



Republic of Lebanon
Ministry of Public Works and Transport
General Directorate of Urban Planning



CLIMATIC ZONING FOR BUILDINGS IN LEBANON

2005

**PROJECT CAPACITY
BUILDING FOR THE
ADOPTION AND
APPLICATION OF
THERMAL STANDARDS
FOR BUILDINGS**



Republic of Lebanon
Ministry of Public Works and Transport
General Directorate of Urban Planning



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:: PREFACE

This study has been developed in the context of Project “Capacity Building for the adoption and application of Thermal Standards for Buildings”. The project was funded by the Global Environment Facility, Managed by the United Nations Development Programme, and Executed under the Lebanese General Directorate of Urban Planning, Ministry of Public Works and Transport. The project falls under the Climate Change focal area and aims at the establishment of Thermal Standards for Buildings, and at enabling their adoption and application through the provision of capacity building and information dissemination.

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:: FORWARD

The climatic zoning and typical year weather files generated in this study can be considered adequate for the purpose of the introduction of the Thermal Standard on a voluntary basis. However, these will need to be fine-tuned and updated in the future as more data becomes available and before the Thermal Standard becomes mandatory in the target year 2010.

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:: INTRODUCTION

The purpose of this study is to determine the appropriate climatic zoning for the Thermal Standard for Buildings in Lebanon.

In the context of building regulations, climatic zones exhibit similar meteorological conditions for the main weather parameters which affect the heating and cooling energy requirements of buildings. In broad terms, it may be stated that the heating and cooling energy requirements of buildings are affected by four main climatic parameters which are temperature, humidity, solar radiation and wind.

Determining the optimum number of climatic zones for a given country is often a trade-off that has to take into consideration the availability of raw meteorological data, population density and a certain threshold of weather difference between the selected regions in order to have a significant change in the heating and cooling patterns among regions. Furthermore, the number of regions should be reasonable to avoid making the application of the Thermal Standard cumbersome. Sometimes, it is better to fit climatic zones within the nearest administrative regions to allow ease of identification and application.

The methodology used for the development of climatic zones for the thermal standard for buildings in Lebanon consisted of several key steps, including the following:

- Review of the climatic characteristics of Lebanon.
- Evaluation of the availability of relevant Climatic parameters.
- Selection of representative climatic indicators for the comparative evaluation of the thermal energy requirements of buildings.
- Identification of the main climatic zones.
- Delineation of the contours of the Climatic zones taking into consideration all the study findings in addition to altitude thresholds, microclimates, and the contours of the administrative districts.

Furthermore, in addition to the establishment of Climatic Zones for the application of the Thermal Standard for Buildings in Lebanon, the study resulted in the following:

- Set up of typical meteorological year weather files (TMY) for use in hourly energy simulation software tools.
- Proposal of outdoor design conditions corresponding to the proposed climatic zones.

The climatic zoning and typical year weather files generated in this study can be considered adequate for the purpose of the introduction of the Thermal Standard on a voluntary basis. However, these will need to be fine-tuned and updated in the future as more data becomes available and before the Thermal Standard becomes mandatory in the target year 2010.

1

REVIEW OF THE CLIMATIC CHARACTERISTICS OF LEBANON

This chapter presents an overview of the climatic characteristics of Lebanon, and provides an introductory background for the subsequent chapters where a more specific discussion on the most important parameters for the establishment of climatic zones for the *Thermal Standard for Buildings* will be considered. This Chapter draws mainly on information from the reference document "*Atlas Climatique du Liban*".

1.1 Geographical Location

Lebanon is located on the eastern coast of the Mediterranean Sea (Beirut: Latitude 33° 49N and Longitude 35° 29E). The Mediterranean Climate is characterized by mild rainy winters and hot dry summers. A Mediterranean climate benefits from the dampening effect of the sea. In winter the sea temperature is higher than the air temperature, and the sea thus warms up the air masses which are then blown over the coastal regions. In summer the sea temperature is lower than the air temperature, and the cool breeze from the sea contributes to the reduction of the coastal temperatures.

The Nasa Jet Propulsion Laboratory extends this definition to western coasts of continents instead of the Mediterranean Basin only. Indeed, this distinctive climatic pattern can be found in four other parts of the world: California, Chile, South Africa, and Australia. All five of the world's Mediterranean climates are located within latitudes 30° and 45°.

1.2 Topography

Understanding the topographic characteristics of Lebanon is a pre-requisite to any climatic analysis. In general, Lebanon's topography can be divided into three features, a coastal strip, mountain ranges, and an inland plateau.

The Western mountain range plays a key influencing role on the climatic pattern of the inland plateau.

While the climatic pattern of the western side of the Western mountain range exhibits Maritime characteristics, the climatic pattern of the eastern side of the Western mountain range exhibits Continental characteristics. Continental climates are typically marked by large annual or daily temperature amplitudes, low relative humidity, and moderate to low rainfall.



Figure 1 - Topographic Map of Lebanon
Source of figure 1: SDATL, CDR

1.3 Climatic Regions as Defined by the Atlas Climatique du Liban

The *Atlas Climatique du Liban* indicates that the Mediterranean climate of Lebanon can be further characterized as an oceanic climate during winter and a sub-tropical climate during summer. Based on a long term trend of weather parameters including temperature, relative humidity, precipitation and wind, the *Atlas Climatique du Liban* generally divides the country into three broad climatic trends: the coastal, the mountainous and the inland. These are further subdivided into a number of sub-regions making up to a total of eight climatic regions.

Figure 2 presents these eight climatic regions along with the location of the various meteorological stations considered in the *Atlas Climatique du Liban*. However it is to be noted that not all the listed stations record all weather parameters, and that some stations are limited to the temperature parameter only. Thus the number of useful stations for this study may be lower than the number of stations listed in the Atlas.

The divisions established by the *Atlas Climatique du Liban* are not necessarily appropriate for the establishment of climatic zones for the thermal standard for buildings, since these divisions were not established for considerations related to their impact on building energy use. However, this initial identification of regions is convenient and will be used in this chapter for the overview of the climatic characteristics of Lebanon.

1.4 Temperature Patterns

1.4.1 Yearly Average Temperature

Figure 3 presents the yearly average temperature pattern in Lebanon. From this figure, we can see the impact of altitude on the weather pattern. All iso-temperature curves at 5 °C and 10 °C are located above 1800 m altitude except for a small area in the Bekaa plateau where the 10 °C line extends to a lower altitude near the town of Serghaya. The 15 °C line is in general slightly higher than the 900 meter altitude isoline and can be estimated to be in the range of 1100 m to 1200 m. A slight portion of the littoral benefits from the dampening effect of the sea and has a yearly average temperature above 20 °C.

From these initial findings, it can be deduced that the climatic zones to be defined for the thermal standard will need to be related to altitude. Normally, this relationship is embedded in the dry-bulb temperature as the temperature recorded at a station includes the effect of altitude. The effect of altitude on temperature is well known. The international organization for aviation determines a standard atmosphere as one in which the gradient in temperature is 6.5 °C for every 1000 meters of elevation. The *Atlas Climatique du Liban* gives a slightly lower value of 6 °C for every 1000 meters altitude rise in Lebanon.

While altitude is one of the main factors that affect the temperature of a region, it is important to recognize that it is not the only factor. Indeed, there are microclimates for which the temperature does not correspond to altitude. These microclimates will thus need to be identified and integrated in the process of definition of climatic zones for the thermal standard.



Figure 2 - Climatic Regions and Stations



Figure 3 - Yearly Temperature Averages



Figure 4 - Annual Temperature Amplitude

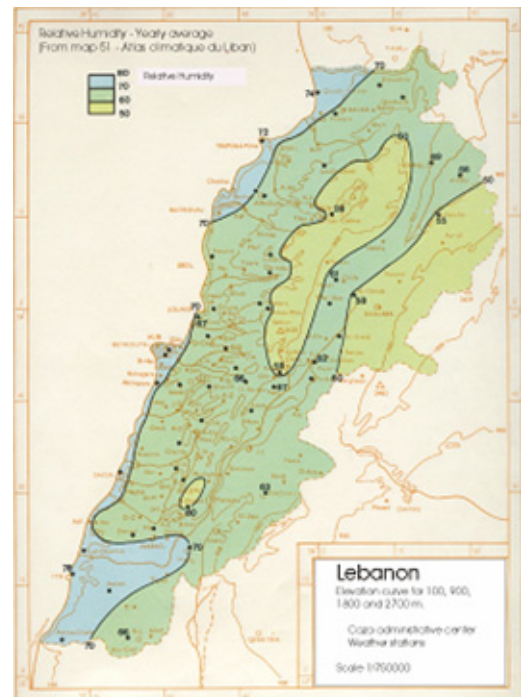


Figure 5 - Relative Humidity Averages

Source of Figures 2, 3, 4 and 5: Atlas Climatique du Liban.

1.4.2 Annual Temperature Amplitude

The annual temperature amplitude is the difference between the monthly average temperature of the hottest month and the monthly average temperature of the coldest month. Figure 4 reveals that the annual temperature amplitude is much lower on the western side of the Western mountain range than in the Inland region. The annual temperature amplitude is one of the characteristics that help classify a climate as maritime (amplitude less than 15 °C) or as a continental (amplitude close to 20 °C).

1.4.3 Daily Temperature Amplitude

The daily temperature amplitude is defined as the difference between the daily maximum temperature and the daily minimum temperature, and provides an indication of the variation of temperature during the day. In the coastal region, and due to the maritime influence, the daily temperature amplitude is small (less than 10 °C) and exhibits little variation during the year. In the Inland region, the daily temperature amplitude is always high, increasing particularly in summer. In Haouch-El-Dahab for instance, the daily temperature amplitude varies from 13 °C in January to 25 °C in August.

The daily temperature amplitude is an important parameter for the thermal energy consumption of Buildings. It is well known that buildings with high thermal mass can generally dampen the effect of the daily amplitude. During the heating season, thermal mass accumulates solar heat gain during the day and releases it during the night allowing the building to maintain the internal temperature with less heating energy. A positive effect is also observed during the cooling season as the thermal mass accumulates and delays solar heat gain, thus allowing the internal temperature to be more comfortable without too much cooling energy. The extra heat can be released in the evening through ventilation.

1.4.4 Microclimates

A microclimate results from a complex combination of factors including topography, precipitation, solar radiation and wind regimes. Typically, a microclimate exhibits temperatures that do not conform to the temperature trends observed for similar regions. A microclimate can exhibit warmer or cooler temperatures than neighboring zones or zones at similar altitudes. In the context of the present study, a micro-climate will be defined as a region where the temperature pattern does not fit the altitude-temperature relationship found in similar parts of the country. This is not the only definition of a microclimate but it is well suited for the purpose of this study.

In a climatic zoning analysis it is important to identify the stations representing microclimates. The *Atlas Climatique du Liban* has identified a number of Lebanon's microclimates. This was done by calculating the yearly average temperature of each weather station reduced to sea level. This allows a direct comparison of climate by removing the effect of altitude on the yearly temperature averages. In this analysis, it was found that in Lebanon, the yearly average temperature reduced to sea level was 20.5 °C. All stations that exhibited a reduced yearly average temperature of less than 20 °C were designated as cold microclimates. All stations that exhibited a reduced yearly average temperature of more than 21 °C were designated as hot microclimates.

Figure 4 presents the microclimates identified in the analysis of the *Atlas Climatique du Liban*.

In the north part of the country, we can see a cold microclimate near Kouachra and Qlaiaât-Aakkar. The Atlas attributes this microclimate as an effect of the Homs passage which brings cold continental air into the coastal region during winter.

In the middle part of the country, five stations experience a hot microclimate. These stations are located on a line running approximately from Qartaba and Laqlouq to Baalbek. The Atlas attributes these hot microclimates to the fact that these stations are sheltered from winds coming from the sea. This explanation however may not be the only reason, since if it were the only reason, sheltering from the sea air during winter would rather lead to a decrease in temperature in winter. One of the hypotheses for the hot microclimate could be that in winter some air passes at lower altitudes between Mount Lebanon and Mount Sannine. But this hypothesis cannot be verified unless a wind station is available at that particular point. The nearest station is the Cedars and we can see from its wind records of February and March a clear trend of strong winds blowing from the western littoral.

In the Inland part of the Country, we can find a cold microclimate that follows approximately a line from Taanayel, to Tell-Amara to Haouch-ed-Dahab. The Atlas Climatique attributes this cold microclimate to the effect of cold air descending from the nearby mountain and accumulating in the inland plateau at night.

In Beirut, there is a hot microclimate that is most probably caused by the urban heat island effect and some sheltering from the wind. The urban heat island is caused by high absorption of solar radiation by concrete surfaces and roads in addition to the obstruction of wind passages by buildings. All these effects contribute to keeping hot air trapped in the city.

1.5 Precipitation and Humidity

The *Atlas Climatique du Liban* provides some information regarding the precipitation and humidity levels in Lebanon. The percentage of humidity present in the air has an important impact on the thermal energy usage in buildings as it induces a latent air conditioning load to remove the water content from the air in order to maintain comfort. For a Thermal standard which targets more specifically the optimization of building thermal transmittance and solar gain, humidity is less important.

In Lebanon, precipitation is largely caused by winds coming from the West or Southwest bringing large masses of humid air over the littoral. As the warm and humid air climbs the western mountain range, the relative humidity increases until it reaches saturation. At that point, rain caused by the relief occurs. On the other hand, dryer air caused by winds coming from the Caucase, contributes to slightly lower rainfall in the northern part of the littoral as compared to the central littoral. Most regions in the northern littoral receive between 50 and 70 days of precipitation while the central region receives between 60 and 80 days.

Therefore, the quantity of rain varies according to the topography and the wind regimes. The largest rainfall occurs in the center mountain region with an annual total of approximately 1200 mm of rain. The littoral zones are the second most exposed to rainfall and the precipitations can reach around 1000 mm in the central littoral region. The northern littoral receives around 900 mm while the south littoral receives around 700 mm a year. The Inland region receives variable amounts of rainfall, the northern portion corresponding to the Internal Oronde region receives between 200 mm and 800 mm a year, the Internal Littani region receives 500 mm to 1000 mm while the Internal Hasbani region receives around 1000 mm.

Figure 5 presents the average relative humidity for the country. We can see that the relative humidity near the littoral is the highest with a yearly average of over 70%. The relative humidity of the slope of the western mountain range facing the sea up to an altitude of approximately 1800 m is between 60% and 70% relative humidity. Above this altitude, the relative humidity drops to less than 60%. This decrease in humidity is caused by relieved rainfall leaving the air with lower humidity content. In the Inland region, we can see that the western side of the plateau experiences higher relative humidity, in the range of 60-70%, than the eastern side which has a relative humidity level below 60%.

1.6 Solar Radiation

Solar radiation for clear sky conditions is mainly a function of the latitude of a location. As Lebanon does not extend very much on the north-south axis, there is no significant difference in the quantity of solar radiation reaching the upper atmosphere. The main difference observed between the Lebanese meteorological stations is thus related to the cloud cover experienced in different parts of the country. Another factor which can be taken into consideration is the rapid topographic change which may project shadows or affect the local sunrise and sunset hours in some stations.

The cloud cover is quite high in the littoral region where 4/10 of the sky, on average, is cloudy during the day. In the higher mountain, the cloud cover is less important in winter (2/10) than in summer. In the inland region, the yearly average is 3/10 of sky covered with a much lower level in summer (0.3/10).

Solar radiation can increase the cooling loads of buildings during summer and can reduce the heating loads of buildings during winter.

1.7 Wind

The wind data in Lebanon is less comprehensive than the temperature or humidity data. The Atlas provides the wind quantity (wind speed x time) for four stations and wind frequency observations for nine stations.

In general, we can say that in Lebanon, maritime air is blown from the sea nine months a year from September to May. It is a humid wind and most precipitations in Lebanon are caused by the humid air mass movement caused by these winds. In winter, continental air from Euro-Asia (the Caucasus and the Balkans) enters Lebanon through the Homs passage and the Internal Oronde valley. This air is mostly dry and cold and produces snow when mixed with warmer and humid maritime air. In summer, the air masses come only from the littoral after traveling around Cyprus. They are warmer and slightly humid after their passage over the sea but are not sufficiently saturated to bring rain. Some hot and dry desert air is also blown from Africa through Egypt but in a much lower quantity.

The wind affects energy consumption in buildings by modifying the temperature of the region according to the temperature of blown air masses. The effect of wind on energy requirements is already captured by the analyses of the temperature characteristics of a station. Another effect of the wind is that it increases the natural infiltration in buildings thus increasing the heating and cooling loads. This effect is important to consider in practice but it is slightly less important for a thermal standard that does not include requirements for air-tightness.

2

SELECTION OF CLIMATIC ZONING CRITERIA

In the context of building regulations, climatic zones are regions which exhibit similar meteorological conditions for the main climatic parameters which affect the heating and cooling energy requirements of buildings. This chapter presents the steps used for the selection of the relevant climatic parameters for the development of climatic zoning for the Thermal Standard for Buildings in Lebanon. The process included the following:

- Ranking the importance of various climatic parameters for the establishment of climatic zones for the thermal standard;
- Review of the available weather data in Lebanon;
- Selection of the indicators to be used for the comparative evaluation of the thermal energy requirements of buildings.

The following is an elaboration of these steps.

2.1 Impact of Climatic Parameters on Thermal Energy Requirements

In broad terms, it may be stated that the potential heating and cooling energy requirements of buildings are affected by four main climatic parameters. These are temperature, humidity, solar radiation and wind.

This section presents a review of the relative importance of these four main climatic parameters for the establishment of climatic zones for the Thermal Standard for buildings in Lebanon. The review takes into consideration the objectives of the proposed thermal standard and weighs the importance of each weather parameter for the analysis.

2.1.1 Dry-bulb Temperature

Dry-bulb temperature is one of the most important parameters that influence the thermal energy usage in buildings. In steady state conditions, the heat loss through the building envelope is proportional to the differential in temperature between inside and outside. The heating and sensible cooling of air is also proportional to the inside-outside air temperature differential. Thus it is easy to have a first appreciation of the thermal energy requirements of a building by calculating the average differential of inside-outside temperature during the heating and cooling seasons.

In the sixties, and in order to forecast the energy requirements of buildings and to properly schedule the delivery of fossil fuel, energy suppliers developed the degree-day method to provide an easy way to determine in a single figure the total thermal energy requirements of buildings over a complete heating or cooling season. This approach then became widely used for the quick estimation of the potential heating and cooling energy requirements of buildings. The heating and cooling degree-days can be calculated using hourly, daily, monthly or seasonal temperature data. In this study, the heating degree-days and the cooling degree-days were calculated using monthly data as per Equations 1 and 2 respectively.

Equation 1 Seasonal Heating Degree-day Calculation

$$DD_{heating} = \sum_{M=1}^n (18 - T_{outside}) \times N_{day}$$

$DD_{heating}$	= Degree-day heating on a base of 18 °C
M	= Months from start of the heating season to the end
n	= Last month of the heating season
18 (°C)	= Base temperature
$T_{outside}$	= Average temperature for the month
N_{day}	= Number of days in the month

Note: the summation is limited to months where $(18 - T_{outside})$ gives a value above zero

Equation 2 Seasonal Cooling Degree-day Calculation

$$DD_{cooling} = \sum_{M=1}^n (T_{outside} - 21) \times N_{day}$$

$DD_{cooling}$	= Degree-day cooling on a base of 21 °C
M	= Months from start of the cooling season to the end
n	= Last month of the cooling season
21 (°C)	= Base temperature in Celsius degree
$T_{outside}$	= Average temperature for the month
N_{day}	= Number of days in the month

Note: the summation is limited to months where $(T_{outside} - 21)$ gives a value above zero

The selection of base temperature for the calculation of the degree-days is somewhat a conventional choice and can be different according to the context. For the heating degree days, the base temperature for calculation is usually selected at a lower temperature than the internal thermostat comfort set point in order to take into consideration the fact that the heating system is not always started when the exterior temperature becomes lower than the interior set point temperature. Solar heat gain and internal heat gain from people, lighting and equipment contribute to provide some energy within the building that will offset the building envelope losses for a slight temperature difference. With an 18 °C base, there is an assumption that the solar and internal heat gain will offset about 2-3 °C of outside temperature drop. Buildings with a lot of internal heat gains or solar loads and buildings that are well insulated should be calculated with a lower base temperature to have a better evaluation of the real energy requirements. As buildings in Lebanon are generally non-insulated and the internal heat gains can be considered average, the 18 °C basis for the Heating Degree day was considered appropriate for Lebanon. A similar reasoning was used for the Cooling degree days, and the base of 21 °C was considered as appropriate.

As the degree-day is approximately proportional to the potential heating and cooling requirements of buildings, it is frequently used in climatic zoning analysis. The degree-day however has some limitations inherent with a simplified method. First, the effect of solar radiation on the building envelope is not taken into account. This means that the degree-day does not capture the impact of solar radiation on the heating and cooling energy requirements of a building. Second, the impact of Humidity on cooling loads is also not captured by this indicator.

Additionally, other parameters which can affect the buildings' energy requirements are not captured by the degree-day method but they are not related to climatic parameters. The effect of the building mass for instance is not considered. Buildings with important thermal mass can store energy from solar radiation during the day and release it at night thus reducing heating requirements for the same quantity of degree-day in a region. A similar effect occurs in the cooling season when during the day the solar radiation is stored in the building mass to be released at night. This can reduce the cooling requirement during the day. At night occupants may use natural ventilation to eliminate excess heat released from the building mass. These effects are normally taken into consideration in energy estimation methods that use hourly simulation of energy requirements of buildings.

2.1.2 Solar Radiation and Cloud Cover

Solar radiation is one of the important factors that affect the thermal energy requirements of buildings. The solar load in summer can be easily higher than the heat gained by conduction through the building envelope. As the solar radiation increases in a region, the cooling loads also increase. In winter the solar radiation can have a beneficial effect as it can heat the building with free energy. The benefits will differ according to the type of window used, its orientation and size as well as the type of internal and external shading protection.

The main indicators used to calculate the impact of solar radiation on the energy requirements of buildings is an integration of the solar radiation received on a horizontal surface or on a plan perpendicular to the sun rays during the heating and cooling season. Seasonal calculations are made separately as the effect of solar radiation is quite different on the energy requirements of buildings during each season.

The main difficulty encountered in using solar radiation for the development of climatic zones is to obtain reliable data sets for a sufficient number of stations. This is due to the fact that solar radiation and cloud cover are not frequently recorded by meteorological stations. This is the situation in Lebanon. National averages can sometimes be found but cannot be used to differentiate the effect of the sun in different zones or regions in the country and thus provide little added value to a climatic zoning analysis.

2.1.3 Humidity Ratio

The humidity ratio provides an indication of the quantity of water contained in the air. It is the ratio of the weight of water in the air over the weight of the total quantity of air in a given volume. The humidity ratio can be derived from the relative humidity, the Wet Bulb temperature or from the Dew point temperature.

The Introduction of humid air in buildings has an impact on the thermal energy requirements of buildings. During the cooling season, it will increase the cooling load since, in the process of cooling the introduced air, the moisture in the air is eventually condensed and cooling energy must be provided for this dehumidification process. The higher the water content in the outside air brought into the building, the higher the energy required.

2.1.4 Wind

Wind velocity, direction and frequency have an effect on building heating and cooling energy requirements both in winter and summer. The first impact of wind is to transport masses of hot or cold air through the country but this effect is already captured in the temperature analysis. Another important effect of wind relates to its impact on infiltration of air through the building envelope. This effect is more important on buildings that do not have mechanical ventilation and that are more affected by the natural infiltration pattern. Natural infiltration means that cold air in winter or hot and humid air in summer infiltrates through the building envelope by a complex process involving the wind (velocity and direction) a chimney effect (differential of temperature inside outside), door and window opening, quality of the construction and more particularly the cracks around the perimeter of window frames and other openings and joints.

2.2 Review of Available Climatic data

In order to identify the climatic data that can be used in the analysis, a review and assessment of the quality, comprehensiveness and span of several climatic data sources was undertaken. These sources included the *Atlas Climatique du Liban* and additional records from the Lebanese Meteorological Service (LMS) and from private climatic stations.

The analysis of climatic records for different weather stations in Lebanon showed variation in span and quality. Some climatic parameters like air temperature and atmospheric pressure were found in most weather stations and had a long history of measurement. Other parameters, such as global solar radiation, have been measured for only a few years and in few stations and thus much less data was available in order to establish long term trends. Other parameters such as diffuse solar radiation are not measured in most weather stations because they are not crucial to weather forecast applications.

Consequently, the data that was used in the study consisted of the following:

- From the Lebanese Meteorological Service : The *Atlas Climatique du Liban* and Post 1998 weather data records for selected stations;
- From Private Stations: the weather station of the American University of Beirut

2.2.1 Lebanese Meteorological Services

a) Atlas Climatique du Liban

The *Atlas Climatique du Liban* presents climatic data for around 50 stations for the pre-1972 years. The data includes temperature, relative humidity, nebulosity, solar radiation, wind and precipitation. However, not all the stations include all the parameters and this constitutes one of the key limitations of this source. Table 1 presents the list of stations of the *Atlas Climatique du Liban*. The temperature data related to these stations was converted to electronic computer excel files in order to be used in the analysis.

Table 1 - List of Stations from the Atlas Climatique du Liban

Station	Years	Altitude (m)	Station	Years	Altitude (m)
Abde	54-70	40	Haouch-El-Dahab	53-72	1009
Ain Ebel	52-72	765	Haouch-Es-Snaid	56-70	995
Alma-Chaab	60-72	385	Jamhour	55-70	410
Amioun	46-66	300	Jezzin	27-37	945
Ammiq	61-71	870	Kfar Dan	67-70	1080
Arbaniye-Jisr	59-70	510	Kfar-Nabrakh	56-70	1020
Baalbek	55-70	1150	Kherbet Qanafar	55-66	940
Beirut - Airport	64-70	15	Kouashra	65-70	400
Beirut - AUB	31-70	34	Ksara	21-72	920
Beirut - Nazareth	21-70	91	Laqlouq	68-70	1700
Beit-Ed-Din	65-70	835	Cedars	37-70	1925
Bhamdoun-Btalloun	46-72	1090	Marjeyoun	47-70	760
Bikfaya	50-70	900	Miniara	48-60	195
Bir-Hassan	50-70	60	Nabatiye	64-70	410
Dahr El-Beidar	62-70	1510	Qartaba	48-72	1140
Dahr-el-Daraje	65-71	1150	Qlayaat-Akkar	49-58	6
Douair	65-70	280	Qornet Shehwan	51-70	603
El-Qaa	65-71	650	Rashaya	65-70	1235
El-Qasmiyeh	47-70	30	Rayak	23-70	920
El-Qraye	00-33	1010	Saida	65-70	5
Fakehe	59-70	1060	Syr Eddiniye	67-70	915
Faraya Mzar	65-71	1840	Taanayel	64-73	880
Flawi	58-70	1170	Tell Amara	53-70	905
Gharife	64-70	680	Tripoli-El-Mina	31-70	4
Ghazir	52-70	415	Yammouneh	61-67	1360
Ghosta	53-70	650	Zouq-Mikayel	47-72	70

b) Post 1975 weather records

The weather data records between 1975 and 1992 were not considered, since as a result of the war (1975-1991) the overall weather data records during this period suffered from lack of continuity and lack of homogeneity, with the exception of few stations such as Beirut Airport.

As of 1998 the Lebanese Meteorological Services launched a New Network of Meteorological Stations in Lebanon. However the majority of these stations became active only in late 1999. As such, and due to the limited number of years, and to the fact that the newly recorded data still requires assessment and validation, its use in the present study was only partial and selective. Among this was the following:

The monthly average temperature data of 22 stations was compiled and compared with the data of the "*Atlas Climatique du Liban*". The comparison revealed no significant difference between the new and old average monthly temperature data. This provided some comfort that the limited time span covered by the new station network will somewhat be representative of long term averages. Table 2 presents the list of the 22 additional stations whose monthly average temperature was included in the present study.

Table 2 - List of 22 Selected Stations from new LMS Records

Station	Altitude (m)	Station	Altitude (m)
Aamchit	135	Jouaya	300
Arsal	1400	Jounieh	10
Bayssour	978	Kaftoun	215
Becharre-factory	1400	Mayfouq	875
Beirut Khalde	15	Quaraoum W Dam	855
Chekka	15	Souq-el-Gharb	700
Chiffa	1000	Sour	5
Falougha	1250	Terbol	890
Faraya-village	1320	Tibnine	680
Halba	170	Zahle	990
Hermel	750	Zgharta	110

To be noted that in the new Lebanese Meteorological Stations network, the Daily total horizontal global solar radiation (GSR) is available for 9 meteorological stations since April 1999. Hourly GSR measurements are available for 2 stations (Beirut Golf and Zahlé) since October 1999. The direct and diffuse components of solar radiation, which are important for building and solar systems design, are not measured.

Furthermore, four stations from the Lebanese Meteorological Stations were selected for the creation of typical year weather files for hourly energy simulation purposes. The files are those of Bayssour (978 m), Qartaba (1140 m), Cedars (1925 m) and Zahle (990 m). The set-up of these files is detailed in chapter 4. The main limitation of this was that the history period of these records was too short to develop weather files that are representative of long term climatic trends. However, these files present a good starting point particularly since the average values of the *Atlas Climatique du Liban* were used to confirm that the files used were reasonable.

In the future, and as more recorded years become available, the data from the new LMS stations network will form the basis for the set-up and update of a greater number of typical year weather files.

2.2.2 Private Stations

Data for the Station operated by the American University of Beirut was acquired. The data of this station (Beirut-AUB altitude 15m) was particularly interesting due to the fact that the data had a reasonable time span (1991-1999), that it was available in the form of hourly electronic files, and that it included the direct and diffuse components of the solar radiation in addition to wind speed, temperature and humidity. Although this set of data was the most comprehensive found, it still suffered from some missing data or anomalies which had to be reviewed and corrected. This station was used to create a typical year weather file for computer simulation purposes.

To be noted that hourly data from other private stations, such as the ENERCO station at Taanayel (start year 1998) are worth investigating in the future.

2.3 Selection of Climatic Parameters for the Development of Climatic Zoning

The proposed Thermal Standard for Buildings in Lebanon will address the conductive heat gains and losses through the building envelope, as well as the solar transmission gains.

Accordingly, the following climatic indicators need to be considered:

- For Conductive heat losses, the key relevant climatic parameter to be considered is the heating degree day;
- For Conductive heat gains, the key relevant climatic parameter to be considered is the cooling degree day; and
- For Solar Transmission gains, the key relevant climatic parameters to be considered are the incident solar radiation and the cooling degree days.

Furthermore, it is to be noted that when issues of building infiltration and ventilation are addressed, the humidity and wind variables become key relevant indicators as well.

In this respect, and since the proposed Thermal Standard for buildings in Lebanon will not address infiltration and ventilation at this stage, the aspects of humidity and wind will not be assessed quantitatively in this analyses. Nonetheless, it is to be noted that these and other climatic factors are already imbedded qualitatively in the analysis since the present climatic zoning study builds upon the findings of the *Atlas Climatic du Liban* which, based on a multi-climatic variable analyses, has already identified the major trends in Lebanon represented by a coastal and mountain regions exposed to the influence of the sea and an inland continental region sheltered from the influence of the sea.

As such, and given the scope of the proposed Thermal Standard, the two climatic parameters which need to be analyzed quantitatively are dry-bulb temperature and solar radiation.

However, where as over 70 appropriately distributed weather stations can be used for the analysis of dry-bulb temperature, only few stations are available for solar radiation. The latter were judged to be too limited to allow for an appropriate analysis. As such, the selected quantitative climatic zoning indicator will be based on temperature only. This will be expressed as degree-days in order to provide a figure that is proportional to the thermal energy requirements of buildings.

Furthermore, and since the *Atlas Climatique du Liban* has revealed that the Inland region with its continental climate and high daily temperature amplitude is quite different from the littoral region where the climate is Mediterranean with much lower temperature amplitudes; it became evident that the calculations of degree-days based on monthly temperature averages will not be able to capture adequately the difference in daily amplitude between these regions and the resulting impact on building thermal energy requirements. It was thus decided to conduct a limited further hourly degree-day analysis for the Inland region.

3

DEVELOPMENT OF CLIMATIC ZONES FOR BUILDINGS

Determining the optimum number of climatic zones for a given country is often a trade-off that has to take into consideration the availability of raw meteorological data, population density and a certain threshold of weather difference between the selected regions in order to have a significant change in the heating and cooling patterns among regions. Furthermore, the number of regions should be reasonable to avoid making the application of the Thermal Standard cumbersome. Sometimes, it is better to fit climatic zones within the nearest administrative regions to allow ease of identification and application.

After an initial classification of the Lebanese regions into two major trends (the littoral and the inland), the following steps were undertaken in order to define the climatic zones for the Thermal Standard for Buildings in Lebanon:

- Calculation of the heating and cooling degree-days for each station;
- Analyses of the relationship between the degree-days and altitude;
- Analyses of micro-climatic trends;
- Identification of the potential number of climatic zones;
- Selection of the number of climatic zones;
- Establishment of an altitude threshold for the climatic zones;
- Delineating of the contours of the climatic zones.

The following sections present an elaboration of these steps.

3.1 Calculation of the Degree-day Values per Weather Station

In this step, the heating degree-days (HDD 18) and the cooling degree-days (CDD 21) were calculated. The selection of the base temperature thresholds for calculation of degree-days was coordinated with local engineers. A more in depth analysis of various base temperature thresholds was outside the scope of this study, nonetheless, it is to be mentioned that recent research suggests that the value used as base temperature does not alter the comparative evaluation.

Table 3 presents the list of stations sorted by region and by increasing heating degree-day value. The cooling degree-day values are also presented in the table.

Table 3 also indicates the stations' altitude and location as defined in the *Atlas Climatique du Liban*, in order to allow a comparison of the degree-day values with altitude and region.

To be noted that the Heating Degree Days and the Cooling degree days presented in Table 3 are based on Monthly average Temperatures, and that this results in an under-representation of degree days particularly in the inland region where the daily temperature amplitude is high notably in summer.

Table 3 – Stations Sorted by Region and by Increasing Heating Degree-day Value

	Station Name	Atlas Region	Altitude (m)	HDD (18)	CDD (21)
LITTORAL AND WESTERN SIDE OF WESTERN MOUNTAIN RANGE	El-Qasmiyé	LS	30	300	665
	Jounieh*	LC	10	304	766
	Chekka*	LN	15	304	1048
	Sour*	LS	5	323	711
	Zouq-Mikayel	LC	70	345	839
	Beirut A.U.B.	LC	34	379	882
	Aamchit*	LC	135	386	790
	Beirut-Khalde*	LC	15	418	616
	Aabde	LN	15	420	579
	Saida	LC	5	467	459
	Aéroport (Beyrouth)	LC	15	472	511
	Jouaya*	LS	300	472	554
	Tripoli-el-Mina	LN	2	561	515
	Halba*	LN	170	627	577
	Qlaiaât-Akkar	LN	5	630	634
	Alma-Chaab	LS	380	632	343
	Kaftoun*	LC	215	636	606
	Miniara	LN	195	642	515
	Amioun	LN	300	696	362
	Tibnine*	LS	680	696	676
	Jamhour	LC	410	723	331
	Nabatiyé-Habbouch	LS	410	741	246
	Zgharta K.D.*	LN	110	743	346
	Douair	LS	280	745	257
	Ghazir	LC	415	793	333
	Qornet-Chehwan	LC	603	799	233
	Arbaniyé-Jisr	LC	510	956	340
	Bayssour*	LC	978	979	267
	Souq-el-Gharb*	LC	700	1001	235
	Aïn-Ebel	LS	765	1010	312
	Kouachra	LN	400	1013	313
	Ghosta	LC	650	1019	169
	Qoubayat	LN	540	1040	259
	Gharifé	LC	680	1073	98
	Beit-ed-Din- Loqch	MC	835	1173	129
	Bikfaya	MC	900	1339	65
	Jezzin	MC	945	1340	50
	Kfar-Nabrakh	MC	1020	1349	148
	Sir-ed-Denniyé	MN	915	1376	96
	Mayfouq*	MC	875	1438	3
	Qartaba	MC	1140	1514	105
	Bhamdoun-Btalloun	MC	1090	1539	37
	El-Qrayé	MC	1010	1622	74
	Falougha*	MC	1250	1670	25
	Faraya-village*	MC	1320	1749	12
	Dahr-el-Darajé	MC	1150	1835	59
	Laqlouq	MC	1700	2466	0
	Dahr-el-Baidar	MC	1510	2522	0
	Becharré-Usine*	MN	1400	2567	0
	Faraya-Mzar	MC	1840	3096	0
	Les Cèdres	MN	1925	3330	0
INLAND REGION	Hermel*	IO	750	1195	501
	Marjayoun	IH	760	1203	108
	El-Qaa	IO	650	1257	463
	Chiffa*	IO	1000	1442	397
	Baalbek	IO	1150	1502	353
	Kherbet-Qanafar	IL	940	1541	176
	Ksara	IL	920	1541	228
	Ammiq	IL	870	1552	105
	Fakehé	IO	1060	1581	228
	Zahle*	IL	990	1600	390
	Haouch-ed-Dahab	IO	1009	1647	353
	Kfar-Dan	IL	1080	1690	179
	Tell-Amara	IL	905	1691	74
	Terbol*	IL	890	1721	121
	Rayak	IL	920	1730	201
	Qaraoun w. dam*	IL	855	1748	130
	Taanayel	IL	880	1780	0
	Flawi	IO	1170	1792	204
	Arsal*	IO	1400	1794	114
	Haouch-es-Snaïd	IL	995	1851	93
	Rachaya	IH	1235	1881	59
	Yammouné	IO	1370	2279	81

* Data not from Atlas Climatique du Liban

3.2 Analyses of the Relationship between Degree-days and Altitude

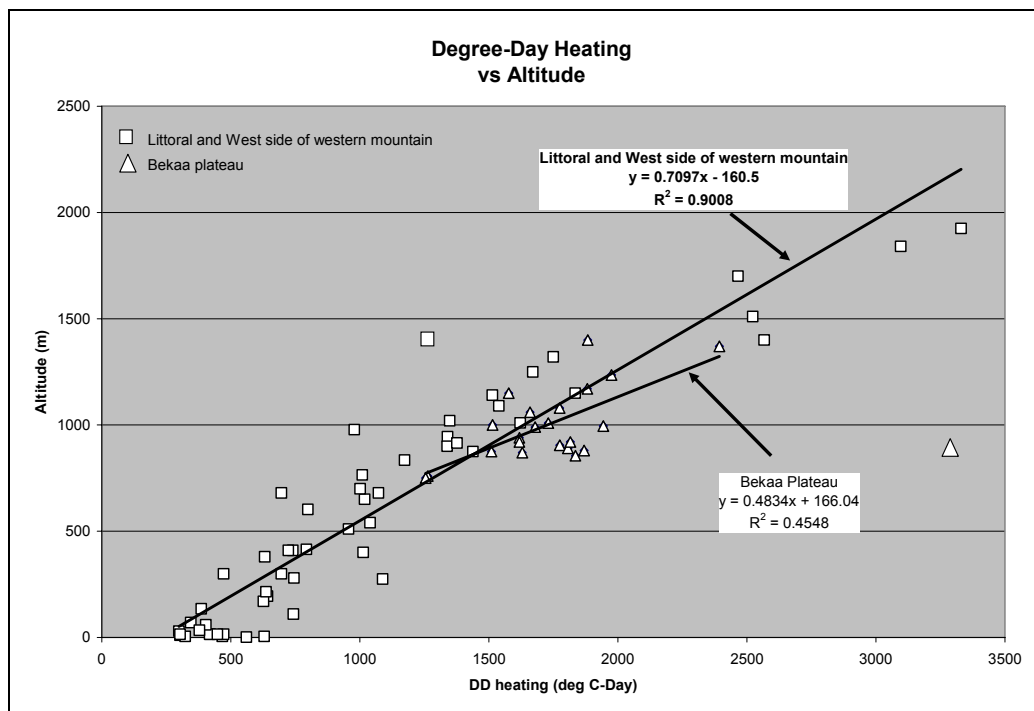
In order to analyze the relationship between altitude and degree-days, regression curves of the annual heating degree-days versus altitude were considered for three groups of stations:

- All country stations
- Stations on the littoral and west side of the western mountain range
- Stations in the Bekaa Plateau and east side of the western mountain range

Figure 6 presents the plotted regression curves for two groups of stations: the stations located on the littoral and western side of the Western Mountain Chain, and the stations located inland and east side of the Western Mountain chain.

The curves resulting for the group of stations from the littoral and western side of the Western Mountain Chain show a good relationship with altitude. The R^2 statistical indicator provides an indication of the soundness of the generated curve. An R^2 of 0.9 or better shows a good fit of the data and is an indication that there is a definite relationship between both variables considered (here the Degree-day and altitude). A lower R^2 indicates a poor fit and reveals that the relationship between the variables considered is weak or inexistent. The second curve was traced using the stations located inland and east side of the Western Mountain chain to see if there was a different trend of altitude versus degree-days for this part of the country. The resulting regression has an R^2 of 0.45 which is weak and which indicates a poor relationship between altitude and heating degree-day in this part of the country. This indicates that the altitude is not the driving parameters for the weather observed inland. For instance, this could imply that solar radiation and wind regimes have a larger impact on local climate in this part of the country than the altitude variation.

Figure 6- Degree-day vs Altitude Curve



3.3 Analyses of Microclimatic Trends

Each station whose degree-day value was outside the degree-day range of its altitude was identified and analyzed.

When the identified micro-climate was also confirmed by observations in the “*Atlas Climatique du Liban*” no further analysis was needed. When the identified micro-climate was not observed in the “*Atlas Climatique du Liban*” or when the station data was not from the Atlas, an additional step was taken. This consisted of calculating the reduced temperature of the station at sea level to assess its micro-climatic trends. This analysis is similar to the one made in the Atlas map 49-50 (tome 1-B).

The *Atlas Climatique du Liban* had classified a station as a hot microclimate when the reduced temperature at sea level was 0.5 °C above the annual country average of 20.5 °C. Thus the threshold in the Atlas for a hot microclimate was 21 °C for the reduced temperature. A cold microclimate was defined as a station where the reduced temperature was 0.5 °C below the annual country average of 20.5 °C. Thus the threshold in the Atlas for a cold microclimate was 20 °C for the reduced temperature.

Table 4 presents a list of the identified microclimates. Of 18 stations where the altitude does not correspond to the climate zone assigned based on the degree-day value, there are sixteen stations that can be confirmed as microclimate either because the authors of the *Atlas Climatique du Liban* have made similar observation or by a recalculation of the reduced temperature at sea level for the station. El-Qaa and Faraya are the only ones that cannot be clearly identified as a hot or cold microclimate. El-Qaa is just a climate with a yearly average comparable to stations at the same altitude but where high annual amplitude of temperature causes two extreme heating and cooling seasons that produce a high degree-day in heating and cooling. This station should be incorporated with zone 3 as it is closer to the climate of other location in the Bekaa plateau. Faraya village is near two stations that are considered hot microclimates in the Atlas and is probably a hot microclimate even if it did not pass the threshold considered in the Atlas as the limit to be included with microclimates.

A clear pattern emerges from the analysis of Table 4 and maps 49-50 from the *Atlas Climatique du Liban* (Tome IB). The region of the Internal Oronde can be considered generally as a hotter climate than what the altitude would suggest compared to the national trend. From the table and the maps, we can note that Fakehe, Haouch Ed Dahab, Chlifa and Baalbek have temperatures reduced at sea level higher than the national average. These stations are all located in the region identified as “Internal Oronde” in the Atlas Climatique. Other groups of stations exhibiting a reduced temperature at sea level lower than the national average are located in the “internal Hasbani” region. These include the stations of Tell Aamara, Taanayel-Labo, Qaraoun-W.Dam, Terbol, and Rayaq. We can see from these patterns that there is a dual trend in the internal region, one in the upper part that is warmer and one in the central part of Bekaa plateau that is colder. These two diverging trends are responsible for the weak regression trend observed in Figure 6.

The stations identified and confirmed as microclimates should then be incorporated in the zone where their degree-days made them fall naturally without consideration to their altitude.

Table 4 – List of Identified Microclimates

Station	Altitude (m)	HDD (18)	Assessment
Bayssour	978	979	Hot micro-climate with degree-day heating similar to a zone slightly under 700 meter. Probably due to the configuration of the valley where this city is located.
Gharife	680	1073	Very close to the boundary of 700 meter
Kouachra	400	1013	Cold microclimate. Identified in the Atlas as the Homs pass effect.
Qoubayat	540	1040	Cold microclimate. Identified in the Atlas as the Homs pass effect.
Kfar Nabrakh	1020	1349	Close to the 1000 meter boundary.
El-Qaa	650	1510	Not identified as a microclimate in the Atlas and the reduced temperature calculation does not explain such a high degree-day heating for the altitude. However, the annual amplitude for the station is quite high which result in high degree-day cooling and heating even if the average seems close to the national level. So it cannot be qualified as a cold or a hot climate but as a highly fluctuating climate resulting in a very cold winter and very hot summer.
Qartaba	1140	1514	Hot microclimate. Was also identified in the Atlas.
Bhamdoun	1090	1539	Hot microclimate. Was also identified in the Atlas.
Baalbek	1150	1577	Hot microclimate. Was also identified in the Atlas.
Tell-Amara	905	1775	Cold climate identified in the Atlas. An effect of the cold air of the mountain accumulating in the Bekaa plateau at night.
Zahle	990	1679	Cold micro-climate (located in a zone close to several others cold micro-climates identified in the Atlas).
Faraya-Town	1320	1749	No specific reason found for this hot micro climate.
Terbol	890	1807	This station had another source than the Atlas. The reduced temperature of 19.9 °C (below 20.5°C) clearly indicates a cold microclimate.
Taanayel	880	1869	Cold climate identified in the Atlas. An effect of the cold air of the mountain accumulating in the Bekaa plateau at night.
Qaraoun w. dam.	855	1836	This station had another source than the Atlas. The reduced temperature of 19.4 °C (below 20.5°C) clearly indicates a cold microclimate.
Rayaq	920	1816	Not identified in the Atlas as a microclimate. Its reduced temperature average is 20.1°C (close to the 20.5°C threshold). So it can be considered a cool microclimate.
Arsal	1400	1883	This station had another source of data than the Atlas. The reduced temperature of 22.7°C (well over the 20.5°C threshold) clearly indicate a hot microclimate.
Haouch-es-Snaïd	995	1943	Cold climate identified in the Atlas. An effect of the cold air of the mountain accumulating in the Bekaa plateau at night.
Laqlouq	1700	2466	Hot climate identified in the atlas.

3.4 Identification of the Potential Number of Climatic Zones

Section 3.1 revealed that the heating degree-day range for Lebanon is between 300 and 3330 HDD, and that the cooling degree-day range is between 0 and 1048 CDD. Ideally, the climatic regions should be based on a fixed cost increment bracket taking into consideration both the heating and cooling requirements to allow a regular progression of the energy requirement of buildings amongst the zones defined.

There is no specific formula to decide on the appropriate number of zones for a country. There is however a practical limit to the number of zones that can be defined since the climatic zones will also need to be fitted with the administrative zones.

In order to demonstrate the implication of the potential number of zones, a quick and hypothetical estimate of the potential heating costs was considered using three scenarios: three climatic zones, four climatic zones and five climatic zones. For each scenario, the heating incremental cost was evaluated for a residential home of medium size that needs heating and cooling all year round to reach comfort conditions. The evaluation was done considering the following data:

- A home that would have a 7 kW heat loss at 15 °C differential temperature
- Electricity heating is assumed in this calculation
- A price of energy of 0.146 US\$ per kWh
- A factor of 0.7 representing the effect of occupants on the heating or cooling requirement of buildings. This factor takes into consideration the fact that in residential buildings not all the rooms are usually heated or cooled while in other types of building the whole structure is maintained to comfort conditions

A quick estimate of the heating cost can thus be estimated using the following formula:

Equation 3 Calculation of Heating Cost Using Simplified Degree-day

$$E = \frac{L}{D} \times DD_{Heating} \times H \times D \times F \times P$$

E	= Cost of electricity for heating
L	= Heating load from building thermal envelope at 15 °C differential between indoor and outdoor temperature
D	= Differential of temperature indoor and outdoor at design conditions (here 15 °C)
DD _{Heating}	= Degree-day heating range for one climate zone
H	= Hours per day (here 24h/day)
F	= Occupancy effect factor (here 0.7)
P	= Price of electricity (here US\$ 0.146/kWh)

Table 5 presents the resulting number of degree-day and incremental cost for heating.

Table 5 - Variation of Incremental Cost with the Number of Zones

Number of Climatic Zones	Heating Degree-day Range by Zone (HDD18)	Estimated Incremental Cost by Zone (\$US)
3 zones	939	1075
4 zones	704	806
5 zones	564	646

3.5 Enhancement of the Degree-day Analysis using Hourly Data

The Degree-Day analysis presented in section 3.1 was based on Monthly average Temperatures. However, given the difference in daily temperature amplitude between the inland region and the rest of the country, it became evident that it would not be accurate to compare on equal grounds a calculation of degree-day on the western side of the western mountain chain and the inland region.

As such, selected degree-day calculations based on hourly data was undertaken. The hourly data was derived from the hourly weather files created for hourly energy simulation. The set up of these files is detailed in Chapter 4.

These files include:

- Two stations to represent the lower and upper parts of the coastal region (Beirut and Baysour)
- One station to represent the mid-altitudes of the western side of Mount Lebanon (Qartaba)
- One station to represent the higher altitudes of Mount Lebanon (Cedars)
- One station to represent the inland region (Zahle)

Hourly energy simulation software incorporates temperature, humidity, solar radiation and wind data. A comparison of the Qartaba and Zahle degree-days was conducted to determine what could be the influence of the larger daily amplitude of the Inland region.

The HDD/CDD outputs of the hourly data revealed that the simple analysis made for the average monthly temperature does not exactly reflect the energy requirement in the Inland region. Using an hourly source for degree-day calculations instead of an average monthly resulted in a higher number of degree-days particularly for cooling. The table below summarizes the difference in degree-day of the monthly average versus the daily average. We can see that the difference in terms of degree-days is approximately 10-15% in heating while in cooling, the difference is much higher.

Table 6 - Comparison of Monthly Average Degree-day vs Hourly Degree-day

Item	Qartaba		Zahle	
	HDD (18)	CDD (21)	HDD (18)	CDD (21)
Degree-day – using Average monthly temp	1514	105	1596	390
Degree-day – using Hourly temperature	1650	143	1817	608
Variation	9%	36%	14%	56%

3.6 Selection of Climatic Zones and Establishment of Altitude Threshold

In order to decide on the appropriate number of climatic zones, all the previously identified factors were carefully considered, and as a result, four zones were identified as follows:

- On the Western side of the Western Mountain range, which features an HDD(18) range between 300 and 3300 and a CDD(21) range between 0 and 1048, three zones are proposed. These are based on a heating degree-day thresholds of less than 1200 HDD (approximately an altitude < 700 m), between 1200 and 2000 HDD (approximately an altitude < 1400 m) and above 2000 HDD.
- On the Eastern side of the Western Mountain range, which features an HDD(18) range between 1200 and 2300, and a CDD(21) range between 0 and 600, a separate zone is proposed to incorporate most of the inland plateau locations with heating degree-days below 1800 and cooling degree-days above 120. This includes most of the locations between an altitude of 750 m and 1150 m. Other inland areas that are outside this altitude range were incorporated with the high mountain zone.

As altitude is obviously one of the most important parameters that has an impact on dry-bulb temperature of a region and on the resulting thermal envelope energy requirements of a building, it was used as an indicator to draw a first outline of the climatic region. The sorted degree-day list, presented in section 3.1, was analyzed comparing the degree-day values with the station altitude to determine the threshold in altitude. This analysis allowed the tracing of a first outline of the climatic regions based on altitude isolines.

The resulting altitude threshold and degree-day limits for each zone are presented in Table 7.

Table 7 – Approximate Altitude and Degree-day Threshold for Four Zones

Climatic Zone	Approximate Altitude range	Approximate HDD(18) and CDD(21) Thresholds
Zone 1: Coastal	0-700 m	300 < HDD < 1200 120 < CDD < 1050
Zone 2: Western Mid-Mountain	700-1400 m	1200 < HDD < 2000 0 < CDD < 120
Zone 3: Inland Plateau	700-1150 m	1200 < HDD < 1800 120 < CDD < 600
Zone 4: High Mountain	Littoral side +1400m	HDD > 2000 CDD = 0
	Inland side +1150 m	HDD > 1800 0 < CDD < 120

These altitude thresholds do not apply to all stations in the list. Several locations with a microclimate may fall outside of these limits as they are either too cold or too hot to have a comparable degree-day heating or cooling to other stations at the same altitude. However, not all microclimates needed adjustment as some stayed within the boundaries of the same climatic zone. Table 8 presents the potential placement of the identified microclimates.

Table 8 – Potential Placement of Identified Microclimates

Station	Altitude (m)	Heating Degree Days (18)	Cooling Degree Days (21)	Potential placement
Bayssour	978	979	267	Zone 1
Gharife	680	1073	98	Zone 2
Kouachra	400	1013	313	Zone 1
Qoubayat	540	1040	259	Zone 1
Kfar Nabrakh	1020	1349	148	Zone 2
El-Qaa	650	1257	463	Zone 3
Qartaba	1140	1514	105	Zone 2
Bhamdoun	1090	1539	37	Zone 2
Baalbek	1150	1502	352	Zone 3
Tell-Amara	905	1691	74	Zone 3
Zahle	990	1600	390	Zone 3
Faraya-village	1320	1749	12	Zone 2
Terbol	890	1721	121	Zone 3
Taanayel	880	1780	0	Zone 3
Qaraoun w. dam.	855	1748	130	Zone 3
Rayaq	920	1730	201	Zone 3
Arsal	1400	1794	114	Zone 3
Haouch-es-Snaïd	995	1851	93	Zone 4
Laqlouq	1700	2466	0	Zone 4

3.7 Delineation of the Contours of the Climatic Zones

The Climatic Zone map was created using GIS based software incorporating the following files: the topographic contour lines of Lebanon, the administrative cazas and the real-estate districts of Lebanon.

In order to delineate the contours of the climatic zones, a series of steps were undertaken. These included the following:

- First, using the altitude threshold identified in section 3.6, a first drawing layer, based on altitude, was created using the altitude iso-curves and the stations locations;
- Second, using the micro-climatic trends identified in section 3.3, and evaluating the micro-climates that fall outside their climatic zone range, a second drawing layer was created based on altitudes and microclimates;
- Third, adding the two layers of administrative zones (real-estate districts and cazas), a third drawing layer was created with the climatic zone contours aligned with the administrative zones.

To be noted that when an administrative real-estate district spanned over more than one climatic zone, a decision was taken to include it in the zone containing the higher proportion of the surface area of the real-estate district.

The proposed contour lines of the climatic zones constitute a foundation for future studies, and may need fine-tuning and updating in the future as more data and analysis becomes available.

Figure 7 presents a snapshot of the process of delineation of the contours of the climatic zones.

Figure 7- Process of Delineation of Climatic Zones

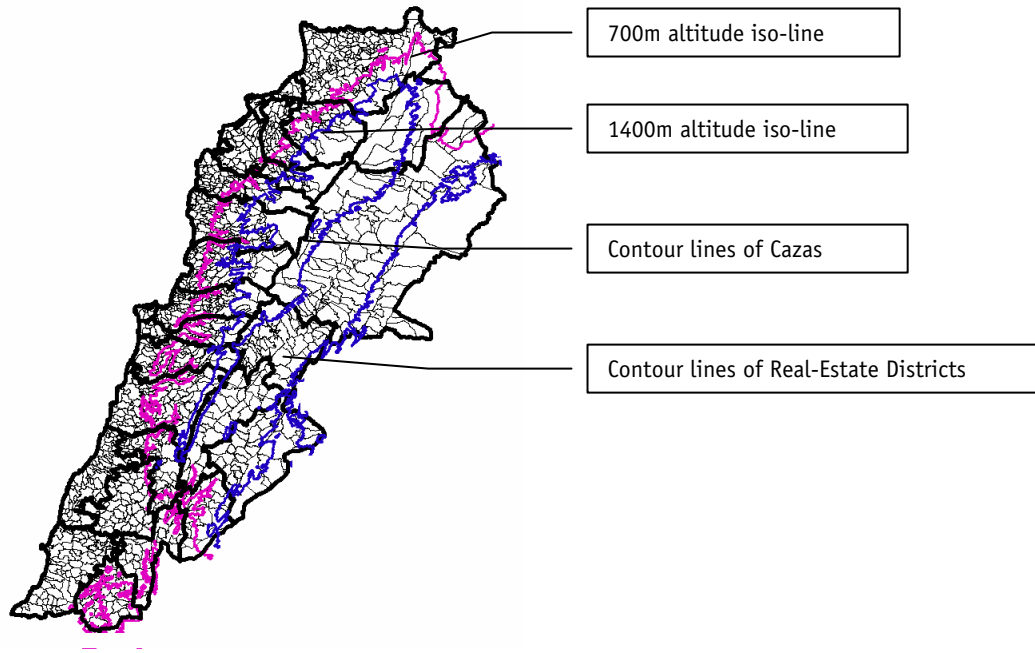
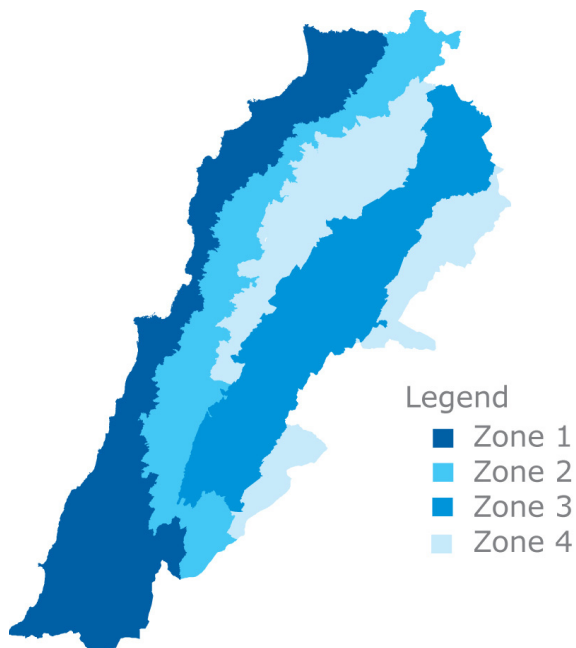


Figure 8 presents the proposed contours of the four climatic zones.

- Zone 1: Coastal
- Zone 2: Western Mid-Mountain
- Zone 3: Inland Plateau
- Zone 4: High Mountain

Figure 8- Proposed Climatic Zones



4

SET UP OF TYPICAL YEAR WEATHER FILES

This chapter describes the preparation of typical meteorological years (TMY) that are used by hourly simulation software to determine the energy usage of buildings in each climatic zone of Lebanon. A typical meteorological year is usually defined as an assembly of representative months coming from the same years or from different years. Weighting factors are often used to determine which month in a history period is the most appropriate for inclusion in the TMY.

4.1 Methodology

In Lebanon, the establishment of reliable TMY faced several constraints. These constraints relate mainly to: insufficient number of years or meteorological records, absence of hourly data for some parameters that should be filled using daily, monthly data or nearby stations. For some stations, there was a fair amount of information and the weather year has been built on the base of information available. However, for other stations a more pragmatic approach of “making the best usage of whatever is available” was required.

Five weather files were created as follows:

- | | |
|--------------------------------|-------------------|
| • Zone 1: Coastal | Station: Beirut |
| • Zone 1: Coastal | Station: Bayssour |
| • Zone 2: Western Mid Mountain | Station: Qartaba |
| • Zone 3: Inland Plateau | Station: Zahle |
| • Zone 4: High Mountain | Station: Cedars |

Two files were created for the zone 1 (to represent the upper limit and the lower limit) since this zone has the highest population density.

In order to establish the Typical Meteorological Year Weather files for the proposed Climatic Zones, two different approaches were used. The first approach applies to two stations (Beirut and Zahle) where hourly information was available for some parameters and for a range of years. The second approach applies to three stations (Bayssour, Qartaba and Cedars) where just daily information was available.

4.1.1 Assembling Data

A typical meteorological year was constituted by assembling typical months, which may have been taken from different years. In order to find which month was the most typical, the average monthly temperature for a considered year, was compared with the average monthly temperature of the “*Atlas Climatique du Liban*” for the same station.

All climatic data for the month in the selected year were checked for the main weather parameters including temperature, humidity, direct and diffuse solar radiation when available.

If the verification showed large anomaly, it was replaced by another month from the history. Smaller anomalies were identified and when possible, replaced by average of the previous or following hour. Other smaller anomalies were not corrected as there was often a lack of appropriate data to make the replacement. When the verification of the climatic data for a month was finished, the procedure was repeated for the next month until a complete year was available.

4.1.2 Selected Data Sources

Table 9 presents the source of temperature, humidity and wind data used for the creation of the typical year weather files.

For the solar data, the close examination of the available data for two stations revealed inconsistencies that were not acceptable for the creation of the file. In all cases, the solar data have been generated from an algorithm in DOE that builds the direct radiation and horizontal radiation data from specific information about the station including the location (latitude, longitude and altitude), the clearness number of the sky, the cloud cover and the type of cloud encountered. The values were inputted into the software to generate solar records that were in general accordance with the global horizontal solar radiation of the two stations where records were available. This allowed building weather files where the data between direct solar radiation and horizontal solar radiation are consistent.

Table 9 - Climatic Data Files Used for the Establishment of the Typical Year

Climatic Zone	Station	Selected Months for the Typical Year
1	Beirut	<ul style="list-style-type: none"> Based on hourly data for dry-bulb temperature, relative humidity, wind direction and speed from the following months: Jan 98, Feb 94, Mar 94, Apr 98, May 96, Jun 94, Jul 94, Aug 94, Sept 92, Oct 92, Nov 92, Dec 94
1	Bayssour	<ul style="list-style-type: none"> Daily data available only and some data missing. Temperature and relative humidity: Year 2001 – Except for the month of October that was missing. Estimates were done based on the months of September and November of the same year. Hourly temperature and relative humidity were estimated with a sinusoid function between the daily maximum and minimum. Wind: January to November 2002 and December 2001. The direction and speed were kept constant for all day.
2	Qartaba	<ul style="list-style-type: none"> Temperature and humidity: Year 2001 – Except for the month of October that was missing. Estimates were done based on the months of September and November of the same year. Hourly temperature and relative humidity were estimated with a sinusoid function between the daily maximum and minimum. Wind: No data. Was estimated by comparing 2 stations where wind information was available. Wind was kept constant for each day in speed and direction.
3	Zahle	<ul style="list-style-type: none"> Temperature: Hourly data was available, the year was created by assembling the following months: Jan 02, Feb 02, Mar 00, Apr 01, May 00, Jun 01, Jul 01, Aug 01, Sept 00, Oct 00, Nov 99, Dec 01. Relative humidity: Same months as temperature. Only the maximum and minimum relative humidity was available for each hour. The average hourly relative humidity was taken as the average of the hourly maximum and hourly minimum. Wind: Only daily data available. The speed and direction had been put constant for each day.
4	Cedars	<ul style="list-style-type: none"> Temperature: Year 1998 – Except for the month of September that was missing. Estimates were done based on the months of August and October of the same year. Hourly temperature was estimated with a sinusoid function between the daily maximum and minimum. Relative humidity: Data estimated using a comparison with other stations data. Wind: Was estimated using another station.

4.1.3 Converting Daily Temperature Maximum and Minimum into Hourly Records

For stations where there was only a daily record of maximum and minimum temperatures, the hourly data were estimated using Equation 4. This equation produces a sinusoidal shape that is centered on the average daily temperature and where the amplitude is equal to half the differential between the maximum and minimum temperature. The sinusoidal shape produced reaches the maximum temperature at 1 p.m. while the minimum is reached at 1 a.m.

Equation 4 Conversion of Daily min. and max. Temperature into Hourly Temperature

$$T_h = (T_{\max} + T_{\min})/2 + [(T_{\max} - T_{\min})/2 \times \sin((15 \times h) - 105)]$$

T_h = Temperature for hour "h"

T_{\max} = Daily maximum temperature from meteorological records

T_{\min} = Daily minimum temperature from meteorological records

H = Hours for which we want to evaluate the temperature

4.1.4 Converting Daily Humidity Maximum and Minimum into Hourly Records

For stations where there was only a daily record of maximum and minimum relative humidity, the hourly data were estimated using equation 5. This equation produces a sinusoidal shape that is centered on the average daily relative humidity and where the amplitude is equal to half the differential between the maximum and minimum relative humidity. The sinusoidal shape produced reaches the relative maximum at 1 a.m. (the relative humidity is generally higher at night) while the minimum is reached at 1 p.m.

Equation 5 Conversion of Daily min. and max. Humidity into Hourly Humidity

$$RH_h = (RH_{\max} + RH_{\min})/2 - [(RH_{\max} - RH_{\min})/2 \times \sin((15 \times h) - 105)]$$

RH_h = Relative humidity at hour "h"

RH_{\max} = Daily maximum relative humidity

RH_{\min} = Daily minimum relative humidity

h = hours for which we want to establish the relative humidity

4.2 Creating Weather Files for DOE 2.1E Calculation Engine¹

After the creation of a complete hourly data set for a Typical Meteorological Year on an Excel spreadsheet, these climatic data were converted into weather files compatible with the DOE 2.1E software. This conversion is a two step process. First, a formatting was performed on a separate Excel spreadsheet using a format known as "fmt". This format is described in the document "DOE-2 Weather Processor" by Fred Buhl from Lawrence Berkeley National Laboratory (LBL) and released by the Simulation Research Group of LBL in April 1999. Then the "fmt" file format produced in an Excel spreadsheet had been saved as a MS-DOS text file. The resulting text file (plain ASCII text that can be read by the window notebook utility) had then been converted into a binary format compatible with DOE using the "Weather File Converter" function provided in the "tool" menu of the VISUAL DOE3 software.

¹ These files were used in the Visual DOE 3 implementation of the DOE 2.1E calculation engine. There is in the market several private software development firms that offer their own user interface to the same DOE 2.1E calculation engine. Visual DOE 3 is only one of several products available on the market; as such the study refers to the calculation engine identification instead of the name of the commercial product interface.

All parameters in the following tables are extracted from the statistical weather report of DOE 2.1E. They have been rearranged for easier reading and comparison of various data.

Table 10- Zone 1 (City 1) Beirut – Temperature, Relative Humidity, Wind and Solar Radiation

Temperature and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Maximum Temperature (C)	19.4	20.6	21.1	29.4	27.2	30.0	31.1	32.8	31.7	28.3	28.9	20.0	32.8
Average Daily Max Temperature (C)	16.4	17.4	18.3	22.7	24.0	28.3	29.9	30.8	28.8	26.3	21.9	17.4	23.6
Average Temperature Day (C)	15.3	16.5	17.2	21.2	23.0	27.1	28.9	29.7	27.8	25.6	20.8	16.4	23.1
Average Dry Bulb temperature (C)	14.2	15.4	16.5	20.1	22.4	26.4	28.3	29.2	26.8	24.6	19.8	15.6	21.6
Average Temperature Night (C)	13.5	14.8	15.9	19.0	21.9	25.6	27.6	28.7	25.9	23.8	19.2	15.1	20.4
Average Daily Min Temperature (C)	11.9	13.3	14.8	17.5	20.7	24.3	26.5	27.4	24.8	22.7	17.8	13.8	19.7
Minimum Temperature (C)	4.4	11.7	12.2	12.8	17.2	22.8	25.6	26.1	20.6	20.6	10.6	10.6	4.4
Degree-Day													
Heating degree-days base (18,3 C)	130.3	82.5	55.8	10.8	0	0	0	0	0	0	33.1	84.4	396.9
Heating degree-days base (15,6 C)	45.6	16.4	7.5	0	0	0	0	0	0	0	9.4	18.9	97.8
Heating degree-days base (12,8 C)	8.9	0	0	0	0	0	0	0	0	0	0.8	0.3	10
Heating degree-days base (10,0 C)	2.5	0	0	0	0	0	0	0	0	0	0	0	2.5
Heating degree-hours /24 base (18,3 C)	129.7	81.8	61.1	15.8	0.2	0	0	0	0	0	35	87.2	410.9
Heating degree-hours /24 base (15,6 C)	52.9	22.1	13.1	0.9	0	0	0	0	0	0	11.9	25.2	125.9
Heating degree-hours /24 base (12,8 C)	11.3	0.9	0.3	0	0	0	0	0	0	0	1.9	1.1	15.4
Heating degree-hours /24 base (10,0 C)	3.9	0	0	0	0	0	0	0	0	0	0	0	3.9
Cooling degree-day base (26,7 C)	0	0	0	0	0	6.1	48.1	75.6	20	0	0.6	0	150.3
Cooling degree-day base (23,9 C)	0	0	0	6.1	3.1	73.6	134.2	161.7	88.1	25	11.7	0	503.3
Cooling degree-day base (21,1 C)	0	0	0	24.2	45.6	156.9	220.3	247.8	171.4	105	33.1	0	1004.2
Cooling degree-day base (18,3 C)	0	0	2.2	63.9	124.4	240.3	306.4	333.9	254.7	191.1	78.9	0	1595.8
Cooling degree-hours /24 base (26,7 C)	0	0	0	1.8	0.1	13.8	50.7	78.9	26.1	1.7	2	0	174.9
Cooling degree-hours /24 base (23,9 C)	0	0	0	10.8	9.3	75.4	135.7	164.9	88.4	30.9	12.5	0	527.9
Cooling degree-hours /24 base (21,1 C)	0	0	0	30	50.8	158.2	221.8	251	170.1	106.8	35.3	0	1024.1
Cooling degree-hours /24 base (18,3 C)	0.2	1.4	4.2	67.3	128.4	241.6	307.9	337.1	253.4	192.8	79.2	1	1614.5
Humidity and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average relative humidity at 4 h (%)	62.2	68.8	69.7	73.1	73.3	76.1	73.9	76.6	68.4	65.3	64.2	65.2	69.7
Average relative humidity at 10 h (%)	56.0	61.6	64.0	64.6	66.9	70.9	72.1	70.4	66.5	62.8	65.1	60.1	65.1
Average relative humidity at 16 h (%)	54.3	59.8	62.0	64.8	66.3	66.2	68.9	69.7	64.9	64.4	64.9	60.3	63.9
Average relative humidity at 22 h (%)	60.1	65.0	66.1	70.6	72.5	71.3	70.6	74.3	67.9	67.1	65.2	62.4	67.8
Wet Bulb Temperature													
Average Wet Bulb temperature (C)	9.9	11.6	12.7	16.1	18.6	22.4	24.1	25.1	22.1	19.8	15.6	11.6	17.5
Wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average wind speed (kmh)	13.7	15.3	13.0	12.2	15.6	15.9	17.9	15.0	4.2	3.2	21.4	14.5	13.5
Average wind speed day (kmh)	15.1	17.2	15.5	15.5	18.7	19.8	21.6	19.5	5.3	4.3	23.7	15.5	16.1
Average wind speed night (kmh)	12.9	14.2	11.1	9.3	12.2	11.3	13.8	10.3	3.4	2.4	20.1	14.0	11.3
Solar radiation and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
(Wh/m2)													
Direct normal radiation													
Maximum Daily Direct Normal Solar	3169.7	3528.9	4700.1	4809.8	4835.4	6767.9	6685.9	7385.0	7082.9	5124.2	4733.5	3590.0	7385.0
Average Daily Direct Normal Solar	2981.7	3364.5	4587.2	4761.0	4829.7	6740.1	6586.6	7240.3	6960.9	4959.0	4514.7	3529.8	5094.9
Minimum Daily Direct Normal Solar	2819.0	3184.5	4424.8	4704.8	4812.4	6690.9	6470.5	7094.3	6841.7	4750.2	4318.5	3506.5	2819.0
Maximum Hourly Direct Normal Solar	383.8	389.2	486	473	452.9	612.4	603.6	708	735.1	562.3	562.3	464.2	735.1
Average Max Hourly Direct Normal Solar	377.5	387.6	481.2	462.9	444.7	607.1	602	697.6	721.9	558.5	560.1	462.6	530.7
Global (horizontal) radiation													
Maximum Daily Total Horizontal Solar	2686.8	3897.5	5586.9	6453.8	7023.3	7209.4	7178.8	6693.8	5848.6	4582.1	3109.4	2385.7	7209.4
Average Daily Total Horizontal Solar	2387.6	3195.8	4898.1	6012.0	6837.0	7192.0	7010.4	6343.7	5374.6	3873.5	2757.2	2273.4	4854.6
Minimum Daily Total Horizontal Solar	2173.8	2712.7	4068.1	5615.3	6472.1	7145.7	6691.3	5875.7	4673.9	3137.8	2462.6	2232.4	2173.8
Maximum Hourly Total Horizontal Solar	425.4	708.6	831.9	883.3	900.3	910.1	906.7	888.4	843.3	760.6	481.9	397.7	910.1
Average Max Hourly Total Horizontal Solar	392.0	524.4	784.0	862.5	894.4	909.2	898.8	869.1	807.9	651.5	443.1	384.1	702.6
Radiation on a vertical plane													
Avg. Daily Total Vertical Solar Azimut N	735.7	996.5	1480.0	1961.2	2562.6	2398.0	2227.4	1408.4	1000.6	925.6	585.9	598.2	1409.3
Avg. Daily Total Vertical Solar Azimut E	1620.0	2137.2	3166.2	3819.9	4325.1	4184.5	4104.4	3577.7	3123.0	2452.9	1776.7	1513.1	2987.7
Avg. Daily Total Vertical Solar Azimut S	3526.6	3798.2	4346.3	3871.3	3461.4	2623.1	2732.9	2995.6	3908.2	4193.6	4061.5	3736.0	3603.0
Avg. Daily Total Vertical Solar Azimut W	1612.1	2148.2	3164.3	3831.0	4324.8	4155.2	4074.4	3626.3	3114.8	2443.4	1777.4	1509.3	2986.1
Max. Daily Total Vertical Solar Azimut N	822.1	1280.7	1751.8	2236.8	2794.1	2435.8	2411.2	1650.6	1142.5	1173.4	658.8	626.6	2794.1
Max. Daily Total Vertical Solar Azimut E	1816.1	2578.7	3603.3	4051.1	4421.9	4191.4	4185.4	3735.7	3352.6	2856.2	1991.2	1575.2	4421.9
Max. Daily Total Vertical Solar Azimut S	3644.0	4119.5	4496.1	4203.4	3654.0	2703.9	2863.1	3387.6	4274.4	4424.2	4072.8	3766.0	4496.1
Max. Daily Total Vertical Solar Azimut W	1818.0	2599.8	3574.9	4138.4	4404.3	4160.2	4144.4	3779.2	3339.6	2865.7	1980.4	1579.3	4404.3
Max. Hourly Total Vertical Solar Azimut N	127.1	260.5	273.1	293.6	302.4	236.2	235.3	190.2	176.9	220.8	96.8	100.6	302.4
Max. Hourly Total Vertical Solar Azimut E	355.7	429.5	630.4	637.0	697.6	692.2	695.0	600.8	589.4	489.4	439.0	358.2	697.6
Max. Hourly Total Vertical Solar Azimut S	544.9	748.0	753.4	673.6	568.9	420.7	461.7	552.8	683.1	754.0	603.9	575.2	754.0
Max. Hourly Total Vertical Solar Azimut W	364.2	425.1	591.3	693.5	694.1	681.5	669.2	671.1	574.6	493.5	446.2	356.7	694.1
Sky Cover, Clearness Number													
Average Sky Cover	6.0	6.0	5.0	5.0	5.0	3.0	3.0	2.0	2.0	4.0	4.0	5.0	4.2
Average Sky Cover Day	6.0	6.0	5.0	5.0	5.0	3.0	3.0	2.0	2.0	4.0	4.0	5.0	4.0
Clearness Number	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Type of cloud	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Ground temperature													
Average ground temperature (deg C)	12.3	11.6	14.8	18.3	20.7	24.4	26.7	28.1	26.9	24.6	20.2	14.2	

Table 11 - Zone 1 (City 1) - Beirut – Hourly Temperature Profile by Month

Hour	Hourly Temperature (deg C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	13.2	14.6	15.7	18.6	21.6	25.4	27.4	28.8	25.9	23.7	19.2	14.9
1	13.2	14.3	15.7	18.4	21.7	25.2	27.3	28.4	25.7	23.6	19.0	14.7
2	13.2	14.1	15.4	18.3	21.6	25.1	27.3	28.2	25.3	23.4	18.9	14.7
3	13.1	13.9	15.4	18.2	21.7	24.9	27.2	27.9	25.2	23.2	18.9	14.6
4	13.0	14.0	15.3	18.3	21.2	24.7	27.3	28.1	25.0	22.9	18.9	14.5
5	13.1	13.9	15.3	18.9	21.7	25.2	27.4	28.2	24.9	22.9	18.7	14.6
6	12.9	14.3	15.4	20.9	22.1	25.7	27.4	28.4	25.4	23.1	18.7	14.8
7	13.4	14.9	15.8	20.7	22.4	26.0	27.7	28.7	26.3	23.9	19.4	14.9
8	14.1	15.5	16.3	20.8	22.6	26.3	28.2	28.9	26.9	24.7	20.3	15.6
9	15.0	15.9	16.8	21.1	22.8	26.8	28.6	29.2	27.4	25.3	20.6	16.2
10	15.4	16.3	17.1	21.4	23.1	27.2	29.0	29.7	27.9	25.8	20.9	16.4
11	15.7	16.6	17.4	21.4	23.2	27.7	29.5	30.1	28.3	26.0	21.1	16.6
12	15.8	16.8	17.7	21.6	23.4	27.8	29.6	30.3	28.6	26.2	21.0	16.7
13	15.8	16.8	17.8	21.4	23.6	27.9	29.7	30.5	28.7	26.1	21.1	16.8
14	15.7	17.0	17.6	21.5	23.4	28.1	29.6	30.4	28.6	26.2	21.1	16.7
15	15.5	17.1	17.6	21.3	23.3	27.9	29.4	30.2	28.3	25.8	20.7	16.4
16	15.1	16.7	17.4	21.6	23.1	27.6	29.2	29.8	27.8	25.4	20.3	16.1
17	14.7	16.3	17.1	20.8	22.9	27.1	28.7	29.6	27.3	25.0	20.0	16.0
18	14.2	16.1	17.1	19.7	22.7	26.6	28.4	29.5	26.9	24.8	19.8	15.8
19	13.8	15.8	16.9	19.6	22.4	26.3	28.2	29.7	26.9	24.7	19.8	15.5
20	13.7	15.5	16.6	19.3	22.3	26.3	28.1	29.4	26.7	24.4	19.6	15.5
21	13.6	15.1	16.4	19.1	22.2	26.2	28.1	29.2	26.4	24.3	19.3	15.3
22	13.4	14.9	16.2	19.2	22.2	25.8	27.6	29.0	26.3	24.1	19.2	15.2
23	13.3	14.8	16.0	19.1	22.1	25.6	27.5	28.7	26.0	23.8	19.1	14.9

Table 12 - Zone 1 (City 2) - Bayssour – Hourly Temperature Profile by Month

Hour	Hourly Temperature (deg C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	7.2	6.7	12.1	12.4	15.1	18.7	20.9	19.9	18.1	14.6	11.2	7.7
1	7.2	6.8	12.2	12.6	15.2	18.9	21	20.1	18.2	14.7	11.2	7.7
2	7.5	7	12.6	12.9	15.7	19.3	21.4	20.3	18.6	15	11.5	8
3	7.9	7.4	13.2	13.6	16.2	19.9	21.9	20.9	19.2	15.5	12	8.4
4	8.5	8	13.9	14.4	17.1	20.8	22.7	21.8	19.9	16.2	12.6	8.9
5	9.2	8.6	14.8	15.4	18	21.8	23.6	22.6	20.8	16.9	13.2	9.6
6	9.8	9.3	15.7	16.5	19.1	22.8	24.6	23.6	21.7	17.8	14.1	10.3
7	10.5	10.1	16.7	17.6	20.1	23.8	25.5	24.5	22.7	18.7	14.8	10.9
8	11.2	10.7	17.5	18.6	21	24.8	26.3	25.4	23.6	19.4	15.4	11.6
9	11.8	11.2	18.3	19.4	21.8	25.7	27.1	26.2	24.3	20.2	16.1	12.1
10	12.2	11.6	18.9	20.1	22.5	26.4	27.7	26.8	24.8	20.7	16.5	12.5
11	12.5	11.8	19.2	20.4	22.9	26.8	28.1	27.2	25.2	20.9	16.8	12.8
12	12.6	11.9	19.4	20.6	23.1	26.9	28.3	27.3	25.4	21.1	16.9	12.9
13	12.5	11.8	19.2	20.4	22.9	26.8	28.1	27.2	25.2	20.9	16.8	12.8
14	12.2	11.6	18.9	20.1	22.5	26.4	27.7	26.8	24.8	20.7	16.5	12.5
15	11.8	11.2	18.3	19.4	21.8	25.7	27.1	26.2	24.3	20.2	16.1	12.1
16	11.2	10.7	17.5	18.6	21	24.8	26.3	25.4	23.6	19.4	15.4	11.6
17	10.5	10.1	16.7	17.6	20.1	23.8	25.5	24.5	22.7	18.7	14.8	10.9
18	9.8	9.3	15.7	16.5	19.1	22.8	24.6	23.6	21.7	17.8	14.1	10.3
19	9.2	8.6	14.8	15.4	18	21.8	23.6	22.6	20.8	16.9	13.2	9.6
20	8.5	8	13.9	14.4	17.1	20.8	22.7	21.8	19.9	16.2	12.6	8.9
21	7.9	7.4	13.2	13.6	16.2	19.9	21.9	20.9	19.2	15.5	12	8.4
22	7.5	7	12.6	12.9	15.7	19.3	21.4	20.3	18.6	15	11.5	8
23	7.2	6.8	12.2	12.6	15.2	18.9	21	20.1	18.2	14.7	11.2	7.7

Table 13 - Zone 1 (City 2) - Bayssour – Temperature, Humidity, Wind and Solar Radiation

Temperature and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Maximum Temperature (C)	19.4	22.8	26.1	29.4	33.9	33.3	31.1	31.7	30.0	26.1	22.2	18.3	33.9
Average Daily Max Temperature (C)	12.6	12.2	19.4	20.6	23.1	26.9	28.3	27.3	25.4	21.1	16.9	12.9	20.6
Average Temperature Day (C)	12.0	11.3	18.3	19.2	21.4	25.2	26.7	25.9	24.2	20.2	16.2	12.3	20.2
Average Dry Bulb temperature (C)	9.8	9.3	15.7	16.5	19.1	22.8	24.6	23.6	21.7	17.8	14.0	10.3	17.2
Average Temperature Night (C)	8.7	8.1	13.8	13.9	16.4	20.1	22.2	21.3	19.6	16.1	12.6	9.1	14.7
Average Daily Min Temperature (C)	7.2	6.6	12.1	12.4	15.1	18.7	20.9	19.9	18.1	14.6	11.2	7.7	13.7
Minimum Temperature (C)	1.1	1.7	5.0	8.3	8.3	12.8	15.6	16.7	15.6	10.6	4.4	2.8	1.1
Degree-Day													
Heating degree-days base (18,3 C)	262.8	251.4	99.2	97.5	53.3	3.9	0	0	0	29.7	131.1	250	1178.9
Heating degree-days base (15,6 C)	176.9	176.4	48.6	44.7	18.6	0	0	0	0	2.8	62.2	163.9	694.2
Heating degree-days base (12,8 C)	95	105.8	11.9	8.6	1.1	0	0	0	0	0	23.1	80.8	326.4
Heating degree-days base (10,0 C)	30.3	46.7	0.3	0	0	0	0	0	0	0	6.4	21.4	105
Heating degree-hours /24 base (18,3 C)	263.2	253.8	108.1	105.7	61.9	10.3	1.8	0.4	5.3	46.1	134.4	250.5	1241.6
Heating degree-hours /24 base (15,6 C)	179.1	179.7	56.8	56.3	25.6	1.8	0	0	0	10.9	70.3	165.4	745.9
Heating degree-hours /24 base (12,8 C)	100.1	111.1	22.8	20.5	6.3	0	0	0	0	1.1	29.1	88.4	379.4
Heating degree-hours /24 base (10,0 C)	39.9	53.4	5.1	2.8	0.4	0	0	0	0	9.3	32.4	143.4	
Cooling degree-day base (26,7 C)	0	0	0	0	2.8	4.4	4.2	3.6	0	0	0	0	15
Cooling degree-day base (23,9 C)	0	0	0	5	12.2	25.6	39.4	21.9	4.7	0	0	0	108.9
Cooling degree-day base (21,1 C)	0	0	3.1	20.6	38.1	69.7	109.4	78.1	30	1.9	0	0	350.8
Cooling degree-day base (18,3 C)	0	0	18.9	42.5	75.6	137.8	193.3	164.2	102.2	14.7	1.4	0	750.6
Cooling degree-hours /24 base (26,7 C)	0	0	0	2.7	8.1	14.4	16.4	10.1	2.3	0	0	0	53.9
Cooling degree-hours /24 base (23,9 C)	0	0	1.2	11.1	21.2	38.2	53.6	38.2	13.9	0.7	0	0	178
Cooling degree-hours /24 base (21,1 C)	0	0.3	8.3	26.8	46.6	82.7	115.8	90.8	49.2	6.1	0.4	0	426.9
Cooling degree-hours /24 base (18,3 C)	0.1	1.6	27.7	50.9	83.8	144.6	194.1	163.8	107.2	30.4	5	0	809.3
Humidity and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average relative humidity at 4 h (%)	81.4	80.5	68.3	70.5	72.4	68.6	74.7	83.1	83.6	83.0	82.9	86.5	78.0
Average relative humidity at 10 h (%)	63.7	63.4	48.1	49.6	49.9	42.0	40.2	56.8	56.1	58.4	62.8	69.9	55.0
Average relative humidity at 16 h (%)	63.8	63.4	48.1	49.7	49.8	42.0	40.2	56.8	56.1	58.4	62.8	69.9	55.1
Average relative humidity at 22 h (%)	81.1	80.5	68.3	70.5	72.4	68.6	74.7	83.1	83.6	83.0	82.9	86.5	77.9
Wet Bulb Temperature													
Average Wet Bulb temperature (C)	7.3	6.7	10.7	11.6	13.8	16.3	18.3	19.4	17.7	14.4	11.2	8.3	13.0
Wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average wind speed (kmh)	42.5	40.6	40.9	40.6	28.5	29.1	24.3	29.6	30.3	30.3	35.7	45.4	34.8
Average wind speed day (kmh)	42.5	40.9	41.0	40.2	28.5	29.1	24.3	29.8	30.3	30.4	35.6	45.7	34.1
Average wind speed night (kmh)	42.5	40.4	40.7	40.7	28.5	29.1	24.3	29.6	30.3	30.3	35.9	45.2	35.4
Solar radiation and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
(Wh/m2)													
Direct normal radiation													
Maximum Daily Direct Normal Solar	3971.3	3532.6	3761.9	4808.3	4833.2	7731.0	7637.0	7381.3	7085.1	5128.7	4741.7	3599.2	7731.0
Average Daily Direct Normal Solar	3737.0	3369.6	3672.3	4761.3	4827.8	7698.8	7523.5	7239.0	6964.4	4965.9	4524.4	3539.6	5242.5
Minimum Daily Direct Normal Solar	3531.7	3191.7	3543.4	4706.7	4810.8	7642.7	7391.0	7096.2	6847.4	4758.4	4329.5	3516.2	3191.7
Maximum Hourly Direct Normal Solar	480	389.2	388.8	473	452.9	700.1	690	708	735.4	562.6	562.6	464.8	735.4
Average Max Hourly Direct Normal Solar	472.1	387.6	385.1	463.3	444.7	693.8	688.1	697.9	722.2	558.8	560.7	463.3	545.3
Global (horizontal) radiation													
Maximum Daily Total Horizontal Solar	2815.8	3909.5	5444.3	6458.2	7023.6	7226.7	7196.1	6696.0	5855.9	4593.5	3122.4	2399.6	7226.7
Average Daily Total Horizontal Solar	2503.6	3208.1	4777.7	6018.3	6833.2	7209.7	7024.0	6353.2	5389.1	3896.9	2770.7	2287.3	4864.1
Minimum Daily Total Horizontal Solar	2280.4	2726.0	3942.0	5624.1	6476.2	7163.7	6713.0	5882.7	4685.0	3150.4	2476.8	2246.3	2246.3
Maximum Hourly Total Horizontal Solar	445.3	710.5	815.8	884.3	900.7	911.7	907.9	889.0	844.5	762.2	483.4	399.2	911.7
Average Max Hourly Total Horizontal Solar	410.3	526.0	769.2	863.4	895.0	910.8	900.3	870.1	809.2	658.8	444.7	386.0	704.5
Radiation on a vertical plane													
Avg. Daily Total Vertical Solar Azimut N	650.9	1000.0	1655.0	1963.4	2562.6	2121.4	1952.7	1412.2	1004.7	934.1	588.5	601.7	1373.1
Avg. Daily Total Vertical Solar Azimut E	1674.2	2144.1	3165.2	3822.8	4319.5	4020.8	3942.6	3580.9	3129.6	2464.5	1783.0	1521.0	2968.5
Avg. Daily Total Vertical Solar Azimut S	3846.7	3800.7	4276.2	3862.8	3447.2	2293.0	2417.2	2986.8	3903.2	4203.7	4064.6	3743.6	3568.9
Avg. Daily Total Vertical Solar Azimut W	1664.1	2154.8	3165.2	3833.2	4321.0	3988.0	3911.4	3631.7	3121.7	2456.6	1783.0	1516.6	2966.6
Max. Daily Total Vertical Solar Azimut N	725.0	1284.5	1938.8	2238.7	2798.5	2159.6	2136.2	1652.5	1143.5	1176.0	661.3	630.1	2798.5
Max. Daily Total Vertical Solar Azimut E	1870.4	2585.6	3610.5	4052.0	4421.9	4027.1	4022.7	3734.8	3354.8	2860.9	1996.2	1582.5	4421.9
Max. Daily Total Vertical Solar Azimut S	3939.4	4120.5	4400.2	4196.1	3623.8	2379.7	2576.8	3375.6	4299.6	4435.8	4075.7	3772.6	4435.8
Max. Daily Total Vertical Solar Azimut W	1873.5	2605.5	3581.2	4139.4	4402.7	3992.1	3977.6	3777.7	3342.2	2869.1	1986.1	1585.6	4402.7
Max. Hourly Total Vertical Solar Azimut N	110.7	261.1	300.9	293.9	302.7	198.0	197.4	190.2	177.2	221.4	97.1	100.9	302.7
Max. Hourly Total Vertical Solar Azimut E	397.0	430.1	626.9	638.0	698.2	688.7	695.0	601.7	590.7	490.1	439.9	359.2	698.2
Max. Hourly Total Vertical Solar Azimut S	578.7	748.0	743.0	672.3	567.3	381.6	426.4	551.2	681.8	755.3	603.9	575.5	755.3
Max. Hourly Total Vertical Solar Azimut W	394.8	425.4	593.5	693.5	694.1	673.9	661.6	671.1	574.9	493.8	447.2	357.9	694.1
Sky Cover, Clearness Number													
Average Sky Cover	5.0	6.0	6.0	5.0	5.0	2.0	2.0	2.0	2.0	4.0	4.0	5.0	4.0
Average Sky Cover Day	5.0	6.0	6.0	5.0	5.0	2.0	2.0	2.0	2.0	4.0	4.0	5.0	3.9
Clearness Number	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	
Type of cloud	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Ground temperature													
Average ground temperature (deg C)	12.3	11.6	14.8	18.3	20.7	24.4	26.7	28.1	26.9	24.6	20.2	14.2	

Table 14 - Zone 2 - Qartaba – Temperature, Relative Humidity, Wind and Solar Radiation

Temperature and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Maximum Temperature (C)	18.3	16.7	27.2	27.8	29.4	31.7	30.6	31.1	31.7	25.0	24.4	18.9	31.7
Average Daily Max Temperature (C)	11.4	9.7	18.1	19.3	22.8	26.1	27.4	26.5	24.9	21.2	17.8	12.1	19.8
Average Temperature Day (C)	10.8	9.0	17.2	18.1	21.3	24.4	26.2	25.2	23.7	20.3	17.1	11.6	19.5
Average Dry Bulb temperature (C)	8.6	6.9	14.6	15.5	19.0	22.2	24.3	22.9	21.4	18.0	14.8	9.3	16.5
Average Temperature Night (C)	7.3	5.6	12.7	13.1	16.4	19.6	22.3	20.7	19.4	16.2	13.2	8.1	14.1
Average Daily Min Temperature (C)	5.7	4.1	11.1	11.6	15.1	18.3	21.1	19.4	17.9	14.7	11.7	6.5	13.2
Minimum Temperature (C)	0.0	0.0	4.4	6.7	10.0	11.7	16.1	16.1	13.9	10.6	6.1	2.2	0.0
Degree-Day													
Heating degree-days base (18.3 C)	301.9	320.6	125.3	117.2	32.2	5.3	0	0	2.2	33.6	110.3	279.4	1328.1
Heating degree-days base (15.6 C)	215.8	242.8	67.2	62.2	6.9	0	0	0	0	4.2	49.4	194.2	842.8
Heating degree-days base (12.8 C)	133.1	165	25.6	21.7	0	0	0	0	0	0	12.8	110.8	468.9
Heating degree-days base (10.0 C)	60	93.9	3.1	2.5	0	0	0	0	0	0	1.4	45.3	206.1
Heating degree-hours /24 base (18.3 C)	302.5	321.1	133.1	123.6	46	13.9	0.8	2.3	12.3	45.4	117.1	279.2	1397.4
Heating degree-hours /24 base (15.6 C)	217.9	243.4	74.7	71.8	15.6	2.9	0	0	1.3	12.3	57.5	194.7	892.2
Heating degree-hours /24 base (12.8 C)	137.5	167.9	33.4	31.8	2.7	0.2	0	0	0	1.2	19.7	117.2	511.6
Heating degree-hours /24 base (10.0 C)	68.9	97.7	9.7	7.7	0	0	0	0	0	0	3.7	54.4	241.9
Cooling degree-day base (26.7 C)	0	0	0	0	0	2.8	2.8	2.5	0.8	0	0	0	8.9
Cooling degree-day base (23.9 C)	0	0	0	1.4	2.5	19.7	34.7	17.5	9.4	0	0	0	85.3
Cooling degree-day base (21.1 C)	0	0	0.8	11.1	18.6	59.7	100.6	60	38.9	0.8	0	0	290.6
Cooling degree-day base (18.3 C)	0	0	9.2	31.1	52.2	120	184.7	143.3	94.2	21.9	3.3	0	660
Cooling degree-hours /24 base (26.7 C)	0	0	0	0.6	1.7	9.9	11.9	7.6	3.8	0	0	0	35.4
Cooling degree-hours /24 base (23.9 C)	0	0	0.8	5.6	8.9	30.2	46.6	29.2	16.6	0.6	0.1	0	138.6
Cooling degree-hours /24 base (21.1 C)	0	0	4.6	17.7	28.4	70.1	108.6	76.4	48.7	8.3	1.6	0	364.4
Cooling degree-hours /24 base (18.3 C)	0	0	17.6	38.3	66.1	128.9	186.8	145.1	104.7	34.6	10.5	0.1	732.6
Humidity and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average relative humidity at 4 h (%)	84.8	86.4	72.7	79.9	75.8	72.3	79.1	86.9	87.7	87.5	84.9	90.4	82.3
Average relative humidity at 10 h (%)	60.6	65.2	48.6	50.5	43.3	38.7	39.9	48.4	50.2	53.2	57.1	62.6	51.4
Average relative humidity at 16 h (%)	60.6	65.3	48.6	50.5	43.3	38.7	39.9	48.4	50.2	53.2	57.1	62.6	51.4
Average relative humidity at 22 h (%)	84.8	86.4	72.7	79.9	75.8	72.3	79.1	86.9	87.7	87.5	84.9	90.4	82.3
Wet Bulb Temperature													
Average Wet Bulb temperature (C)	5.9	4.7	9.9	11.0	13.5	15.6	18.2	18.2	17.1	14.2	11.5	7.1	12.3
Wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average wind speed (kmh)	33.5	39.1	34.6	39.9	39.4	38.8	37.0	33.3	31.2	34.6	29.1	38.8	35.7
Average wind speed day (kmh)	33.8	39.8	35.3	40.7	40.1	39.9	38.0	34.4	31.6	34.8	29.5	39.0	36.5
Average wind speed night (kmh)	33.3	38.6	34.0	39.1	38.6	37.7	35.9	32.2	30.9	34.4	28.8	38.6	35.1
Solar radiation and related parameters (Wh/m2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Direct normal radiation													
Maximum Daily Direct Normal Solar	3949.2	3524.1	3757.8	4812.0	4838.2	6772.3	7646.5	7390.1	7079.1	5118.3	3936.0	2862.2	7646.5
Average Daily Direct Normal Solar	3714.0	3357.6	3666.3	4760.3	4832.2	6744.6	7532.6	7242.2	6956.2	4949.9	3751.5	2813.3	5034.7
Minimum Daily Direct Normal Solar	3513.7	3174.1	3535.2	4702.0	4814.6	6695.7	7400.2	7091.1	6834.1	4740.1	3586.6	2794.4	7294.4
Maximum Hourly Direct Normal Solar	479.3	388.8	388.5	472.7	452.5	612.4	689.7	707.7	734.5	561.7	468.3	370.9	734.5
Average Max Hourly Direct Normal Solar	471.1	387.3	384.7	462.9	444.7	606.7	688.1	697.6	721.5	558.2	466.4	369.6	522.2
Global (horizontal) radiation													
Maximum Daily Total Horizontal Solar	2784.0	3881.7	5424.2	6448.1	7022.7	7210.3	7197.7	6690.9	5838.8	4567.0	3014.2	2270.3	7210.3
Average Daily Total Horizontal Solar	2471.8	3165.9	4734.8	5991.8	6834.1	7192.7	7032.8	6337.4	5362.0	3851.8	2669.5	2162.4	4825.6
Minimum Daily Total Horizontal Solar	2249.1	2695.4	3914.5	5603.6	6466.7	7145.4	6708.3	5866.0	4658.8	3120.8	2381.9	2123.0	7212.0
Maximum Hourly Total Horizontal Solar	441.8	706.4	812.7	882.4	899.4	909.5	907.0	887.4	842.0	758.4	467.4	379.1	909.5
Average Max Hourly Total Horizontal Solar	406.5	515.9	765.7	860.9	893.4	908.9	899.1	868.2	806.1	649.0	429.5	366.1	698.2
Radiation on a vertical plane													
Avg. Daily Total Vertical Solar Azimut N	643.3	984.2	1637.0	1951.7	2558.5	2392.6	1951.7	1406.5	998.7	919.0	698.5	672.3	1403.3
Avg. Daily Total Vertical Solar Azimut E	1656.3	2119.2	3138.8	3809.5	4323.9	4185.1	3954.9	3576.8	3117.6	2441.5	1756.5	1459.8	2965.9
Avg. Daily Total Vertical Solar Azimut S	3831.9	3779.9	4264.6	3874.2	3475.2	2639.2	2453.8	3012.0	3921.8	4190.2	3815.2	3401.4	3553.1
Avg. Daily Total Vertical Solar Azimut W	1646.2	2130.6	3139.7	3815.5	4325.8	4158.6	3922.1	3626.6	3111.9	2433.3	1756.9	1457.9	2964.4
Max. Daily Total Vertical Solar Azimut N	717.4	1275.6	1931.6	2234.0	2787.8	2430.5	2128.0	1647.7	1141.0	1170.3	786.8	704.8	2787.8
Max. Daily Total Vertical Solar Azimut E	1853.0	2569.5	3598.2	4049.5	4421.6	4192.0	4024.0	3737.0	3348.8	2849.6	1976.3	1524.8	4421.6
Max. Daily Total Vertical Solar Azimut S	3928.7	4115.4	4382.5	4212.9	3667.9	2720.0	2605.8	3403.7	4285.7	4426.4	3844.2	3442.4	4426.4
Max. Daily Total Vertical Solar Azimut W	1854.0	2592.2	3572.1	4137.5	4406.8	4163.7	3983.9	3781.5	3336.2	2861.6	1965.9	1528.2	4406.8
Max. Hourly Total Vertical Solar Azimut N	109.7	259.5	299.9	293.3	302.4	235.3	196.5	189.8	176.6	220.1	117.6	114.5	302.4
Max. Hourly Total Vertical Solar Azimut E	395.1	428.9	623.8	635.1	696.9	691.3	694.1	598.5	587.2	489.1	410.9	322.6	696.9
Max. Hourly Total Vertical Solar Azimut S	578.7	748.0	743.6	675.2	570.8	423.2	431.1	555.0	684.6	754.3	573.6	535.8	754.3
Max. Hourly Total Vertical Solar Azimut W	393.6	424.5	593.8	693.5	694.1	682.1	663.2	671.7	574.6	493.5	413.4	319.1	694.1
Sky Cover, Clearness Number													
Average Sky Cover	5.0	6.0	6.0	5.0	5.0	3.0	2.0	2.0	2.0	4.0	5.0	6.0	4.2
Average Sky Cover Day	5.0	6.0	6.0	5.0	5.0	3.0	2.0	2.0	2.0	4.0	5.0	6.0	4.1
Clearness Number	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Type of cloud	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Ground temperature													
Average ground temperature (deg C)	12.3	11.6	14.8	18.3	20.7	24.4	26.7	28.1	26.9	24.6	20.2	14.2	

Table 15 - Zone 2 - Qartaba – Hourly Temperature Profile by Month

Hourly Temperature Profile by Month													
Hour	Hourly Temperature (deg C)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	5.7	4.1	11.1	11.6	15.1	18.3	21.1	19.4	17.9	14.7	11.7	6.5	13.2
1	5.8	4.2	11.2	11.8	15.3	18.5	21.3	19.5	18.1	14.9	11.8	6.7	13.3
2	6.1	4.4	11.5	12.1	15.7	18.8	21.7	19.9	18.4	15.2	12.1	6.9	13.6
3	6.5	4.8	12.1	12.7	16.2	19.4	22.1	20.4	19	15.7	12.7	7.3	14.2
4	7.2	5.6	12.9	13.6	17	20.2	22.7	21.2	19.7	16.3	13.3	7.9	14.8
5	7.9	6.1	13.7	14.5	18	21.2	23.5	22	20.5	17.1	14	8.6	15.7
6	8.6	6.8	14.6	15.5	19	22.2	24.3	22.9	21.4	18	14.8	9.3	16.5
7	9.3	7.7	15.5	16.5	19.9	23.2	25.1	23.9	22.3	18.9	15.6	10.1	17.4
8	9.9	8.3	16.4	17.4	20.9	24.1	25.9	24.7	23.1	19.6	16.3	10.7	18.2
9	10.6	8.8	17.1	18.2	21.7	24.9	26.6	25.4	23.9	20.3	16.9	11.3	18.9
10	11.1	9.2	17.7	18.9	22.3	25.5	27.1	26	24.4	20.8	17.4	11.7	19.4
11	11.3	9.7	18	19.2	22.6	25.9	27.3	26.4	24.8	21.1	17.8	12.1	19.7
12	11.4	9.7	18.1	19.3	22.8	26.1	27.4	26.5	24.9	21.2	17.8	12.1	19.8
13	11.3	9.7	18	19.2	22.6	25.9	27.3	26.4	24.8	21.1	17.8	12.1	19.7
14	11.1	9.2	17.7	18.9	22.3	25.5	27.1	26	24.4	20.8	17.4	11.7	19.4
15	10.6	8.8	17.1	18.2	21.7	24.9	26.6	25.4	23.9	20.3	16.9	11.3	18.9
16	9.9	8.3	16.4	17.4	20.9	24.1	25.9	24.7	23.1	19.6	16.3	10.7	18.2
17	9.3	7.7	15.5	16.5	19.9	23.2	25.1	23.9	22.3	18.9	15.6	10.1	17.4
18	8.6	6.8	14.6	15.5	19	22.2	24.3	22.9	21.4	18	14.8	9.3	16.5
19	7.9	6.1	13.7	14.5	18	21.2	23.5	22	20.5	17.1	14	8.6	15.7
20	7.2	5.6	12.9	13.6	17	20.2	22.7	21.2	19.7	16.3	13.3	7.9	14.8
21	6.5	4.8	12.1	12.7	16.2	19.4	22.1	20.4	19	15.7	12.7	7.3	14.2
22	6.1	4.4	11.5	12.1	15.7	18.8	21.7	19.9	18.4	15.2	12.1	6.9	13.6
23	5.8	4.2	11.2	11.8	15.3	18.5	21.3	19.5	18.1	14.9	11.8	6.7	13.3

Table 16 - Zone 3 - Zahle – Hourly Temperature Profile by Month

Hourly Temperature (deg C)													
Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	1.9	6.6	5.5	11.5	13.3	17.9	20.5	19.7	16.9	12.8	8.9	6.1	11.8
1	1.6	6.3	5.1	11.1	12.7	17.4	19.8	18.8	16.5	12.4	8.8	5.8	11.4
2	1.2	5.8	4.9	10.8	12.2	16.8	19.4	18.4	16.2	12.1	8.4	5.6	11
3	1	5.4	4.6	10.6	11.6	16.1	18.9	17.9	15.6	11.5	8.1	5.3	10.6
4	0.8	4.9	4.5	10.6	12	16.3	19.2	17.8	15.4	11.5	7.9	5.2	10.6
5	0.6	4.7	4.8	11.6	14.7	20.2	22.1	18.9	16.3	11.7	8	5.3	11.6
6	0.8	5.3	6.4	14.3	17.6	23	25.2	22.9	19.8	13.8	8.7	5.6	13.7
7	1.4	6.7	8.1	16.6	20	25.4	27.7	25.5	22.1	16.3	10.7	6.4	15.6
8	3.5	9.3	9.9	18.3	21.9	27.7	30.1	28.1	24.6	18.7	13.5	7.6	17.8
9	4.7	11.4	11.3	19.8	23.6	29.6	32.2	30.7	26.9	20.7	16.4	9.3	19.7
10	6.3	13.3	12.5	20.8	24.5	30.5	33.1	32.4	28.8	21.8	18.2	10.4	21.1
11	6.9	14.7	13	21.3	24.9	30.8	33.1	33.2	29.3	22.2	18.9	11.2	21.7
12	7.2	15.3	13.3	21.4	24.9	30.7	32.8	33.3	29.3	21.9	19.1	11.3	21.7
13	7.5	15.2	13.2	21.3	24.6	30.3	32.6	33.1	28.8	21.3	18.8	11.1	21.5
14	7	14.9	12.8	20.8	23.9	29.6	31.9	32.1	27.8	20.5	17.6	10.3	20.8
15	5.3	12.6	11.8	19.6	22.6	28.5	30.9	30.7	25.6	18.6	15.8	9.3	19.3
16	4.7	11	10.6	17.3	20.8	26.2	28.6	27.8	23.9	17.6	14.6	8.7	17.7
17	4.2	9.9	9.6	16.2	19.5	24.8	26.9	26.3	22.8	16.8	13.9	7.9	16.6
18	3.7	9.4	8.7	15.2	18	23.5	25.9	25.1	21.6	16.1	13.1	7.5	15.7
19	3.3	8.8	8.1	14.6	17.2	22	24.7	23.8	20.5	15.4	11.9	7.1	14.8
20	2.9	8.2	7.6	13.7	16.3	21.2	23.7	22.7	19.7	14.8	11.3	6.8	14.1
21	2.6	7.8	7	13.2	15.6	20.3	22.7	21.8	18.9	14.4	10.9	6.5	13.5
22	2.2	7.4	6.7	12.7	14.8	19.5	21.9	21.1	18.3	13.9	10.2	6.3	12.9
23	2.1	6.9	6.4	12.2	14.2	18.9	21.1	20.4	17.4	13.2	9.7	6.2	12.4

Table 17 - Zone 3 - Zahle – Temperature, Humidity, Wind and Solar Radiation

Temperature and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Maximum Temperature (C)	16.1	21.1	22.8	30.6	29.4	37.8	39.4	38.9	34.4	31.1	27.2	15.6	39.4
Average Daily Max Temperature (C)	8.2	16.3	13.9	22.3	25.4	31.3	33.4	33.8	30.0	22.8	20.0	11.9	22.5
Average Temperature Day (C)	6.0	12.9	11.7	19.1	22.2	27.7	30.1	29.8	26.2	19.8	16.7	9.9	20.3
Average Dry Bulb temperature (C)	3.5	9.2	8.6	15.6	18.4	23.7	26.1	25.1	21.8	16.2	12.6	7.6	15.7
Average Temperature Night (C)	2.1	7.0	6.3	12.3	14.2	18.9	21.5	20.5	17.9	13.4	9.9	6.3	11.9
Average Daily Min Temperature (C)	-0.2	3.9	3.7	9.6	11.2	15.8	18.6	17.7	15.2	10.8	6.9	4.5	9.8
Minimum Temperature (C)	-6.7	-1.1	-2.8	5.6	3.3	10.0	14.4	13.9	10.6	4.4	-2.2	0.0	-6.7
Degree-Day													
Heating degree-days base (18,3 C)	445	229.7	294.4	90	28.9	0.3	0	0	2.5	76.1	146.7	313.3	1626.9
Heating degree-days base (15,6 C)	358.9	151.9	208.3	36.1	7.8	0	0	0	0	33.9	81.4	227.2	1105.6
Heating degree-days base (12,8 C)	272.8	76.9	130.3	4.2	0.6	0	0	0	0	13.6	35.3	141.1	674.7
Heating degree-days base (10,0 C)	186.7	21.9	64.7	0	0	0	0	0	0	4.7	18.3	59.7	356.1
Heating degree-hours /24 base (18,3 C)	460.6	255.6	305.1	119.5	69.5	16.3	2.9	4.9	23.6	111.2	187.7	332.2	1888.9
Heating degree-hours /24 base (15,6 C)	374.5	183.8	225.1	68.4	32.7	4.5	0.3	0.2	4.8	61.1	123.9	246.1	1325.4
Heating degree-hours /24 base (12,8 C)	289.6	118.7	151.4	30.8	10.6	0.5	0	0	0.5	26.6	70.6	162.3	861.7
Heating degree-hours /24 base (10,0 C)	206.6	64.1	88.9	8.3	3.1	0	0	0	0	7.6	33.9	87.5	500
Cooling degree-day base (26,7 C)	0	0	0	0	0	3.6	19.2	13.1	0	0	0	0	35.8
Cooling degree-day base (23,9 C)	0	0	0	0	0	26.9	71.9	62.5	9.2	0	0	0	170.6
Cooling degree-day base (21,1 C)	0	0	0	2.2	1.7	82.2	152.5	143.6	58.1	7.5	0	0	447.8
Cooling degree-day base (18,3 C)	0	0	0	19.7	27.8	156.1	238.6	229.7	130.6	29.7	1.4	0	833.6
Cooling degree-hours /24 base (26,7 C)	0	0	0	1.6	2.2	36.9	63.9	58	20.6	3.2	0.1	0	186.4
Cooling degree-hours /24 base (23,9 C)	0	0	0	7.2	13.8	70.8	109.3	97.2	44.3	10	1	0	353.6
Cooling degree-hours /24 base (21,1 C)	0	0	0.4	18.3	36.7	116.3	167.8	148.3	79.1	23.6	5.7	0	596.2
Cooling degree-hours /24 base (18,3 C)	0	1	3.1	38.6	71.6	175.5	241.8	215.3	127.5	46.4	16.6	0	937.4
Humidity and related parameters													
Average relative humidity at 4 h (%)	86.8	75.9	81.5	71.6	68.9	58.4	55.7	72.2	70.1	77.4	68.6	90.6	73.2
Average relative humidity at 10 h (%)	68.9	57.0	56.2	42.5	35.8	30.6	28.9	31.8	35.2	46.9	46.2	72.8	46.1
Average relative humidity at 16 h (%)	68.8	52.5	54.0	43.7	39.0	33.9	32.8	36.5	40.1	54.8	47.2	72.5	48.0
Average relative humidity at 22 h (%)	81.2	71.9	74.2	66.2	57.1	49.5	48.9	61.5	59.9	68.1	61.2	88.9	65.7
Wet Bulb Temperature													
Average Wet Bulb temperature (C)	1.7	5.8	5.3	10.3	11.9	14.8	16.5	17.2	14.7	11.4	7.8	5.9	10.3
Wind													
Average wind speed (kmh)	33.5	37.5	38.5	44.8	44.8	45.6	49.9	42.5	39.8	39.6	34.9	35.1	40.6
Average wind speed day (kmh)	33.3	37.8	38.6	44.8	44.8	45.7	49.9	42.5	39.8	39.6	34.9	35.3	41.2
Average wind speed night (kmh)	33.5	37.5	38.5	44.8	44.8	45.7	49.9	42.5	39.8	39.6	34.9	35.1	39.9
Solar radiation and related parameters (Wh/m2)													
Direct normal radiation													
Maximum Daily Direct Normal Solar	4727.5	4401.1	4694.7	4813.6	4840.4	7743.3	7650.3	8318.8	7962.1	5113.8	5502.0	3568.9	8318.8
Average Daily Direct Normal Solar	4445.0	4190.2	4579.6	4760.0	4834.1	7712.1	7536.7	8149.2	7821.5	4942.9	5241.2	3507.1	5647.1
Minimum Daily Direct Normal Solar	4207.8	3957.7	4415.0	4699.8	4816.1	7656.3	7404.3	7974.1	7681.8	4732.6	5008.8	3483.1	3483.1
Maximum Hourly Direct Normal Solar	574.6	485.7	485.7	472.7	452.5	699.8	689.7	796	825.9	561.3	655	463.3	825.9
Average Max Hourly Direct Normal Solar	564.8	483.8	480.6	462.9	444.7	693.5	688.1	784.6	811.4	557.9	652.2	461.4	590.7
Global (horizontal) radiation													
Maximum Daily Total Horizontal Solar	2842.6	4005.0	5566.1	6443.7	7022.4	7229.3	7198.4	6758.1	5930.9	4555.7	3125.2	2353.5	7229.3
Average Daily Total Horizontal Solar	2522.2	3282.2	4861.2	5979.5	6837.6	7211.3	7037.5	6405.2	5466.1	3828.4	2765.4	2241.2	4877.6
Minimum Daily Total Horizontal Solar	2293.9	2797.2	4039.4	5594.8	6462.3	7163.0	6706.4	5957.7	4844.2	3108.5	2465.5	2200.2	2200.2
Maximum Hourly Total Horizontal Solar	451.6	720.0	828.8	881.4	899.1	910.1	906.7	892.5	846.1	756.5	484.7	393.3	910.1
Average Max Hourly Total Horizontal Solar	415.3	532.6	780.5	860.0	892.8	909.2	898.8	872.6	809.5	641.8	445.3	380.0	703.9
Radiation on a vertical plane													
Avg. Daily Total Vertical Solar Azimut N	533.0	863.1	1466.4	1946.4	2558.8	2109.4	1951.7	1171.6	814.6	910.4	449.1	590.7	1283.2
Avg. Daily Total Vertical Solar Azimut E	1668.2	2154.2	3145.4	3802.9	4328.3	4021.8	3959.9	3489.1	3091.5	2429.8	1754.3	1494.8	2949.2
Avg. Daily Total Vertical Solar Azimut S	4098.4	4019.9	4345.0	3878.6	3489.4	2335.9	2469.9	2842.3	3924.3	4180.1	4263.9	3718.1	3627.6
Avg. Daily Total Vertical Solar Azimut W	1655.6	2167.5	3143.2	3807.0	4329.5	3996.8	3927.5	3533.6	3088.6	2420.4	1756.9	1492.9	2947.3
Max. Daily Total Vertical Solar Azimut N	591.9	1132.4	1745.8	2231.8	2783.3	2147.6	2124.2	1404.3	930.6	1167.8	504.9	619.0	2783.3
Max. Daily Total Vertical Solar Azimut E	1861.9	2594.4	3591.0	4047.9	4421.0	4028.4	4023.6	3635.4	3291.1	2844.2	1965.3	1559.1	4421.0
Max. Daily Total Vertical Solar Azimut S	4170.3	4309.4	4471.1	4220.1	3698.2	2422.3	2638.3	3313.1	4346.3	4414.4	4279.7	3750.5	4471.1
Max. Daily Total Vertical Solar Azimut W	1862.2	2618.4	3566.7	4136.5	4408.7	4001.3	3986.8	3672.0	3285.4	2858.7	1951.4	1564.8	4408.7
Max. Hourly Total Vertical Solar Azimut N	89.2	235.3	272.2	293.0	302.1	196.5	195.8	155.5	143.5	219.8	72.2	99.7	302.1
Max. Hourly Total Vertical Solar Azimut E	430.8	466.4	626.6	633.2	696.6	686.2	693.5	600.4	602.0	489.1	459.2	355.7	696.6
Max. Hourly Total Vertical Solar Azimut S	608.6	762.8	754.7	676.4	572.4	388.2	433.0	536.4	678.3	752.8	628.8	574.9	762.8
Max. Hourly Total Vertical Solar Azimut W	419.4	457.6	592.9	693.5	694.4	676.4	664.1	674.2	604.9	493.5	473.7	353.5	694.4
Sky Cover, Clearness Number													
Average Sky Cover	4.0	5.0	5.0	5.0	5.0	2.0	2.0	1.0	1.0	4.0	3.0	5.0	3.5
Average Sky Cover Day	4.0	5.0	5.0	5.0	5.0	2.0	2.0	1.0	1.0	4.0	3.0	5.0	3.4
Clearness Number	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Type of cloud	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Ground temperature													
Average ground temperature (deg C)	12.3	11.6	14.8	18.3	20.7	24.4	26.7	28.1	26.9	24.6	20.2	14.2	

Table 18 - Zone 4 - Cedars – Temperature, Humidity, Wind and Solar Radiation

Temperature and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Maximum Temperature (C)	10.0	10.6	11.1	22.8	23.9	27.8	34.4	31.7	27.2	25.6	20.0	15.6	34.4
Average Daily Max Temperature (C)	3.3	4.8	4.9	12.0	17.8	21.4	25.6	27.6	23.8	19.9	14.9	7.9	15.4
Average Temperature Day (C)	2.6	3.8	3.7	10.5	15.7	18.9	23.0	25.4	21.9	18.2	13.8	7.2	14.6
Average Dry Bulb temperature (C)	-0.1	0.6	0.9	7.8	12.7	15.6	19.4	21.6	17.9	14.0	10.3	4.2	10.4
Average Temperature Night (C)	-1.6	-1.4	-1.2	5.2	9.3	11.6	15.3	17.9	14.4	10.8	8.1	2.4	7.1
Average Daily Min Temperature (C)	-3.5	-3.6	-3.1	3.6	7.6	9.7	13.2	15.8	12.0	8.2	5.8	0.4	5.6
Minimum Temperature (C)	-10.6	-11.1	-8.9	-3.9	2.8	5.0	7.8	11.1	7.8	2.2	2.2	-6.1	-11.1
Degree-Day													
Heating degree-days base (18,3 C)	570.6	496.4	539.2	316.7	176.1	96.9	23.3	0.3	35	135.6	238.9	439.2	3068.1
Heating degree-days base (15,6 C)	484.4	418.6	453.1	234.7	105.3	42.5	2.2	0	6.7	63.6	155.6	353.1	2319.7
Heating degree-days base (12,8 C)	398.3	340.8	366.9	161.1	44.7	9.4	0	0	0	24.7	75.6	266.9	1688.6
Heating degree-days base (10,0 C)	312.2	263.1	280.8	98.3	11.4	1.1	0	0	0	6.7	18.9	183.9	1176.4
Heating degree-hours /24 base (18,3 C)	570.8	496.9	540.8	318.9	185.3	116.6	55.7	26.8	67.1	153.6	240.2	440	3212.7
Heating degree-hours /24 base (15,6 C)	484.7	419.2	454.7	241.1	118.6	67.9	25.2	9	31.6	94.8	161.4	353.9	2462
Heating degree-hours /24 base (12,8 C)	398.6	341.4	368.6	169.6	67.8	33.1	7.9	1	10.6	50.7	94.3	269.4	1813
Heating degree-hours /24 base (10,0 C)	312.4	263.8	282.8	108.9	31.9	11.7	0.7	0	1.7	21	43.8	188.6	1267.4
Cooling degree-day base (26,7 C)	0	0	0	0	0	0	2.8	0	0	0	0	0	2.8
Cooling degree-day base (23,9 C)	0	0	0	0	0	0	8.3	9.2	0	0	0	0	17.5
Cooling degree-day base (21,1 C)	0	0	0	0	0	1.4	20	42.2	1.4	0	0	0	65
Cooling degree-day base (18,3 C)	0	0	0	0	1.4	13.3	56.1	104.2	22.2	2.2	0	0	199.4
Cooling degree-hours /24 base (26,7 C)	0	0	0	0	0	0.2	6.2	9.9	0.1	0	0	0	16.3
Cooling degree-hours /24 base (23,9 C)	0	0	0	0	0	3.1	18.4	33.3	4.6	0.4	0	0	59.9
Cooling degree-hours /24 base (21,1 C)	0	0	0	0.2	2.3	12.6	45.9	74	22.4	4.1	0	0	161.4
Cooling degree-hours /24 base (18,3 C)	0	0	0	1.6	10.8	32.9	87.8	129.2	55.4	19	0.6	0	337.2
Humidity and related parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average Humidity													
Average relative humidity at 4 h (%)	81.4	83.0	64.2	62.6	64.7	64.5	74.8	85.9	79.1	96.2	98.4	98.3	79.4
Average relative humidity at 10 h (%)	80.3	76.5	60.8	52.7	55.8	56.8	64.0	76.8	82.8	95.7	96.6	97.9	74.7
Average relative humidity at 16 h (%)	71.6	76.4	58.5	52.4	49.9	49.4	55.4	69.2	76.5	90.0	93.7	97.0	70.0
Average relative humidity at 22 h (%)	70.5	69.4	55.8	53.8	50.4	49.8	53.0	63.3	59.7	83.0	90.8	90.3	65.8
Wet Bulb Temperature													
Average Wet Bulb temperature (C)	-2.2	-1.4	-2.2	3.2	6.9	9.2	12.5	15.7	12.9	11.6	9.0	3.1	6.6
Wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average wind speed (kmh)	43.5	50.9	44.9	51.8	51.4	50.5	48.1	43.3	40.6	44.9	37.8	50.4	46.5
Average wind speed day (kmh)	44.1	51.7	45.9	52.8	52.2	51.8	49.4	44.8	41.0	45.1	38.3	50.7	47.5
Average wind speed night (kmh)	43.1	50.2	44.3	50.9	50.4	48.9	46.7	41.9	40.2	44.8	37.3	50.1	45.6
Solar radiation and related parameters (Wh/m2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Direct normal radiation													
Maximum Daily Direct Normal Solar	3151.7	3520.7	3755.9	3850.8	4840.4	7743.3	7650.3	7394.5	7077.3	4261.4	3930.0	2854.9	7743.3
Average Daily Direct Normal Solar	2963.4	3352.3	3663.5	3807.9	4834.1	7712.1	7536.7	7243.8	6952.4	4119.2	3743.9	2805.7	4900.0
Minimum Daily Direct Normal Solar	2805.4	3166.2	3532.0	3759.7	4816.1	7656.3	7404.3	7088.0	6828.4	3943.9	3577.7	2786.5	2786.5
Maximum Hourly Direct Normal Solar	383.2	388.5	388.5	378.1	452.5	699.8	689.7	707.3	734.2	467.7	468	370.5	734.2
Average Max Hourly Direct Normal Solar	376.5	386.9	384.4	370.2	444.7	693.5	688.1	697.6	721.2	464.8	465.8	369.3	505.5
Global (horizontal) radiation													
Maximum Daily Total Horizontal Solar	2656.9	3869.4	5415.3	6275.9	7022.4	7229.3	7198.4	6689.0	5831.9	4478.1	3001.9	2257.0	7229.3
Average Daily Total Horizontal Solar	2357.3	3153.3	4718.4	5817.1	6837.6	7211.3	7037.5	6327.6	5347.2	3750.2	2656.3	2149.2	4788.4
Minimum Daily Total Horizontal Solar	2143.8	2682.4	3902.5	5443.4	6462.3	7163.0	6706.4	5858.7	4647.4	3029.6	2368.3	2109.7	2109.7
Maximum Hourly Total Horizontal Solar	422.3	704.8	811.7	863.1	899.1	910.1	906.7	886.8	840.7	750.2	465.8	377.2	910.1
Average Max Hourly Total Horizontal Solar	388.2	514.3	764.4	842.0	892.8	909.2	898.8	867.2	804.5	633.6	427.6	364.6	693.2
Radiation on a vertical plane													
Avg. Daily Total Vertical Solar Azimut N	726.9	980.8	1630.1	2135.9	2558.8	2109.4	1951.7	1403.0	994.6	1066.5	695.4	668.2	1412.8
Avg. Daily Total Vertical Solar Azimut E	1601.1	2111.9	3129.0	3815.2	4328.3	4021.8	3959.9	3573.3	3110.7	2438.3	1750.2	1451.9	2945.1
Avg. Daily Total Vertical Solar Azimut S	3510.2	3777.0	4261.4	3953.3	3489.4	2335.9	2469.9	3020.5	3926.8	4054.6	3810.8	3392.9	3497.9
Avg. Daily Total Vertical Solar Azimut W	1593.8	2123.9	3129.6	3818.7	4329.5	3996.8	3927.5	3621.3	3105.6	2429.5	1751.2	1450.6	2943.9
Max. Daily Total Vertical Solar Azimut N	813.3	1272.2	1928.7	2423.2	2783.3	2147.6	2124.2	1645.5	1140.0	1348.2	784.0	701.0	2783.3
Max. Daily Total Vertical Solar Azimut E	1797.9	2562.3	3592.6	4069.7	4421.0	4028.4	4023.6	3737.3	3345.3	2873.5	1971.6	1517.5	4421.0
Max. Daily Total Vertical Solar Azimut S	3631.3	4114.2	4373.1	4228.6	3698.2	2422.3	2638.3	3415.6	4260.5	4316.3	3841.7	3434.9	4373.1
Max. Daily Total Vertical Solar Azimut W	1798.8	2586.9	3568.3	4161.5	4408.7	4001.3	3986.8	3783.3	3334.6	2886.5	1960.3	1521.6	4408.7
Max. Hourly Total Vertical Solar Azimut N	126.1	259.2	299.6	321.3	302.1	196.5	195.8	189.8	176.6	249.1	117.3	114.2	321.3
Max. Hourly Total Vertical Solar Azimut E	354.5	428.3	622.2	635.8	696.6	686.2	693.5	596.7	585.0	465.5	410.0	321.7	696.6
Max. Hourly Total Vertical Solar Azimut S	544.9	748.3	743.9	682.1	572.4	388.2	433.0	556.9	685.9	748.0	573.3	535.2	748.3
Max. Hourly Total Vertical Solar Azimut W	362.7	424.2	594.4	681.2	694.4	676.4	664.1	672.3	574.6	469.3	412.5	317.6	694.4
Sky Cover, Clearness Number													
Average Sky Cover	6.0	6.0	6.0	6.0	5.0	2.0	2.0	2.0	2.0	5.0	5.0	6.0	4.4
Average Sky Cover Day	6.0	6.0	6.0	6.0	5.0	2.0	2.0	2.0	2.0	5.0	5.0	6.0	4.2
Clearness Number	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Type of cloud	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Ground temperature													
Average ground temperature (deg C)	12.3	11.6	14.8	18.3	20.7	24.4	26.7	28.1	26.9	24.6	20.2	14.2	

Table 19 - Zone 4 - Cedars – Hourly Temperature Profile by Month

Hour	Hourly Temperature (deg C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	-3.5	-3.6	-3.1	3.6	7.6	9.7	13.2	15.8	12	8.2	5.8	0.4
1	-3.3	-3.4	-2.9	3.7	7.8	9.8	13.4	15.8	12.2	8.3	5.9	0.4
2	-3	-3	-2.6	4.1	8.3	10.5	14.1	16.4	12.8	8.9	6.3	0.8
3	-2.5	-2.3	-1.9	4.8	9	11.4	15	17.4	13.7	9.9	7.1	1.5
4	-1.8	-1.5	-1.1	5.7	10.1	12.7	16.3	18.7	15	11.1	8.1	2.2
5	-0.9	-0.5	-0.2	6.7	11.3	14	17.8	20.1	16.4	12.5	9.2	3.2
6	-0.1	0.6	0.8	7.8	12.7	15.6	19.3	21.7	17.9	14	10.3	4.2
7	0.8	1.7	1.9	8.8	14.1	17.1	21	23.2	19.5	15.5	11.5	5.1
8	1.7	2.7	2.8	9.9	15.3	18.5	22.4	24.6	20.9	16.9	12.7	6
9	2.3	3.6	3.7	10.7	16.3	19.7	23.7	25.9	22.1	18.1	13.6	6.8
10	2.8	4.2	4.3	11.4	17.1	20.6	24.6	26.8	23.1	19	14.3	7.4
11	3.2	4.5	4.7	11.8	17.7	21.2	25.3	27.4	23.7	19.6	14.8	7.8
12	3.3	4.8	4.9	12	17.8	21.4	25.6	27.6	23.8	19.9	14.9	7.9
13	3.2	4.5	4.7	11.8	17.7	21.2	25.3	27.4	23.7	19.6	14.8	7.8
14	2.8	4.2	4.3	11.4	17.1	20.6	24.6	26.8	23.1	19	14.3	7.4
15	2.3	3.6	3.7	10.7	16.3	19.7	23.7	25.9	22.1	18.1	13.6	6.8
16	1.7	2.7	2.8	9.9	15.3	18.5	22.4	24.6	20.9	16.9	12.7	6
17	0.8	1.7	1.9	8.8	14.1	17.1	21	23.2	19.5	15.5	11.5	5.1
18	-0.1	0.6	0.8	7.8	12.7	15.6	19.3	21.7	17.9	14	10.3	4.2
19	-0.9	-0.5	-0.2	6.7	11.3	14	17.8	20.1	16.4	12.5	9.2	3.2
20	-1.8	-1.5	-1.1	5.7	10.1	12.7	16.3	18.7	15	11.1	8.1	2.2
21	-2.5	-2.3	-1.9	4.8	9	11.4	15	17.4	13.7	9.9	7.1	1.5
22	-3	-3	-2.6	4.1	8.3	10.5	14.1	16.4	12.8	8.9	6.3	0.8
23	-3.3	-3.4	-2.9	3.7	7.8	9.8	13.4	15.8	12.2	8.3	5.9	0.4

5

PROPOSAL OF OUTDOOR DESIGN CONDITIONS

5.1 Winter Design Conditions

Recommended design temperatures for winter are presented for two frequency levels for each climatic zone representing temperatures that have been equaled or exceeded by 99% or 97% of the total hours during the months of December, January and February (a total of 2,160 hours). In a normal winter it would be approximately 22 hours at or below the 99% value and 54 hours at or below the 97.5% value.

5.2 Summer Design Conditions

Recommended design dry-bulb and wet-bulb temperatures for summer conditions are presented for three frequency levels for each climatic zone representing temperatures that have been equaled or exceeded by 1.0%, 2.5% or 5.0% of the total hours during the months of June through September (a total of 2928 hours). The coincident wet-bulb temperature listed with each design dry-bulb temperature is the average the coincident wet-bulb temperatures occurring at the specific dry-bulb temperature retained. In a normal summer, approximately 30 hours would be at or above the 1.0% design value, 75 hours at or above the 2.5% design value and 150 hours at or above the 5.0 % design value.

These findings are especially based on the analysis of climatic data from the meteorological stations stated below and on the “*Atlas Climatique du Liban*”. The values for Beirut were corrected slightly to take into account the effect of the Urban Temperature. A measure campaign is recommended in the future in order to confirm the level of correction for urban effect.

Climatic Zone	Weather Station
1	Beirut Gulf (3 years) + AUB (9 years)
1	Bayssour (2 years)
2	Qartaba (2 years)
3	Zahle (6 years)
4	Cedar (6 years)

Table 20 – Proposed Outdoor Design Conditions for Lebanon

Climatic Zone	Winter (°C)		Summer (°C)					
	Design Dry-Bulb		Design Dry-Bulb			Design Wet-Bulb		
	99%	97.5%	1%	2.5%	5%	1%	2.5%	5%
1 (Beirut)	6	7	34	33	32	26	26	25
1 (Baysour)	2	3	33	32	31	24	23	23
2	-2	-1	32	31	31	22	22	21
3	-5	-4	37	36	35	22	21	21
4	-10	-7	31	30	30	22	21	21

:: CONCLUSIONS AND RECOMMENDATIONS

The Climatic Zoning Study resulted in the definition and delineation of four Climatic Zones representing the range of thermal energy requirements for Buildings in Lebanon.

In order to develop the climatic zones, the main source of information used in the analysis was the *Atlas Climatique du Liban* which featured homogeneous information for an adequate number of stations. An additional 22 stations were reconstituted from available LMS records and were added to the analysis.

This first exercise in defining climate zones for buildings in Lebanon faced a number of challenges mainly due to the short term history of data and to the non validated raw data. The selected configuration for the climatic zones used degree-day analysis and previously defined climatic zones in the *Atlas Climatique du Liban* in order to define the most realistic zoning.

It is suggested that the climatic zoning study be updated in five years time to take advantage of new stream of data generated by the meteorological department. With better solar and humidity data, it then becomes possible to incorporate in the analysis more parameters that can affect energy usage. This will allow additional fine-tuning to the temperature difference (in the form of degree-day) and to the energy analysis used to classify climatic zones.

The best approach to incorporate the results of the solar, humidity and temperature with proper weighting is to realize large number of energy building simulation in different zones while varying the parameters of design and construction of the building. With this approach, it is not necessary to limit the analysis to degree-days as the simulation output (energy usage of building) becomes the criterion to use for zoning by itself with a much greater precision than any other simplified approach. The disadvantage of this approach is the resources needed to perform and analyze thousands of building simulations.

With respect to the set-up of typical weather files for the energy simulation of buildings, the limited information reduced the ability to properly simulate the solar and humidity components. The temperature information was the most precise parameter used as there was often several years of data available from which it was possible to select representative months and to compare with long term trends observed in the *Atlas Climatique du Liban*. With respect to humidity, the data was considered fairly reliable except in periods where measurement problems were observed in the raw data, but comparison with long term trends from the *Atlas Climatique du Liban* provided a solution. With respect to solar radiation, it was necessary to use the automatic radiation calculator included in DOE considering the incoherence between the direct normal radiation and the horizontal component in records.

As a Conclusion, and although building design requires only a subset of the meteorological data (mainly surface observations: temperature, humidity, wind and solar radiation), it was often difficult to obtain all the weather data in complete form. The lack of solar radiation data was one of the most important problems encountered and should be remedied in the future.

Nonetheless, the climatic zones and weather files generated in this study can be considered adequate for the purpose of the introduction of the thermal standard on a voluntary basis. However, these will need to be fine-tuned and updated as more data becomes available and before the Thermal Standard becomes mandatory in the target year 2010.

:: REFERENCES

- "Atlas Climatique du Liban" in four Volumes, Lebanese Meteorological Service, 1977.
- "Feasibility Study – A national Approach to energy Efficiency measures for houses" edited by the Australian Greenhouse Office, 2000.
- "Climate Classification for Building Energy Codes and Standards", R. Briggs, R. Lucas, Z. Taylor, Pacific Northwest National Laboratory, March 2002.
- Article "The Development of Typical Weather Years for international locations" Part 1 – Algorithm by Didier J. Thevenard and Alfred P. Brunger, Ph. D. P.eng. Ashrae Transactions: Research 4588 (RP 1015) p. 376.
- Article "The Ashrae clear sky model" by Gary L. Powell, Ashrae Journal 1982.
- Levermore, G., 1997. The new CIBSE weather and solar data guide, CIBSE Virtual Conference 1997, Chartered Institution of Building Services Engineers, London.
- Keeble, E., 1990. Availability of UK Climatic Data for Use in Simulation, BEPAC Technical, Note 90/1, Building Research Establishment, UK, October.
- Lam, J. C., Hui, S. C. M. and Chan, A. L. S., 1996. A statistical approach to the development of a typical meteorological year for Hong Kong, Architectural Science Review, 39 (4): 201-209.
- Tu, Fengxiang and Wang, Meijun, 1996. Climatic incidence on building energy consumption of China, HV&AC (Nuantong Kongtiao), 26 (4): 11-15.
- CIBSE, 1996. Draft CIBSE Guide Volume J - Weather and Solar Data, Chartered Institution of Building Services Engineers, London, May.
- "Capacity Building in Local and Regional Systematic Observation Networks" (UNDP/GEF/MOE, October 2002).
- "Guide to thermal Insulation and summer comfort for buildings in Lebanon", NL: 1999 Lebanese Standards Institution, LIBNOR.
- Climatic Data supplied by Lebanese Meteorological Service.
- Climatic Data supplied by American University of Beirut.
- Climatic Data supplied by ENERCO weather station at Taanayel.
- Hui, S. C. M. and Cheung, K. P., 1997. Climatic data for building energy design in Hong Kong and Mainland China, In Proc. of the CIBSE National Conference 1997, 5-7 October 1997, London (paper for CIBSE Virtual Conference 1997).
- Karl, T. R., H. F. Diaz, and G. Kukla. 1988. "Urbanization: its detection and effect in the United States climate record," Journal of Climate, 1, pp. 1099-1123.
- Karl, T. R., and C. N. Williams Jr. 1987. "An approach to adjusting climatological time series for discontinuous inhomogeneities," Journal of Climate and Applied Meteorology, 26, pp. 1744-1763.