ANALYSIS OF THE TYPICAL METEOROLOGICAL YEAR (TMY) OF CYPRUS AND HOUSE LOAD SIMULATION

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ABSTRACT

The objective of this paper is to present an analysis of the weather data contained in a Typical Meteorological Year (TMY) and observe the effect of these data on the simulated load of a typical building. The weather data, contained in the TMY, are analysed with respect to the global and diffuse radiation falling on surfaces facing the four orientations, ambient temperature, wind speed and direction, and humidity ratio. Collective results for the whole year indicate that the east wall receives 30% more total radiation than the south wall and the west wall receives only 20% of the beam radiation of the east wall. Three different construction types of a typical house layout are also used in this study and simulated with respect to the heating and cooling loads for a complete year. For the weather encountered in Cyprus the maximum cooling load occurs in July and the maximum heating load in January. The monthly saving in loads by using insulation is of the order of 50% for cooling and 75% for heating.

INTRODUCTION

To simulate the transient thermal energy requirements of buildings, detailed weather data are needed. Usually, these weather data are included in files and are used by a simulation program that performs the calculations. TRNSYS (Klein *et al*., 1996) is such a program and runs through hourly values of various weather parameters included in a Typical Meteorological Year (TMY) file. Such an analysis can be used to determine the hourly load of buildings throughout the year and thus the annual energy use and the maximum load for equipment selection.

The selection of typical weather conditions for a given location is very crucial in computer simulations for performance predictions and has led various investigators either to use observational data of long periods or to select a particular year, which appears to be typical from several years of data. The present Typical Meteorological Year was generated from hourly measurements, of solar irradiance (global and diffuse on horizontal surface), ambient temperature, wind speed and direction, and humidity ratio, for a seven-year period, from 1986 to 1992 using the Filkenstein – Schafer statistical method (Petrakis *et al.*, 1998). The measurements were performed by the Meteorological Service of the Ministry of Agriculture, Natural Resources and Environment of Cyprus, at the Athalassa region, an area very close to the town of Nicosia. Athalassa is at a latitude of 35°09’, longitude 33°24’ and 162 m high, above the mean sea level. The TMY is considered as a representative year for the Cypriot environment.

ANALYSIS OF TMY WEATHER DATA

The weather data contained in the TMY are analyzed with respect to the radiation falling on every wall facing the four orientations estimated by the radiation processor of TRNSYS. Such an analysis, although very useful for designers, is done for the first time. Examining the data for the direct beam radiation on a day-by-day basis it is observed that in the morning hours it is usually much greater than it is during the afternoon hours. The pattern emerging shows that usually haze and clouds form in the afternoon blocking the sun.

Collective results for the whole year, shown in Table 1, indicate that the east wall receives 30% more total radiation than the south wall. The west wall receives only 20% of the beam radiation of the east wall. The diffuse radiation for the afternoon is about the same for all walls. In the morning hours the east wall receives about 75% more diffuse radiation than the south wall. This of course depends on the model used for the contribution of diffuse radiation on a tilted surface. In the case of this study, the Reindl model was used which accounts for circumsolar diffuse (an increased intensity of diffuse radiation in the area around the sun) and also includes a horizon brightening diffuse term besides the isotropic radiation.

Table 2 presents a monthly analysis of the total and beam radiation falling on building surfaces facing the four cardinal points and the horizontal. It is of interest to note that the west wall receives approximately the same amount of total radiation as the north wall. This is partly due to the sun trajectory during summertime when the sun faces the north wall at sunrise and some time before sunset, therefore a small amount of beam radiation strikes the north wall. Also, according to the Meteorological Department of Cyprus, because of the heat of the morning hours and the position of Nicosia in the valley of Mesaoria, usually clouds form around 2 pm. in summertime, which obstruct the west beam radiation.

The falling beam radiation on different orientations, for every month of the year, is indicated in Figure 1. It should be noted that for all orientations, the beam radiation falling during the morning hours (sunrise till noon) is indicated separately than that falling during the afternoon (from noon to sunset).

Table 1. Collective results of the sun radiation for the morning and afternoon hours

Wall direction	Total radiation per year (kWh/m^2)			Beam radiation per year (kWh/m^2)			Diffuse radiation per year (kWh/m^2)		
	From sunrise to 12 noon	From 12 noon to Sunset	Total	From sunrise to 12 noon	From 12 noon to sunset	Total	From sunrise to 12 noon	From 12 noon to Sunset	Total
South	803	404	1208	408	207	615	395	198	593
East	1488	176	1664	793	0	793	695	176	871
North	338	176	515	43	1	43	295	176	471
West	261	358	619	0	162	162	261	196	457
Horizontal	1114	571	1685	691	324	1015	423	247	670

Table 2. Sun radiation falling on building surfaces per month

Month	Horizontal Total (kWh/m^2)	Horizontal Beam (kWh/m^2)	South Total (kWh/m^2)	South Beam (kWh/m^2)	East Total (kWh/m^2)	East Beam (kWh/m^2)	North Total (kWh/m^2)	North Beam (kWh/m^2)	West Total (kWh/m^2)	West Beam (kWh/m^2)
JAN	74	41	115	72	84	39	22	0	33	10
FEB	82	49	102	65	93	49	22	0	33	10
MAR	135	62	105	46	127	53	45	0	56	9
APR	169	90	94	36	166	74	56	3	62	10
MAY	182	98	75	19	167	78	68	8	64	10
JUN	205	132	69	17	167	87	71	13	66	13
JUL	219	151	74	25	182	97	68	13	71	21
AUG	201	135	93	42	184	96	55	6	67	20
SEP	152	99	109	62	190	85	37	1	53	17
OCT	119	76	136	85	137	63	28	0	51	22
NOV	82	47	124	76	95	39	22	0	34	12
DEC	68	35	112	69	74	34	21	0	29	8
Total	1685	1015	1208	615	1664	793	515	43	619	162

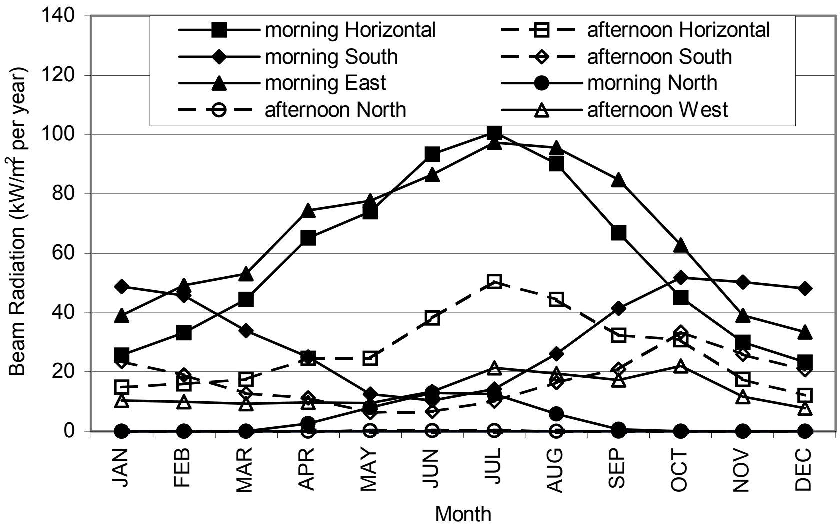

Figure 1. Beam radiation falling on different orientations, for every month of the year.

As it is observed, the beam radiation on horizontal and east facing surfaces is very high during the hot months of the year (June to September). South facing surfaces receive the highest radiation during November to February and much lower during the hot months. This is due to the sun trajectory which, for the latitude of Cyprus (35°), brings the sun at a maximum altitude angle of about 78° during noon in June and a minimum of 32° in December. West and obviously north facing surfaces receive the lowest beam radiation throughout the year.

The mean hourly temperature of the day, for every month of the year, is presented in Figure 2.

As it is observed, the temperature regimes fall within two close bands, one rather cold for the months of December, January, February and March, and another very hot for the months of June, July, August and September. The rest of the months exhibit intermediate temperatures, which are rather comfortable. The coldest temperature recorded in the TMY file occurs in January and is about 6°C, whilst the highest is about 36°C in July. The daily variation in temperature for the hot months is about 14°C and for the cold months about 10°C.

An examination of the mean wind speed is presented in Table 3. As can be seen, during the morning hours the wind speed is always lower than the afternoon hours. The morning wind speed during the whole year is about 60% of the afternoon speed. The mean direction of wind is generally SSW.

A detailed analysis of the mean hourly wind speed of a day, for every month of the year, is presented in Figures 3 to 5. As it is observed the wind speed in the night hours is very low about 2-3 m/s during the winter months and about 3-4 m/s during summer. The wind speed reaches its minimum just before sunrise (about 2 m/s) and after that the wind speed increases reaching a maximum about 1 to 2 hours after the temperature reaches its maximum during the day. The maximum wind speed is about 6.5 m/s and occurs during the months of March to September.

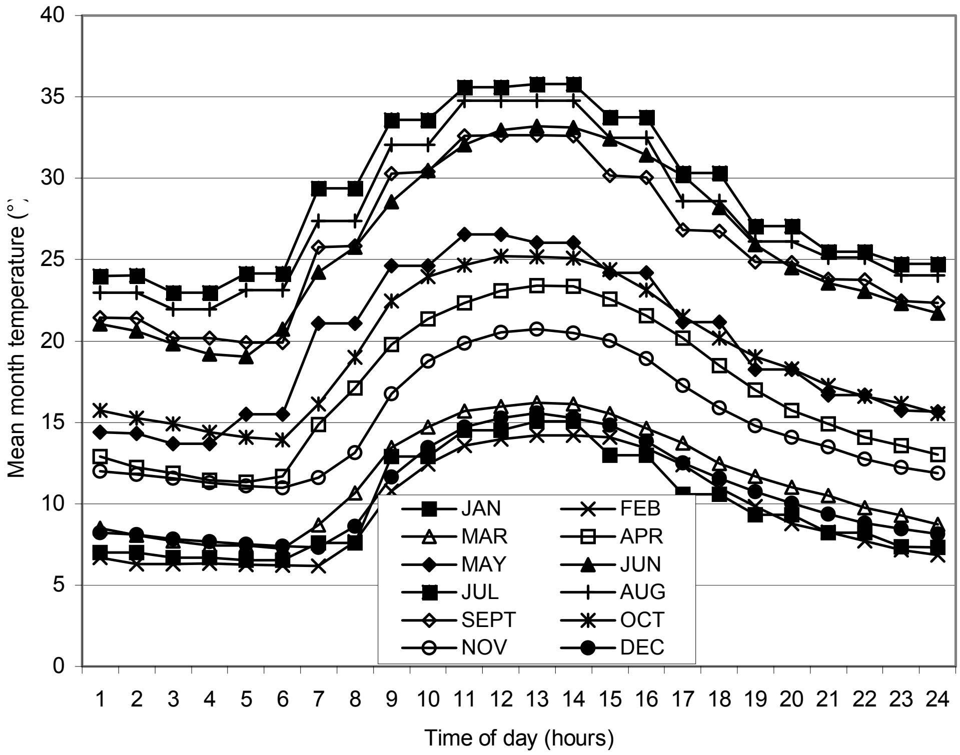

Figure 2. Mean hourly temperature of the day, for every month of the year.

Table 3. Collective results for mean wind speed and wind direction for the morning and afternoon hours

Mean wind speed (m/s)		Mean wind direction (degrees)	
Morning 5 a.m. –12 noon	Afternoon 12 noon – 7 p.m.	Morning 5 a.m. –12 noon	Afternoon 12 noon – 7 p.m.
2.7	4.7	205 (SSW)	204 (SSW)

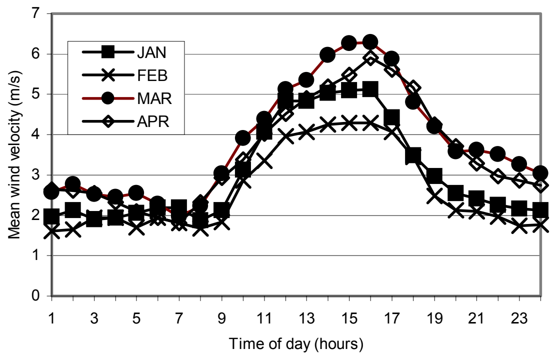

Figure 3. Mean hourly wind speed during a day for January to April.

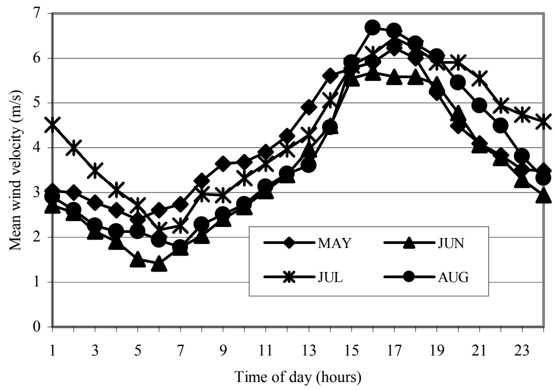

Figure 4. Mean hourly wind speed during a day for May to August.

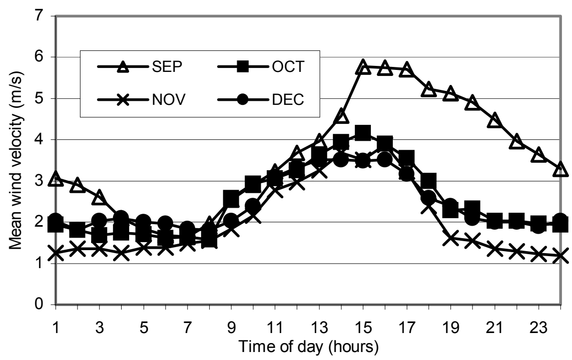

Figure 5. Mean hourly wind speed during a day for September to December.

The wind direction is indicated in Figures 6 and 7 and, as it is observed, it follows the same pattern throughout the year, varying between 150° and 290°.

The mean hourly humidity during the day, for the cold months of a year is indicated in Figure 8 and for the hot months in Figure 9. The humidity ratio is greatest during the months of June to September. Generally, the humidity ratio is increased during the morning and early night hours of a day.

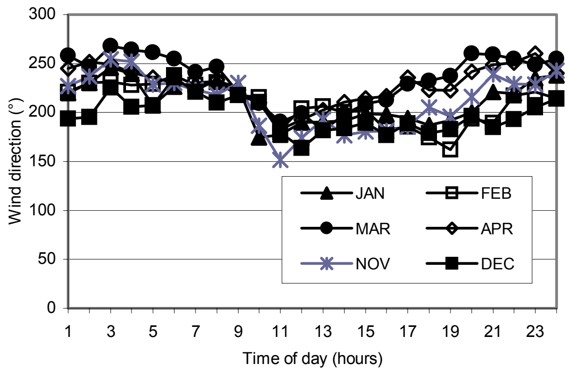

*Figure 6. Mean hourly wind direction during a day for the cold months of a year. (**Note:** Wind direction is expressed as 0° for wind from north, 90° for east, 180° for south and 270° for west).*

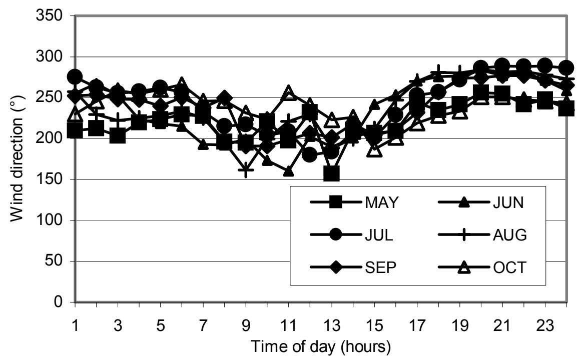

*Figure 7. Mean hourly wind direction during a day for the hot months of a year. (**Note:** Wind direction is expressed as 0° for wind from north, 90° for east, 180° for south and 270° for west).*

The mean hourly humidity ratio during a day, for the cold months of a year varies between 5 and 9 gr of moisture per kg of dry air and for the hot months between 6 and 18. The humidity ratio is greatest during the months of June to September.

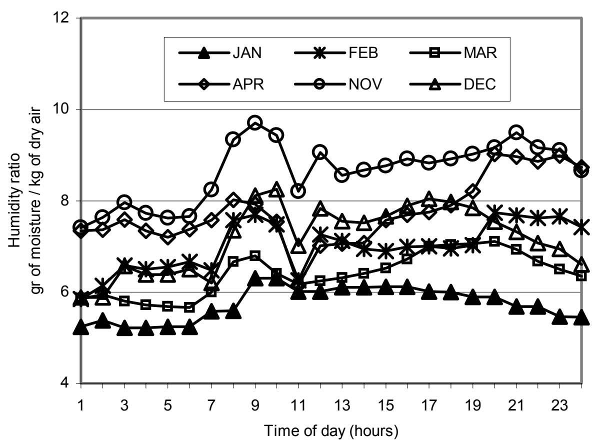

Figure 8. Mean hourly humidity ratio during a day for the cold months of a year.

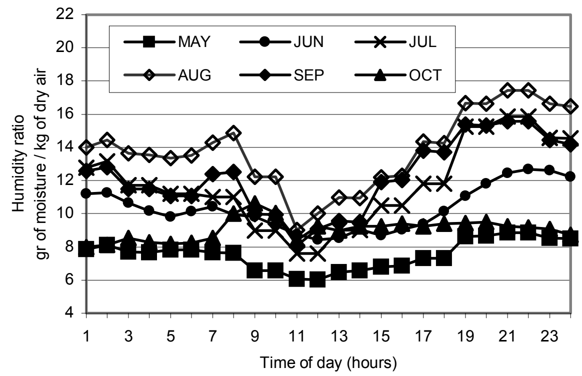

Figure 9. Mean hourly humidity ratio during a day for the hot months of a year.

EFFECT OF WEATHER PATTERN ON BUILDING LOADS

The above analysis, indicating the peculiarities of the Cyprus weather profile, will help to explain the thermal loads arising from building elements facing different orientations.

The TRNSYS model 19 is used in order to simulate the temperature variation observed within a model house in Nicosia, Cyprus. The model house, illustrated in Figure 10, has a floor area of 196 m^2 and consists of four identical external walls, 14 m long by 3 m high, with a total window opening of 5.2m^2 in each wall. The window area is approximately equal to the area that a typical house would have, but instead of considering a number of single windows on each wall, only one double glazed window is considered. The model house is further divided into four identical zones and the partition walls are considered as walls separating the four zones.

Details of the input parameters required to model the typical house shown in Figure 10 are given in Florides *et al*. (2000).

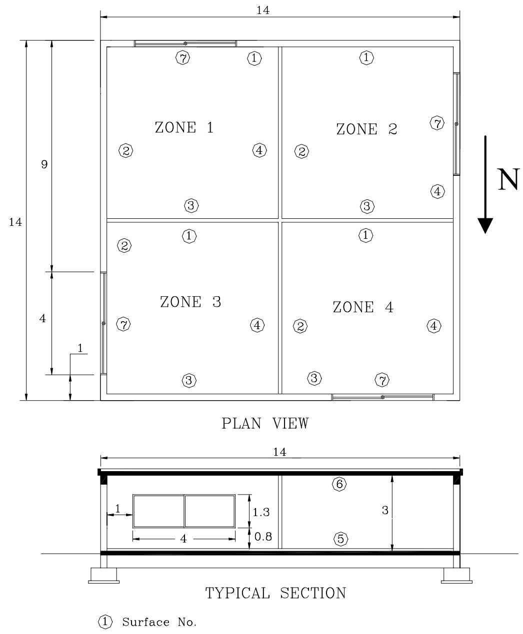

Figure 10. Model house.

Three different construction types were considered; one with no insulation, one with insulated roof and walls and one with light construction and insulation. Details of the construction types are indicated in Table 4. The loads of the above constructions are analysed with respect to the monthly cooling and heating loads for keeping the house temperature at 25°C during summer and 21°C during winter. The annual cooling and heating load of the above three constructions is also shown in Table 4.

The monthly cooling and heating load for the three types of buildings is indicated in Figure 11. For the weather encountered in Cyprus the maximum cooling load occurs in July and the maximum heating load in January. The monthly saving in load by using insulation is of the order of 50% for cooling and 75% for heating.

Table 4. Details of the construction types.

Case	Wall type	Roof type	Heating load (kWh)	Cooling load (kWh)
A	Single wall, hollow brick 0.2 m and 0.02 m plaster on each side	Flat non-insulated roof, constructed from fair-faced 0.15 m heavy- weight concrete	16,010	42,300
B	Double-wall, 0.1 m hollow brick, 0.02 m plaster on each side and a layer of 0.05 m polystyrene insulation in between	Flat insulated roof, fair-faced 0.15 m heavy weight concrete, 0.05 m polystyrene insulation, 0.07 m screed and 0.004 m asphalt covered with aluminum paint of 0.55 solar absorptivity	3,480	21,730
C	0.1 m face brick, 0.1m insulation, 0.025 m wood	Clay tile, 0.01 m felt and membrane, 0.1 m insulation and 0.025 m wood	2,880	21,060

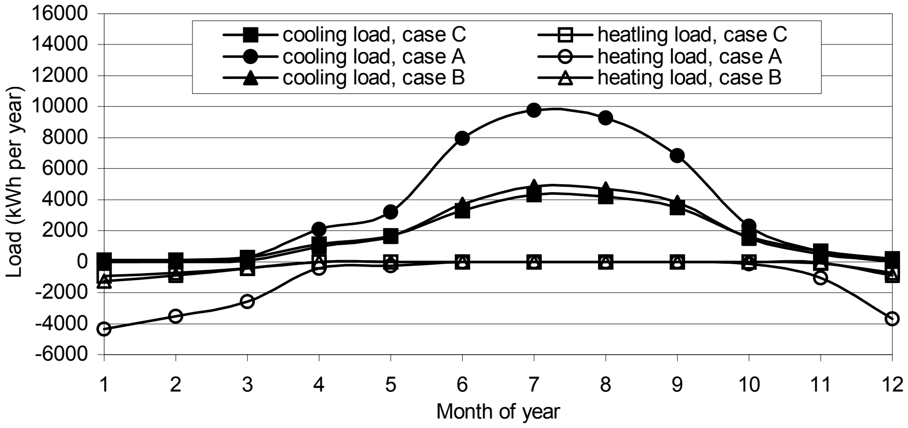

Figure 11. Monthly cooling and heating loads for the three types of buildings.

LOAD ANALYSIS OF THE MODEL HOUSE

This section presents the predicted indoor temperatures and heating and cooling loads of the model house. Since similar patterns are exhibited by all three construction types only the non-insulated house (case A) is presented.

Initially, the variation of the zone temperatures is examined. As shown in Figure 12, in mid-January the sun rises at 7.40 am with a solar azimuth angle of about 60° East (0° south).

During this time, the direct solar radiation falling on the east window and wall causes the temperature of the N-E Zone (3) to increase sharply.

The direct solar radiation then strikes the south window and wall increasing the temperature of the S-E Zone (1), which gives the highest temperature and thus the lowest heating load.

During the afternoon hours in these particular days, haze and clouds obstruct the direct beam radiation and therefore the change in the temperature of the S-W Zone (2) is not so sudden. The N-W Zone (4) gives the highest load. This zone receives no direct radiation, as the sun sets at 5:28 p.m., with an azimuth angle of about 60° west.

It is also of interest to observe the effect of the wind speed and ambient temperature on the zone temperatures. During the afternoon hours of the 13th of January the wind speed is between 1 and 4 m/s and the ambient temperature does not drop below 8°C. This does not happen on the next day, 14th January, at which the greater wind speed (up to 10 m/s) and lower ambient temperature cause lower zone temperatures. The wind pattern affects mostly the zones with west and south walls as the direction of the wind is SSW (see Table 3). Therefore, as shown, the temperature of the N-W Zone (4) at 12 p.m. on 13 January is 16°C but on 14 January the temperature is 2°C lower.

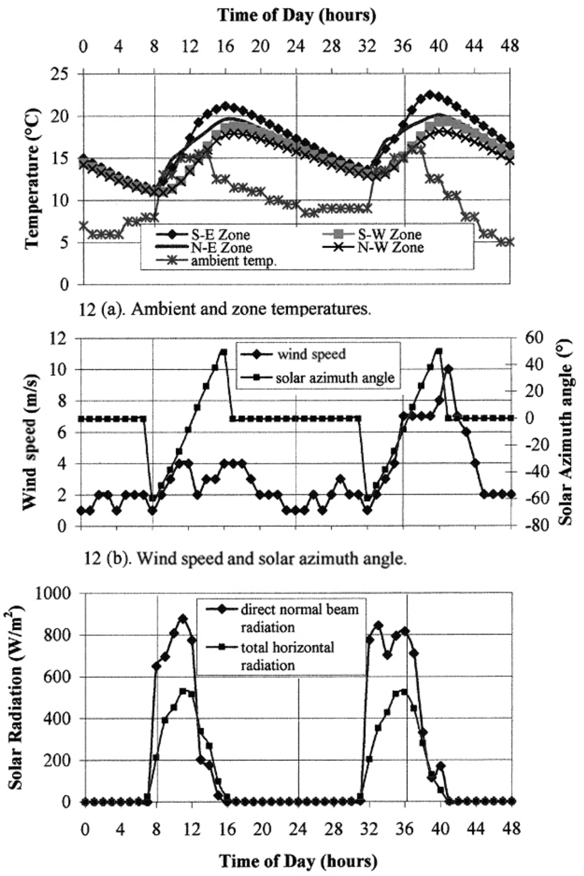

Figure 12. Zone temperatures and respective weather data during 13 and 14 January.

The respective behaviour for summer is shown in Figure 13. During mid July, the sun rises at 5:15 am with a solar azimuth angle of about 120° East. The temperature of the N-E Zone (3) increases sharply because of the direct radiation striking the window on the east side of the building. The direct solar radiation then strikes the south window causing the temperature of the S-E Zone (1) to increase and nearly reach the temperature of the N-E Zone (3). Also, for these days, during the afternoon hours, haze and clouds obstruct the direct radiation thus the temperature of the S-W Zone (2) does not show any sudden increase. The lower temperature of this zone, as indicated in Figure 13(a), is also due to the higher wind speed that prevails in the afternoon hours of the summer as compared with the morning wind speed.

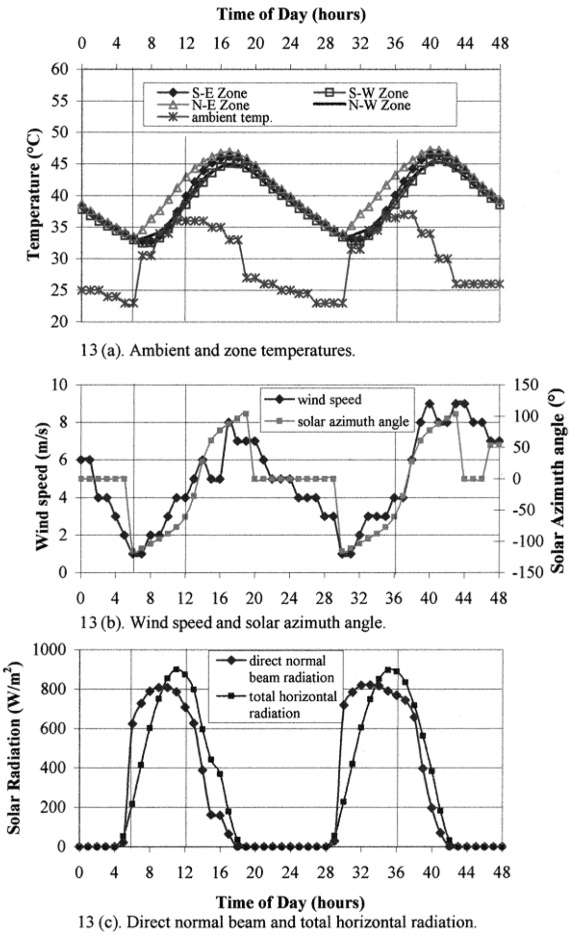

Figure 13. Zone temperatures and respective weather data, during 16 and 17 July.

The annual cooling and heating loads arising from every zone for the non-insulated house (case A), is indicated in Table 5. These loads are estimated by considering that the room temperature is maintained at 25°C during summer and 21°C during winter.

As it is observed, the cooling load is bigger for the N-E (3) and S-E (1) zones and the heating load is bigger for the N-W (4) and S-W (2) zones where the gains from the environment are smaller. This load distribution is attributed to the weather pattern as outlined above, which shows that east walls receive the highest total radiation followed by the south walls, while in the afternoon, winds blowing at a mean speed of about 5 m/s from the SSW to SW direction, cool the south and west walls.

An analysis of the heat gains and losses arising from basic elements of the model house (case A) is shown in Table 6. As can be observed, the main load is caused by the roof, which is horizontal and not insulated. Concerning the wall orientation, the heat gains are higher for the east and south external walls which receive and transfer inside the house more solar heat during the early hours of the summer days. The large difference observed between the load of the external east and west walls is due to the fact that the east wall warms earlier during the morning hours and maintains its temperature throughout the day. The west wall is cool in the morning hours and is exposed to the afternoon winds, which usually blow during the summer, thus keeping the wall temperature low. Also, the reduced solar radiation in the afternoon hours due to the formation of clouds and haze does not cause a sudden rise in the west wall temperature and load.

The heating load is higher for the north and west external walls since they receive and transfer less solar heat during the winter days.

Based on the above results it can be concluded that special attention should be paid to the roof and the east wall construction and insulation as they contribute to a higher cooling load.

Table 5 Annual zone cooling and heating loads

Zone	Cooling load per year		Heating load per year	
	kWh at 25°C	Percentage of total load	kWh at 21°C	Percentage of total load
S-E (Z1)	11,125	26.3	3,612	22.6
S-W (Z2)	9,855	23.3	4,227	26.3
N-E (Z3)	11,715	27.7	3,694	23.1
N-W (Z4)	9,605	22.7	4,479	28.0
Totals	42,300	100	16,022	100

Table 6 Heat gains and losses per year, arising from the external walls and roof of the model house (case A)

House Element	Heat Gains	Heat losses
	(kWh/m^2 per year) at 25°C	(kWh/m^2 per year) at 21°C
External East Wall	61.3	12.7
External South Wall	46.6	14.8
External West Wall	38.1	20.6
External North Wall	43.2	18.5
Roof	80.2	32.6

CONCLUSIONS

The weather data, contained in the TMY are analysed with respect to the radiation falling on every wall facing the four orientations. Collective results for the whole year indicate that the east wall receives 30% more total radiation than the south wall and the west wall receives only 20% of the beam radiation of the east wall. The diffuse radiation for the afternoon is about the same for all walls. In the morning hours the east wall receives about 75% more diffuse radiation than the south wall. The total radiation per year received on a horizontal surface is approximately equal to that received on the east surface. Therefore the most important heat gain surfaces of a building are the horizontal and east.

The temperature falls within two close bands, one rather cold for the months of December, January, February and March, and another very hot for the months of June, July, August and September. The rest of the months offer intermediate temperatures, which are rather comfortable. The coldest temperature recorded in the TMY file occurs in January and is about 6°C, whilst the highest is about 36°C in July. The daily variation in temperature for the hot months is about 14°C and for the cold months about 10°C.

The mean wind speed of the year is 2.7 m/s for the morning hours and 4.7 m/s for the afternoon hours blowing from SSW.

The mean hourly humidity ratio during a day, for the cold months of a year varies between 5 and 9 gr of moisture per kg of dry air and for the hot months between 6 and 18. The humidity ratio is greatest during the months of June to September. Generally, the humidity ratio is increased during the morning and early night hours of a day.

Three different construction cases were considered for the analysis of a typical Cypriot house. The annual cooling load of these constructions, for keeping the house temperature at 25°C during summer and 21°C during winter is 42,300 kWh, 21,730 kWh and 21,060 kWh per year. The annual heating loads are 16,010 kWh, 3,480kWh and 2,880 kWh per year. For the weather encountered in Cyprus the maximum cooling load of buildings occurs in July and the maximum heating load in January. The monthly saving in loads by using insulation is of the order of 50% for cooling and 75% for heating.

As explained in this paper, the analysis of the weather pattern helps to understand the behaviour of thermal loads of buildings in Cyprus and directs designers to apply measures to lower the thermal loads. According to the findings, special attention should be paid to the roof and the east wall construction and insulation.

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