Summer Thermal and Daylighting Conditions in 19th Century Traditional Buildings of Florina in North-Western Greece

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ABSTRACT: The aim of this paper is to explore the summer thermal and daylighting conditions in traditional buildings of Florina using a typical house. The issues of thermal and visual comfort are approached from two distinct viewpoints: in-situ measurements and computer analysis. The temperature measurements were conducted in the main living spaces of the two levels of the house, throughout the summer using dataloggers. The computer thermal analysis was performed with the Ecotect software. The results of the computer analysis are compared with the recorded air temperature measurements. The daylighting measurements were conducted in the main living spaces of both the ground floor and the upper storey, on a date near the summer solstice at 09:00, 12:00 and 15:00 TST. The daylighting analysis and simulations were conducted using the Ecotect and the Radiance software. The results of these two approaches are compared.

Keywords: Traditional architecture, north-western Greece, summer thermal and visual comfort

1. INTRODUCTION

The traditional architecture of every area is based on the accumulated experience and practice of many centuries and can constitute a continuous source of knowledge. To a large extent, traditional buildings of 19th century in north-western Greece are oriented in such a way that the best possible exploitation of daylight and natural ventilation in the living spaces could be achieved. The large number of windows, in the summer living spaces, aim at the thermal and visual comfort of the users. Architectural elements, such as enclosed open spaces and projections constitute an evolution of the open sunspace and are characteristic examples of using the sun as a light source for the visual comfort of users.

2. GENERAL DATA

2.1 Location

The prefecture of Florina is located in North-Western Greece, close to the prefectures of Kastoria, Kozani and Pella. The town of Florina lies in a mountain valley, which is crossed by a river from East to West. The longitude of the town is 21°23'59'', the latitude is 40°46'58'', and the altitude is 662 m.

2.2 Climatic data

Florina has a cold continental climate, with long, cold, humid winters and short, warm, and dry summers. The mesoclimate of the area is affected by the presence of large mountainous volumes. The climate is characterised by significant inter-seasonal and diurnal differences, due to the high latitude and the morphology of the area. For a more detailed presentation of the summer climatic conditions in Florina, refer to [1].

2.3 Description of the typical house

From a sample of 40 remaining houses, 4 houses, which are still occupied, were chosen for monitoring (air temperature and daylighting levels measurements). Due to the restricted size of this paper, only the results of the study, which involve one of the examined houses, will be presented.

The house has an eastern orientation. It is a large mansion with inner *sofa* of the 19th Century and is characterised by heavy mass construction (60-cm thick stone walls) on the ground floor, except for the main façade of the building. (Fig. 1) The upper storey is constructed with lightweight wooden frame walls filled with adobe bricks (*tsatmas*). The thermophysical characteristics of these walls are presented in [1], [2].

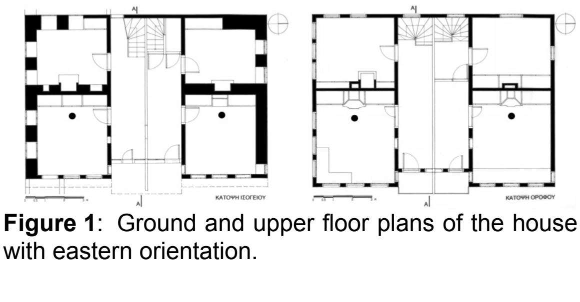

Figure 1: Ground and upper floor plans of the house with eastern orientation.

3. TEMPERATURE MEASUREMENTS

3.1 Description of the field study

The measurements were performed with Gemini Tinytag ultra dataloggers during the summer months (June to September). In this paper, only the measurements for the period when the highest environmental temperatures were recorded (July 30th to August 4th, 2005) will be presented.

3.2 Aims of the field study

The main aim of the in-situ measurements was to examine the effect of the different construction elements, namely the heavyweight structure of the ground floor and the lightweight structure of the upper storey, on the internal air temperature fluctuation. Furthermore, the measurements aim at investigating the effect of orientation on the internal air temperatures. For this reason, dataloggers were placed in the southern and the northern spaces of the house. Finally, it was the intention of the author to investigate the ways in which summer thermal comfort was achieved at the end of the 19th century.

3.3 Air temperature measurements

During the period from July 30th to August 4th, the ambient air temperatures in Florina were high. The minimum temperatures ranged from 19.8 ºC to 23.1 ºC, while the maximum temperatures ranged from 29.7 ºC to 33 ºC. The diurnal range was between 9.8 and 11 degrees. In the south eastern main living space of the ground floor, the minimum temperatures ranged from 23.1 ºC to 25.3 ºC, while the maximum temperatures ranged from 25.3 ºC to 27.5 ºC. The diurnal range was between 1.5 and 2 degrees. In the north eastern main living space of the ground floor, the minimum temperatures ranged from 25.1 ºC to 27.2 ºC, while the maximum temperatures ranged from 27.2 ºC to 29.1 ºC. The diurnal range was between 2 and 2.5 degrees. In the south eastern main living space of the upper storey, the minimum temperatures ranged from 21 ºC to 24.7 ºC, while the maximum temperatures ranged from 30.9 ºC to 33.3 ºC. The diurnal range was between 8.5 and 11 degrees. In the north eastern main living space of the upper storey, the minimum temperatures ranged from 24.1 ºC to 26.9 ºC, while the maximum temperatures ranged from 28.3 ºC 31 ºC. The diurnal range was between 4and 5 degrees. (Fig. 2)

It can be seen that the air temperatures of the ground floor rooms have a smaller diurnal range compared to the upper storey ones. It is obvious that the stable air temperatures of the ground floor are the direct effect of the high thermal inertia of the 60-cm thick adobe walls. In the upper storey, the air temperatures of the rooms follow the outside air temperature variation more closely. The steep rise and drop of the air temperatures in the upper storey indicate that due to its low thermal inertia, the space heats up during the day and cools down very quickly in the evening. (Fig.2) Nevertheless, the temperatures of the northern main living space do not rise as much as those of the southern one. This is a direct effect of the orientation and the thermal loads of the roof.

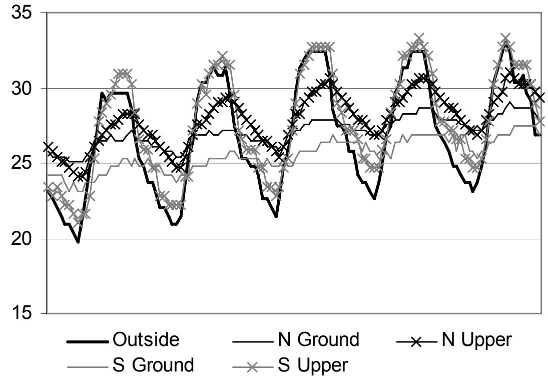

Figure 2: Air temperature measurements in the house.

4. THERMAL ANALYSIS USING COMPUTER MODELLING

4.1 Thermal Modelling

The thermal analysis calculations were performed with the Ecotect software v5.2 [3]. A model of the monitored house was constructed. Two basic wall configurations were created and used appropriately: a thick stone wall and a lightweight timber-frame wall.

4.2 Aims of the computer modelling

The basic aim of the computer modelling was to compare the modelled air temperatures with the ones, which were actually measured in the spaces of the monitored house. For this reason, the internal air temperatures, which were recorded during the period from July 30th to August 4th, 2005, were plotted against the modelled internal air temperatures that the computer software generated for a representative midsummer day (August, 12th). Even though the dates do not coincide, the ambient diurnal temperature range used by the computer software is very close to the actual temperatures, which were measured during the period in question. The comparison of the modelled and the measured data is very important, as it can define the extent to which the chosen software can be used to analyse the thermal behaviour of traditional buildings of Florina.

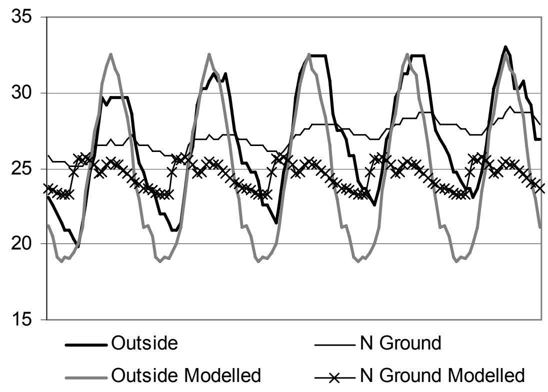

Figure 3: Modelled and measured air temperatures in the northern living space of the ground floor.

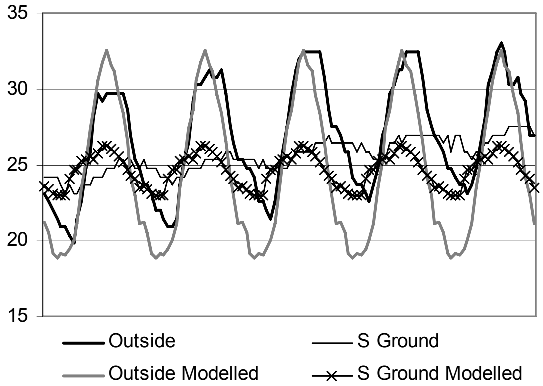

Figure 4: Modelled and measured air temperatures in the southern living space of the ground floor.

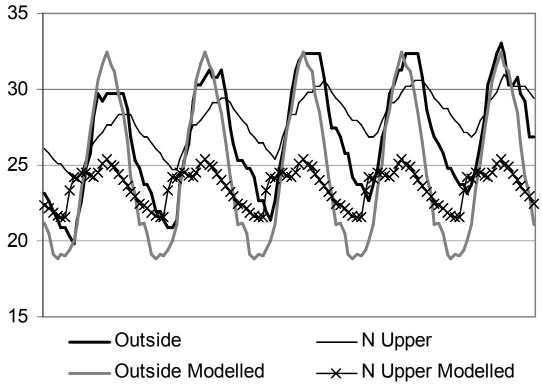

Figure 5: Modelled and measured air temperatures in the northern living space of the upper storey.

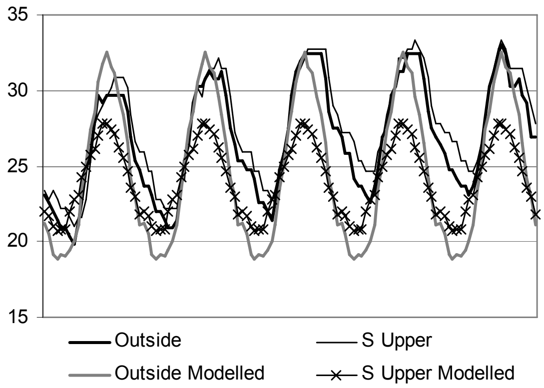

Figure 6: Modelled and measured air temperatures in the southern living space of the upper storey.

In all the graphs, the minimum air temperatures, which occur during the night, are lower in the model than in reality. This could be the result of the lower night-time environmental temperatures of the weather data file, which was used by the software.

In both rooms of the ground floor (Figs. 3-4), the diurnal temperature range of the actual measurements is smaller than the modelled one. Furthermore, both the highest and the lowest air temperatures occur earlier in the model, than in the actual house. All the above-mentioned discrepancies can be linked to the effect of thermal mass. So, it is possible that the software does not take fully into account the effect of the substantial thermal mass of the ground floor of the building.

In the rooms of the upper storey (Figs. 5-6), the modelled and the measured air temperatures demonstrate the same diurnal variation. Nevertheless, the measured air temperatures are significantly higher than the modelled ones by about 5 ºC. It is possible that the thermal calculations under-estimate the effect of the roof zone on the thermal loads of the upper storey rooms.

5. DAYLIGHTING MEASUREMENTS

5.1 Description of the field study

The measurements were performed with a Gossen Mavolux 5032C digital luxmeter, on a date near the summer solstice (June 23rd, 2005). The daylighting measurements were conducted in the main living spaces of both the ground floor and the upper storey. The time of the measurements, the sky illuminance values and the cloud cover fraction are presented in Table 1.

Table 1: Details concerning the measurements.

LCT	TST	Mean sky illuminance	Cloud cover fraction
10:35	09:00	90165 lux	0/8
13:35	12:00	108600 lux	0/8
16:35	15:00	83450 lux	0/8

Abbreviations: LCT: Local Clock Time, TST: True Solar Time

5.2 Daylighting measurements in the upper storey

At 09:00 TST (10:35 LCT), daylighting conditions in the living spaces of the upper storey were very good (Fig. 7). The minimum value for the south-eastern main living space was 75 lux, the maximum value was 3350 lux, and the average was 1170 lux. The minimum value for the north-eastern main living space was 180 lux, the maximum value was 7350 lux, and the average was 2070 lux. The average value for the south-western secondary living space was 550 lux. The average value for the north-western secondary living space was 315 lux.

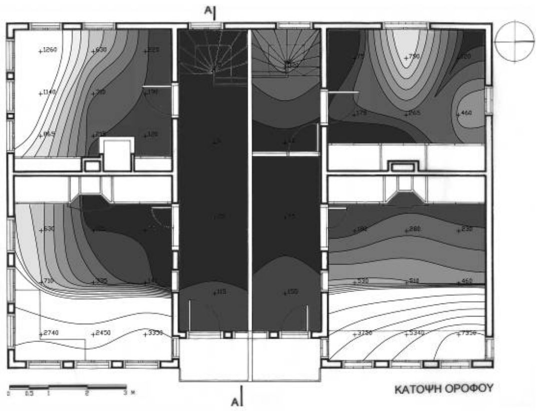

Figure 7: Upper storey. Daylighting measurements at 09: 00 TST.

At 12:00 TST (13:35 LCT), daylighting conditions in the living spaces of the upper storey were also satisfactory (Fig. 8). The minimum value for the south-eastern main living space was 70 lux, the maximum value was 1140 lux, and the average was 525 lux. The minimum value for the north-eastern main living space was 65 lux, the maximum value was 940 lux, and the average was 345 lux. The average value for the south-western secondary living space was 530 lux. The average value for the north-western secondary living space was 280 lux.

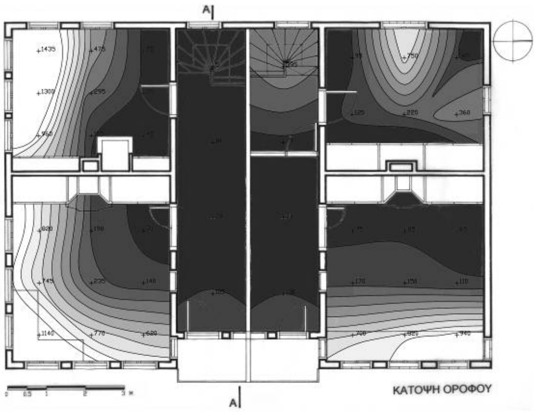

Figure 8: Upper storey. Daylighting measurements at 12: 00 TST.

Finally, at 15:00 TST (16:35 LCT), daylighting conditions in all the spaces of the upper storey were very good (Fig. 9). The minimum value for the south-eastern main living space was 190 lux, the maximum value was 1430 lux, and the average was 680 lux. The minimum value for the north-eastern main living space was 90 lux, the maximum value was 835 lux, and the average was 390 lux. The average value for the south-western secondary living space was 995 lux. The average value for the north-western secondary living space was 1235 lux.

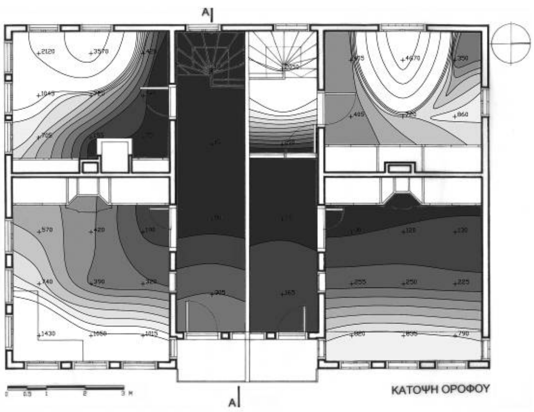

Figure 9: Upper storey. Daylighting measurements at 15: 00 TST.

5.3 Daylighting measurements in the ground floor

At 09:00 TST (10:35 LCT), daylighting conditions in the main living spaces of the ground floor were good, whereas in the secondary rooms, the conditions were poor (Fig. 10). The minimum value for the south-eastern main living space was 75 lux, the maximum value was 1250 lux, and the average was 310 lux. The minimum value for the north-eastern main living space was 360 lux, the maximum value was 2460 lux, and the average was 1175 lux. The average value for the south-western secondary living space was 25 lux. The average value for the north-western secondary living space was 125 lux.

Figure 10: Ground floor. Daylighting measurements at 09:00 TST.

At 12:00 TST (13:35 LCT), daylighting conditions in the main living spaces of the ground floor were good, whereas in the secondary rooms, the conditions were poor (Fig. 11). The minimum value for the south-eastern main living space was 30 lux, the maximum value was 370 lux, and the average was 115 lux. The minimum value for the north-eastern main living space was 80 lux, the maximum value was 780 lux, and the average was 320. The average value for the south-western secondary living space was 30 lux. The average value for the north-western secondary living space was 120 lux.

Figure 11: Ground floor. Daylighting measurements at 12:00 TST.

Finally, at 15:00 TST (16:35 LCT), daylighting conditions in the main living spaces of the ground floor were good, whereas in the secondary rooms, the conditions were poor (Fig. 12). The minimum value for the south-eastern main living space was 40 lux, the maximum value was 610 lux, and the average was 170 lux. The minimum value for the north-eastern main living space was 60 lux, the maximum value was 640 lux, and the average was 275 lux. The average value for the south-western secondary living space was 10 lux. The average value for the north-western secondary living space was 120 lux.

Figure 12: Ground floor. Daylighting measurements at 15:00 TST.

6. DAYLIGHTING ANALYSIS USING COMPUTER MODELLING

6.1 Description of the computer analysis

The daylighting analysis was performed with the Ecotect v5.2 [3] and Radiance [4] software. Ecotect was used to export the daylighting analysis grid to Radiance. The results of the Radiance simulation were then reinserted into Ecotect and the daylighting analysis figures were obtained from there. The isolux contours have a range from 0 lux to 1000 lux, with a step of 100 lux.

The model of the house was constructed with great detail, concerning the design of the windows. The window openings were extruded in order to account for the shading, which is caused by the depth of the walls. Furthermore, the frames of the windows were designed and extruded in order to obtain a shading coefficient close to that of the windows of the real house. (Fig. 13) The interior walls of the model were assigned colours similar to those, which were found in the actual building. The furniture of the rooms of the house was omitted from the model.

All the calculations were done for clear sky conditions (0/8). The working plane for both the ground and the upper was assumed at 100 cm from the floor, similar to the in-situ measurements.

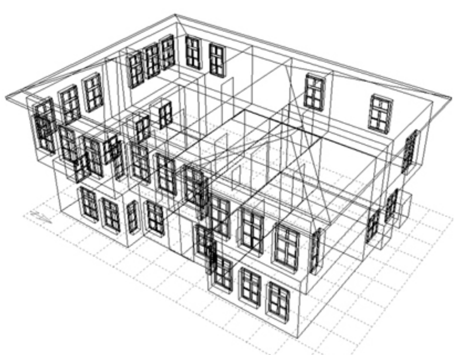

Figure 13: 3D model constructed with Ecotect. [3]

6.2 Daylighting modelling in the upper storey

At 09:00 TST (10:35 LCT), daylighting conditions in the living spaces of the upper storey are fairly good. The average value for the whole level is 2090 lux, and values near the eastern and southern windows well exceed 1000 lux. (Fig. 14)

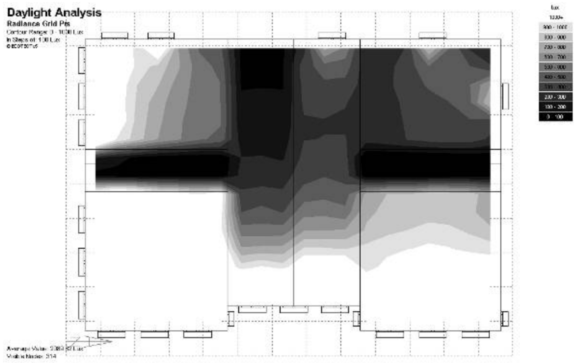

Figure 14: Upper storey. Daylighting analysis at 09:00 TST with Ecotect [3] and Radiance [4].

At 12:00 TST (13:35 LCT), daylighting conditions in the living spaces of the upper storey are also good. The average value for the whole level is 590 lux, but values near the southern windows well exceed 1000 lux. (Fig. 15)

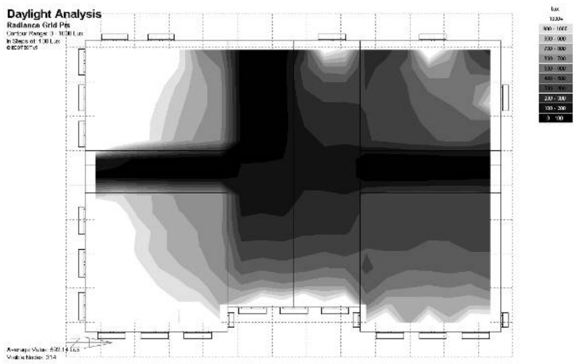

Figure 15: Upper storey. Daylighting analysis at 12:00 TST with Ecotect [3] and Radiance [4].

At 15:00 TST (16:35 LCT), daylighting conditions in the living spaces of the upper storey are good. The average value for the whole level is 650 lux, but values near the western windows exceed 1000 lux.

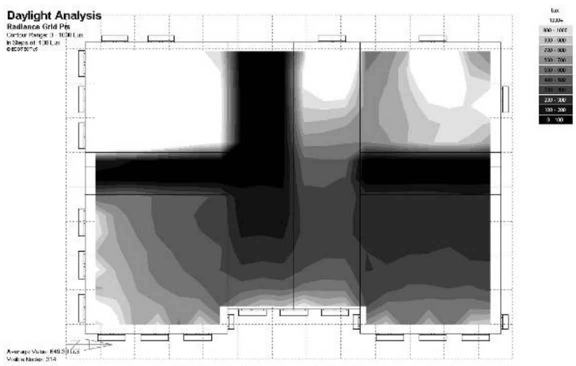

Figure 16: Upper storey. Daylighting analysis at 15:00 TST with Ecotect [3] and Radiance [4].

6.3 Daylighting modelling in the ground floor

At 09:00 TST (10:35 LCT), daylighting conditions in the living spaces of the ground floor are fairly good. The average value for the whole level is 945 lux, and values near the eastern and southern windows exceed 500 lux. (Fig. 17)

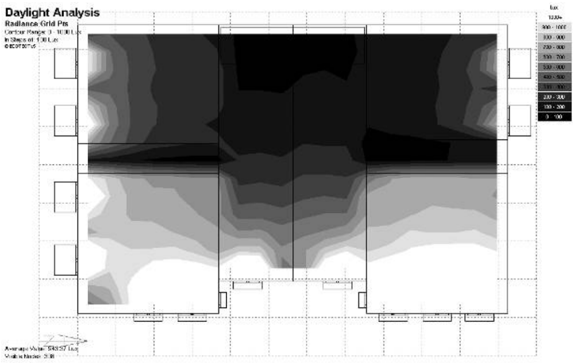

Figure 17: Ground floor. Daylighting analysis at 09:00 TST with Ecotect [3] and Radiance [4].

At 12:00 TST (12:35 LCT), daylighting conditions in the living spaces of the ground floor are fairly good. The average value for the whole level is 365 lux, but values near the southern windows exceed 500 lux. (Fig. 18)

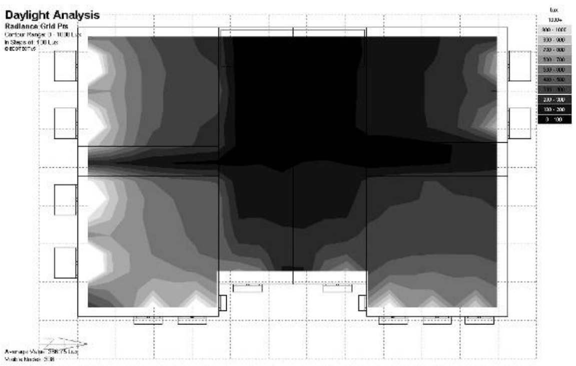

Figure 18: Ground floor. Daylighting analysis at 12:00 TST with Ecotect [3] and Radiance [4].

Finally, at 15:00 TST (15:35 LCT), daylighting conditions in the living spaces of the ground floor are fairly poor. The average value for the whole level is 230 lux. (Fig. 19)

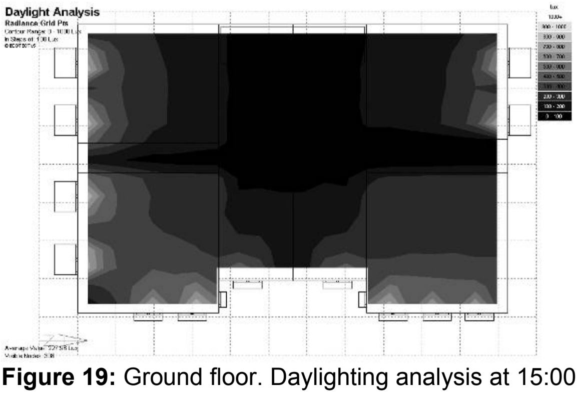

Figure 19: Ground floor. Daylighting analysis at 15:00 TST with Ecotect [3] and Radiance [4].

7. CONCLUSION

The results of the air temperature measurements and the thermal analysis clearly demonstrate the effect of the high thermal inertia of the ground floor and the effect of the low thermal inertia of the upper storey, as well as the effect of orientation. The rooms of the ground floor demonstrate a small diurnal air temperature range, whereas the temperatures on the upper storey follow the outside air temperature variation more closely.

The thermal behaviour of the heavy ground floor and the light upper storey structure explains why the winter rooms were located in the ground level, while the upper level comprised of the summer living spaces. The design of the summer living spaces along with the creation of many windows and openings helped achieve efficient natural ventilation and night cooling. This explains why the upper storey was a preferred location during the summer nights.

The results of the daylighting measurements and the computer modelling are fairly close. A strong agreement was found concerning the distribution of daylight in the living spaces, which is presented by isolux contour lines. Furthermore, the daylighting levels in the in-situ measurements and the computer analysis were found to be very similar. Minor deviations can be attributed to the presence of furniture in the actual building, as well as to issues of terrain and adjacent buildings.

The daylighting analysis clearly demonstrates that daylighting conditions on the upper storey are very good, whereas in the ground floor are considerably worse. This fact is due to a compromise between thermal and visual comfort. The winter spaces have thick walls and few openings in order to minimise the thermal losses during the cold period. As a result, the amount of daylight, which reaches the winter spaces, is significantly reduced.

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