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A Building Ecology Index for Residential Buildings in Beirut

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PREFACE

The main intent of this thesis is to develop an assessment method that will allow professionals to measure the degree to which a multi-level residential building is environment friendly (or climate responsive). By following a step-by-step process that addresses the important issues, the reader will be able to define and quantify the extent to which a residential building, in Beirut, is climate responsive.

The issues that are studied address parameters that an architect would consider at different stages of the design process, the construction phase, as well as the operational phase. The design issues relate to orientation, massing, ventilation, daylighting, etc. and are discussed with respect to the favourable role they play in relation to the climate. Next, each material is studied in terms of embodied energy. The building materials mentioned are the ones that are most commonly used in Beirut, namely concrete (cement, sand, gravel), hollow concrete blocks, plaster, paint, aluminium, glass and floor tiles. The stages these materials go through before they are finally installed on site are analysed in order to understand and evaluate the impact that they have on the environment. Finally, the way a material ages and the amount of maintenance it requires are taken into account as important factors relating to the overall energy intensity of the material.

All these parameters are given a weighting coefficient according to their level of energy intensity so that the reader can allocate a quantitative value to each assessment issue that will lead to an overall estimate of the climate responsiveness of the building under study.

The information in this thesis could serve as a guideline for architects and builders that are environmentally conscious. This document should increase awareness that will result in a more thorough understanding of the impact that design and construction have on the environment. Consequently, the integration of these parameters into the design and execution of a building will produce climate-responsive architecture.

ACKNOWLEDGEMENT

I would like to express my gratitude and appreciation for all those who made this work possible. I would like to thank my tutor, Sophie Pelsmaker, for her guidance, patience and support. I am grateful for the time and effort she spent helping me to understand and appreciate the subject matter as well as the contributions she made to the final writing of this thesis. I would also like to thank Mr. Simon Tucker for the advice he provided while developing this document. Finally, I would like to thank my family and colleagues for their continuous support and encouragement.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

An assessment system, the Building Ecology Index, is proposed to account for the impact that a residential building has on the environment. In an attempt to improve upon the already developed methods and define a system specific to the context of Beirut, the proposed assessment method constitutes a number of parameters that pertain to both the design parameters as well as the material's life cycle (extraction to demolition). This method entails two separate assessments, one for the design (Design Ecology Index) and another for the materials used (Material Ecology Index).

Identifying design parameters is important since it affects the performance of the building throughout its lifetime. For example, a building that is designed to take advantage of the low winter sun angle, to naturally heat a space, may substantially decrease the cost of power resulting from artificial heating. Consequently, several factors are defined after an overview of the passive design strategies that are important to be adopted in Beirut.

Concerning the building materials, the weighting process consists of assigning a weight that will serve to indicate its sustainability. In this way, a designer who is environmentally conscious would be able to acquire an objective evaluation of the value of a certain material in a more environment friendly structure.

The two indices resulting from the two assessments would then be joined to form a final evaluation of the environment friendly quality of the building (Building Ecology Index).

The climate of Beirut, which is the area that this research focuses on, provides a favourable opportunity to investigate and apply climate responsive design and produce buildings that take advantage of climatic variations in order to provide more comfortable spaces that consume less energy[1]. Currently, the lack of awareness pertaining to environmental matters results in the construction of energy intensive buildings that not only use a lot of energy to operate, but are also uncomfortable to live in. For example, there are 2993 hours of sunshine per year in Beirut[2]. Yet, lack of proper shading, ventilation and/or insulation causes most spaces to overheat in the warm season, which extends seven to eight months, when the temperature is at its highest[3]. In winter, on the other hand, the sun is not taken advantage of to provide passive heating[4]. By studying and integrating these parameters in all the phases of the design, construction and operation of a building, architects will be able to ensure a substantial reduction in energy use while simultaneously providing a higher comfort level in living spaces.

Multi-level residential buildings were chosen for this thesis since they constitute the majority of buildings in the city as shown in the chart below.

Mode of Use	Percent (%)
Residential	65
Non-Residential	11
Mixed	20
Other	4

Breakdown of buildings in Beirut according to the mode of use[5]

Prior to defining the parameters to be addressed, two issues need to be discussed:. First, the passive design strategies that are applicable to the climate of Beirut are defined. Second, the impact of the use of construction materials is studied. To achieve these objectives the thesis is organized in the following manner.

Chapter 2 summarizes three assessment methods in an attempt to understand their structure, as well as the choice and weights of the parameters. The three assessment methods are EcoHomes[6], which is an environmental assessment process that is based on a rating system for homes, LEED[7] which is a rating system whereby the certification tool aims at occupant well being, environmental performance and economic returns of the building, and BMAS[8], an assessment method that addresses all stages of a material. Any relevant information will be retained and used as a guide to construct a new assessment method tailored to the local climate and residential building typology of Beirut.

Chapters 3 and 4 look at the issues of climate, environment and comfort in Beirut. Chapter 5 addresses design issues in terms of passive strategies favourable for climate responsive building in winter, summer and mid season in Beirut. Following that, chapter 6 relates buildings to the climate in terms of mass and envelop while chapter 7 defines the building typologies specific to Beirut and discusses the construction methods used.

Chapter 8 consists of the development of the weighting parameters for both the Design and Material ecology Indices in Beirut. Next, chapter 9 deals with the construction materials analysing them in terms of energy use and the effect they have on the environment. Following that, chapter 10 applies the assessment method by calculating the building ecology index for a residential building in Beirut. Finally, chapter 11 concludes by stating the limitations of the method and suggestions for future work.

CHAPTER 2: EXISTING ASSESSMENT METHODS

There are numerous assessment methods that exist in different countries. After investigating these methods, three methods, namely EcoHomes[6], Leadership in Environmental and Energy Design[7] (LEED) and Building Materials Assessment System[8] (BMAS) are looked at thoroughly because of the following reasons:

First, Ecohomes was studied during Unit 7 of the current MSc. Program;
Second, LEED, being one of the most important assessment methods in the United States, is often referred to in professional publications;
Third, the three methods can be applied to residential projects.

These three existing assessment methods are analysed in an attempt to develop meaningful categories for the proposed method.

EcoHomes assesses the environmental quality of a development. The seven environmental categories considered under this method, include:

Energy operational energy and CO_2;
Transport: location issues related to transport;
Pollution: air and water pollution;
Materials
Water: consumption issues;
Ecology and Land Use
Health and Well Being

The materials component refers to items such as the environmental implications of material selection and the possibility of using recyclable materials, while ecology and land use assesses the ecological value of the site as well as the Greenfield and Brownfield issues; and finally, health and well-being measures internal and external aspects of health and comfort.

In each of the above categories, credits are awarded where specific performance levels are achieved. Various options are available to developers to gain these credits. The number of credits available in each category does not necessarily reflect the relative importance of the issue, as the total rating is calculated according to a series of weighting factors.

Analysis of this assessment method shows that it is very thorough in the issues it addresses. However, since it deals with already built structures, the issues tackled during the design process are not mentioned. On the other hand, water consumption issues are relevant in Beirut since the water distribution system does not satisfy population needs, although underground rivers and pools are abundant.

Leadership in Energy and Environmental Design (LEED) aims to improve occupant well being, environmental performance and economic returns of buildings, using established and innovative practices, standards and technologies.
Projects earn one or more points toward certification by meeting or exceeding each credit's technical requirements. Points add up to a final score that relates to one of four possible levels of certification. The project checklist is divided as follows:

Sustainable Sites
Water Efficiency
Energy and Atmosphere
Materials and Resources
Indoor Environmental Quality

Innovation and Design Process

This method is comprehensive in that it addresses issues of design as well as physical issues pertaining to the construction and operation periods. However, the division of items within each checklist is confining and may not be flexible enough in a city like Beirut. The information locally available does not allow for the degree of precision needed in allocating the appropriate credit definition.

Building Materials' Assessment System (BMAS) is a method that thoroughly addresses the different stages of a materials' lifespan: Extraction, manufacture, construction, use and demolition, as follows:

Extraction

1. Damage to the environment in the extraction of the raw material;
2. Extent of the damage relative to the amount of material produced;
3. Abundance of source or renewability of material;
4. Recycled content.

Manufacture

5. Solid and liquid wastes in manufacture and production;
1. Air pollution in manufacture and production;
2. Embodied energy (energy used for its production);

Construction

3. Energy used for transportation to the site;
4. Energy used on site for assembly and erection;
5. On site waste including packaging.

In-use

6. Maintenance required during life cycle;
7. Environmental effects during life cycle (e.g. toxic emissions)

Demolition

8. Energy use in and effects of demolition at the end of the life cycle;
9. Recyclability of demolished material.

The BMAS presents a thorough understanding of the different phases of the material's lifespan.

Since the proposed assessment method integrates issues relating to design and building materials, none of the methods discussed above can be totally adopted. Therefore a custom designed method will propose a system that yields a Design Ecology Index as will be seen in the following chapters, and a Materials' Ecology Index that is based on the BMAS method described above.

CHAPTER 3: CLIMATE AND ENVIRONMENT IN BEIRUT

Beirut, the capital of Lebanon is located on the eastern coast of the Mediterranean Sea, Latitude 33º49N and Longitude 35º29E[9]. Most of the industrial, commercial and financial activities in the country are concentrated on this coast, which encompasses the majority of the big cities of Lebanon. Forty percent (40%) of the 500m wide strip parallel to the sea is urbanized space while the remaining 60% is divided into agricultural land (41%) and beaches[10].

Beirut has a climate of mild, rainy winters and hot summers[3]. In fact, by analysing the temperature data for all the months in one year, it becomes evident that although the weather in Beirut is varied, it remains characterized by the existence of a short cold season and a relatively lengthy hot season.

Topography

The Beirut area is mainly flat with some slopes as one approaches the Mount Lebanon mountain range. The fact that the city is directly on the Mediterranean Sea results in the following two situations. First, the high relative humidity during the warm months, creates an uncomfortable effect. Second, the wind directions are a result of the difference in thermal capacity that exists between the sea and the land. As illustrated in the adjacent figures, in the daytime, the earth heats up faster than the sea, which results in the movement of air from the cool area to the warm area. The reverse happens in the evening[11].

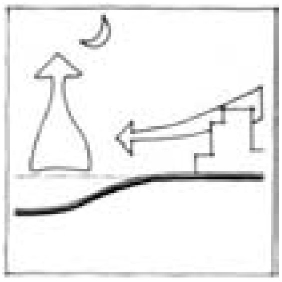


Figure 3.1
Wind movement / night

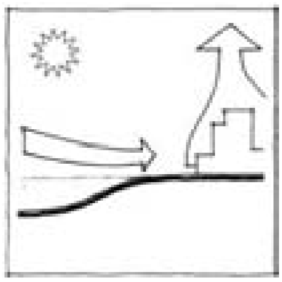


Figure 3.2
Wind movement / day

Electricity generation

The total CO_2 emissions resulting from the energy sector in Lebanon amount to 85% of the total greenhouse gas emissions[12]. The gases expelled from the electricity producing plants, represent 31% of the total CO_2 emissions. These plants include three thermal plants that have a capacity of about 1300 MW and 15 hydro-electric plants with a combined capacity of about 281 MW[12]. The electricity production plants are powered by fossil fuels that are imported from surrounding countries such as Saudi Arabia and Kuwait[12].

Seven percent (7%) of the total CO_2 emissions in Lebanon are generated by the residential sector[5]. Of these, 44% are used for heating and cooling purposes while the remaining 56% is divided between electric hot water, lighting and refrigerators[5]. The considerably large amount of harmful gases emitted through the reliance on electricity to provide power for the air-conditioning units (heating and cooling) impacts the environment negatively. Since, using air-conditioning for cooling requirements in Beirut is growing in importance as the living standard of people rises steadily[12], designing buildings to reduce the reliance on artificial cooling and heating devices will inflict less damage to the environment. It is also important to note that the urban heat island effect may produce higher temperatures in the centre of Beirut than in the surrounding areas[13] thus involving higher uses of air conditioning in that area.

Climatic characteristics

The following graphs show some climatic characteristics for Beirut[3]:

The minimum temperatures vary from about 6ºC in January to about 16ºC in July and August.
The maximum temperatures vary from about 18ºC to about 31ºC in the same months.

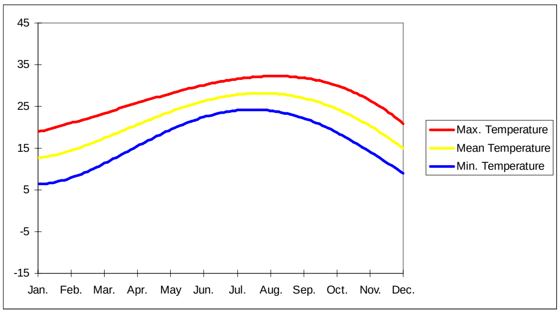


Figure 3.3
Minimum, mean, and maximum temperatures

The minimum relative humidity varies from about 55% in January to about 67% in June.
The maximum relative humidity varies from about 63% and 75% for the same months.

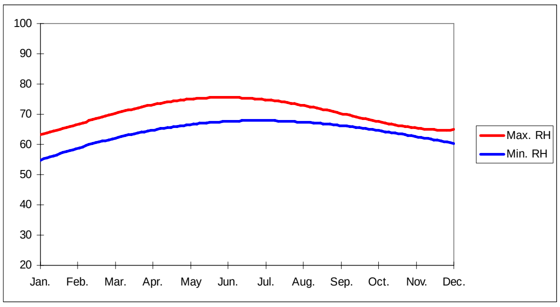


Figure 3.4
Minimum and maximum relative humidities

The diurnal range varies from about 12-13ºC in January to about 6-7ºC in July.

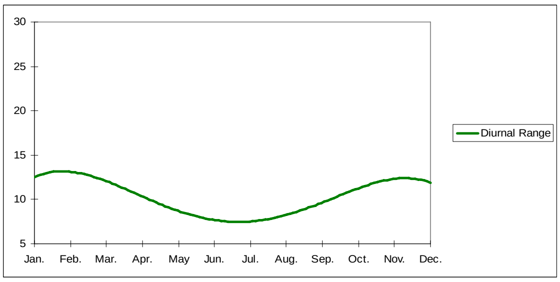


Figure 3.5
Diurnal range

The average direct normal solar radiation varies from about 3100 Whr/m^2 in January to about 6500 Whr/m^2 in August.

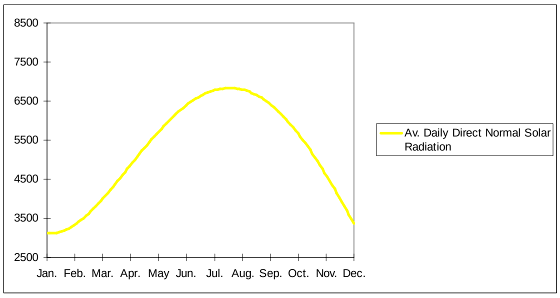


Figure 3.6
Average daily direct solar radiation

The average wind speed varies from about 6 km/hr to about 17 km/hr over the year.

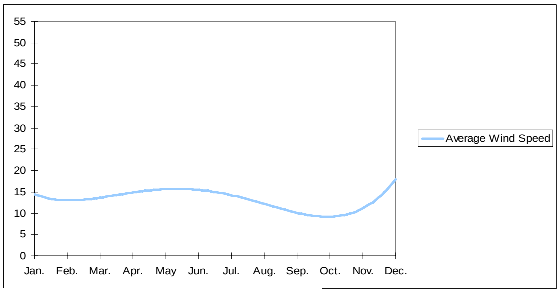


Figure 3.7
Average wind speed

The dry bulb temperature, as well as the relative humidity values (according to the charts on the previous page), are plotted on a psychrometric chart.
The dry bulb temperature in ºC is shown on the x-axis and the moisture content in the air is on the y-axis.

The curvilinear lines represent the percentage of relative humidity present in the air. The readings are indicated (in percent) at the top, (100% to 50%), and on the y-axis (40% to 0%).
Each line indicates a monthly range. The starting point of each line (at the left) is the minimum temperature and the maximum relative humidity, while the end point (at the right) is the maximum temperature and the minimum relative humidity. The numbers (1 to 12) represent the months from January to December respectively.

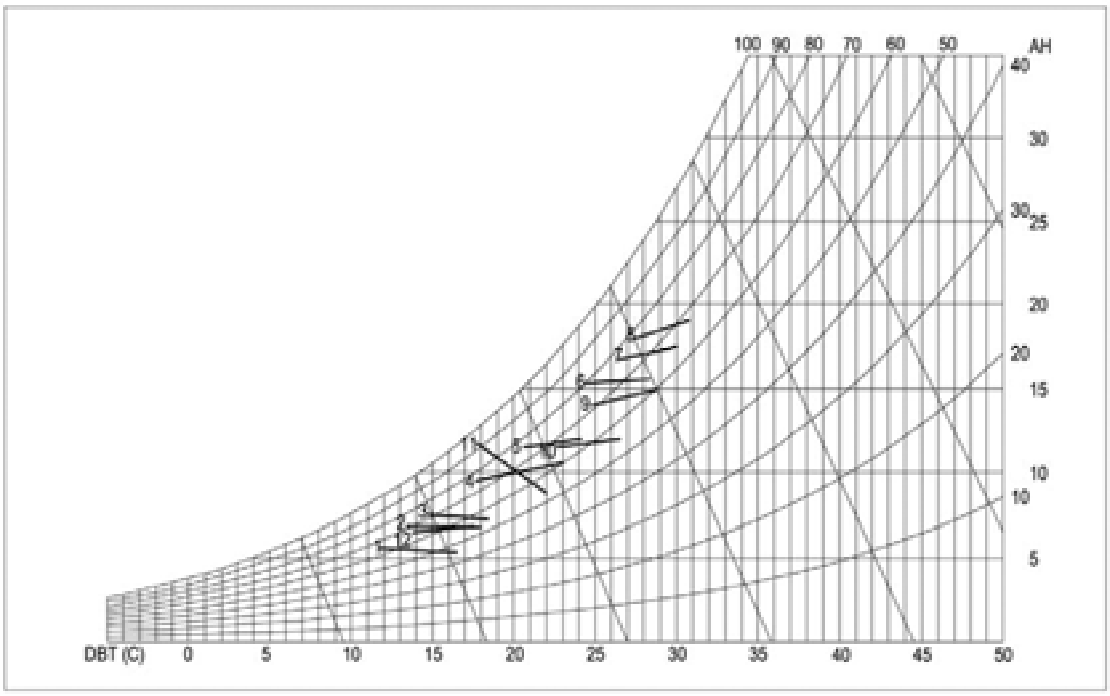


Figure 3.8
Monthly climatic data plotted on the psychrometric chart

The next chapter will discuss the relationship between the monthly lines and the comfort zones for each season.
Solar radiation, wind speed and diurnal range, though not included in these charts should be considered when designing in response to climate.

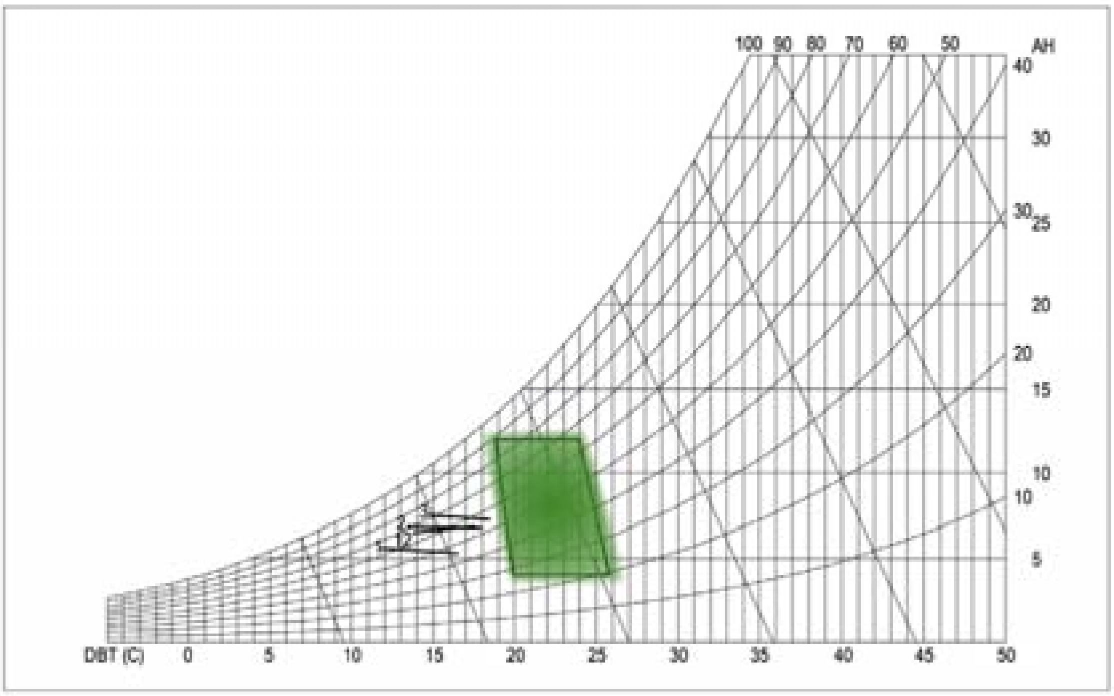
CHAPTER 4: CLIMATE AND COMFORT IN BEIRUT

The skin temperature (normally at 33ºC) must always be lower than the deep-body temperature. The temperature of the environment should be below the skin temperature so that heat can dissipate from the body. The comfort zone is the range of environmental temperatures that allow for the right amount of heat to dissipate from the body.[14]

The construction of the comfort zones on the psychrometric charts follows Szokolay's method[8]. The method consists of graphically drawing a zone that represents the comfortable range of temperatures and their relative humidities. This zone is then analysed with respect to the monthly climatic characteristics.
Consequently, 3 comfort zones are graphically constructed, one for the summer season, one for the mid season and one for the winter season. This process is similar to the one presented in the UNDP document Climate and Comfort Passive Design Strategies for Lebanon, 2005. Dividing the year into 3 seasons is consistent with local customs and habits.

Comfort zones for Beirut

The first diagram illustrates the comfort zone for the winter season. The chart shows that temperatures below 19ºC lie outside the comfort zone. This indicates that there is a necessity to introduce passive and/or active strategies to improve this condition.



The second diagram illustrates the comfort zone for the mid seasons. The chart shows that temperatures below 21ºC with a corresponding relative humidity of about 30% to 100% or temperatures above 28ºC with a corresponding relative humidity of about 30% to 90% are not comfortable.

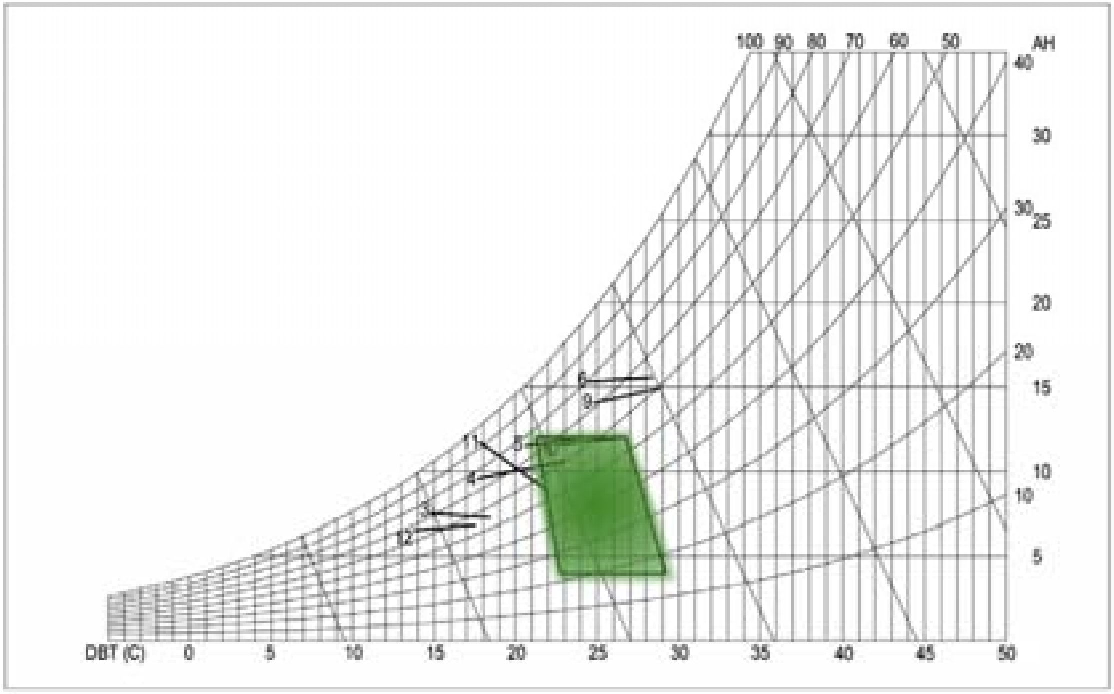


Figure 4.2
Mid season: comfort zone

The third diagram illustrates the comfort zone for the summer season. All the temperatures and relative humidities corresponding to this season do not fall in the comfort zone.

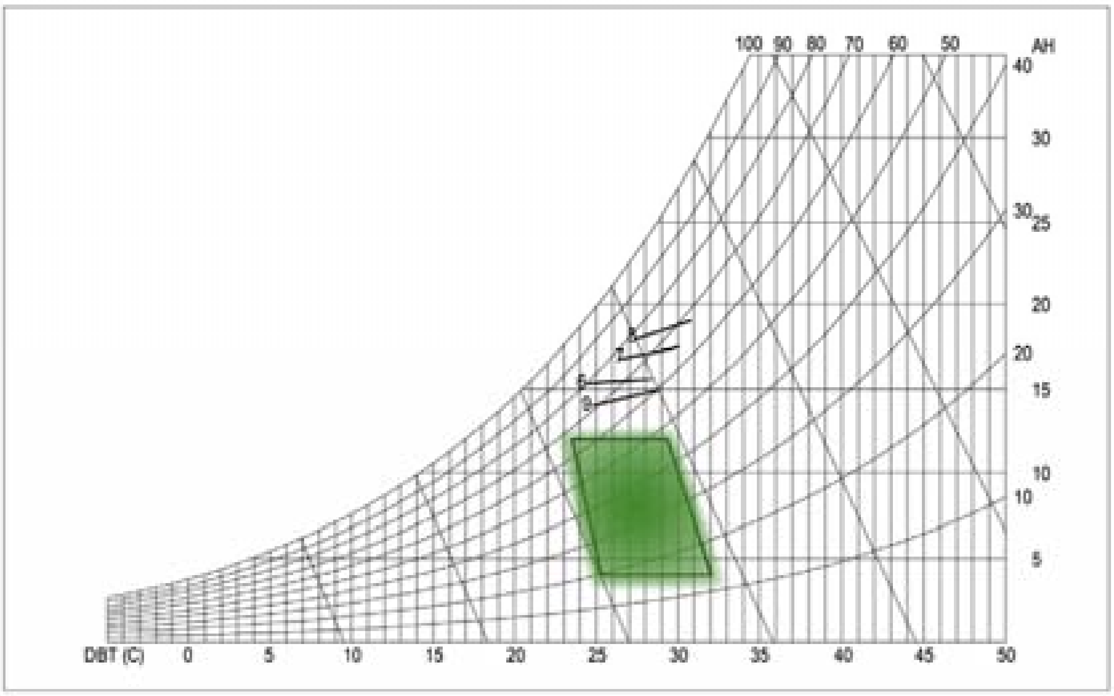


Figure 4.3
Summer season: comfort zone

These charts illustrate the necessity of integrating passive design strategies in architectural design in order to improve comfort conditions.

The resultant temperature that affects a person's perception of comfort is a function of numerous varying parameters that interact dynamicaly throughout the day, week, month, and year. These parameters include:[15]

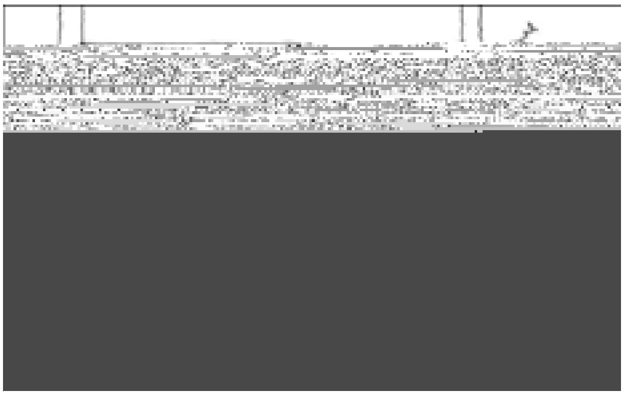


Figure 4.4
Parameters affecting comfort

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

The passive design strategies discussed in the next chapter relate only to the building envelope parameters.

CHAPTER 5: PASSIVE STRATEGIES FOR BEIRUT

Passive design strategies are methods for improving the internal sensation of comfort by relying, to the largest extent possible, on natural climatic givens. For example, in summer, maintaining comfort by using passive design would imply the proper positioning and shading of a window as opposed to increasing artificial cooling systems.

The following illustrations show the extent to which a particular comfort zone can be modified by using passive strategies[16]. Since these strategies are interventions on an architectural level, they affect the perception of comfort inside a space.

For example, with well designed natural ventilation, the comfort zone can be enlarged in humid and hot weather by increasing the wind velocity[11].

In Beirut and during the summer, a good naturally ventilated building can push the comfort zone an extra 4-5ºC in temperature. Therefore, a dry bulb temperature of 32ºC and a relative humidity of 55%-60% becomes pleasant and comfortable if brushed by an air velocity of around 0.5m/sec[17].

Some applications of the passive strategies constructed according to Szokolay's[8] method on the comfort zone particular to Beirut are shown below.

The graphic construction of the passive strategies on the psychrometric charts shows to what extent each strategy may influence the comfort zone. The first strategy addressed is thermal mass.

Thermal Mass
With higher thermal mass, the comfort zone extends to include lower or higher temperatures (depending on the season) as shown in the adjacent figure.

Winter season
The use of the thermal mass strategy in winter improves the indoor comfort condition. With higher thermal mass, temperatures as low as about 18-19ºC can be included in the comfort zone.

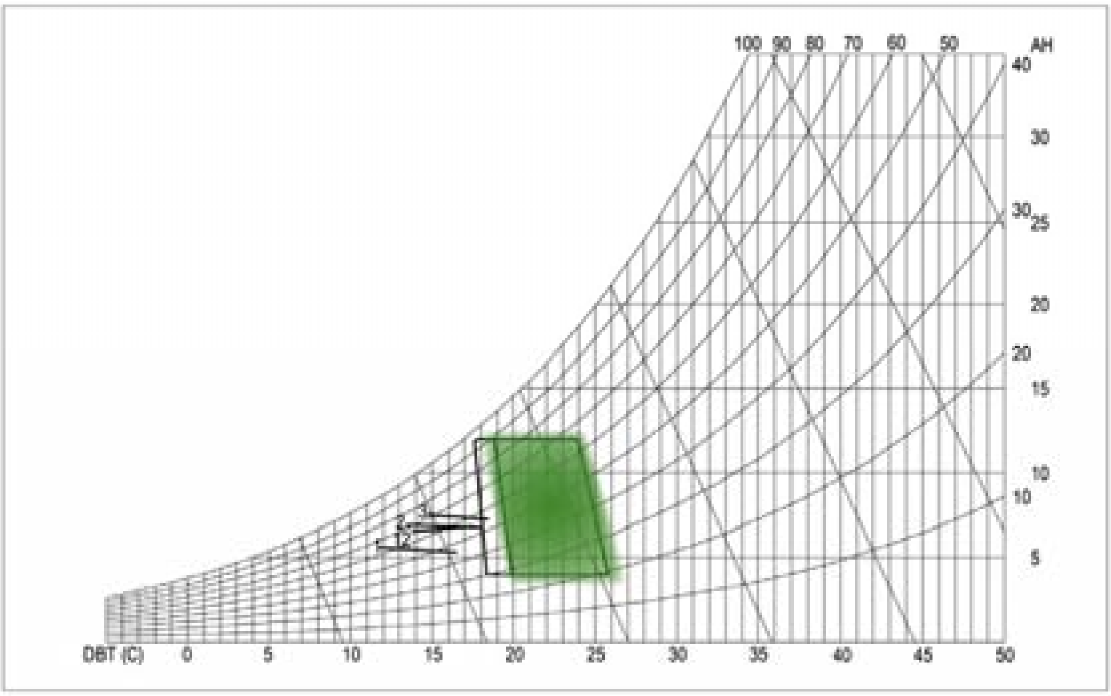


Figure 5.1
Winter season: thermal mass

Summer season
The use of the thermal mass strategy in summer considerably improves the condition of comfort. Thermal mass can improve the comfort conditions for the summer season except when temperatures reach above 33-34ºC.

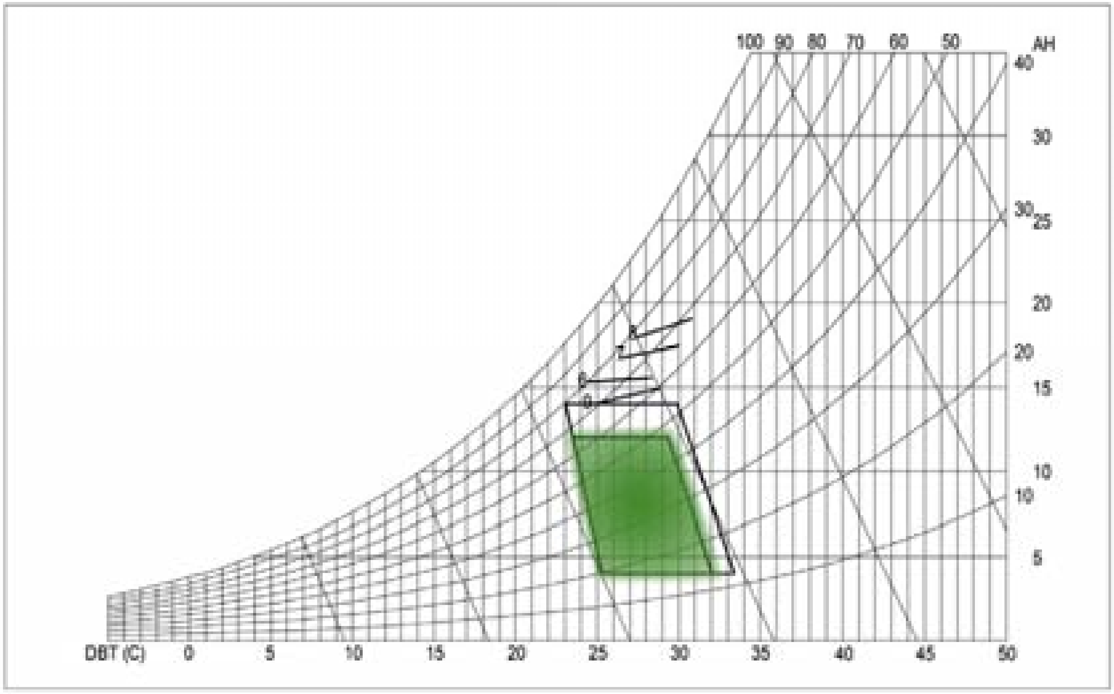


Figure 5.2
Summer season: thermal mass

Passive solar heat gain

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

With passive solar heating, the comfort zone extends to include lower temperatures[11].

In Beirut, this strategy would be useful during the winter months where solar heat gain can provide comfort for temperatures as low as 8-9ºC.

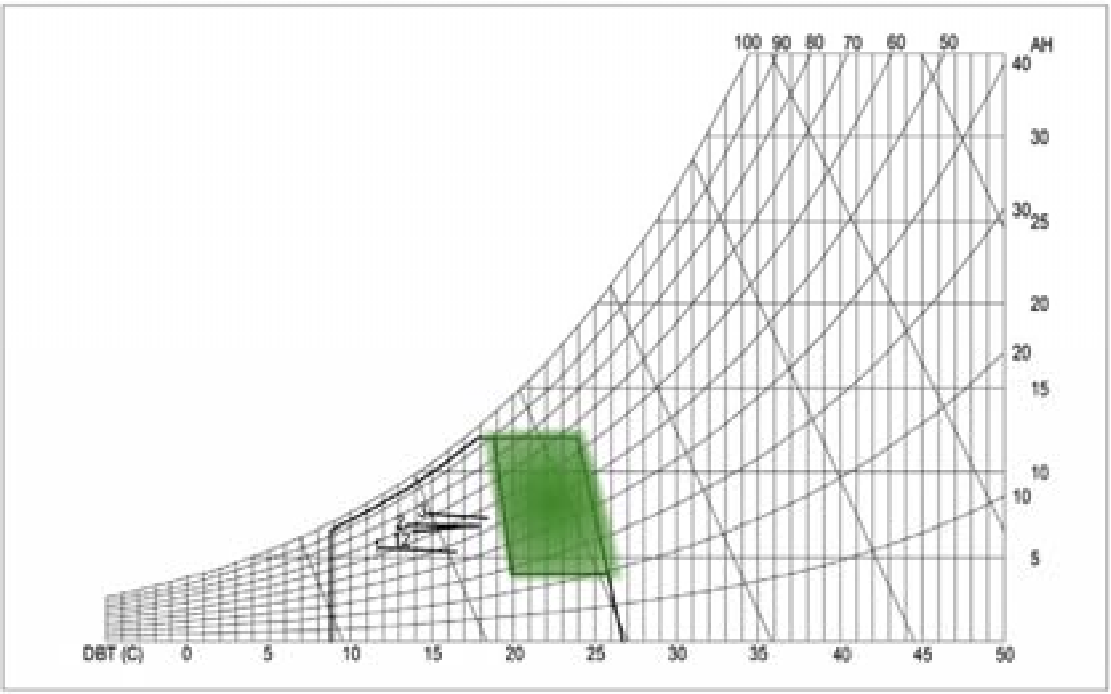


Figure 5.3
Winter season: passive solar heating

Ventilation and air movement

Mid season
Air movement improves the comfort conditions when the temperature ranges from around 23ºC to 35ºC. If the natural ventilation strategy is integrated in the design scheme, then the comfort zone would include areas of higher temperature (figure below). In other words, a person would still be comfortable at higher temperatures (i.e.29°C) if the space he is in is ventilated.

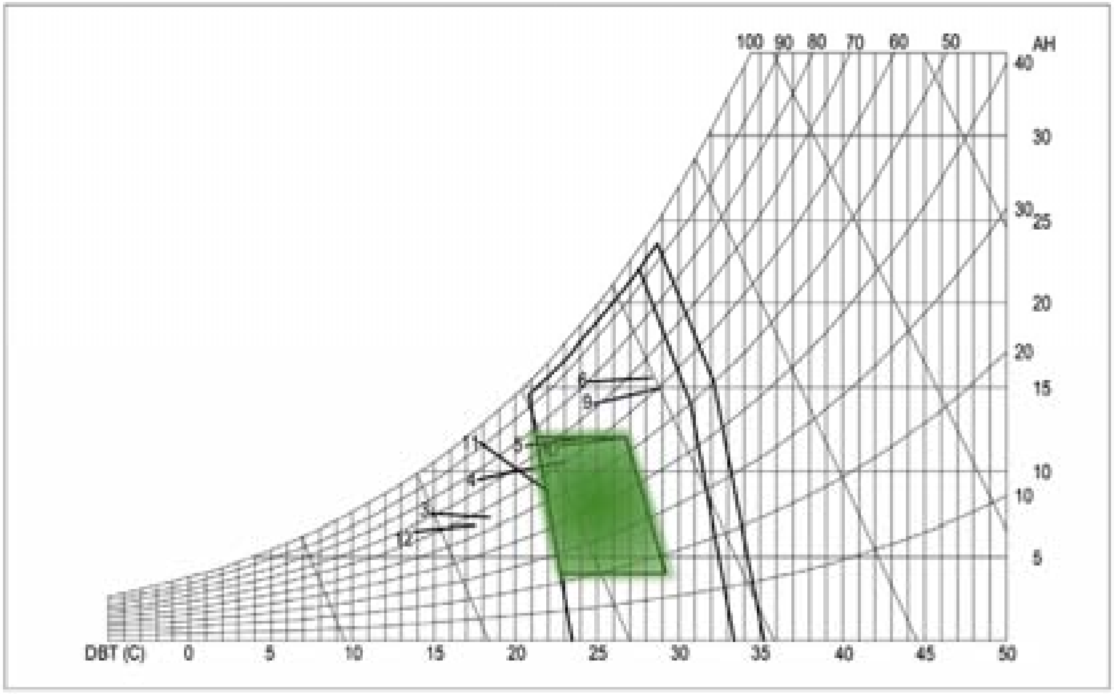


Figure 5.4
Mid season: air movement

Summer
Air movement resulting from natural ventilation is due to air pressure differences generated by temperature or wind[18].
Air movement improves the comfort conditions for higher temperatures and higher relative humidities.

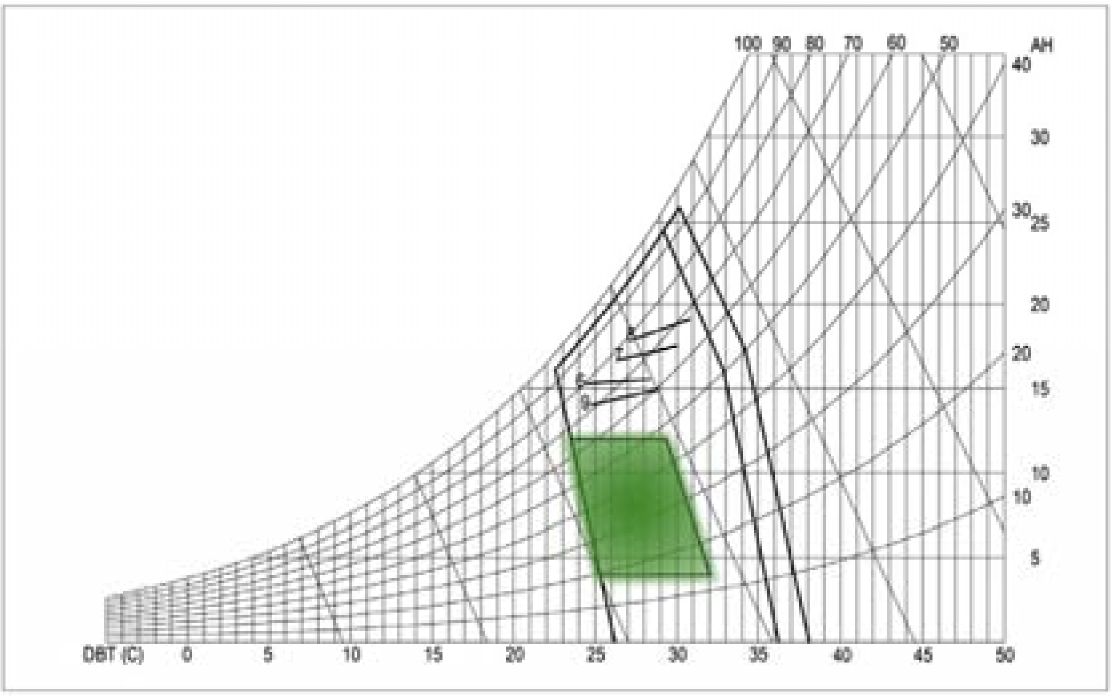


Figure 5.5
Summer season: air movement

This strategy can affect buildings in several ways:

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

Inside the buildings
In the summer season, a natural breeze passing through a living room can create a comfortable space without relying on artificial cooling systems.
In the winter season, air movement reduces the risk of condensation when there is an increase in indoor humidity (cooking in the kitchen, having a bath). The lack of proper ventilation results in the formation of mold, which is unhealthy.

Figure 5.6
Internal surface condensation

Shading

Figure 5.7
Shading device 1

Shading an envelope minimizes direct solar incidence on it. Although shading devices are mostly needed in summer, some movable systems can allow sunrays through during winter. Shading by vegetation (vines) could reduce the amount of heat gain during summer while achieving sun exposure during winter[19].
Some parameters that help reduce heat impact are insulation and colour.

Insulation of the roof slab helps decrease heat gain in summer and heat loss in winter.

Figure 5.8
Shading device 2

The colour of the roof strongly affects the amount of reflected and absorbed heat. Dark, matt or textured surfaces absorb and re-radiate more energy than light, smooth, reflective surfaces.

In conclusion, this section presents a summary of the parameters that result in energy efficient and climate responsive architectural design. These parameters should be taken into consideration at the early design stages and developed as the design becomes more elaborate. Every design project is an opportunity that permits the investigation and study of any number of these parameters. Consequently, their importance differs within each project.

Taking into account the strategies described above, the next chapter elaborates on the relationship between a building's mass and envelop and solar radiation and wind movement.

CHAPTER 6: BUILDINGS AND CLIMATE IN BEIRUT

As discussed in the previous chapters, climatic characteristics are important to take into consideration when designing a building that relates to its context[20]. Two important architectural issues are building massing and building envelope[21].
The building massing referred to here is the three dimensional shape of the building. The building envelope consists of the external opaque elements (walls, roof, etc.) and the external transparent elements (windows, skylights, etc.)
This chapter addresses the interaction between these two and the two climatic parameters: solar radiation, and air movement and includes other parameters that affect thermal comfort.

A – BUILDING MASSING

Building massing and solar radiation
Although Beirut receives a substantial amount of solar radiation (refer to the climatic characteristics in Chapter 2), this renewable source of energy is not sufficiently exploited.

In Beirut, the yearly average daily direct normal solar radiation is 5093 Whr/m^{2} [3]. Consequently, the amount of solar radiation received on a building depends on the angle of the plane receiving the radiation. (Figure 6.2)

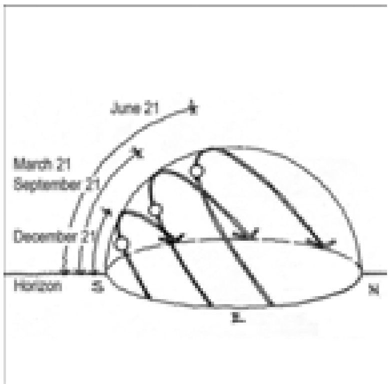


Figure 6.1
Seasonal sun path

This free source of energy can be useful in winter, while its effect can be reduced in summer. The quantity of solar heat gain to be absorbed or rejected depends on the degree of heating and/or cooling strategies studied during the design process.
The following diagrams illustrate the sun path for Beirut and its changing position in the different seasons[22].

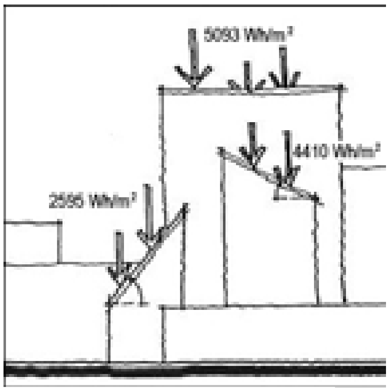


Figure 6.2
Solar radiation and slope

The sunpath diagrams for the summer, mid and winter seasons are shown below.

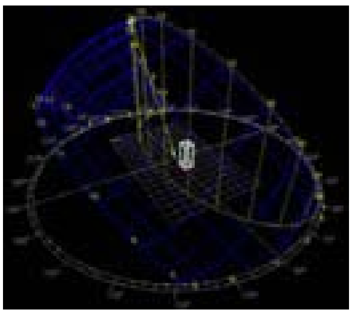


Figure 6.3
Summer season: sun path

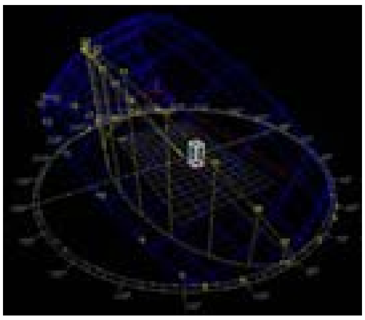


Figure 6.4
Mid season: sun path

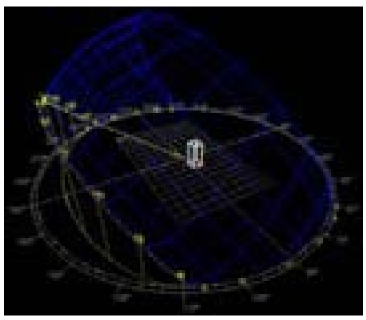


Figure 6.5
Winter season: sun path

As shown in figure 6.6, Beirut is crowded with buildings. Therefore, overshadowing is another issue to account for when analysing a building site.
The positions of buildings adjacent to a site affect the amount and quality of sun reaching the site (Figure 6.7)[23].

Figure 6.6
Beirut: overshadowing

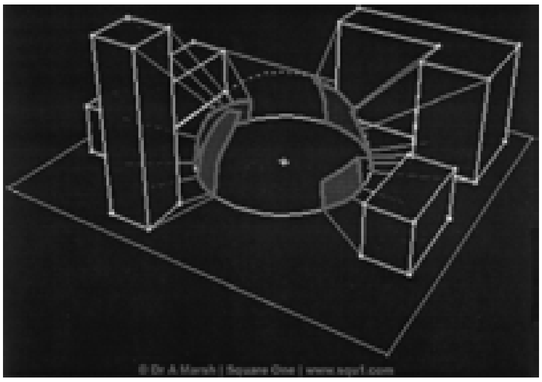


Figure 6.7
Overshadowing

Building massing and wind movement
Wind movement is important in this city due to the following two reasons:

1 – In summer, when the relative humidity is high (refer to the climatic characteristics of Beirut in Chapter 2), natural ventilation can be an effective strategy that can improve the conditions of indoor and outdoor comfort.

2 – In winter, ventilation can alleviate the build up of indoor humidity.[24]

In Beirut, the prevailing wind directions are from the southwest and are mostly moderate winds (6-10m/sec). Some mild winds (2-5m/sec) also arrive from the east. Very strong winds (above 16m/sec) occur rarely[25].

Management of air movement can be an important tool for modifying site microclimate. The pattern of air movement can be controlled and modified using vegetation belts, landscaping and suitable massing of buildings[26]. The position and relation of the building with respect to the prevailing wind directions can enhance

natural ventilation during summer and mid seasons. The shape of a building affects the wind movement in its vicinity.
The figures below show how the relationship between building form and wind direction can result in the redirection of air movement. This can influence wind movement within the building and consequently enhance natural ventilation.

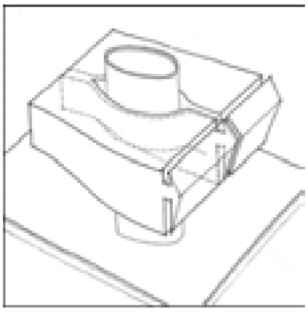


Figure 6.8
Wind movement and massing

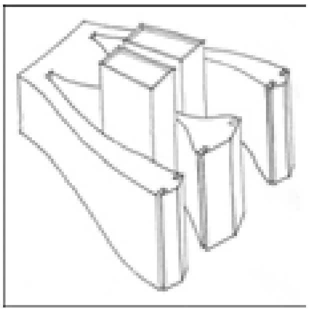


Figure 6.9
Wind movement and massing

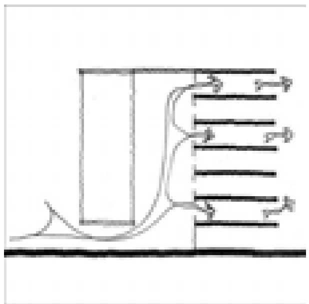


Figure 6.10
Wind movement and building

B – Building envelope and Solar Radiation
The building envelope, which regulates the flow of heat to and from the building[26], consists of the roof, the external walls, the window openings as well as the slab on the ground and the walls that are in contact with the earth backfill. In buildings with pilotis, the slabs above and below the pilotis are considered as additional components of the envelope[26]. This building envelope performs the function of protecting and controlling the interior environment in terms of heat, light, sound, ventilation and air quality[26].

Behaviour of the Components

<u>Roof</u>

The roof has the greatest exposure to solar radiation[26]. Measures should be taken to protect it from sunrays during the summer to minimize heat gain. In winter, exposing it to radiation maximizes heat gain. The main design parameters that can provide such solutions are:

- Roof forms: flat, arched, domed or pitched;
- Composite construction with eight weight roof and dense ceiling separated with air space;
- Heavy weight construction for heat storage;
- Air movement over roof surface for ventilation;
- Orientation of slope towards prevailing winds;
- Insulation;
- Roof colour and reflectivity.

<u>Walls</u>

Walls provide protection from heat, rain, wind, and dust. Depending on the orientation of the wall, the exposure to solar radiation varies considerably[27].

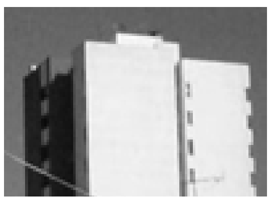


Figure 6.11
Solar radiation on building 1

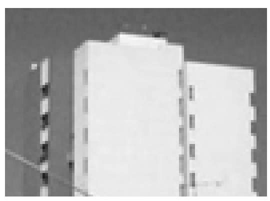


Figure 6.12
Solar radiation on building 2

North-facing walls do not receive direct solar radiation whereas south-facing walls receive a high intensity of solar radiation. East and west-facing walls receive direct solar radiation only for part of the day. The forms of the building can be designed to reduce the surfaces of walls that are subject to a higher incidence of solar radiation

Openings

In general, heat is transmitted through windows at a higher rate than through opaque wall components[28]. This depends on the quality of the glazing and the quantity of infiltration through the joints. To minimize heat transmission and air infiltration through windows while providing adequate natural light, it is necessary to use the appropriate window size, glazing, shading coefficient, and shading device.

Building envelope and Wind Movement

Natural air movement in buildings relies substantially on the building skin. Some key issues are internal air hygiene and correct amount of ventilation needed per season. Forms, shapes of roof and openings of buildings will create more aerodynamic effect that can increase the airspeed and create pressure and depression between opposite facades or low and high levels, which is an effective mean to stimulate natural ventilation and increase the thermal comfort in summer[29].
In general, natural ventilation can be achieved in spaces whose depth does not exceed 6m (see figures below). If a space is deeper (up to 10m), then cross ventilation can provide for natural air movement. This would require openings on the opposite sides of a space[30,31].

Mechanical regulators can increase the effectiveness and, in turn, the occupants' comfort when operable elements are placed in the building skin[32].

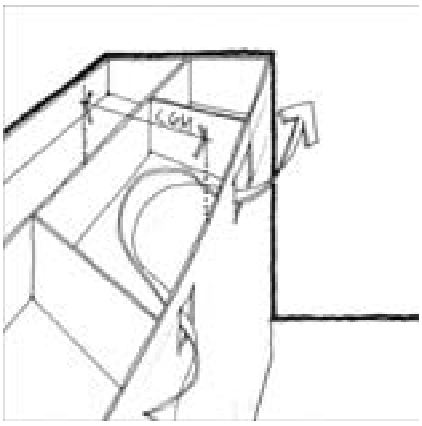


Figure 6.13
Natural single sided ventilation

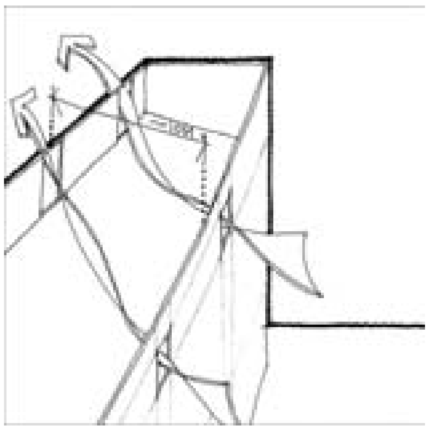


Figure 6.14
Natural cross ventilation

Double skin
The system of double skin (see figure below) is referred to when a second envelope is added to the building skin. In general, this results in having two independent skins with a space in the middle. The dimension of this space varies in accordance with different requirements for shading devices, maintenance "passage", or just an air space[33].

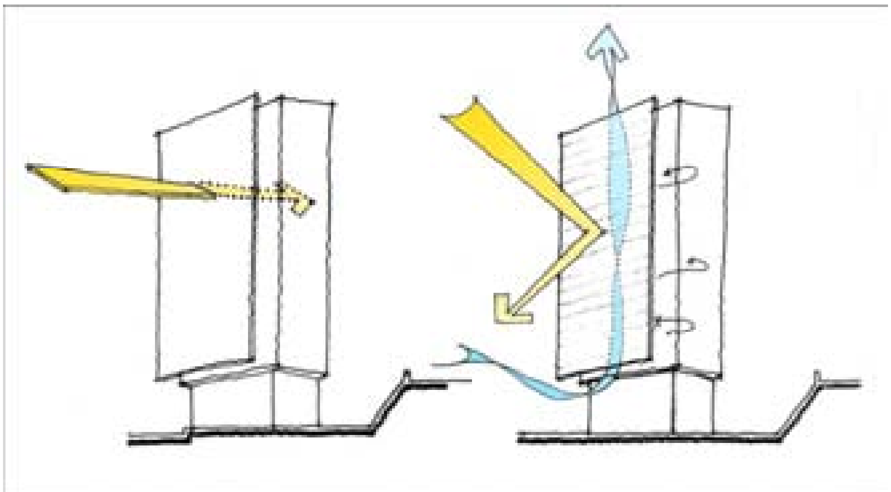


Figure 6.15
Double skin: winter and summer seasons

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

Other parameters that influence the perception of comfort in a building because they control the energy balance through its envelope are:

Envelope to area ratio
This is the ratio of the total envelope area to total floor area. The higher the ratio, the more contact between the building and the outside, resulting in higher heat loss/gain[34].
For example, external heat gains and losses are less for spherical buildings than for other shapes of equal volume.
This issue is important during the initial design stages when the overall shape of the building is being studied.

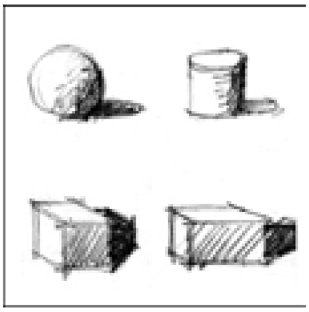


Figure 6.16
Envelope to floor area ratio

Heat flow
The amount of heat flow through a building component depends mainly on the resistance the material has. Insulating materials strongly resist heat flow.
Insulation materials are used on roofs, external walls and ground floor slabs of buildings to ensure protection against cold or hot outdoor conditions[35].

a- Building with mass, insulated internally.

The adjacent diagrams illustrate the benefits of insulation in different seasons.
In summer, the internal temperature remains stable because the space is surrounded by insulation. This maintains a comfortable environment and reduces energy consumptionError! Reference source not found..
The heat from the sun penetrates through the external wall but it is strongly resisted by the insulation.

Similarly, any heat generated indoors will not dissipate through the wall.
This results in a reduced fluctuation of internal temperatures[37].

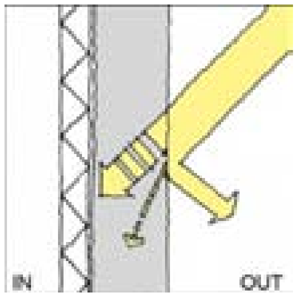


Figure 6.17
Internal insulation: summer

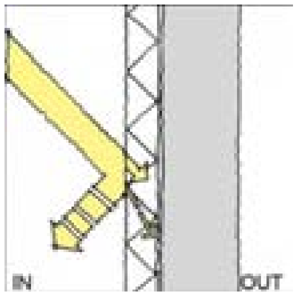


Figure 6.18
Internal insulation: winter

b- Building with core insulation inside two layers of mass.
Local construction methods normally entail placing the insulation in a cavity between two walls. This implies that the composition of the wall and the choice of its individual components can be defined to improve the performance of the envelope during the different seasons.

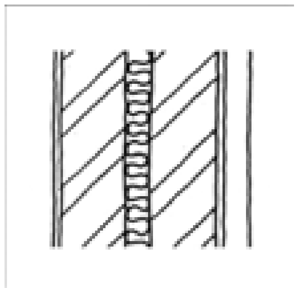


Figure 6.19
Core insulation

Effective fenestration ratio
The orientation of an opening has a strong effect on controlling the level of solar gain into the building[19].
The amount of solar heat gain depends on the size of the window, the shading coefficient, and the architectural shading device[17].
This is an important strategy in the summer season of Beirut because it aims at reducing solar heat gain. This can be achieved to different degrees by the manipulation of the three parameters.

Condensation
In general, the cold winter external temperatures result in cold indoor surface temperatures[28]. As a result, the moisture generated by indoor activities of occupants (breathing, smoking, and cooking) condenses on these cold surfaces at corners of rooms and around window frames. Such condensation causes mould growth on the wall, which is both unsightly and unhealthy[38]. This is a common problem in Beirut since the single glazing is used very often.

Thermal bridges

Thermal bridges are areas where the heat flow is higher than through adjacent areas due to the presence of high conductivity materials (such as metals) in building components[39]. The higher heat flow through thermal bridges reduces internal surface temperatures, thus creating local discomfort and encouraging mould growth due to condensation. Again, this is a very common problem in the city because the concrete post and beam structure (used in the majority of buildings) results in beams and columns being exposed to both the external and internal environments.

Air leakage – infiltration

Infiltration is uncontrolled air movement through cracks, fissures, gaps, and openings in the building envelope. When excessive, it is called air-leakage, which can become a serious problem accounting for 30 to 50% of heat loss or gain in a building. If not controlled, especially in winter, air temperature drops to uncomfortable levels[40].
This is a common defect in local construction due to poor workmanship.

These issues affect the passive design strategies.

The following chapter describes the typology of the residential building in Beirut and elaborates on the construction methods used locally.

CHAPTER 7: BUILDING TYPOLOGY AND CONSTRUCTION METHODS IN BEIRUT

Characteristics and components

The local residential typology is divided into 5 sections depending on the different rates of heat gain and heat loss[41].

1 - The roof floor is a residential space having peripheral walls and a roof as an external envelope.
2 - The typical floors are residential spaces having the walls as an external envelope.
3 - The ground floor can be a residential space (usually with a garden as an extension) having walls as an external envelope. This floor could also consist of pilotis and in most cases house the building's entrance lobby.
4 - Basements are most often carparks and storage spaces that have the envelope (walls and floor slab) in contact with the soil.
5 - The building core is a vertical element that contains the lifts, stairs and electrical / mechanical shafts. The core can be seen as the backbone of the building.

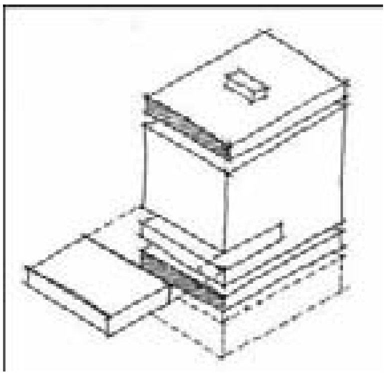


Figure 7.1
Building sections

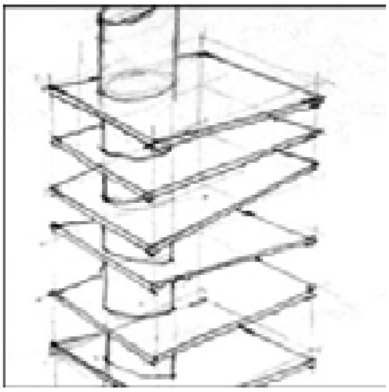


Figure 7.2
Multi-level building

Consequently, it is important to address different parts of the building differently. For example, it may be very beneficial to address the issue of roof shading and west elevation shading in the summer, wind movement on the groung level, etc.

Building components42

The choice and position of the layers of building materials influences the heat flow through the components mentioned below[37].

Roof

A building method widely used for roof construction is shown in the adjacent figure. Several materials are usually laid on the suspended concrete slab that is made of hollow concrete blocks that are covered with 6 cm of concrete. When the quality of construction is compromised due to cost imperatives, the thermal insulation layer is omitted. This results in short term financial gains but increases the building's running cost.

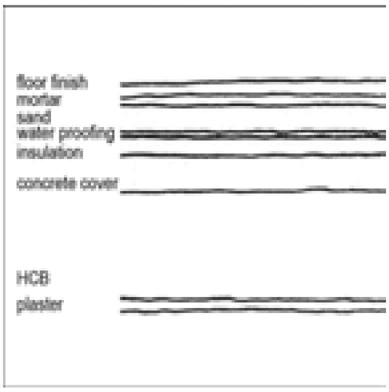


Figure 7.3
Roof slab section

Slab on grade

Slabs that are placed directly on grade are usually cast in-situ reinforced concrete. A layer of damp proof membrane is sometimes placed on the grade before casting the concrete. This sheet decreases the possibility of humidity reaching the slab by capillarity.

Walls

Some of the building methods widely used for the wall construction are illustrated in the adjacent figures.
The adjacent figure shows a single wall that is plastered on both the inner and outer sides. This method of construction is used quite often in low to moderate cost housing. It results in substantial problems of heat transfer and condensation depending on the seasons. Nevertheless, due to economic constraints and the absence of building laws that govern this type of practice, these types of walls keep on being built.

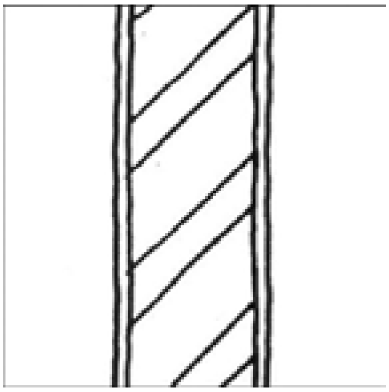


Figure 7.4
Single wall section

The second sketch illustrates a double wall. This wall consists of two independent hollow concrete block walls with an air cavity or rigid insulation in the middle. Both the inner and outer faces are plastered and painted. This wall can be clad with stone on the outside in buildings that are tagged with the label of good quality construction. This insulated wall may have an appropriate performance if its thermal transmittance (heat flow through it), and thermal mass (its ability to store heat) are studied in relation to the local climatic situation.

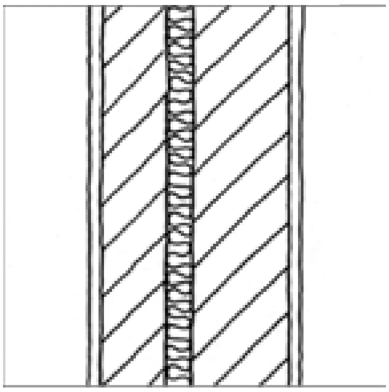


Figure 7.5
Double wall section

Openings

The materials used for window frames are aluminium, wood, steel and PVC. The shutter can be designed in a number of ways be it folding, rolling or sliding. It is either integrated in the window frame or may be a separate component.
The specifications of the glass used can vary from a single layer float glass to a more sophisticated double glazed panel. These issues are usually decided on based on a building's quality of construction.

CHAPTER 8: DEVELOPMENT OF WEIGHTING PARAMETERS FOR THE DEI (DESIGN ECOLOGY INDEX) AND THE MEI (MATERIAL ECOLOGY INDEX) IN THE PROPOSED ASSESSMENT METHOD

DESIGN and the DEI (design ecology index)

The following parameters summarise the issues discussed in Chapters 4 and 5. They are the important parameters to be considered for the evaluation of the design phase. Each item is assigned a weight that varies from 1 to 3 according to its relative importance in environmental friendly design as will be discussed in this chapter.
Then, each item is assigned a score from 1 to 3 that reflects the relationship of that parameter with the environment in a particular application. A score of 1 would thus indicate a “low” impact while a score of 3 would imply a “high” one. Each point follows with an explanation that justifies why the particular score is assigned.

1 – Massing of the building 3 points

Relationship to the sun angles
Relationship to wind directions

2 - Proper shading of openings 3 points

Shading devices for the south orientation
Shading devices for the south, east and west orientations

Providing for the appropriate shading devices on the south and east/west oriented openings can prove to be very beneficial especially since the solar radiation can prove to be uncomfortable for the majority of months in the year.
This parameter also includes visual comfort and adequate daylighting. The two main issues addressed here are reducing glare and providing for the adequate daylight factor. This aspect is important in providing for comfortable interiors and relying less on the use of electricity.
Since requirements of views in residential buildings are primordial, their definition overrides other considerations. Therefore, proper shading by using architectural devices or landscape items becomes very necessary.

3 – Natural ventilation 3 points

Benefitting from the prevailing winds
Enhancing natural ventilation in the spaces

It is important to integrate this strategy in the design and execution of a building due to its numerous benefits in both summer and winter seasons.
In summer, the high moisture content in the air makes natural ventilation essential to improve the sensation of comfort.

This relates to how the building’s volume is defined with respect to solar radiation and wind movement.
Although a result of stringent site shape, building law constraints and program requirements, the massing of a building is of major importance is creating the base that will lend itself to further climate responsive development.

4 – Orientation of the building 2 points

Addressing the south orientation
Addressing the north orientation

Addressing the east / west orientation

The high summer angles at noon reach 78° whereby the maximum altitude in winter is 40°[40]. The summer afternoons are very hot and the low sun altitudes often result in serious heat gains and glare within the apartment. In Beirut, orientation is often a function of the views that the future inhabitants will have. Therefore, these two givens should be studied simultaneously in order to provide for the best possible solution.
The way a building's envelope interacts with the orientation it is facing complements the building's massing strategy and may allow for a more comfortable relationship with the outdoors.

5 – Thermal mass and thermal transmittance 2points

Providing the adequate thermal mass in the building envelope
Providing the adequate thermal mass in the building interior
Providing the adequate U-values for the different building components

This issue is less important due to the relatively low diurnal range that exists in this region.
The thermal characteristics of a properly designed envelope may provide for the required climatic buffer.

6 – Landscaping 2 points

Locating trees to shade the envelope in the summer
Locating trees to deviate the cold winter winds
Providing green ground cover to reduce heat reflection in the summer.

Landscaping can improve the environmental situation of a building in numerous ways. First, vegetation can provide shade. Second, the evaporative process on the leaves can increase the vapour content in the air (in a dry micro-climate) and hence make it more comfortable. Third, vegetation can create a buffer zone from unwanted winds and noise.
The Mediterranean weather provides an adequate context for vegetation to grow. Therefore, using trees, shrubs, etc. can substantially reduce the extreme climatic conditions.

7 –Winter passive solar gain 1 point

Allowing for the winter sun to enter the spaces

This issue is of moderate importance because the climate in Beirut requires addressing cooling strategies for a large part of the year the cold season is relatively short.

The maximum score that can be achieved is 48. This would represent a serious effort to address the different strategies in the design process.
Another approach that addresses all these issues with a moderate intention would yield a score of 32.
An approach representing low intention would result in a score of 16.

The numbers remain indicative. They could be used to establish a benchmark for this building in order to compare it to other buildings. If the project was still in the design stage, such a number would have served as a reference to compare with if the design of the building is modified. For example, how would the score change if the massing is improved or if the potential for natural ventilation is increased?

Since the intent of this assessment method is to qualitatively measure the degree of response to the climate, the scores are divided into ranges that reflect a low, medium or high level of design as follows:
A score of 40 and above is considered high;
A score between 24 and 40 would be considered medium;
A score below 24 would be considered low.
This is based on the fact that a maximum score (all parameters would get a 3) is 48, the medium score (all parameters would get a 2) is 32 and the low score (all parameters would get a 1) is 16.

MATERIALS and the MEI (material ecology index)

Based on the context of Beirut, the application of the BMAS method using impact factors per material is suggested. This consists mainly of calculating an ecological factor per material using a weighted sum of the square of the ratings assigned to each criterion. The fourteen criteria included in the BMAS method are each rated between 0 (no impact) and 5 (high impact) depending on the impact of that criterion on the environment per material. This rating is then squared, to get a better resolution, and weighted according to the contribution of that criterion to the total ecological factor score. The ecological factor for that material is therefore, the sum of these products.
The ecological factors for all the materials used in a building will be combined in proportion to their presence within the building to yield the materials' ecology index (MEI). This score will serve as a benchmark to compare various MEI score for the same building modifying the percentages of material used in the building.

CHAPTER 9: ECOLOGICAL FACTORS OF CONSTRUCTION MATERIALS IN BEIRUT

All stages in the lifetime of buildings, from the extraction of raw materials from quarries or through cement production to the use of these buildings (disposal of wastewater, energy consumption and emissions) passing through the execution (transport, noise, dust) have an impact on the environment[43]. In addition, inadequate construction standards and the lack of sound urban planning regulations and enforcement further aggravate environmental degradation.

Buildings consume space and natural resources. They require building materials, some of which are extracted from quarries (aggregate, sand), while others are imported and further transformed locally.

Building materials are hauled long distances, resulting in CO_2 emissions and exerting pressure on the road network[43].
During construction, workers and people in the vicinity of the project are exposed to a wide range of pollutants (particulates) and noise. Nearby residents also are subjected to extensive noise and air pollution.
Buildings also consume energy and release carbon dioxide and radon.
Building tenants consume water and generate wastewater and solid waste. Ultimately, when buildings are demolished, rubble and debris are hauled away and disposed of at sea or in abandoned quarries.

The most commonly used materials for construction in Beirut are:

Stone Aggregate and Sand

The following chart yields the Ecology Index of stone:

Group	Criteria	Rating	$Rating^2$	Weight	Product	Remarks
Extraction	Damage to the environment in the extraction of the raw material;	5	25	3	75	High impact due to negative impact quarrying inflicts on the environment.
	Extent of the damage relative to the amount of material produced;	2	4	2	8	Most the material extracted is used in one way or the other
	Abundance of source or renewability of material;	5	25	4	100	Sources are very limited especially that the area of Lebanon = 10 452 km².
	Recycled content.	3	9	3	27	Very little recycled content mainly when used to produce reconstituted stone GRC (glass fibre reinforced concrete).

Manufacture	Solid and liquid wastes in manufacture and production;	3	9	3	27	Water is used in the cutting process. This water (mixed with dust particles) is disposed off in an uncontrolled manner.
	Air pollution in manufacture and production;	3	9	4	36	When cutting, fine dust particles are airborne.
	Embodied energy (energy used for its production);	2	4	5	20	Direct effect: The exhaust from the mechanical appliances. Indirect effect: The use of electricity for the saws in the plant, and the jackhammers in the quarry.
Construction	Energy used for transportation to the site;	4	16	3	48	Trucks and lorries that run on diesel.
	Energy used on site for assembly and erection;	1	1	1	1	Small crane elevators that require electrical energy usually provided by a diesel generator on site.
	On site waste including packaging.	0	0	2	0	Wooden crates are sent back to the plant and reused.
In use	Maintenance required during life cycle;	0	0	3	0	Cleaning (using water jets or sandblasting) every about 10 years.
	Environmental effects during life cycle (e.g. toxic emissions)	0	0	3	0	Stone is a natural material.
Demolition	Energy use in and effects of demolition at the end of the life cycle;	3	9	2	18	Is sometimes dismantled or broken down, depending on the method of construction.
	Recyclability of demolished material.	1	1	4	4	Old stones are reused in new buildings. Broken material is crushed and used as backfill.
Material Ecology Index					364	

Metal

The following chart yields the Ecology Index of metal:

Group	Criteria	Rating	Rating^2	Weight	Product	Remarks
Extraction	Damage to the environment in the extraction of the raw material;	0	0	3	0	Metal mines are locally inexistent.
	Extent of the damage relative to the amount of material produced;	0	0	2	0	Metal mines are locally inexistent.
	Abundance of source or renewability of material;	0	0	4	0	Metal mines are locally inexistent.
	Recycled content.	0	0	3	0	Metal mines are locally inexistent.
Manufacture	Solid and liquid wastes in manufacture and production;	0	0	3	0	Metals are not manufactured locally.
	Air pollution in manufacture and production;	1	1	4	4	Production results in dust particles
	Embodied energy (energy used for its production);	2	4	5	20	Bending and cutting require relatively little energy.
Construction	Energy used for transportation to the site;	3	9	3	27	The use of trucks and lorries p\that run on diesel oil pollutes the environment.
	Energy used on site for assembly and erection;	2	4	1	4	Benders, cutters, welding machines and cranes require electric energy produced by a generator on site.
	On site waste including packaging.	2	4	2	8	Substantial leftovers from cutting metal components to size.
In use	Maintenance required during life cycle;	1 4	1 16	3 3	3 48	Reinforcement bars do not need a lot of maintenance. Exposed metal structures require maintenance every 2 years.
	Environmental effects during life cycle (e.g. toxic emissions)	1	1	3	3	Metal products do not produce toxic emissions.

Demolition	Energy use in and effects of demolition at the end of the life cycle;	2 1	4 1	2 2	8 2	Reinforcement is a product of concrete demolition. Metal structures are dismantled.
	Recyclability of demolished material.	1	1	4	4	Very little quantities are recycled at an artisanale scale; the rest is transported to neighbouring countries for recycling.
Material Ecology Index					131	

Aluminium

The following chart yields the Ecology Index of aluminium:

Group	Criteria	Rating	Rating^2	Weight	Product	Remarks
Extraction	Damage to the environment in the extraction of the raw material;	0	0	3	0	There is no local production.
	Extent of the damage relative to the amount of material produced;	0	0	2	0	There is no local production.
	Abundance of source or renewability of material;	0	0	4	0	There is no local production.
	Recycled content.	0	0	3	0	There is no local production.
Manufacture	Solid and liquid wastes in manufacture and production;	2	4	3	12	The extrusion process produces foams and the drained water from this phase may contaminate the river it is discarded in.
	Air pollution in manufacture and production;	1	1	4	4	The exhaust from the production process and the generator supplying electricity pollute the air surrounding the production plant.
	Embodied energy (energy used for its production);	2	4	5	20	The energy is obtained from the generators located on the production sites.
Construction	Energy used for transportation to the site;	1	1	3	3	Trucks and lorries transport the material to the site.
	Energy used on site for assembly and erection;	1	1	1	1	Small cranes are sufficient to get the elements to their point of installation.
	On site waste including packaging.	0	0	2	0	Practically no waste since the elements are precut and assembled in the production plant.

In use	Maintenance required during life cycle;	1	1	3	3	The material itself needs very little maintenance, but sealants and accessories (brushes, gaskets, wheels) need to be checked and maybe replaced.
	Environmental effects during life cycle (e.g. toxic emissions)	2	4	3	12	Some emissions may result from the paint applied on the material.
Demolition	Energy use in and effects of demolition at the end of the life cycle;	1	1	2	2	Dismantling this material is a clean process. Some electrical energy may be needed to transport it from building levels down (by crane or lift).
	Recyclability of demolished material.	1	1	4	4	Completely recyclable if transported (usually by trucks) to a neighboring country.
Material Ecology Index					61	

Cement
The following chart yields the Ecology Index of cement:

Group	Criteria	Rating	$Rating^2$	Weight	Product	Remarks
Extraction	Damage to the environment in the extraction of the raw material;	3	9	3	27	Quarries are confined to particular areas.
	Extent of the damage relative to the amount of material produced;	3	9	2	18	The limited quarries result in a large amount of material used for construction purposes.
	Abundance of source or renewability of material;	4	16	4	64	Limited quarries but not abundant or renewable.
	Recycled content.	4	16	3	48	Can't be recycled.
Manufacture	Solid and liquid wastes in manufacture and production;	4	16	3	48	Water is wasted due to washing the material and cleaning the klinkers.
	Air pollution in manufacture and production;	3	9	4	36	Most production plants provide continuous air filtering.
	Embodied energy (energy used for its production);	4	16	5	80	Some companies are improving the process. The high temperature burners consume a lot of energy.
Construction	Energy used for transportation to the site;	3	9	3	27	Air polluting trucks and concrete mixers transport the material to the construction sites.
	Energy used on site for assembly and erection;	3	9	1	9	Pumps and site installed concrete mixers consume energy provided by diesel engine generators.
	On site waste including packaging.	1 2	1 4	2 2	2 8	Residual material from the concrete mixers. Dust and paper bags result from the cement that is received and mixed on site.
In use	Maintenance required during life cycle;	1	1	3	3	Needs some maintenance due to carbonation resulting from the existing air pollution.
	Environmental effects during life cycle (e.g. toxic emissions)	0	0	3	0	Does not produce any toxic emissions.

Demolition	Energy use in and effects of demolition at the end of the life cycle;	4	16	2	32	Jackhammers and swingballs are among the methods used to demolish this material. It is a time consuming process.
	Recyclability of demolished material.	2	4	4	16	Most of the material is used as backfill or under tile screed.
Material Ecology Index					418	

Paint and Varnish

The following chart yields the Ecology Index of paint:

Group	Criteria	Rating	$Rating^2$	Weight	Product	Remarks
Extraction	Damage to the environment in the extraction of the raw material;	0	0	3	0	Locally, there is no extraction of linseed oil or titans used in the process of paint production.
	Extent of the damage relative to the amount of material produced;	0	0	2	0	There is no local production.
	Abundance of source or renewability of material;	0	0	4	0	There is no local production.
	Recycled content.	0	0	3	0	There is no local production.
Manufacture	Solid and liquid wastes in manufacture and production;	2	4	3	12	Water is used and discarded when the drums are cleaned.
	Air pollution in manufacture and production;	1	1	4	4	Volatiles are released in this phase.
	Embodied energy (energy used for its production);	1	1	5	5	Mixing equipment consume electrical energy.
Construction	Energy used for transportation to the site;	1	1	3	3	The proportionally little quantity needed (in proportion to other materials) is transported to the site by trucks.
	Energy used on site for assembly and erection;	2	4	1	4	Electrical machines are used for spraying the material.
	On site waste including packaging.	2	4	2	8	Turpentine used to dilute the paint causes toxic emissions. The metal and plastic paint containers are reused.
In use	Maintenance required during life cycle;	3	9	3	27	Building components need to be repainted at about 2-3 year intervals, depending on the component.
	Environmental effects during life cycle (e.g. toxic emissions)	2	4	3	12	Locally, the paint that is provided in the market has no lead base.

Demolition	Energy use in and effects of demolition at the end of the life cycle;	2	4	2	8	Burning requires relatively little energy and produces smoke. Scraping produces dust.
	Recyclability of demolished material.	5	25	4	100	Can’t be recycled.
Material Ecology Index					183	

Marble

The following chart yields the Ecology Index of marble:

Group	Criteria	Rating	Rating²	Weight	Product	Remarks
Extraction	Damage to the environment in the extraction of the raw material;	0	0	3	0	There are no local quarries.
	Extent of the damage relative to the amount of material produced;	0	0	2	0	There are no local quarries.
	Abundance of source or renewability of material;	0	0	4	0	There are no local quarries.
	Recycled content.	0	0	3	0	There are no local quarries.
Manufacture	Solid and liquid wastes in manufacture and production;	2	4	3	12	When cutting, water is wasted in the cooling process of the saws.
	Air pollution in manufacture and production;	1	1	4	4	When cutting, fine dust particles are produced and released into the air.
	Embodied energy (energy used for its production);	1	1	5	5	The direct effect results from the mechanical cutting appliances' exhaust. The indirect effect is due to the use of electricity for the saws in the plant.
Construction	Energy used for transportation to the site;	4	16	3	48	Transportation is done by trucks and lorries that run on diesel.
	Energy used on site for assembly and erection;	1	1	1	1	The small elevators and cranes used, require electrical energy usually provided by a diesel generator on site.
	On site waste including packaging.	1	1	2	2	Very little waste is produced from breakage. The wooden crates are sent back to the plant and reused.
In use	Maintenance required during life cycle;	0	0	3	0	Cleaning the material is required rarely (every about 10 years).

	Environmental effects during life cycle (e.g. toxic emissions)	1	1	3	3	Marble is a natural material that does not produce toxic emissions.
Demolition	Energy use in and effects of demolition at the end of the life cycle;	3	9	2	18	This material can be either dismantled or demolished, depending on the method of construction. Demolition requires the use of electrically powered equipment.
	Recyclability of demolished material.	1	1	4	4	Dismantled marble can be reused. Broken material is crushed and used as backfill.
Material Ecology Index					97	

Glass

The following chart yields the Ecology Index of glass:

Group	Criteria	Rating	$Rating^2$	Weight	Product	Remarks
Extraction	Damage to the environment in the extraction of the raw material;	1	1	3	3	Not produced locally.
	Extent of the damage relative to the amount of material produced;	0	0	2	0	Not produced locally.
	Abundance of source or renewability of material;	0	0	4	0	Not produced locally.
	Recycled content.	2	4	3	12	Not produced locally.
Manufacture	Solid and liquid wastes in manufacture and production;	1	1	3	3	Pieces of glass and dust result from the cutting process.
	Air pollution in manufacture and production;	1	1	4	4	The generators that provide energy for the electrically powered machines pollute the air.
	Embodied energy (energy used for its production);	1	1	5	5	The energy consists of the electricity used for cutting and polishing the edges.
Construction	Energy used for transportation to the site;	1	1	3	3	Trucks that are powered by fossil fuels transport the material to the site and pollute the air at the same time.
	Energy used on site for assembly and erection;	1	1	1	1	Elevators and cranes are use to place the glass close to the place they will be installed in.
	On site waste including packaging.	2	4	2	8	Some breakage may occur due to accidents or mishandling. Packages and wraps are re-used.
In use	Maintenance required during life cycle;	1	1	3	3	Cleaning the glass represents its maintenance. Panels may require change if breakage occurs.
	Environmental effects during life cycle (e.g. toxic emissions)	0	0	3	0	Glass itself has no effect but the cleaning material used may contain volatiles that produce emissions.
Demolition	Energy use in and effects of demolition at the end of the life cycle;	1	1	2	2	Can be dismantled.

	Recyclability of demolished material.	2	4	4	16	Locally it is recycled for artisanale use of glass blowing. Otherwise it is transported to a neighboring country to be included in the manufacturing process.
Material Ecology Index					60	

Ceramics
The following chart yields the Ecology Index of ceramics:

Group	Criteria	Rating	Rating^2	Weight	Product	Remarks
Extraction	Damage to the environment in the extraction of the raw material;	2	4	3	12	Clay quarries are locally available and wide spread.
	Extent of the damage relative to the amount of material produced;	2	4	2	8	A delicate process consists of removing the topsoil from a certain area to extract the clay. When that area is consumed, the topsoil is reconstituted (to serve as an agricultural area) and another area in the vicinity is used as a quarry.
	Abundance of source or renewability of material;	1	1	4	4	The material is available abundantly in certain areas.
	Recycled content.	3	9	3	27	There is no recycled content in the initial raw material.
Manufacture	Solid and liquid wastes in manufacture and production;	4	16	3	48	Water used for washing the material is discharged in rivers. Its turbidity is very harmful for the fauna and flora.
	Air pollution in manufacture and production;	2	4	4	16	Generators that run on fossil fuels pollute the air.
	Embodied energy (energy used for its production);	3	9	5	45	Generators produce the energy needed for the furnaces.
Construction	Energy used for transportation to the site;	2	4	3	12	Trucks usually transport the material to the construction site.
	Energy used on site for assembly and erection;	1	1	1	1	Manual tools are needed.
	On site waste including packaging.	1	1	2	2	Very little waste results from breakage. In most cases, packaging is reused.
In use	Maintenance required during life cycle;	1	1	3	3	Maintaining the joints may be required.
	Environmental effects during life cycle (e.g. toxic emissions)	1	1	3	3	There are no toxic emissions.

Demolition	Energy use in and effects of demolition at the end of the life cycle;	2	4	2	8	Can be manually dismantled are demolished using a pneumatic hammer.
	Recyclability of demolished material.	4	16	4	64	Can not be recycled. The material could be used for backfilling.
Material Ecology Index					253	

It is important to consider that the impact of these materials is affected by the proportion of material they represent in a building. The following chart shows the approximate truckloads of material needed to build a typical 5 floor (300 m² of floor area per level) residential building. A truckload is considered to be the contents of a truck with a 30 ton capacity.

Description	Material used in the building
Cement:	8 trucks
Concrete masonry units:	10 trucks
Aggregate:	45 trucks
Sand:	30 trucks
Paint (including putty):	less than 1 truck
Marble:	1 truck
Stone:	2 trucks
Ceramics (including jointing):	1 truck
Terrazzo tiles:	2 trucks
Glass (including accessories):	less than 1 truck
Aluminium:	1 truck
Metal reinforcement:	3 trucks
Total	105 trucks

It is interesting to note that the truckloads needed to remove the debris from the site at the end of its life cycle adds up to more than 130 trucks.

CHAPTER 10: APPLICATION OF THE METHOD TO TWO EXISTING BUILDINGS

Building 1

The first residential building is located at the corner of two streets. Is it an eight-story building with a commercial ground floor and two underground basements. As the pictures show, it is a typical modern apartment building of decent quality, similar to many others in the city. It's main elevation is oriented south (right hand elevation in the upper picture), and the back elevation (lower picture) is oriented north.
The building factors that relate to climate responsive design are addressed as shown below. Each factor is given a score and that score is multiplied by the weight assigned to that item in chapter 8.

Figure 10.1
Residential building 1: view 1

Design Ecology Index

Assessing the DEI requires looking at the issues described in Chapter 8, as follows:

1 – Massing of the building

Due to the constraints of plot size and construction regulations, this building is a safe and standard response to functional program needs. It does not have any creative responses to the problem of typical apartment building in Beirut. The score assigned is 2.
Therefore, 2 x 3 = 6

Figure 10.2
Residential building 1: view 2

2 – Proper shading of openings

The south oriented living room openings are shaded by the cantilevered balconies. Although the openings to the east and west are not shaded, they remain relatively small so the inconvenience of heat gain remains minimal. The bedroom openings to the south are standard in size.
The small openings to the east, and particularly the west, result in a low possibility of having glare. The rolling shutters on the south elevation also reduce that problem on sunny winter days when the sun angle is low.
The score is 3.
Therefore, 3 x 3 = 9

3 – Natural ventilation

The building does not rely on natural ventilation. The building width does not permit cross ventilation. The spaces have single sided openings that, in the best of cases, provide for single sided ventilation. The score is 1.

Therefore, 1 x 3 = 3

4 – Orientation of the building

Again, the building satisfies the functional requirements in an ordinary way. The public areas (living and dining rooms) and their balconies overlook the main street; whereas the private areas (bedrooms) are located to the back of the building. This has resulted in north oriented bedrooms that only receive the early morning sun in the summer and none in winter. The score is a 2.

Therefore, 2 x 2 = 4

5 – Thermal mass and thermal transmittance

This building's walls are composed of a double wall with an air cavity in between. The roof layering integrates rigid insulation. The windows are locally assembled double-glazing with standard (not thermally broken) aluminium sections. Thermal bridges exist at the structural components of reinforced concrete columns and beams (the double walls are made of hollow concrete blocks and fill in the areas between the structural elements. There is a high risk of condensation in the winter season at the structural members in the envelope and at the aluminium sections. The score is a 1.

Therefore, 1 x 2 = 2

6 – Landscaping

The trees to the north act as wind breakers to the cold northern winds in the winter season. Their height only permits the protection of the lower floors (reference the picture). Other than that there is no vegetation on site. The score is 1.

Therefore, 1 x 2 = 2

7 – Winter solar gain

The bedrooms do not benefit from winter solar gain due to their north orientation. The living room areas, on the other hand, have a better exposure. The score is 0.5.

Therefore, 0.5 x 1 = 0.5

The overall score of the building is 26.5
Therefore this building has a medium DEI rating.

Materials' Ecology Index

Concerning the MEI, the calculations are based on the following:

A rough calculation yields the following weights of the building materials used in the building[1]:

Cement	1710 tons
Aggregate	9142 tons
Sand	2123 tons
Stone cladding	130 tons
Aluminium	10 tons
Glass	35 tons
Tiles	356 tons

Multiplying the weight of each material by its corresponding MEI yields the following total material ecology index:

Material	weight	MEI	weight*MEI
Cement:	1710 tons	418	714780
Aggregate:	9142 tons	408	3729936
Metal reinforcement:	205 tons	131	26855
Sand:	2123 tons	408	866184
Stone cladding:	130 tons	408	53040
Aluminium:	10 tons	61	610
Glass:	35 tons	60	2100
Tiles:	356 tons	253	90068
Total material ecology index			5483573

Analysing the index obtained shows that, replacing a percentage of the opaque components (cement, aggregate, sand and stone cladding) with glass, for example, should yield a lower index. In fact, using the tables below, the index decreases by approximately 17% when the opaque elements are reduced and the glass is increased by 25%. In addition, the index decreases by around 37% when the opaque components are reduced and the glass is increased by 50%.

Material	weight	MEI	weight*MEI
Cement:	1454 tons	418	607772
Aggregate:	7771 tons	408	3170568
Metal reinforcement:	205 tons	131	26855
Sand:	1592 tons	408	649536
Stone cladding:	117 tons	408	47736
Aluminium:	10 tons	61	610
Glass:	44 tons	60	2640
Tiles:	356 tons	253	90068
Total material ecology index =			4595785

[1] Appendix 2

Material	weight	MEI	weight*MEI
Cement:	1112 tons	418	464816
Aggregate:	5942 tons	408	2424336
Metal reinforcement:	205 tons	131	26855
Sand:	1062 tons	408	433296
Stone cladding:	98 tons	408	39984
Aluminium:	10 tons	61	610
Glass:	53 tons	60	3180
Tiles:	356 tons	253	90068
Total material ecology index =			3483145

The two elements DEI and MEI allow the architect to define a building in terms of response to climate and environment. Had the architect gone through this exercise during the actual design phases prior to execution, he or she would have implemented passive design strategies in a more successful way. The architect would also have chosen the materials differently so as to achieve lower MEI scores while maintaining the architectural concept, of course.

To further understand the utility of this index, a second building is evaluated as follows.

Building 2

Each of the five floors of the second residential building has one residential unit. The building has a render finish on all sides and single glazing on all the windows. The openings are protected by aluminium shutters (which replaced the wooden ones often used in the 1960s when the building was built).
The plan area is approximately 30m X 11m and it has a finish to finish floor height of about 3.2 meters.
The building is surrounded by other structures on three sides and a parking lot on the fourth side. The parking lot is located to the south of the building.
It must be noted here that the parking lot is for sale, so eventually, a building may be built. In such event, the ventilation strategy will be totally compromised since the prevailing south-west summer winds will no longer reach the building.

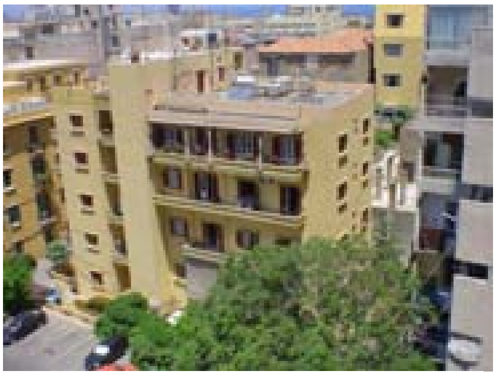


Figure 10.3
Residential building 2: view 1

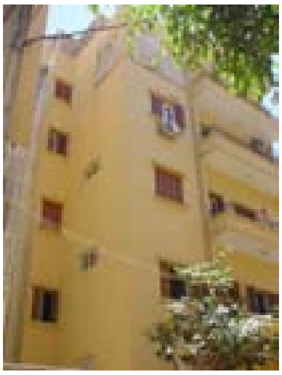


Figure 10.4
Residential building 2: view 2

Figure 10.5
Residential building 2: view 3

Design Ecology Index

Assessing the DEI is based on addressing the following issues:

1 – Massing of the building

This building has a relatively narrow mass. Although this may probably be due to plot size constraints and functional program needs, the fact that the mass has its long axis oriented east / west ensures a favourable relationship to the sun path and the wind movement. The score assigned is 3.
Therefore, 3 x 3 = 9

2 – Proper shading of openings

The south oriented living room openings are shaded by the cantilevered balconies. The photographs show that the shading is effective at noon time in May. The pictures above were taken on May 28 at around noon.
The openings to the east and west are exposed to the sunrays but they remain relatively small so there is relatively little nuisance due to heat gain.
The wooden louvers provide the necessary shading when the sun angle altitude is smaller. The score is 3.
Therefore, 3 x 3 = 9

3 – Natural ventilation

The building has a strong potential to use natural ventilation. The width of about 11 meters encourages cross ventilation. The living space has double sided openings that induce ventilation. The bedroom located to the east side of the building may benefit from natural ventilation due to the windows located on both sides of the corner. The buildings to the north act as wind breakers to the cold northern winds in the winter season. The score is 3.
Therefore, 3 x 3 = 9

4 – Orientation of the building

The public areas (living and dining rooms) and their balconies overlook the parking lot; whereas the private areas (bedrooms) are located to the sides of the building. The result is north-east and north-west oriented bedrooms that receive the early morning and afternoon sun in the summer and none in winter. The score is a 1.
Therefore, 1 x 2 = 2

5 – Thermal mass and thermal transmittance

This building's walls are composed of a single wall which was a common construction method in the 60s. Rigid insulation was added to the roof. The windows have single-glazing with wooden sections. Thermal bridges exist at the structural components of reinforced concrete columns and beams. There is a high risk of condensation, in the winter season, at the structural members in the envelope and on the glass. The score is a 1.

Therefore, 1 x 2 = 2

6 – Landscaping

The couple of trees at the entrance of the building do not contribute to the climate responsiveness of the building. The score is 0.

Therefore, 0 x 2 = 0

7 – Winter solar gain

The bedrooms do not benefit from winter solar gain due to their orientation and to the fact that the low winter sun will be obstructed by the surrounding buildings. The living room areas, on the other hand, have a good exposure. The score is 0.5.

Therefore, 0.5 x 1 = 0.5

The overall score of the building is 31.5 and it has a medium DEI rating.

Materials' Ecology Index

Concerning the MEI, the calculations are based on the following:

A rough calculation yields the following weights of the building materials used in the building[2]:

Cement:	429 tons
Aggregate:	1330 tons
Sand:	394 tons
Metal reinforcement:	75 tons
Aluminium:	0.5 tons
Glass:	10 tons
Ceramic tiles:	50 tons

Following the same process as for the first building yield the following:

Material	weight	MEI	weight*MEI
Cement:	429 tons	418	179322
Aggregate:	1330 tons	408	542640
Sand:	394 tons	408	160752
Metal reinforcement:	75 tons	131	9825
Aluminium:	0.5 tons	61	30.5
Glass:	10 tons	60	600
Ceramic tiles:	50 tons	253	12650
Total material ecology index			905819.5

[2] Appendix 2

In summary, the building has a medium DEI rating and MEI score of approximately 906,000. Once again these two values give an indication of what could have been done in the design phase to improve its response to climate (design) and environment (materials).

Comparing building 1 to building 2:

When attempting to compare the indices of these two buildings two issues emerge.

1. Given that the DEI relates to passive design concepts and is measured on a scale, it is possible to compare the DEI values for different buildings and evaluate their relative response to the climatic characteristics. For example, although the DEI for the two buildings is within the medium range, the slight difference in scores indicates that building two given its context responds better to the climate of Beirut.
2. The same cannot be applied to the MEI as the score is highly dependent upon the weight of the building itself. Therefore a heavier building such as building one relative to building two will always have a higher MEI regardless of the materials used. However, this index can be used as a reference for the building itself to analyse the behaviour of the building as the percentage of materials within it varies.

CHAPTER 11: CONCLUSION

Attempting to define climate responsive buildings in Beirut, Lebanon is a challenging task as the geographic location of the city encourages the application of passive design strategies that have yet to be wide spread in the country. Limited research has been done on the materials used for construction and little is documented pertaining to the damage this is causing the environment. This effort comes at a time when local awareness is starting to rise and this issue is being given its due importance in the professional field.

This assessment method is a starting point in trying to initiate awareness pertaining to how a building is climate responsive and environment friendly. It is not an exact method of assessment but it allows for the understanding, in a broad sense, of how a building behaves in its environment. It is a first step in Beirut and is meant to be used as a building block to be added upon and improved in a context that is beyond the scope of this thesis.

Such assessment methods exist internationally but they to be customized to the local context. In addition, some of these methods focus only on materials while the objective of this work was to include the design aspect which can either serve as a guide for a designer or be used to evaluate existing buildings.

The proposed method defines two separate indices to evaluate passive design strategies integrated into the design process (design ecology index) and assess the materials used in building (material ecology index). Important issues were identified within each index and a scoring mechanism was suggested to provide a weighted sum of these concepts based on their relevance in the context of Beirut.

The resulting index proved to be an efficient way of evaluating a building in the design stage prior to its completion. It provides a measure for architects to analyse and better understand the behaviour of the building. By varying the parameters included in the calculations, architects can implement changes to improve its performance.

The limitations of this proposed method lie mainly in the material ecology index. This index is closely related to the weight of the building and therefore tends to be as much a function of its weight than a reflection of its materials. This makes it rather impossible to use this index to compare between buildings. The MEI plays a useful role in simulating different material compositions for the same building. This is only possible during the design phase. Once the building is executed implementing changes to its materials will remain hypothetical.

To make the index more precise and reflective of the local situation, a substantial amount of information pertaining to the local life cycle of the material has to be gathered and studied. Moreover, an evaluation system has to be defined for the materials that are imported from abroad. Lebanon is a small country with limited resources. Many building materials such as marble, glass, paint, and aluminium are imported. That being the case, their harm to the local environment is minimal compared to locally extracted materials such as stone. That does not mean however that the harm does not exist just that it is not quantified with respect to this context. This harm factor needs to be incorporated in the material ecology index as the final concern lies in the well-being of the environment as a whole.

Other issues that need to be addressed to make the assessment method more complete include the integration of active systems and the consumption of water and electricity during the lifespan of the building. Active systems such as solar hot water panels when installed in the buildings, result in substantial energy savings due to the abundance of sunshine in the country[3].

The operation phase basically consists of two items namely water and electricity consumption. The fixtures and appliances used can strongly influence consumption over the lifespan of the building. Concerning electricity, the use of energy efficient lighting fixtures, help rely less on energy consumption. Methods that make water use more efficient could include: rainwater recuperation, using water from underground streams, installing water saving sanitary fixtures, recycling grey water for toilet use or for irrigation and planting Vegetation that is low maintenance and does not need excessive watering.

This assessment method proved to be a successful first attempt to tackle the issue of assessing climate responsive buildings in Beirut. It lends itself to be further developed and elaborated. Although the focus in this thesis was on residential buildings only, the indices could just as well be developed applied to buildings with different functions. Given the importance that this issue is generating on a worldwide scale, this thesis could prove to be a timely effort in raising local awareness as to the need for conserving energy while making use of natural resources to provide human comfort. With the continuing rise in the costs of oil the only alternative is designing buildings that relate to their context and respect their environment.

APPENDIX A

The general information in this appendix is a compilation from the scarce publications discussing building materials in Lebanon. Other than providing a general overview of the materials, the information is integrated in chapter 9 and used to calculate the material ecology index.

STONE

"Stone is healthy and non-polluting if it is set in plain cement mortar and on a damp-proof foundation; however, quarries disfigure the landscape and high energy costs are involved in the quarrying, handling, and transporting of stone."[44]

Quarries exert significant pressures on the environment. They disrupt the natural landscape, may cause structural damage to nearby houses from blasting, and generate nuisance to nearby populations through noise and dust. Quarrying also damages or destroys natural habitats and vegetation. Moreover, quarrying affects the natural hydrogeology at many sites (e.g., springs dry up). Finally quarrying is also threatening sensitive ecosystems near natural heritage sites. For example, the quarries of Ain Dara are located within the tentative boundaries of the Al Shouf Cedar Nature Reserve, and large quarries (now closed) have irreversibly spoiled the valley of Nahr Ibrahim, a candidate site for inclusion on the World Heritage List[45].

Figure A1
Stone quarry © Fareed Abou-Haidar, 1983

"Today, there are an estimated 780 active and inactive quarries in Lebanon. The majority are in Mount Lebanon with 42% of all quarries concentrated in the qada' of the Metn due to its proximity to Beirut and the high construction rate in the area. Around 90% of production is in the form of aggregates which include stone for pavements, roads, cement, and concrete; stone fragments; dimension stones, or cut and polished stone; square blocks used for marine protection.
Most of the output is for domestic use with only some dimension stones exported. The total amount of material quarried each year is in excess of 1.2bn tons. Up to 5,000 cubic meters of stone are being quarried per annum. With the minimal overheads incurred, profits can exceed as much as $12,000 a day thereby making quarrying a highly lucrative business[46]

METAL

According to Morcos[47], the total national production, in 2001, was 140 thousand tons. The total import was 298 thousand tons; total export was 15 thousand tons.
The national consumption was 423 thousand tons.
Metal is imported into Lebanon from the following countries: 70 % from Ukraine, 10 % from Bellarussia, 10 % from Lithuania and 10% from Egypt. Boats transport the material from its country of origin to Lebanon[48].

ALUMINIUM
This material was first introduced in Lebanon in 1953.
In 2001, total import was16,324 tons, divided as 15,561 tons of raw aluminium and 757 tons of processed aluminium.
That year, the total export was 13,074 tons[44]
Therefore, the difference of 3,25 tons was the yearly consumption.
The ovens use electric power or liquid propane gas. Since the electric power delivery is not reliable, factories generate their own power by having generators that run on fossil fuels.

CEMENT
Cement is a main ingredient that enables the production of hollow concrete blocks, solid concrete blocks, different types of concrete and plaster.
"The demand for cement peaked during 1995, in response to large-scale reconstruction projects after the war (buildings and infrastructure). Between 1993 and 1996, Lebanon relied on local production as well as imports (mostly from Syria) to satisfy demand. Compared to other countries in the region, Lebanon had in 1995 the highest per capita consumption of cement. Since then, cement consumption has declined and imports have stopped. Despite a notable recession in the construction industry, the construction of roads and bridges has kept the annual demand for cement and aggregates above the two million tones mark[47]".
"Cement production in Lebanon has been a very environmentally destructive industry, polluting the air and damaging the landscape around Shikka with extensive quarrying. Instead of exporting cement, Lebanon should be working to reduce its own demand of cement. This can be done by using other material for interior walls, by recycling old concrete for use in non-load-bearing structures, and by refurbishing old high-rise apartment buildings instead of demolishing and replacing them[46]."
The cement industry is said to be an energy-intensive industry. The percentage of energy cost in portland cement production cost is 20 to 30%. Ninety percent or more of fuel is consumed for clinker burning. About 40% of electric power is consumed for finish grinding, and a little under 30% is consumed by the raw material process and the clinker burning process[49]

Black cement (used for gray concrete and mortar)
According to Morcos[47], 80 % of black cement production is used in the building industry, while the remaining 20 % are used in the domain of public works.
The national production of cement in 2001 was 2.6 million tons.
The yearly national production of clinker was 3 million tons, and the cement and clinker Import = 204 thousand tons per year.
The local consumption was 5.8 million tons.
Export cement and clinker = 47 thousand tons per year.

White cement (used for fairfaced concrete or other architectural finishes)
National production = 28.4 thousand tons per year.
Import = 32.6 thousand tons per year

PAINT
National production = 25 thousand tons
Import = 4500 tons
Export 3500 tons
National consumption = 26 thousand tons

MARBLE
Import = 85 thousand tons

Export = 7.8 thousand tons

GLASS

Import = 33.8 thousand tons from Italy, Romania, France, Spain, Bulgaria, Russia and some Arab countries
Export = 1.1 thousand tons

CERAMICS

National production = 4.7 million m^2
NATIONAL CONSUMPTION = 7 MILLION M^2

APPENDIX 2

In order to simplify the calculation method in the aim of making it more user friendly, the calculations of the materials are based on the following:
The weight per square meter of slab, by material, is equal to (from top to bottom):

Floor tiles: 2.5 cm thick	55 kg/m^2
Mortar bed: 2 cm thick	44 kg/m^2
Fill: 10 cm thick	185 kg/m^2
Hourdi slab: 25 cm thick	450 kg/m^2 (approx. 400 kg/m^2 concrete and 50 kg/m^2 steel reinforcement)
Plaster: 2 cm thick	44 kg/m^2

The total weight of 1 m^2 of a standard slab = 778 kg/m^2

The weight per square meter of wall, by material, is equal to (from outside to inside):

Stone cladding: 5 cm thick	105 kg/m^2
Mortar: 3 cm thick	66 kg/m^2
Hollow concrete block: 20 cm thick	376 kg/m^2
Rigid insulation: 5 cm thick	1.8 kg/m^2
Hollow concrete block: 10 cm thick	200.5 kg/m^2
Plaster: 2 cm thick	44 kg/m^2

The total weight of 1 m^2 of a standard wall = 793.3 kg/m^2

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