melbourne Sound Tube and some other samples, the needs of using some controller elements is obvious. Therefore, use of transparent louvers, blinds or awnings will dramatically control heat gain by transparent roofs [89].

It should be noted that, by proper design of transparent roofs buildings would have some benefits. The most important benefit is, entry of large amount natural light from roof to building, which can reduce the electrical energy consumption, the need for artificial lighting and provide fresh, clean and open feelings for people inside of building [89].

1.5.1.2 Building problems in Under-heated Periods

Passive solar systems are based on the careful design, organization of the building's areas and proper selection of building materials in order to obtain heating and cooling benefits from the natural free energy resources to decrease electricity consumed by air conditioning systems [36].

In hot climates areas, the use of passive solar systems will add the advantage of solar heat gain to building and decrease the energy consumption. Because of its importance in under-heated periods, and their dominant role in order to provide natural ventilation in overheated periods, Passive Solar systems will be discussed in more details in following.

Passive Solar Systems

The various strategies for designing and building a passive system can be grouped into two major methods controlled heat gain methods or passive heat gain and passive cooling methods. Each of these methods can be divided to four basic systems: direct gain, thermal storage wall, attached sunspace and convective loop.

These basic passive systems are each composed of five mutually dependent basic components: collector, absorber, storage, distribution and control [36]. In this part each of those methods and related subsystems will be described.

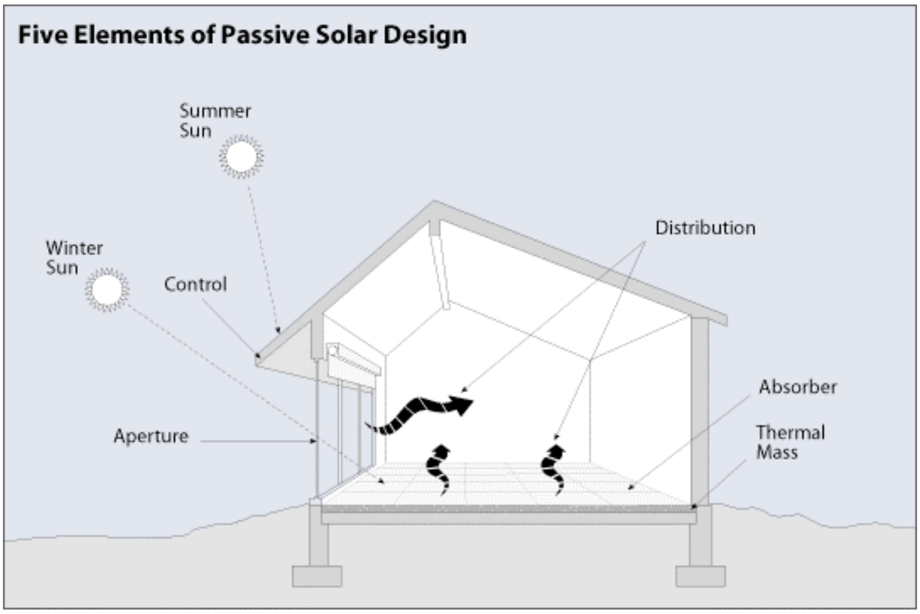


Figure 1.13: five elements of passive solar system
(Source: URL evereco.org/sustainable_building.html)

A. Passive Heating Systems

As mentioned above we have 4 different passive methods. In this section each of those will be briefly reviewed to compare their functionality in heating seasons.

Direct gain system

In heating seasons, sunlight radiates into building through collector, which is faced to south and usually made by glass. This solar radiation will be turned into heat by elements, which absorbed it and warm the area or are kept in storage element for later use. Normally, it is difficult to provide direct solar radiation over the whole surface area. So reflecting sunlight from light colored surfaces to the dark surfaces will be acceptable solution. [36]

Thermal storage wall system

In summer season, solar radiation enters through the collector, strike the storage wall and make it warm. In the case of unvented thermal storage wall, the generated heat is stored and slowly transferred to the interior. Because of tendency of hot air to go up and cool air to come down, with vented wall system a natural ventilation system will provide warm air to the building. Although, using vents will provide light, view and some direct gain daytime heating for building, but they will also reduce the effective area of the storage wall. [36]

Attached sunspace system

In this system, sunlight passes through the collector, which is faced to south side and then it is absorbed by elements and is converted to heat. This process is the same for all its subsystems as like as open wall, direct gain, air exchange and thermal storage wall subsystems. For instance, in open wall and direct gain subsystem, because of no opening there is a direct and free transfer of warm air between two spaces. In order to avoid excessive loss of heat it is recommended that high-performance glazing be used, or in direct gain systems, the use of portable insulation located at the shared wall glazing will reduce more heat losses from building. [36]

Convective loop systems

In this system, sunlight will be transferred through the collector of the convective loop TAP (thermo-siphon air panel) and strikes the absorber surface. The absorber is metallic surface with back color, which converts solar radiation to heat. It could be found in two subsystems, which are vertical and U-Tube panel. In vertical panel, in order to avoid warm room air from being drawn back into the panel simple back-draft dampers are mostly provided at the vents. But, in U-Tube panels, close proximity of the inlet and outlet vents will provide an advantage for this system in compare to vertical panels. [36]

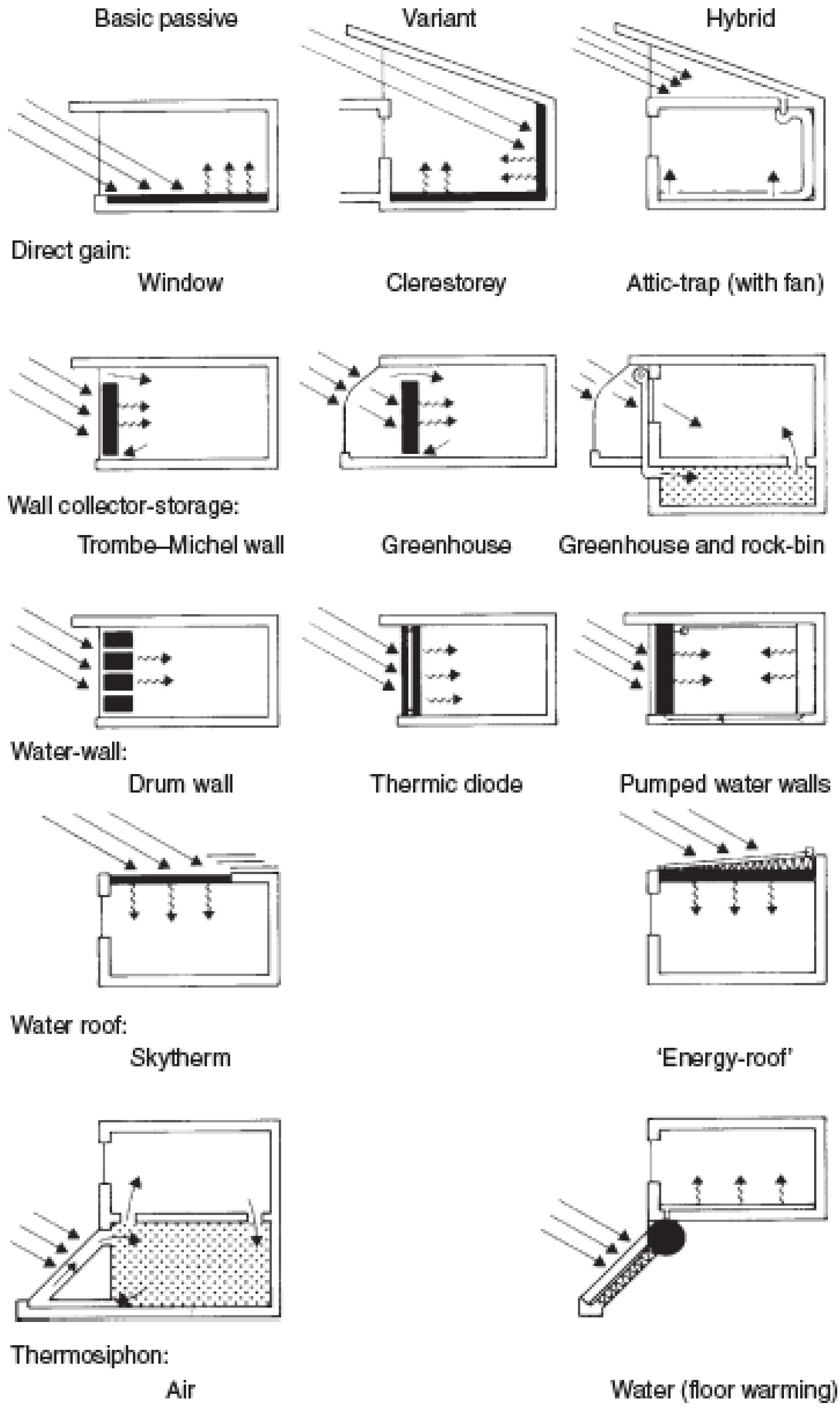


Figure 1.14: Main types of passive solar heating systems
(Source: *Introduction to ARCHITECTURAL SCIENCE the basis of sustainable design Steven,* V. Szokolay, Elsevier, Amsterdam, 2004)

B. Passive Cooling (ventilation) Systems

As mentioned at the beginning of this chapter, the main function of the building is to provide barrier from external temperature condition to avoid thermal comfort problems. One of the factors, which usually create thermal comfort problems, is relative humidity level and moisture content of the building envelope.

Since in hot and humid climate, usually there is an extra amount of water vapor in air, therefore, in cold seasons this amount of water vapor will be absorbed by building envelope and during hot seasons it will be released back to the air from building envelope. Thus, excess amount of moisture content in building envelope could be a sufficient resource for different types of problems in the case of thermal comfort or structural defects. These types of defects could be listed as condensation, structural heat loss and moisture movement by affecting durability of building materials, which will be discussed later [2], [3], [4], [90], [91], [92].

On the other hand, excessive amount of water vapor in air, will dramatically affect the thermal comfort level in building. Because of vapor pressure of the moisture in air depends only on the humidity or moisture content, so that the vapor pressure of the more humid air within a warm building will be higher than the vapor pressure of even saturated external cool air. Increasing the level of water vapor could increase sweating and makes life difficult. Therefore, ventilation becomes an important feature in the avoidance of excessive humidity. In this case it should be provided to allow moisture in the warm internal air diffuse to the exterior through the influence of the difference in vapor pressure. There are several ways to provide air ventilation. Using of passive or active systems could provide them. In cooling season, some by applying some controls to passive methods benefits of natural ventilation and passive cooling systems could be added to building. Those controls can be described as following.

Direct gain system

During the overheated period, collectors should be well shaded to avoid excessive heat gain. Shading elements, such as overhangs, should be sized properly to maximize overall system performance. [36]

Thermal storage wall system

In summers, same as direct gain system collector should be well shaded and sized to prevent excessive heat gain. In case of wall vents, vents should be placed on the exterior side of the collector component in form of opaque panels. More, portable insulation could be used to cover collector from outer side and keep as long as possible the cool temperature of the wall. [36]

Attached sunspace system

In cooling periods, this system can easily be overheated. Thus, the collector should be well shaded in take advantage of moveable insulation. In addition, sunspace should be vented properly. It is highly recommended to place low vents in the shade on the windward side of the system, and high vents on the leeward side. More, the storage mass in this system can also help to cool building if properly designed and controlled. [36]

Convective loop systems

Since convective loop systems are designed for heating only, they will be inactive during the cooling season.

1.5.2 Building construction problems

As discussed at beginning of this chapter, parameters as like as, high temperature, high humidity and high solar radiation are general resources of building problems in hot climates. Those problems divided into three main categories as thermal comfort problems, building construction problems and building service systems problems. In previous sections thermal comfort problems has been reviewed and methods to avoid such problems discussed. In this section, second set of problems related to building construction will be studied. In order to get into this study, factors, which affect building during constructional stage and after constructional stage will be mentioned briefly and then constructional problems will be mentioned [2], [21], [22], [23], [30], [33], [90], [93], [94], [95], [96], [97], [98].

1.5.2.1 Factors, which affect the Building during the Construction Stage in Hot Climates

During construction stage building construction is subjected to the effects of a number of factors, which may influence negatively durability and performance. Excluding failures caused by human, solar radiation, moisture or water vapor, chemical gas or particles and biological agencies like fungi and bacteria's are factors will affect the building construction in hot climates. For example, water in the form of rain-washing over a surface can retard or prevent mould growth, but moisture in the form of repeated condensation can be highly conducive to its formation. For any particular situation, it is necessary to assess the likely combination of agencies and their effects upon durability and performance, and succeeding chapters seek to make this assessment for the most common building situations. As a basis to considering these more complex inter-relationships, it is, nevertheless, useful to consider separately the agencies mentioned and their general effects. In next chapters, problem caused by above factors will be reviewed [21], [93], [94], [95].

1.5.2.2 Factors, which affect Building Structural and Non-structural Elements after Construction Stage in Hot Climates

Although, previous factors, which mentioned in section 1.5.2.1, are the resources of the problems even after construction stage, but their consequences as thermal movement and moisture movement will play the most important role of defects in building structural and non-structural elements after construction stage. In next sections, these defects in different structural systems as like as reinforced concrete, steel and timber structure will consider in details [21], [93], [94], [95].

1.5.2.3 Construction Problems of Building Structure in Hot Climates

In order to review construction problems in hot climates, three different structures: reinforced concrete structure system, steel structure system and timber structure systems will be evaluated.

1.5.2.3.1 Construction Problems of Reinforced Concrete (RC) Structure Systems

As we know, concrete is a type of material, which is strong in compression and weak in tension. For strengthening and reinforcing the tensile strength of concrete, engineers started to use steel inside of the concrete. The combination of steel and concrete in order to provide strong bonds has been known as Reinforced Concrete. [93]

Nowadays, Reinforced concrete is widely used for the construction of suspended floors, and eventually for beams and posts, as it enables a thinner slab and less concrete to be used to achieve the same strength and reliability in compare to unreinforced concrete [94]. Accordingly, it has a relatively high compressive strength, long life with low maintenance cost and in compare to steel structure high fire resistance. But some of its disadvantages should be taken into consideration as well as its needs to appropriate mixing, casting and curing, all of which affect the final strength of concrete, low compressive strength as compared to steel (the ratio is about 1:10 depending on material) which leads to large sections in columns/beams of multistory buildings.

Although reinforced concrete structure is widely used in building construction process, it's better to have a quick review on its general problem and then analyze the major problem of this product in specific weather condition, which is focused in this study as Hot climates.

According to reviews, [21], [90], [93], [94], [95], [97] different types of problems rise up when architects talk about reinforced concrete structure. These defects could be categorized as following in the chemical reactions:

- Carbonation, Corrosion and other Chemical damages
- Hot weather concreting

In many hot climates regions, buildings are designed with flat roofs, small openings, and heavy weight materials. These materials include dried mud in rural areas and reinforced concrete in urban areas [11]. In this manner, there is a specific term called as "Hot Weather Concreting" by American Concrete Institute. ACI indicates "The success of many hot-weather concreting operations depends on the steps taken to slow the cement hydration reactions within the concrete and to minimize the rate of evaporation of moisture from the freshly mixed concrete." So Potential concrete problems in hot weather are likely to include:

- Increased water demand
- Increased rate of slump loss
- Increased rate of setting
- Increased tendency for plastic-shrinkage cracking
- Increased difficulty in controlling entrained air content
- Decreased 28-day and later strengths
- Increased tendency for differential thermal cracking
- Greater variability in surface appearance
- Increased permeability

High temperatures accelerate the hardening of concrete and more water is generally required to maintain workable consistencies. If the water-cement ratio is not maintained by adding additional cement, strength and durability will be reduced. For example, if the temperature of concrete is increased from 10º C to 38º C, about 15 liters of additional water is needed per cubic yard of concrete to maintain a three-inch slump. If the water content of concrete is increased without increasing the cement content, the strength and durability are negatively affected.

Problems resulting from hot weather at various stages in the concrete production process can be shown in the form of below table [98]. Amount of water in concrete has to taken into consideration, because high water contents also mean greater drying shrinkage.

Table 1.3: Problems resulting in hot weather in the concrete production [98]

Stage	Effect
production	Increased water demand for given workability Increased difficulty in controlling entrained air content
Transit	Loss of water by evaporation Increased rate of loos of workability Increased rate of setting Increased tendency to plastic shrinkage cracking Higher peak temperature during hydration leading to increased tendency to cracking and lower long-term strength
Long-term	Lower strength Decreased durability Variable appearance

On the other hand, M. N. Haque & H. Al-Khaiat have been reported the results of a condition survey of 50 concrete buildings undertaken in the State of Kuwait in the hot dry salty environment. In their research density, compressive strength and depth of carbonation were evaluated. The results suggest that to limit the depth of carbonation of concrete to an acceptable level in hot climates, structures should be built with a concrete compressive strength in the range of at least 30-50 MPa (1 Mega Pascal = 10^6 N/m^2). [22]

In the case of effects of high temperatures on reinforced concrete bars, a group of civil engineers from Eskisehir Osmangazi University found out that a cover of 25 mm thick provides protection to reinforcing steel when the structure is exposed to high temperatures. It reduces the yield strength and tensile strength losses of the steel and gives it higher strengths compared to the plain reinforcing steel. It was observed that 25 mm cover thickness was not sufficient to protect the mechanical properties of reinforcing steel when the structure is exposed to temperatures over 500° C. Considering the reports that temperatures in fires could reaches 815° C and peak as high as 1093° C, the required concrete cover thickness can be calculated to protect reinforcements from fire reaching these temperatures [23].

In the case of suitable cement types in hot climates following points needs to be mentioned. It is possible to obtain high-strength concretes by using portland composite cements. In lower strength classes such as C20, higher cement content and lower w–c ratio should be used in PKC mixtures as compared to PC mixtures for the same strength and workability. In the case of curing concretes produced in rainy months such as winter and spring to provide sufficient moisture within the first 7 days in the mild climate areas, surrounding conditions do not cause negative results in strength development. This is valid for all cement types with or without additives [21], [22], [23], [90], [93], [94], [95], [96], [97], [98].

Table 1.4: summary of measures to reduce the adverse effects of hot weather [98]

Stage	Measure
Production	Shade aggregate stockpiles
	Spray stockpiles with water
	Increase cement silo capacity
	Paint batching plant white
	Shade water tank
	Paint water tank white
	Insulate water pipelines
	Use chilled water
	Use ice as part of mixing water
	Use admixtures to counteract slump loss
	Use cement or combinations with low heat evaluation
	Minimize mixing times
Transit	Paint mixer trucks white
	Minimize transit times
	Batch dry and add water at site
Placing and curing	Plan operations carefully
	Match production to placing rates
	Reduce layer thickness
	Provide adequate standby vibrators
	Place concrete at night
	Minimize placing time
	Shade workplace
	Use windbreaks
	Apply curing early

1.5.2.3.2 Construction Problems of Steel Structures

Steel as a member of metals family, which has reasonable cost and design flexibility in compare to reinforced concrete, benefits from high durability. Different factors in this type of structure always affect its high durability. These factors in regions with hot climates can be classified as moisture and temperature.

High temperature distortion

High temperature is the main source to occur reversible movement in metals according to their coefficient of expansion. Failure to allow for this at joints and changes of direction will produce buckling, distortion and cracking. Decking and supporting materials, which have different moisture and/or temperature movement coefficients, will produce differential movement stresses at the interface, which may lead to forced dimensional change [21], [93], [94], [95].

Corrosion caused by Moisture

Moisture, which is the source of specific chemical defects, called as corrosion. Unprotected steel will corrode in an environment with moisture and oxygen. This chemical reaction will consequently produce hydrated ferric oxide ($Fe2O3 \cdot H2O$). The corrosion of reinforcement steel operates through an electro chemical process determined in part by the presence of differential oxygen levels within the reinforced concrete. Different regions act as cathodes or anodes according to whether oxygen is present or not. The occurrence of differential oxygen concentrations in pore water and anionic solutions of pollutants such as carbonates, chlorides or sulphates leads to the creation of micro galvanic corrosion cells [21], [93], [94], [95].

Other factors affecting the corrosion resistance of the steel in reinforced concrete include the effective depth of cover to the reinforcement and the dense of the concrete.

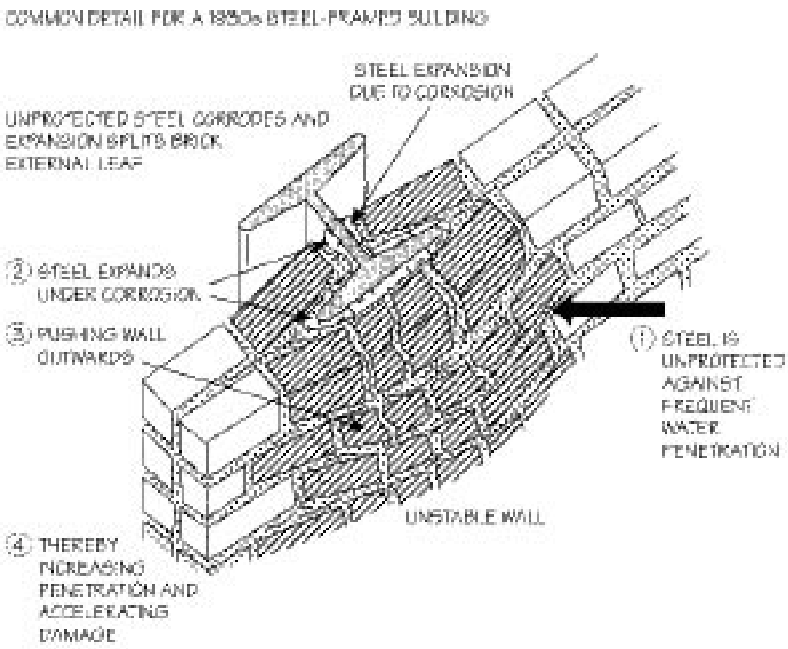


Figure 1.15: Corrosion in unprotected mild steel
(Source: Barry A. Richardson, *Defects and deterioration in building*, SPON Press, 2001)

In this case we have to mention that in contrast to steel, the oxides formed from some metal ions take less space than the original metal. This produces a porous oxide layer, which allows oxidation to continue into the body of the metal. [94]

Any holes in the coating or variable thickness will affect the durability locally. Hence hardeners, which create catchment areas for water, will be the source of problems. Up to here temperature and moisture are discussed as main sources of problems in steel structures. Moisture, which is the basis of most steel chemical reaction with pollutants such as carbonates, chlorides or sulphates and high temperature will be the source of reversible movement and melting of steel. So it should be noted that during the fire event in building with steel structures, high temperature rises up eventually. The very high temperature in this issue will bend the main structure of the building, which consequently enters building into collapsing stage. [21]

1.5.2.3.3 Construction Problems of Timber Structures

One of the construction materials, which have been used extensively since the very earliest forms of shelter, is Timber. It is still widely used in modern construction because of several useful properties. Those specific properties are:

- Ease of working
- High strength to weight ratio
- Durability

Timber is generally categorized into two types:

- Softwoods
- Hardwoods

In hot climates very few research has been done around timber structure. According to W.H.Ransom [21], problems in Timber structure can be classified as following:

- Moisture Movement
- Fire
- Fungal attack and insect attack

Moisture Movement

Moisture movement is one of the most significant problems raise up in timber frame structure. Wherever there is no sufficient protection, there is a risk of high moisture content in the timber. One of the consequences of this amount of moisture in timber is corrosion in metal fixing like nails. Other consequences can be shown as expansion or contraction in vertical direction. Although the amount of movement may be less, a failure to handle movement around window or door openings can destroy frames.

Fire

Although timber burns, the charring of the external surfaces acts, as an insulator and moisture in the timber must be evaporated before burning can progress. This slows down the rate of burning, and for large-sized timbers may mean that significant amounts of mechanically sound timber remain in the centre of the section. This complicates the visual assessment of the structural integrity of timber sections, which have been subject to fire. [21]

Fungal attack of timber

The risk of attack depends largely on the species of timber and the proportion of sapwood, and also on the surroundings and the type of fungal spores present. Chronic dampness occurring in conjunction with poor ventilation and a normal internal temperature range represent ideal conditions for potential fungal attack. Not surprisingly, many of the locations prone to rot are also the most difficult to survey. [21]

Insect attack of timber

Alongside fungal attack, insects are one of the biggest causes of timber decay. The main external symptoms of insect attack are the flight holes formed by adult insects leaving the wood. The main structural damage to the wood is internal, caused by the insect larvae extracting the glucose from the cells, leaving wormholes. Timber with high sapwood content is a frequent target.

1.5.2.4 Construction Problems of Building Non-Structural Components

Construction problems of building non-structural components can be organized in four sections [2], [21], [85], [93], [94], [95]. These non-structural components are external wall, wall opening, roofs and internal finishing components. About non-structural components of building, again just few number of researchers work around problems of these components in hot climates.

1.5.2.4.1 Construction Problems of External Walls

According to Barry A. Richardson, Isolation the interior of the building from the exterior condition is defined as main function of External walls. However, the efficiency of walls can be greatly improved in relation to excluding dampness and thermally insulating the interior with a certain aesthetic effect.

A second function of a wall is structural and to support the load imposed by any suspended floors and the roof above. [94] General problems of external walls can be listed as following:

- Dampness and moisture
- Thermal movement
- Moisture movement
- UV defects

Dampness

In the hot and humid climate, the height of dampness is depend on different types of factors, which pore structure of material can be the most important one.

The risk of condensation depends simply on the moisture content of air and the temperatures that it will encounter. Condensation occurs when air encounters temperatures below its dew point, and the dew point depends only on the moisture content of the air. The most common form of condensation is dew on the cold internal surfaces of glazing, window frames or even walls. Condensation dampness is one of the initial points for structural heat loss. As discussed before, in order to avoid structural heat loss in buildings, thermal insulation material it should be dry, because air space in wet material replaced with water and decrease their functionality. On the other hand, moisture content variations are the usual cause of movement in structural materials, such as concrete, masonry and wood because of chemical damages as like as corrosion or carbonation.

Therefore, to avoid condensation dampness in insulation materials or moisture movement problems, which usually caused by moisture absorption and lack of proper solution to release it back to air, we have to take some strategies. Many researches like Bomberg and Shiftliff, Epstein and Putnam, Tye, Tobiasson and Reichard reported that the effect of moisture content on the heat flow depends on the type of insulation material and the moisture content discussed before. [2], [3], [4], [90], [91], [92] They suggested that before to apply any techniques to reduce humidity, it is better to simulate the real situation with some software in order to find out the best solution and have a good choice for insulation materials or proper ventilation with passive solar systems. But in general two basic strategies could be applied in order to have acceptable level of moisture in building envelope. Those are use of vapor barriers for insulation materials and ventilation. Appling vapor barriers on thermal insulation materials could strongly protect them against condensation dampness. For example, vapor barriers should apply to inorganic cellular thermal insulation and organic fibrous materials with high water vapor permeability and moisture storing properties but they are not necessary in water impermeable organic cellular materials and closed cell cellular thermal insulation.

On the other hand, since some building materials as like as bricks are porous; moisture can easily enter to them. This happened when the inside of building becomes hot; dampness can evaporate from interior surfaces leaving behind hygroscopic salts. These can absorb moisture from the air within the building, which can add to the general dampness problem. If rising dampness occurs, the DPC (Damp-Proof Course) material may have failed or have been inadequately jointed [93]. In figure 1.16, a scheme of excellent wall with proper insulation and vapor barries has been shown.

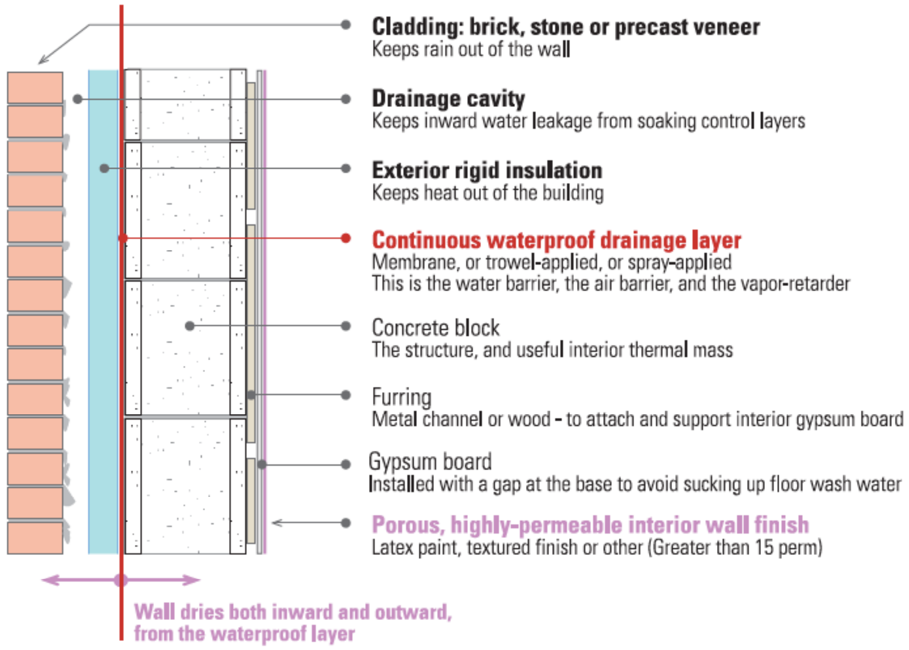


Figure 1.16: Control layers in an excellent wall
(Source: Lewis G.Harriman, Joseph W. Lstiburek, *The ASHRAE Guide for buildings in Hot and Humid Climates*, ASHRAE, Atlanta, USA, 2009)

Thermal Movement

Expansion and contraction of wall is the most important consequence of temperature changes. In the case of expansion and contraction, which mostly happened in hot climates, the exact amount of expansion does not equal to amount of contraction, which will result in permanent cracking. The cracking usually occurs in cooling phase of this cycle. Thermal movement of other elements of construction can also cause problems due to the pressures placed on adjoining walls as a result of the expansion of roofs and floors.

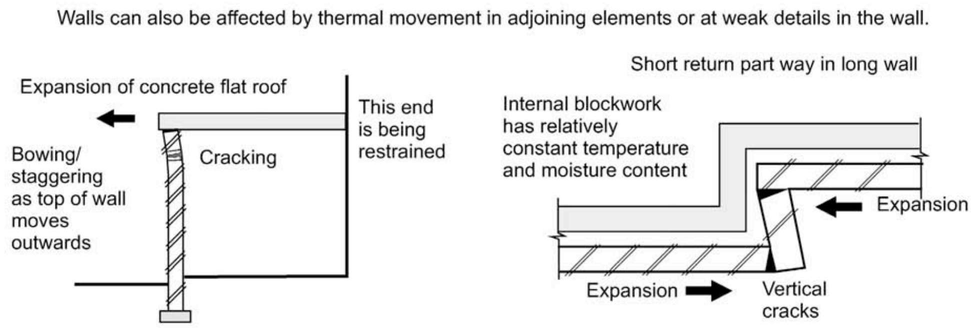


Figure 1.17: wall problems caused by expansion and contraction
(Source: Douglas J., Ransom B., *Understanding building failures*, third edition, Taylor & Francis, London, 2007)

Nowadays, usage of expansion joints reduces the defect of thermal movement. Also using lime-based mortar, which is more flexible material in compare to cement-based mortar can avoid some problems caused by thermal movement.

Moisture Movement

Except expansion and contraction due to changes in temperature, moisture absorption can create the same effect. In this case moisture can have different sources as like as rain, snow, leak, condensation, or as the result of the building process. Geoff Cook reported that contraction of material in initial drying phase and expansion of materials because of moisture absorption are commonly seen as defects in buildings. Portland cement products, lightweight concrete, sand-lime bricks, calcium silicate bricks, some plasters and timber are all subject to initial drying out and cracking.

On the other hand, the majority of moisture-induced expansion occurs in the first few months but it can continue for up to 20 years after construction and is irreversible.

In addition, movement whether caused by moisture absorption or changes in temperature can have other effects as following:

- Failure of Arches and Lintels
- Corrosion of steel and iron components
- Lateral pressure on retaining walls

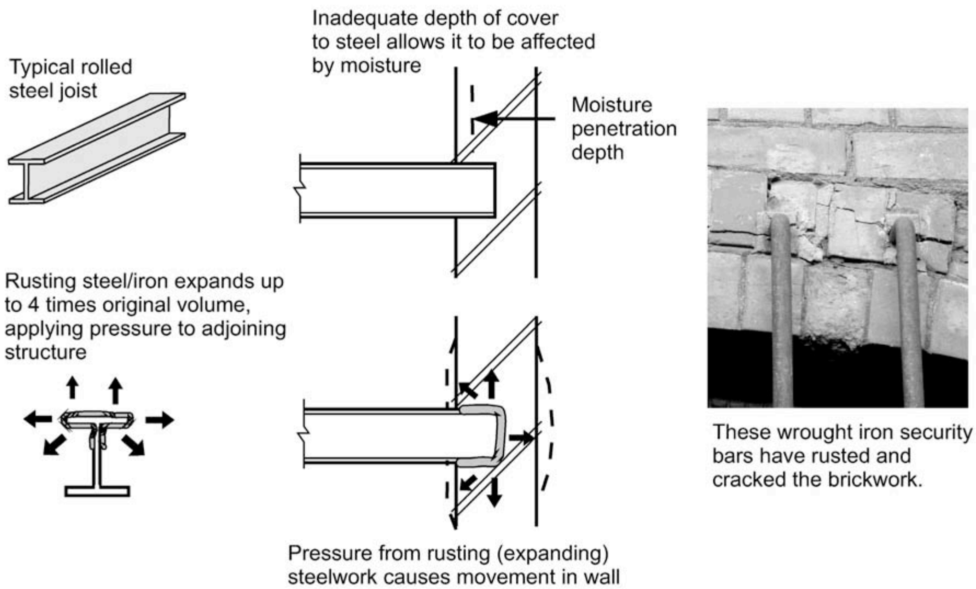


Figure 1.18: moisture in external wall
(Source: Douglas J., Ransom B., *Understanding building failures*, third edition, Taylor & Francis, London, 2007)

A simple solution to avoid or reduce the effect of movement can be achieved by incorporating movement joints with sufficient filler material.

UV Defects

UV defects, which mostly mentioned in hot climates areas with heavy solar radiation has to be controlled. Ultraviolet (UV) light destroys many materials, including wood, fabric, plastics, and paint not even limited to hot climates, this noted by Sage Blossom Consulting. Paying attention to UV rays and their harmful effects in human life becomes one of the main concerns of scientific, but still numbers researches focus on building and construction progress are rare. Florida Solar Energy Center as one of the pioneer centers to control UV defects said that there are some materials that can be applied to block the UV spectrum of sunlight, but they are toxic which create additional set of problems. Therefore, in order to have proper solution to control UV rays more researches by scientists are needed. Before to introduce exact solution for these types of problems by specialists, selecting UV resistant materials among those which are less toxic will improve a building's durability and reduce defects occurs in external wall and opening materials and their paintings. [99]

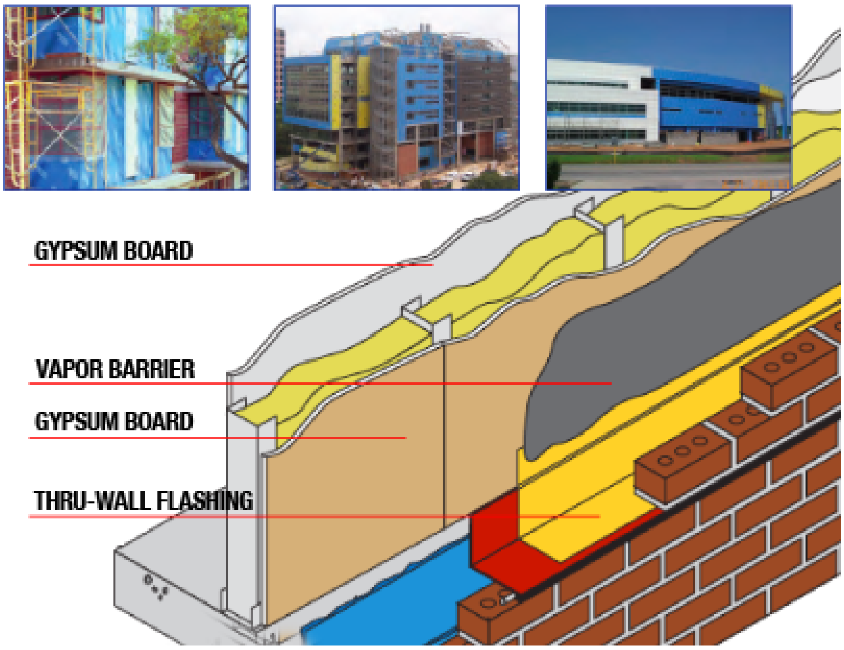


Figure 1.19: vapor barriers for hot climates
(Source: Henry building envelope systems, California, USA, 2006)

1.5.2.4.2 Construction Problems of Wall Openings (windows, doors, openings)

Problems, which usually appear in wall openings in hot climates again comes from main factors as below:

- High temperature
- Moisture

Above resources creates problems, which can be classified as:

- Thermal movement
- Moisture movement
- Chemical damages
- UV defects

In following section, problems of two major types of wall openings, door and window will be reviewed.

Doors

Doors can be divided into groups as below:

- Hollow-core flush
- Stamped hardboard
- Solid-core flush
- Fiberglass
- Medium density fiberboard
- Insulated wood panel
- Stave-core exterior
- Steel exterior

Figure 1.20: Possible types of doors
(URL www.diyadvice.com/diy/doors-windows/planning/selecting-door-materials)

In addition to different types of doors in terms of materials, doors also could be categorized as interior and exterior doors. Interior doors are protected from the weather so they can be made of less-substantial materials than exterior doors. Hollow-core flush, stamped hardboard and MDF doors are mostly used in interior, while solid0core flush, fiberglass, stave-core and steel doors used as exterior doors. Insulated wood panels could be used as interior or exterior doors according to customer’s choices. In the case of wooden doors, because of wood characteristic in order to wrap and to expand and contract with temperature and moisture, doors usually made in multi slab wood and interlocking pieces.

In doors, moisture usually enters from joints. In glazed doors, this situation will be the same but moisture can also enter where putty or glazing beads have come away from the glass. A contributory cause of rain penetration has been inadequacy of the tenons of the bottom rail, leading to slight dropping of the rail and consequent exposure of the joint between the rail and the panel. The absence of a weatherboard on the outer face at the bottom of the door has meant that rain is not thrown clear of the gap under the door. This problem has often been made more serious by the omission of the weather bar from the sill or its incorrect positioning [93], [94], [95].

Entry of water at the joints can lead to failure of the urea formaldehyde glue usually employed. It can also promote differential moisture movement where the grain of the timbers, which meet at the joint, runs in different directions. The stressing of the joint through moisture movement, and its weakening through failure of the glue, leads to loosening of the joint and an increased opportunity for moisture to enter and cause decay. Delaminating of plywood panels in external doors has occurred when internal-grade plywood has been used. Distortion of doors is also likely if moisture penetrates and may occur, too, if humidity and temperature conditions are markedly different on the two sides, as they often are for an external door, and the door is poorly protected from such changes by the lack of an adequate paint treatment. Doors may then jam or give a poor fit in the doorframe. [21]

Windows

Windows are made with different materials. Those types of windows are:

- Aluminum
- Vinyl
- Wood
- Fiberglass

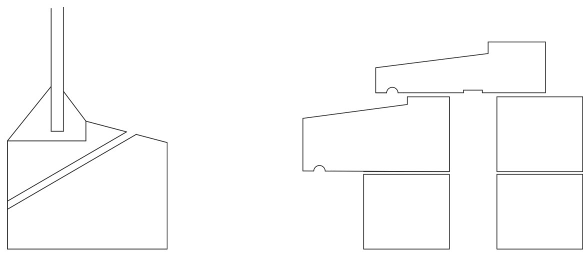
A) Aluminum B) Fiberglass C) Vinyl D) Wood

Figure 1.21: Different types of windows
(Source: URL www.replacementwindows-match.com)

As mentioned above, moisture is one of the problem's sources in windows. Moisture may find its way into window frames for different type of reasons.

Any shrinkage away from the wall will leave a gap for moisture to pass directly between the frame and the wall, if the junction there has not been well pointed with a mastic sealant. Even if it has, the DPC (Damp-Proof Course) can be bypassed if the construction is such that internal plaster can be directly in contact with the external brickwork at the jamb. This can happen when the inside face of the frame does not extend beyond the inside face of the external brickwork.

Setting windows back from the face of the wall helps in giving the window assembly some protection from the weather but will usually necessitate the use of a sub-sill to throw rain clear of the wall.



A B

Figure 1.22: A) Removal of condensed water B) Sill position
(Source: Douglas J., Ransom B., *Understanding-building failures*, third edition, Taylor & Francis, London, 2007)

Metal window frames have a high thermal conductivity and provide a cold bridge between exterior and interior. This can lead to condensation problems, too, which can be quite severe. Insulation needs to be added to the frame to reduce the problem and this can be nearly impossible after installation. It may be noted that, while double-glazing can reduce the risk of condensation on the glass itself, it will not necessarily prevent all condensation there; this will depend upon the internal humidity and temperature.

A thermal expansion problem can arise with windows made from uPVC or Rigid PVC (Unplasticized polyvinyl chloride). Dark colors can give rise to dimensional instability and enhance the risk of cracking of the glass. This is because the material has naturally a high coefficient of thermal expansion and dark colors will lead to greater temperature changes. It is safer to choose white frames and to keep them clean to avoid the build-up of dirt.

Finally, external doors and windows need to be selected to fit the probable exposure conditions [21]. According to above review, major problem of wall openings in hot climates is related to reduction of their usability and functionality. Because of moisture and frequent changes in temperature, wall openings as like as windows and doors lose their functionality within couple of years. Moisture in wooden doors and windows especially in summer with high humidity will be swelled and may spoil. Also corrosion will be appeared in joints and openings frames. Because of thermal expansion problem in wall openings, it is better to not use dark colors which can give rise to dimensional instability and enhance the risk of cracking of the glass. It is safer to choose white frames and to keep them clean to avoid the build-up of dirt [94].

1.5.2.4.3. Construction Problems of Roofs

Roof is one of the most elements of building, which its failure has effect on other elements elsewhere within the building. It can be categorized into to main categories:

- Sloped roofs
- Low-sloped roofs

Generally problems in roofs could be categorized as thermal movement, damp penetration and interstitial condensation and UV defect.

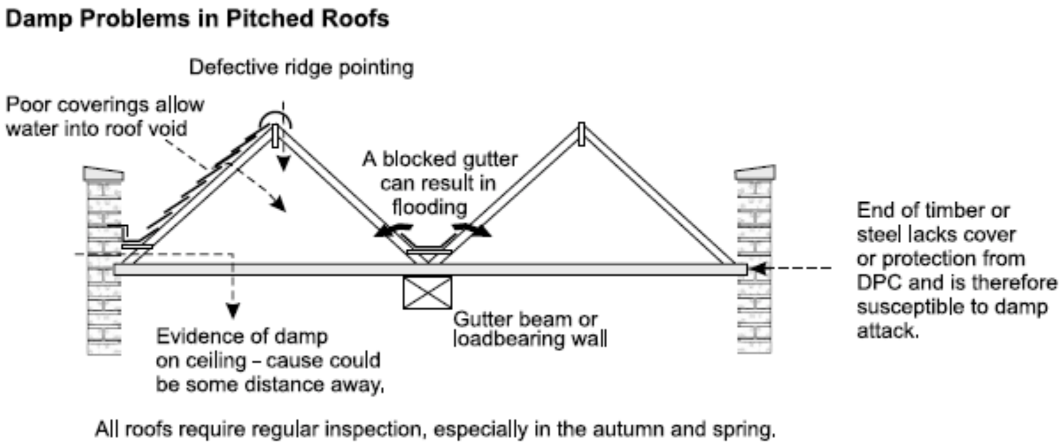


Figure 1.23: Damp problems in Pitched roofs
(Source: Douglas J., Ransom B., *Understanding building failures*, third edition, Taylor & Francis, London, 2007)

In case of sloped roofs, one of the most important defects is the effect of damp penetration. Roof always faces with big difference in daytime and nighttime temperature. So if there is a failure in preventing damp penetration both the roof itself and adjoining elements of construction may be affected.

Whenever we deal with a low-sloped roof, three different types of roof have to be taken into consideration. Those are cold roof, warm roof and reverse roof.

In cold roof form, insulation takes place above the ceiling and between the joists. Therefore, the gap above the insulation needs to be ventilated to avoid moisture condensing. It should be noted that, it is necessary to install a vapor check on the warm side of the insulation.

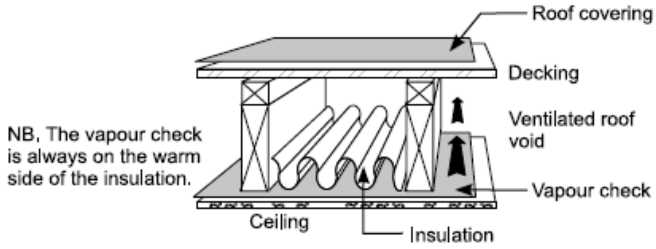


Figure 1.24: Cold roof
(Source: Barry A.Richardson, *Defects and deterioration in building*, SPON Press, 2001)

In warm roof or sandwich type, the insulation will be placed on the decking and under the weatherproof covering. The reason to have this type of roof is to remain in room temperature as it is warm than cold.

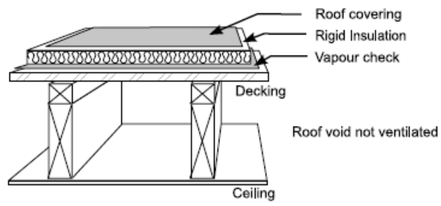


Figure 1.25: Warm roof – sandwich type
(Source: Barry A.Richardson, *Defects and deterioration in building*, SPON Press, 2001)

With this type of flat roof the insulation is installed above the weatherproof covering, which is placed on the decking. These interstitial condensation problems in warm roof construction can in theory be avoided by providing an impermeable vapor barrier as close as possible to the ceiling to prevent the humid air migrating into the roof structure.

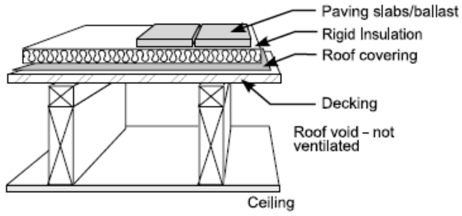


Figure 1.26: warm roof – inverted type
(Source: Barry A.Richardson, *Defects and deterioration in building*, SPON Press, 2001)

Failure to take account of thermal movement is a common cause of flat roofing problems. Large areas of roof covering will tend to expand or contract greatly in respect to different temperature in day and night. The expansion and contraction are mainly depending on material expansion coefficient and external temperature. The thermal movement cycle in the covering material (especially), or the underlying structure, may subject the covering to unacceptable stresses. If the sheet sizes of the covering are not controlled according to design and expansion details, the continual expansion and contraction cycle at the end will result in failure. In addition to this, flat roof may be affect by horizontal and vertical movement stress of building elements and an adjoining element of construction. This will end up with buckling or rippling, stepping and splitting or cracking.

Interstitial condensation, which can affect flat roofs has been seen when the outside temperature is low. Warm, moist internal air from the building passes through the roof structure, as its pressure is higher than the cold external air. On meeting any colder air or structure within the roof, the warm air condenses and the result will be appear in the form of damp at roof. There are other problems that are related to covering materials.

So, different parameters are involved in construction problems of roofs. Specifically in hot climates, thermal movement and interstitial condensation are most sources of problems. Also as mentioned in the thermal comfort issue, heat gain and heat loss through roof will be a source of set of problems, which brings uncomfortable feeling to occupants. M. B. Ozdeniz and P. Hancer, in a comprehensive research examined 14 different types of roof in hot region of northern Cyprus and find out that the roofs with thermal insulation showed the best performance. The location of the thermal insulation materials towards the inner surface of the section increased the performance. Inclined timber roof constructions on reinforced concrete ceiling save the buildings from solar bombarding in summer. However, to prevent the humidity accumulated, the attic space should be very well ventilated. On flat roofs, not only the thermal resistance of the roof section, but also the light reflectance of outside surface materials affected the thermal performance. Outside surface materials with very high light reflectance reduced heat gain in summer considerably. In buildings, which are air conditioned in summer, there is condensation risk. The defects due to this condensation can be avoided by the use of thermal insulation materials, which are not effected from water. There is also condensation risk for winter. However, it was found that this condensation could dry if the building is ventilated. [85]

In hot climates, because of large amount of sunlight which contains lots of UV rays and even high temperature differential movement will be occur in the building. This differential movement can be an initial step in order to destroy structure of covering which results in leakage. In order to avoid defect caused by thermal and differential movement or interstitial condensation, it is recommended to use mastic asphalt with proper insulation material at the top, which is painted by bright reflective colors [93]. Also ceilings or roofs should be insulated to at least R-30. If the house has an unconditioned attic, we have to specify radiant-barrier roof sheathing. As mentioned before we have to use highly reflective roofing, white metal roofing or white concrete tile roofing. In this case reflective foil insulation in the roof and walls is essential.

1.5.2.4.4 Construction Problems of Internal Building Component

Internal non-structural components could be divided into two major groups. Those are:

A. Stair, elevator, partition walls, chimney

B. Internal finishes, suspending ceiling, rising floor

Although there are not many researches available related to non-structural components, in this section tried to have a review on problems occur in non-structural components in hot climates.

A. Stair, elevator, partition wall

Stair

"Stairs provide means for moving from one level to another and therefore important links in the overall circulation scheme of a building." [100] Stairs could be found in timber, concrete and steel. In this case any types of problems mentioned previously related to concrete, timber and steel in hot climates would be valid for related type of stairs as well.

Elevator

Elevator as a mechanical-electrical device, which provides accessibility in multistory buildings have to face will some problems which are normally related to mechanical or electrical parts. Therefore, investigation related to elevator problems will be left for linked engineers.

Partition wall

Framed partition systems, that will be finished in plaster or gypsum board are usually framed with wood or metal studs. Gypsum is a major component of interior materials in most buildings. It has but one major disadvantage, which is solubility in water. Based on timber or steel structure of partition walls, their internal structure will be subjected to defects caused by high temperature or high moisture level in air. Those defect, which has been mentioned previously are in form of thermal movement, moisture movement and corrosion in steel structure. Thus, reduction in indoor air temperature or indoor moisture level will increase the durability of partition walls and decline their damages. [101]

B. Internal finishes, suspending ceiling, raised floor

Suspending ceiling and raised floor

Suspending ceiling can be made of almost any materials. The ones most widely used are gypsum board, plaster and various proprietary panels and tiles in order to cover provide proper space for ducts, pipes and conduits. The same concept will be applied to floors where there is a need for large scale wiring or piping through floors by considering appropriate covering materials. Each of these materials is supported on its own special system of steel framing members.

Unfortunately, most researches related to suspending ceiling and raised floors have been concentrated on the acoustical properties. But by considering their steel structure, which usually use in these components, thermal movement and corrosion will be predictable in hot regions.

Internal finishes

Construction problems of internal finishes in hot climates usually come from moisture and high temperature in these regions [21], [93], [94], [95]. Because of high temperature and high amount of moisture as discussed before internal finishes as like as screed, terrazzo, clay floor tiles, clay wall tiles, timbering floors and plaster will behave in an opposite direction of their normal reaction.

Screed

Due to high moisture even in the form of damp, an inadequate bond between the screed and the base concrete will be happened.

Terrazzo

Shrinkage effects may become concentrated and the rapid drying-out of the mix because of high temperature may mean that long-term strength is reduced.

Clay floor tiles

Differential movement between the tile and the base material can be a problem. Shock waves, due to impact loading passing through the floor, may detach tiles. Thermal expansion coefficient differences may exist. When the floor becomes cold the screed may contract more then the clay tiles and they can become detached. Differential moisture movement may also occur. Fresh concrete shrinks as it hydrates and becomes dry, whilst the clay tiles may go through an initial, irreversible expansion as they take up moisture from the air. The tiles may take up moisture from the screed or concrete where the DPM has failed. Expansion of the tiles may cause arching. Where movement accommodation is not provided around the perimeter, or by dividing the area into bays, failure can occur [95].

PVC tiles

The moisture from an insufficiently cured screed, a failed DPM or a failed DPC/DPM junction can cause loss of tile adhesion. The moisture, being alkaline, attacks the adhesive used to stick down the tiles. Tiles with adhesive attached may become detached from the concrete, some curling at the edges. The tiles may be sodium carbonated because of evaporation of the moisture. The sodium carbonate can be absorbed into the tile and cause cracking. Under dry conditions tiles may lift because of the delay between laying the adhesive and laying tiles. [21]

Timber flooring

Many problems with timber flooring can occur owing to the timber being, or becoming, damp. Where boarding is fixed directly to a ground floor concrete slab, typically by the use of timber battens, then failure of the DPM or failure of the junction between the DPM and DPC can allow moisture to migrate through the slab. Moisture may also come from the screed where there is insufficient time for the screed to cure and dry out. Where moisture movement is not accommodated then expansion can cause arching and lifting. This is a particular problem with wood block flooring. Movement joints, usually compression, provided around the wall can accommodate this movement. Floorboards laid with the heartwood downwards can produce convex surfaces and curled edges. This can also cause a pattern when thin coverings are laid over the boards. Chipboard flooring can expand irreversibly when wetted. There can also be substantial strength loss. Poor fixing or inadequate chipboard thickness for the span can cause excessive deflection or cracking [21].

Plaster

A failure to wet high-suction backgrounds can reduce the bonding between plaster and background and may reduce the strength and durability of the plaster. A plaster finish coat can be applied to certain types of plasterboard. Because gypsum plaster is very sensitive to dampness, it may fail in locations where the background has high moisture content, e.g. walls above a newly inserted DPC or in defective basements. Moist plaster can cause corrosion of ferrous metals within it. This is due to the relatively acidic nature compared to cement, of gypsum plaster. Cracking of plaster may be associated with the thermal and moisture movement of the background. They may also be due to structural movement. Differential movement can cause cracking at internal corners where a plasterboard ceiling meets an in-situ plaster wall. In-situ plaster on concrete block walls can fail where the blocks were damp when the plaster was applied. Also UV rays, which are high in hot climates, can reduce the durability of the plaster. [93]

1.5.3 Building service system problems

After thermal comfort problems and building construction problems, building service system problems is the last group of problems in hot climates. According to few studies have been done in air conditioning systems [78], [102], [31], [38], [71] and in electrical and water supply systems [30], [33], these problems are usually grouped in building air conditioning systems, electrical supply systems and water supply and waste systems. This section will briefly go through these topics.

1.5.3.1 Building Air Conditioning Systems

Air-conditioning (HVAC) systems play an important role in regulating the indoor climate in order to provide comfortable environment for users of buildings. In most buildings the performance of the HVAC system can influence energy consumption as well as indoor air quality. The interaction between a building and its HVAC system is a complex thermal process, which involves radiative and connective heat transfer as well as conduction [78], [38].

Humidity problems can be found in many applications of HVAC systems. In many HVAC applications, the cooling and dehumidification coil is unable to properly meet the dehumidification requirements of the building when the latent load is high, either due to large internal moisture generation or through communication with humid outdoor conditions.

Huh Jung-Ho, Brandemuehl M. J. from Colorado university, done an analysis based on realistic model and found that depending on the application, the mismatch between building latent load and equipment latent capacity can degrade occupant comfort and productivity, cause damage from mold and condensate, and increase energy costs through reheating. These problems will be grown by the increased demand for outdoor air in buildings to address indoor air quality. [102]

Further more, Marc Rosenbaum in his research mentioned that dehumidification is a byproduct of conventional cooling system, which has coil temperatures well below the dew point of the desired room air temperature. As temperature of the cooling coil rises, the ability of the system to remove moisture from the air drops off dramatically. For example, the evaporation of water from surfaces in evaporative coolers is an important method for cooling buildings in hot climates. In addition, the control of migration of moisture through building materials must be considered in building design to avoid structural damage [31], [38].

In winter the interior of the building is more humid than the exterior. Hence, water vapor will tend to diffuse from the interior to exterior. If the winter is cold, the migrating moisture may reach a location in the wall where the insulation is at the dew point and condensation occurs. The condensed water saturates insulation, rendering it useless as a heat loss barrier. If condensation levels are extreme, wooden structural members can deteriorate or steel ones can rust, compromising the structural integrity of a building [38].

So in hot climates it is highly recommended that depends on the type of building and its functionality appropriate single or multi zone air conditioning systems which highly reduces the indoor moisture being used, to not have any defects in structural and non-structural building elements and provide maximum thermal comfort for occupants.

1.5.3.2 Electric Supply Systems

All electric cables give off heat in use and this is usually dissipated without any difficulty. However, cables can get overheated if placed beneath loft insulation, behind insulated dry lining or if placed in a position where the temperature of the surrounding environment is high. Getting overheated in electric cables are common problem of electric supply systems, but will be more critical when we deal with hot regions [30].

Electric cable should not be covered by thermal insulation nor, ideally, should it be used where ambient temperature regularly exceeds 30˚ C. where this is not feasible, cables will need to be de-rated in accordance with the regulations prepared by the Institution of Electrical Engineers. It may be worth noting that a cable de-rating factor as low as 0–5 will be needed where cable is insulated on both sides. There can also be an interaction between PVC cables and expanded polystyrene often used for insulation and this can cause degradation of the PVC. The two should be kept apart. As noted by Noy and Douglas, loose connections can trigger an electrical fire as well as cause malfunction of the electrical system. In addition, an inadequate cable rating to appliances such as shower units and cookers can also cause heat build-up, thus increasing the fire risk [30].

1.5.3.3 Domestic Water Supply Systems and Waste Water Systems

Domestic water supply systems and waste water supply systems will be faces by major problems caused by large difference of temperature in day and nigh time. This difference usually brings expansion and contraction to piping systems in hot regions. In order to decrease the damage caused by these movements, it is recommended that using PVC pipes instead of other types could be a successful solution. On the other hand, durability and lifetime of new generation of PVC pipes has been reported by number of researchers in hot climates [33].

In the case of using pipes within walls, ground and floors, a force and pressure applied to piping system should be considered carefully. In addition to this, all pipes, which have been placed within walls, roofs and floors, has to be covered by flexible and insulated materials. Insulation for piping systems will ensure that less corrosion or rusting will be occurred in pipes and in hot water supply systems thermal loss will be reduced [30], [33].

Chapter 2

EVALUATION OF BUILDING PROBLEMS IN HOT CLIMATES

In this chapter the collected data from the literature survey about building problems in hot climates used for evaluation process in buildings. These problems as mentioned before are classified under three main subjects as,

- Thermal comfort problems,
- Constructional (structural and non-structural) problems
- And building services systems problems.

Therefore, summarized knowledge for each subject will provide list of problems and evaluation criteria's for the existing buildings. In addition to this the gaps in this issue were determined for further researches.

2.1. Evaluation of Building problems in Terms of Thermal Comfort in hot climates

Buildings have different thermal comfort problems in summer and winter seasons in hot climates regions. As mentioned in previous chapter,

- High indoor air temperature in overheated period
- High relative humidity level in overheated period
- Low indoor temperature in under-heated period

are three major sources of problems in terms of thermal comfort.

In overheated period indoor air temperature and relative humidity level increase, while in wintertime, it creates just an opposite condition. Therefore, by evaluating building problems in terms of thermal comfort, it will be more easy to calculate cooling and heating requirements, design of heating, ventilating and HVAC systems and finally minimize energy consumption of the buildings.

In this case, during overheated period, reduction of heat gain and combination use of passive and active cooling systems are design strategies, while controlled heat gain with passive systems in under heated period, provide comfortable indoor thermal condition for occupants. In addition to those strategies,

- Thermal insulation,
- Natural ventilation in order to decline effect of moisture level of indoor air,
- UV controlled materials

will provide the thermally comfortable indoor environment inside of the buildings. Therefore, by considering all investigations have been mentioned in chapter 1, following points can be listed as evaluation criteria for building problems in terms of thermal comfort.

2.1.1. Building problems in overheated periods

As discussed before, heat gain and moisture reduction methods are two most important strategies in order to provide thermally comfortable environment. In order to minimize the heat gain solar control and thermal insulation will be two major precautions. On the other side, natural ventilation could be added to solar control methods to reduce the moisture level of indoor air. These three factors will be evaluated in terms of building orientation, layout, form, building envelope etc.

Building Layout, Forms and Orientation

In order to have appropriate evaluation of building layout two factors have to be considered carefully:

- Topography
- And vegetation.

In order to evaluate topography elevation, slope, hills, valleys and ground surface conditions have to consider carefully in order having proper interaction with vegetation of the environment. Therefore, interaction between topography and vegetation around building should be able to provide access to cooling breezes in the summer. In figure 2.1 different order of vegetation used to protect building from undesirable breezes and solar radiation

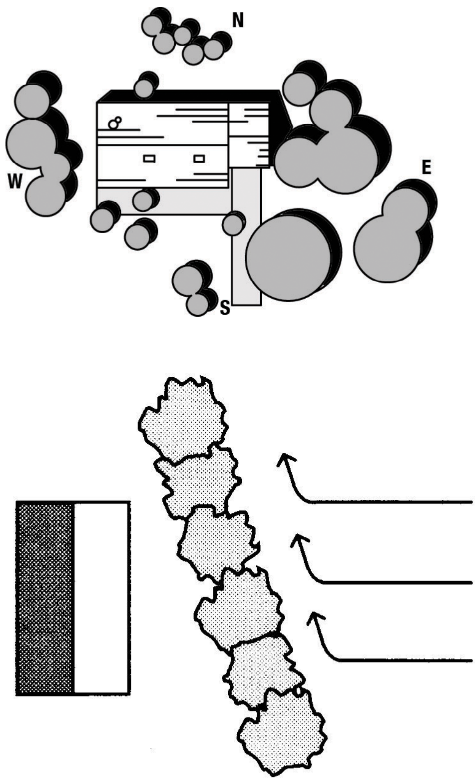


Figure 2.1: possible topography and vegetation for Building layout
(Source: *Stay Cool a design guide for the built environment in hot climates*, Holger Koch-Nielsen, Cromwell Press, UK, 2002)

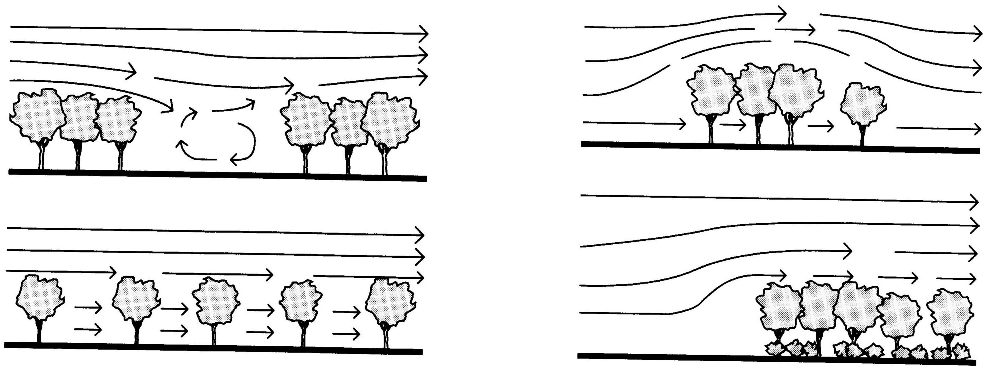


Figure 2.2: Vegetation and grouping to have an effect on wind movement (Source: *Stay Cool a design guide for the built environment in hot climates*, Holger Koch-Nielsen, Cromwell Press, UK, 2002)

For building form, according to few studies, it is recommended that in hot climates those forms, which have ratio of width/height equal to 1:2, are the most successful forms by considering that mostly cores should be located in south side with proper shading elements, because of high sun dept in this location. It should be noted that building form should be extended along east-west axis to minimize east and west exposure.

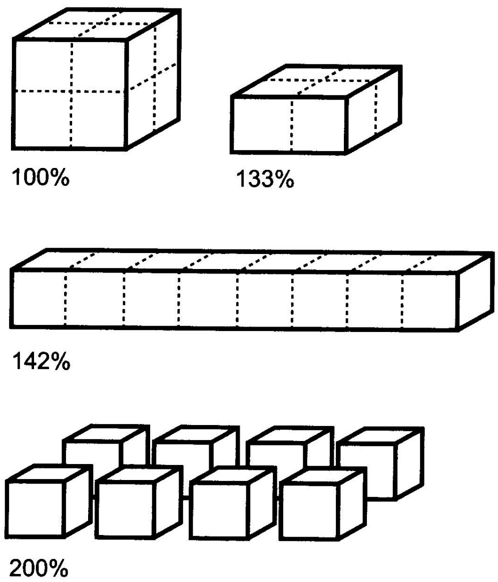


Figure 2.3: the surface area to volume ratio of various building layouts
(Source: *Stay Cool a design guide for the built environment in hot climates*, Holger Koch-Nielsen, Cromwell Press, UK , 2002)

In addition to length-width ratio, the illustration above shows surface to volume ratio as another factor in order to have proper building form. The difference in percentage indicates the difference in heat gains and loss due to surface.

Finally orientation building should be somehow, where lobbies, stairs, circulation and balconies could be placed in north and south because natural ventilation is sufficient there. For those locations, which need to have solar heat gain, should be placed in east and west sides, while atrium should be located at the center of the building for cooling and shading purpose.

Building Envelope

Building envelope, which categorized as two major types:

- Opaque envelope
- And transparent envelope

has to be evaluated to complete criteria mentioned in section A. Thus, each type of building envelope has to design with some specifications, which will be listed below.

A. Opaque Envelope

In order to have opaque envelope with less heat gain or less heat loss during overheated or under heated period two methods as

- Reflective surface
- And thermal insulation

have to be considered in its two major components, walls and roofs.

Opaque walls

Opaque walls should be designed or covered by reflective materials in order to reduce the absorption level of solar radiation. This property is optional for external walls.

Since a reflectivity property of building envelope is necessary but not sufficient, thermal insulation techniques have to be applied to buildings to reduce the level of heat loss and head gain accordingly in winter and summer. As reviewed in chapter 1, insulation materials could be divided into two groups: organic and inorganic materials. In order to have building with acceptable thermal insulation level, designers have to pay attention to three parameters during insulation process. Those parameters are

- Type of insulation materials,
- Location of installation
- And thickness of insulation materials.

Different researches have been done to find out the best insulation materials in hot climates but to choose the best material in addition to R-Value and Labeling properties of those material, cost of the materials usually bring some limitations and restrictions. Therefore, if there is no problem with the cost of insulation materials Extruded polystyrene foam has the best performance and then foam polyurethane, mineral wools and extruded polystyrene will provide acceptable insulation level for buildings. Therefore, based on discussions in second chapter, by combining use of capacitive insulation materials and resistive thermal insulation materials, building will have great thermal performance, especially in hot weather countries.

Location of insulation materials is a second important property, which will affect the level of thermal comfort. As mentioned before, thermal insulation material could be placed either at the inner, middle or outer part of the building surface. It is highly recommended by large number of research mentioned in previous chapter that if we have building with air-conditioning system switch on continuously, it is better to placed the insulation material in inner surface and vice versa if there is no air conditioning systems indoor and building just use natural ventilation for cooling purpose.

It should be noted that the optimum insulation thickness strongly depends on the cost of insulation material and cost of acclimatization. Most of the studies mentioned that by keeping thickness of insulation material around 5cm and increasing the thickness of the masonry walls above 10cm building would take the advantage of acceptable insulation cost.

Opaque roofs

In order to control solar radiation, proper selection of roof type is another important factor. Opaque roof is one of the most important types of roofs used normally in hot climates.

In chapter 1 noted that opaque roof could be grouped as:

- Sloped as two way pitched roof, hipped roof, mansard roof
- Low-sloped roof

In second chapter, we mentioned that heat transfer from roof is the most important factor in the case of heat gain in summer and even heat loss in winter. Therefore, in order to control heat gain and loss from roof, it is better to control heat transfer from roof by

- Covering roof with reflective materials or paintings
- Ventilating roof spaces and
- Insulating roofs.

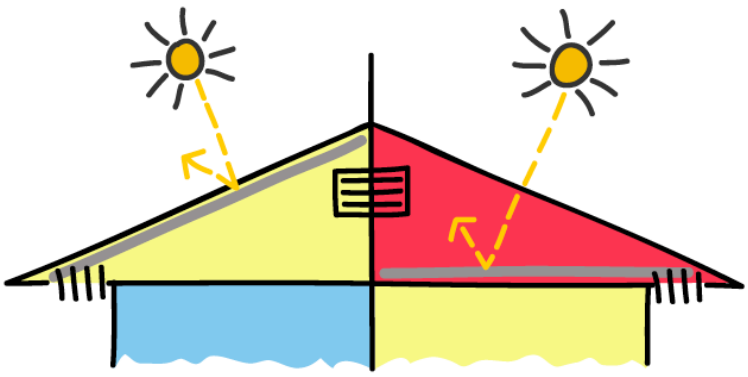


Figure 2.4: Reflective foil under the roof sheeting keeps the roof-space cooler than if placed on the ceiling
(Source: URL www.townsville.qld.gov.au/resources)

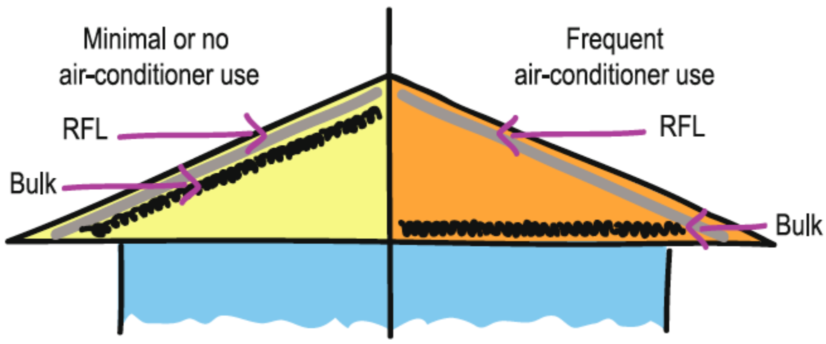


Figure 2.5: the best location for the installation of bulk insulation depends on how often the house will be air-conditioned (RFL is reflective foil laminates)
(Source: URL www.townsville.qld.gov.au)

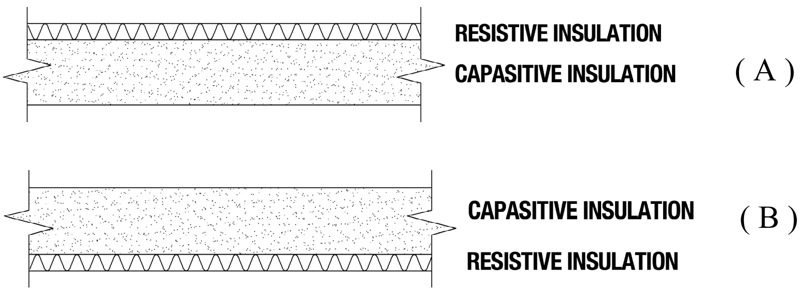


Figure 2.6: flat roof with thermal insulation, in shape A capacitive insulation stores the heat energy during daytime and discharge it during night time and vice versa in shape B.

According to different studies have been done in hot climates, low-sloped and sloped roof like inclined roofs with attic space with inner side insulation and terrace roofs are the best-performed roofs. There reason which provides better performance for inclined roof, is inclined part of roof makes shade and protect the slab against solar radiation, while attic ventilates this space during daytime and discharge the stored energy by attic. It should be noted that inclined roofs with attic space show higher performance in overheated period, while low-sloped roofs with solar gain properties have better performance in under heated season. Also terrace roof with thermal insulation located close to the external surfaces has shown the best performance. Therefore, it is highly recommended for roofs, to use reflective materials and placing insulation material in inner side to increase the thermal performance of roof when there is acclimatized indoor space.

B. Transparent Envelope

Transparent envelope as one of the most important decision by architects grows rapidly these days. Glass as a main object in this type of design strategy has to be selected properly to not bring additional thermal comfort defects. As mentioned in second chapter, glass types are reflective and diffuse reflective glasses, solar control glass or low-E glasses, decorative glass and normal glass. In hot climates, diffuse reflective glasses and solar control glasses are highly recommended, based on their heat gain reduction characteristics. In such cases, it could be noted that, if glasses powered by tinting or laminating techniques, total thermal performance of transparent envelope would increase tremendously. Transparent envelope could be evaluated by use of appropriate glasses in its wall and roof.

Transparent walls

As mentioned before, walls in transparent envelope usually consist of two subsystems. These are double-glazing and double façade. To refresh our mind, double-glazing is a system where there is a space between two panes of glasses usually in few millimeters thickness. Therefore, dry air will be trapped between two panes and creates an insulation layer. Double façade is obtained by adding an extra layer of glazing outside the façade to provide the building with ventilation or additional soundproofing. This system may be realized in various ways, depending on the functions desired and the requirements made on the façade. [88]

The most effective version of the double façade is undoubtedly the shaft-box façade. In these systems discrete box windows or other façade elements release their exhaust air into a shaft mounted on the façade and extending over several floors for greater thermal efficiency. The height of the shaft means that a stack effect ensures vertical motion of the air in the shaft, hence enhancing the efficiency of the system.

In addition to the type of double skin façade, mentioned by different research groups as like as ASHRAE, west-facing glass increases the size and complexity of the cooling systems. Therefore, selecting appropriate type of glass with reflectivity or low emissivity property will provide additional insulation layer for the façade of the building to neutralize the disadvantage of transparency in building envelope. So as recommended in chapter 1, a double skin façade with careful material choice, which has reflectivity and air gap including vents, will be a successful solution. Last issue in transparent envelope is shading elements. Because of high solar radiation it is recommended to apply horizontal projection over the whole window of about 1 meter. It should be noted that in hot climates always studies mentioned that shading elements should mostly located on the west and south side of the buildings.

Transparent roofs

There are different ways of achieving the benefits of transparent roofs but there is lack of information in order to evaluate their problems in hot climates. As obvious in hot climates, high heat gain from transparent roofs is the most important problem during overheated periods. Therefore, one possible way to control this situation is a system that uses fully movable transparent louvers, built between two layers of transparent polycarbonate sheeting. These adjustable louvers, which can be operated manually or automatically, could direct controlled-light to building. [89]

In addition to adjustable louvers, use of blinds or awnings will dramatically control heat gain by transparent roofs. Blinds are installed under transparent roofs on the inner side of building, and they are available in different types as like as block out, solar control, and the insulating honeycomb-type blinds and several colors. [89]

On the other hand, Awnings are installed outside on the top transparent roof and it could be completely or partially closed transparent roofs by needs of occupants. They are available in fabrics from canvas through to acrylic and solar control. [89]

It has to be noted that, although use of transparent roofs are very risky and need proper design, but they have some benefits. The most important benefit is, entry of large amount natural light from roof to building, which can reduce the electrical energy consumption, the need for artificial lighting and provide fresh, clean and open feelings for people inside of building. [89]

2.1.2 Building problems in under-heated Periods

Building in hot climates areas should be design properly specially for overheated periods, but at the same time its problem in under-heated period should be minimize as well. Low indoor temperature is the main problem during under-heated period. Heat gain method should be controlled somehow to maximize heat gain in under-heated period. It should be noted that the same system should be fully controlled in order to provide natural ventilation in overheated period. Therefore, passive solar systems or in particular, passive heating systems will be evaluated as design strategy in under-heat period. As mentioned in chapter 1 mentioned that there are two major groups of passive systems in respect to heating and cooling systems. Each group can be divided to four basic systems:

- Direct gain,
- Thermal storage wall,
- Attached sunspace
- And convective loop.

According to properties of each of those systems discussed in previous chapter, attached sunspace has the best performance because of its integration with other systems, but still it is not clear enough that which subsystem of attached sunspace has more performance in compare to others.

But it should be noted that in all the cases proper shading devices and dynamic insulation layers will extremely increase the performance of the passive system either in cooling or heating seasons.

As summery to section 2.1, it should be noted that most of the studies focused on solar control methods related to opaque envelope, building layout, forms and orientation in overheated periods and under heated period. But there is a need for more investigation on transparent envelope and particularly transparent roofs. Also there is a lack of information in order to clarify the best passive solar systems.

2.2 Evaluation of Building Structure in Terms of Structural Problems in Hot Climates

Structural elements of buildings in hot climates always face with major defects because of parameters like

- High temperature
- And high humidity level in these regions.

As mentioned before, in this type of climate, different factors influence negatively durability and performance of buildings during construction stage and after construction stage. These factors will generate different side effects in

- Reinforced concrete,
- Steel
- And timber structure systems.

In this section these three structures will be evaluated.

2.2.1 Evaluation of Reinforced Concrete Structure System

Concrete as a material with weak tension and high strength is one the materials, which uses frequently nowadays. Because of long life with low maintenance cost and resistance against fire, this material is widely used in building construction process. According to reviews mentioned in chapter 1, different types of problems rise up in buildings with reinforced concrete. Those could be listed as

- Carbonation, Corrosion, Chemical damage
- And hot weather concreting problems.

In this case in order to avoid or reduce those problems following precautions recommended applying to this specific type of structure. Most of the chemical damages reported in concrete structure are related to steel bars. In the case of carbonation, corrosion and chemical damage of steel bars used to reinforce the concrete, use of reinforcing steel which covered by 25mm protective layer will reduce the yield strength and tensile strength losses of the steel and gives it higher strength against chemical damages, high temperature and moisture.

On the other hand, in case of hot weather concreting problems, any strategy, which slow down the cement hydration reactions within the concrete and minimize the rate of evaporation of moisture from the fresh mixed concrete, will increase durability and strength of the structure. Therefore, in any stages of concrete production some points have to be taken into consideration. In production stage, water demand should not increase too much and entrained air content should be controlled carefully. In transit step, water evaporation level should control in order to not loss workability. Finally in placing, finishing and curing stage, evaporation should be control carefully in order to avoid tendency to cracking and loss of workability. It should be noted that in addition to following points, compressive strength range between 30 to 50 MPa (1 Mega Pascal = 10^6 N/m^2) is highly recommended by civil engineers to protect building from carbonation and increase durability of the structure.

2.2.2 Evaluation of Steel Structure System

Steel as a member of metals family with reasonable cost and flexibility in design has benefit of high durability. In this structure, two major distortion reported by different researchers. Those are

- High temperature distortion
- And corrosion caused by moisture.

It should be noted that between above factors, corrosion could be appeared in any different climates, where moisture level in building materials is exceed its standard amount and thermal distortion mostly reported in very high temperature in hot climates regions.

To evaluate this type of structure, designers should be aware of some precautions. In the case of high temperature distortion, because of differential movement stresses at the structure, which lead to forced dimensional change; structure has to have decking and supporting materials like joints with appropriate moisture and thermal movement coefficients.

On the other hand, because of natural chemical reaction between steel and moisture in front of oxygen, which called as corrosion, all steel columns and beams should be protected with proper insulated materials to reduce the corrosion in steels bars and eventually increase the heat resistant ratio in the case of fire. It should be noted the in the case of fire, when there is no insulation materials to protect steel beams and columns, very high temperature will bend the main structure and consequently collapse the building.

2.2.3 Evaluation of Timber Structure System

Timber as one of first construction material is still widely used in construction because of

- Ease of working,
- High strength
- And durability.

But as mentioned in chapter 1, these days it is not used specially in hot climates. Reasons, which decrease the use of timber in today's construction, are

- Moisture movement,
- Flammability
- And insect-fungal attack to timber.

Unfortunately, there is no research related to timber structure in hot climates. But just a few reports indicated that moisture in timber columns and beams could reduce the durability of them and bring corrosion to metal fixing like nails. Also, high moisture will generate expansion or contraction deformity in vertical direction to structure.

Same as steel structure, it is highly recommended to insulate beams and columns with any type of insulation materials. Thus, these types of insulation could be able to increase durability and fire resistance level while decrease the probability of insect and fungal attack to timber structure.

In the case of building structural problems in hot climates, there is a lack of information in steel and timber structure, which somehow indicates the low interest in use of these type of structures in compare to reinforced concrete structure.

2.3 Evaluation of Building Non-Structural Elements in Terms of Constructional Problems in Hot Climates

After evaluation building problems in terms of thermal comfort and structural elements, in this section building problems in terms of non-structural elements will be evaluated. Non-structural components divide into four main categories:

- External walls,
- Wall openings,
- Roofs
- Internal components.

2.3.1 Evaluation of External Walls

As we know, main function of external walls is isolating the interior of the building from the exterior condition. In hot climates following factors are mentioned as general problems of external walls.

- Moisture, which when absorb by building materials could result defects like moisture movement and chemical damages in forms of salts and condensation
- Thermal movement
- UV defects

In order to avoid these problems some precautions have to be considered. As mentioned before, because of mostly use of concrete and brick, which are porous, moisture can easily enter to them. Because of difference between in inside and outside temperature, dampness can evaporate from interior surfaces leaving behind hygroscopic salts. These can absorb moisture from the air within the building and generate the dampness problem. In this case, in order to avoid such situation, as mentioned in thermal insulation section, applying adequate insulation material with proper thickness will reduce the amount of condensation and its side effects. It should be noted that because of moisture absorption by materials like lightweight concrete, calcium silicate bricks and timber, moisture creates excess movement, which is reported in some studies as well.

In terms of thermal movement, expansion and contraction are the most important consequence of temperature changes, which usually happened in hot climates. Use of expansion joints can extremely reduce the defect of thermal movement. These expansion joints accompany with lime-based mortar, which is more flexible in compare to cement can increase performance of expansion joints.

Finally, defects created by ultra violet, which mostly observed in hot climates areas has to be avoided. As mentioned by Sage Blossom Consulting, Ultraviolet (UV) light degrades many materials, consisting wood, fabric, plastics, and paint not even limited to hot climates. Unfortunately, there are some materials that can be applied to block the UV spectrum of sunlight, but they are toxic with create additional set of problems. Therefore, Selecting UV resistant materials will improve a building's durability and reduce defects occurs in external wall and opening materials and their paintings. Several products are moderately effective in order to block UV. For example, Low-E glass could be able to provide additional protection from UV. However, even the best of low-E glasses still transmits 26% of the UV radiation among its whole amount. It should be stated that laminated architectural glass made with clear or tinted interlayer is essentially opaque to UV radiation. [99]

2.3.2 Evaluation of Wall Openings

Wall openings, which grouped as Doors and windows, are faced with following problems as mentioned in previous chapter.

- Moisture
- Thermal movement
- Chemical damages
- UV defects

Doors

In order to reduce doors problems in climate, it is highly recommended to select an appropriate type of doors among those mentioned in chapter 1. For instance, use MDF doors as interior doors, which are harder and durable than other doors, though not as strong as solid wood but cheaper. This type of doors are usually suitable for indoors in hot areas, because of their characteristics and their strength against moisture, thermal movement of indoor. If cost of the doors leaved out, then use of insulated wood panel or even fiberglass doors will be reasonable substitution for MDF doors. In case of exterior doors, fiberglass doors, stave-core and steel doors will provide high performance in terms of thermal movement, moisture movement and chemical damages. It should be noted that in case of UV defects, use of fiberglass doors or UV resistive paintings on exterior doors would decrease the negative affects of solar UV radiation and will improve durability.

Thus, high-insulated doors will eliminate moisture movement and use of light covering color will minimize the expansion or contraction because of changes in temperature.

Windows

In order to avoid common problems mentioned above for wall openings in hot climates, vinyl and fiberglass windows show better performance in compare to aluminum and wooden windows. Aluminum windows are not used widely in residential buildings because of high heat loss/gain through this type of window in form of conduction. Pure wooden windows also bring high maintenance cost to building's owners caused by rain, moisture and the effects of damaging UV rays emitted by the sun. In order to reduce disadvantage of these two types of windows, window manufacturers cover the exterior of wooden window with aluminum. This protects the exterior, and provides a wood finish for the interior.

But the most energy efficient windows use nowadays, are Vinyl windows and fiberglass windows. Although both of these windows eliminate common problems appeared in hot regions, they have their own advantages and disadvantages. Vinyl is a material that can be extruded. Solid windows usually are expensive, heavy and low insulated, where in Vinyl windows it will be in contrary. The only disadvantage of the Vinyl windows is a limitation on color selection.

In order to have all advantages related to Vinyl windows and eliminate the color limitation, fiberglass windows are introducing to market. It has high strength, resistance to extreme temperatures, and practical frame construction. Fiberglass windows made by fiberglass cloth and epoxy resins, which provide smooth, strong finish that even could be painted and more flexible than Vinyl. For standard sized opening flexibility will not be a factor but if you have a particular situation where the opening is a good deal larger, fiberglass could provide a better application. [103]

2.3.3 Evaluation of Roofs

Problems appeared in roofs can be because of reasons as like as poor design, poor construction, roof spread and moisture penetration. In addition to these reasons especially in hot climates, because of large difference between day and night temperatures, horizontal and vertical forces will provide thermal movement. These forces which created vertical or horizontal movement in roofs directly depends on materials expansion coefficient and external temperature. In this case by controlling the sheet size and expansion details of covering materials, distance of the movement could be controlled.

Also, it is recommended in different studies that use of mastic asphalt with painted reflective insulation material at the top will provide the best solution to reduce differential movement and heat gain in roofs.

In the case of low-sloped roofs it is suggested to use reverse roof or upside down roof, which is a kind of protected membrane roof system (PMR). In this system, roof deck, waterproofing membrane, moisture-resistant insulation creates specific arrangement of roofing materials. With these types of roof, the membrane's temperature range and rate of temperature change are greatly reduced. In fact, the PMR system protects decking and waterproofing materials against negative effects of UV as well. By just reversing the position of insulation and the membrane the cause of lots of problems in roofs could be eliminated. [104]

On the other side, interstitial condensation, which can affect flat roofs has been seen when the outside temperature is low. In interstitial condensation, warm and moist internal air passes through the roof and when it meets colder air, warm air condenses and it result will be appear in the form of dampness. These interstitial condensation problems in warm roof can in theory be avoided by providing an impermeable vapor barrier as close as possible to the ceiling.

2.3.4. Evaluation of internal non-structural components

Based on what discussed in chapter 1, non-structural components divided into two major categories. For non-structural components, there are few studies available in order to define classification for problems in non-structural components. This could be because of large amount of non-structural materials with various types. But as we can conclude by consider issues mentioned in 2.3.1, 2.3.2 and 2.3.3, moisture, which creates moisture movement and corrosion and high temperature, which creates thermal movement could affect internal components and bring some changes in case of misplacement and distortions.

2.4 Evaluation of Building in Terms of Building Services Systems Problems in Hot Climates

After constructional (structural) problems mentioned, building services system problems is the last category, including air conditioning systems, electrical supply systems and water supply systems, which will be reviewed in this study.

2.4.1 Evaluation of Building Problems in terms of Air Conditioning System

Previously mentioned that HVAC systems are regulators of indoor climate by controlling temperature and humidity level. As reported in many studies, humidity problems can be found in many applications of HVAC systems. They mentioned that usually mismatch between building latent and equipment latent capacity could degrade occupant comfort and productivity, cause damage from mold and condensate. On the other side, as temperature of the cooling coil rises, the ability of the system to remove moisture from the air drops off dramatically. Reasons for problems discussed above, are wrong installation location and wrong capacity selection for HVAC systems.

So in hot climates, it is highly recommended that depends on the type of building and its functionality appropriate single or multi zone air conditioning systems being used to not have any defects in building and provide maximum thermal comfort for occupants.

2.4.2 Evaluation of Building Problems in terms of Electrical Supply System

Related to electrical supply systems, there are few studies. They mentioned that since electric cables give off heat in use, they could be overheated in cooling seasons especially in hot climates. Therefore, to prevent risk of short circuit and possibly fire, it is highly recommended to place them beneath loft insulation where the temperature of the surrounding environment is high. More details related to insulation of electrical circuit and cables should be done under the supervision of electrical engineers and technicians.

2.4.3 Evaluation of Building Problems in terms of Domestic Water Supply and Waste Water System

Piping systems used in water supply systems and waste water systems usually made by metals family or PVC. In the case of metal pipes, because of sensitivity of metals to temperature, they usually faced with expansion and contraction during day and night. On the other side, because of reaction with mineral particles inside of water and even water running in these pipes, corrosion always happen specially in joints. To protect metal pipes from thermal movement, proper insulation and placement decision highly proposed in construction stages. Therefore, professions usually recommend using PVC pipes because of their durability, long lifetime and even installation process. Unfortunately there is no scientifically research in this field to find out the proper material, but same as electrical systems consultancy with mechanical engineers suggested to have well-designed building.

2.5 Overall Evaluation of Building Problems in Hot Climates

In order to have overall evaluation of building problems in hot climates, table below could be as a summery of this chapter:

Table 2.1: Evaluation of the building problems in terms of thermal comfort in hot climates

<table>
<tr><th>Problems</th><th>Considerable factors</th></tr>
<tr><td rowspan="3">High indoor air temperature
because of high heat gain
&
High relative humidity of
indoor air
During overheated period</td><td>Heat gain reduction methods</td></tr>
<tr><td>Solar Control
Building Layout
Building Form
Building Orientation
Building Envelope
Opaque Envelope (Wall & Roof)
Transparent Envelope (Wall & Roof)</td></tr>
<tr><td>Passive Cooling (Ventilation) Systems</td></tr>
<tr><td>High Heat Loss during
under-heated period</td><td>Proper thermal insulation</td></tr>
<tr><td colspan="2">More information could be found in following publication in section references:
1,2,4,10,11,12,13,14,15,16,17,18,19,20,25,26,27,28,29,31,34,35,36,37,40,41,42,43 ,44,45,46,47,48,49,50,51,53,54,555,56,60,61,62,63,64,66,67,68,69,70,71,72,73,74, 75,76,77,82,83,88,90,92.</td></tr>
</table>

Table 2.2: Evaluation of the building structures in terms of structural problems in hot climates

<table>
<tr><th colspan="2">RC Structure</th></tr>
<tr><th>Problems</th><th>Considerable factors</th></tr>
<tr><td>Corrosion
Carbonation
Chemical Damages</td><td>Proper insulation</td></tr>
<tr><td>Hot weather concreting</td><td>Proper progress in production, transit and long term</td></tr>
</table>

Table 2.2: Evaluation of the building structures in terms of structural problems in hot climates (Cont.)

Steel Structure	
Problems	**Considerable factors**
High temperature distortion Corrosion caused by moisture	Proper insulation
Timber Structure	
Problems	**Considerable factors**
Moisture movement Flammability Insect & fungal attack	Proper insulation
More information could be found in following publication in section references: 11,21,22,23,25,28,29,30,33,35,36,48,49,52,57,58,59,60,61,62,63,71,72,85,90,91,92,94,96,97,98,99,100,101	

Table 2.3: Evaluation of the building non-structural elements in terms of constructional problems in hot climates

External Walls	
Problems	**Considerable factors**
Moisture movement Dampness Chemical Damages	Proper insulation
Thermal movement	Proper insulation & expansion-contraction joints
UV defects	Proper covering by appropriate materials
Wall Openings	
Problems	**Considerable factors**
Moisture movement Chemical damages	Proper insulation
Thermal movement	Use of materials with limited expansion-contraction ratio Use of light colors
UV defects	Proper covering by appropriate materials
Heat gain/loss	Use of proper glass types (reflective or low-E)

Table 2.3: Evaluation of the building non-structural elements in terms of constructional problems in hot climates (Cont.)

Roofs	
Problems	**Considerable factors**
Thermal movement	Proper use of expansion & contraction joints
Interstitial condensation	Proper insulation and ventilation
Internal Components	
Problems	**Considerable factors**
Moisture movement	Proper design for building envelope
More information could be found in following publication in section references: 11,21,22,23,25,28,29,30,33,35,36,48,49,52,57,58,59,60,61,62,63,71,72,85,90,91,92,94,96,97,98,99,100,101	

Table 2.4: Evaluation of the building in terms of building services systems problems in hot climates

HVAC Systems	
Problems	**Considerable factors**
High indoor humidity	Proper use of HVAC systems (Relation between building latent and equipment latent capacity)
Electrical Supply Systems	
Problems	**Considerable factors**
Short circuit & fire	Proper insulation
Water & Waste Water Supply Systems	
Problems	**Considerable factors**
Thermal movement Corrosion	Proper use of piping materials Proper insulation
More information could be found in following publication in section references: 2,3,21,28,29,38,64,78,79,80,81,82,90,102	

Chapter 3

CONCLUSION

In this study, building problems in hot climates have been referenced. These problems are divided into 4 major groups:

- Building problems in terms of thermal comfort
- Building problems in terms of structural systems
- Building problems in terms of non-structural components
- Building problems in terms of building services systems

In previous chapters, building problems have been evaluated in each of above groups, in order to suggest some precautions. Furthermore, in this section as conclusion for this study and as complementary to chapter 2, gaps and possible research areas will be mentioned for those researchers who are interested for further studies.

3.1 Conclusion of building problems in terms of thermal comfort in hot climates

Based on all discussion around building problems in terms of thermal comfort, buildings face with problems in overheated and under-heated seasons in hot climates regions. Those problems, which evaluated in this study, are three sources of problems in terms of thermal comfort.

- High indoor air temperature and high relative humidity level in summer
- Low indoor temperature in winter
- High level of UV radiation

For building problems in terms of thermal comfort in hot region, many researchers have done numbers of research and studies, and evaluated different impressive parameters to decline those problems.

According to investigation had been done by researchers and scientist, it could be mentioned that most of researches in thermal comfort issue focused on following areas:

- Thermal comfort measurement techniques in buildings
- Simulation methods building for comfort achievement
- Building envelope design for comfort achievement
- Thermal comfort models
- Thermal comfort standards
- Effect of moisture, humidity and natural ventilation on thermal comforts
- Impact of insulation strategies and materials on thermal comfort
- Relationship between thermal comfort and user satisfaction
- Relationship between thermal comfort and energy conservation

By considering all topics listed above and those, which referenced in chapters 1 & 2, large numbers of studies have been done, to address building problems in hot climates in terms of thermal comfort principles. As consequence of those studies, two methods, heat gain reduction method in overheated and heat gain methods in under-heated periods suggested as possible solutions.

In case of heat gain reduction method in summer, although there are large numbers of resources, but they mostly focused on solar control methods related to opaque envelope, building layout, forms and orientation. Therefore, the need of further investigation on transparent envelope and particularly transparent roofs strongly feels.

In addition to importance of solar control methods, it should be noted to not forget the complementary role of thermal insulation. However, many resources are available, but those studies mostly concentrate on installation position and very few on thickness and types of thermal insulation materials. Therefore, because of daily growth in thermal insulation materials, more studies based on variation of insulation materials and their optimal thicknesses are highly recommended.

On the other side, in under-heated period, nearly most of the scientists are agreed that passive solar system is the best solution to provide comfortable indoor temperature for occupants in hot regions. But noted that, this suggestion is valid when we deal with passive system as first priority.

Based on materials reviewed in this study, still there is a lack of information in order to find the best passive solar systems, but attached sunspace is the first choice of many designers, architects and even scientists. Although attached sunspace is the first choice among other types, but it is very difficult to say which subsystems of this system should be selected in advance. Thus, a big gap in such a sophisticated issue still remains to fill with those designers and architects, who are interested in it.

Finally, by review on what mentioned up to this point, it can be concluded that, in order to have proper building design with minimum defects in terms of thermal comfort issue, architects and designers have to design following points properly:

- Building layout, form and orientation
- Building envelope, either opaque or transparent
- Passive solar systems, either cooling (ventilation) or heating
- Thermal insulation (type, thickness, location)

3.2 Conclusion of building problems in terms of structural systems in hot climates

In the case of building problems in terms of structural systems in hot weather, three major structures have been taken into consideration. Those structures were reinforced concrete, steel and timber structures. Structural elements of buildings in hot climates faced with major defects because of parameters listed below.

- High temperature, which affects durability of concrete in RC structure, creates thermal movement in steel structure and cause fire in timber structure.
- High humidity, which carbonates concrete, makes steel and timber to be corroded.
- High level of UV radiation, which downgraded the durability of concrete and timber.

In reinforced concrete some problems are classified as RC structure problems. Those were hot weather concreting problems, corrosion, carbonation and chemical damages. According to studies reviewed in this research, there are number of studies which have been done by engineers especially by civil engineers, which indicates that this topic should be one of the main subjects to be consider by civil engineers in corporation with architects who design the building.

Unfortunately related to steel and timber structure there are not enough researches, which somehow indicates the low interests in this type of structures in hot climates. By the way, it is not the statistical result and it could be because of thermal advantage of reinforced concrete as a kind of capacitive insulation in compare to steel or timber structure.

3.3 Conclusion of building problems in terms of non-structural systems in hot climates

About building problems in terms of non-structural systems in hot climates, four components have been investigated. Those are external walls, wall openings, roofs and internal finishing material. Many studies have been reviewed with priority of roofs and external walls, because of great resources related to this area. There are numbers of professional studies have been done in order to evaluate problems of roofs and external wall, but there is a huge gap related to the internal finishing materials, which announce research possibilities to scientific societies.

On the other side, in the case of roofs and external walls, the need for further scientific investigation on moisture problems is dominant and just few studies have been focused in this specific issue.

However, general factors, which caused problems in terms of non-structural systems and evaluated in this study, could be listed as below.

- Moisture
- Thermal movement
- Chemical damages
- UV defects

3.4 Conclusion of building problems in terms of building services systems in hot climates

Related to building problems in terms of building services systems in hot regions, as mentioned before, air conditioning systems, electrical supply systems and water waste systems have to be designed carefully to bring great performance to building.

In the case of HVAC systems, there are numbers of studies done in the field of design such systems, and very few related to integration of those systems with buildings in architectural perspective. Therefore, study on this integration will be a new idea even to design HVAC systems more efficiently.

Related to electrical and water supply systems, there are lack of information related to these to systems especially in hot climates and seems these topics tend to mechanical and electrical engineers side.

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