Study on the thermal and visual performance of eleven residential buildings

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ABSTRACT

The thermal and visual performance of eleven residential building has been studied during the architectural design. In order to evaluate the performance of the building a number of thermal and visual simulations have been done. The outputs of thermal simulations are the monthly values of heating and cooling load. Concerning the visual performance the calculations outputs are spatial distribution of the daylight factor, luminance and illuminance pictures. The final architectural design and the proposed interventions results to low energy consumption for cooling and heating too.

1. INTRODUCTION

The aim of the study is to improve the thermal comfort conditions and minimize the energy consumption for cooling and heating load in eleven residential buildings. An additionally target is the achievement of visual comfort. The building site is in the region of Tirintha, in Peloponnese.

The required thermal simulation calculations have been done using the precise thermal simulation software TRNSYS. The calculations have been done for a whole meteorological year and with hourly time step and it have been taken into account the given architectural design and the topography. Concerning the daylight calculations the DAYLIGHT and RADIANCE software have been used.

The architectural design and the study aim to:

- Adaptation of the buildings to the surrounding environment - minimum intervention in the natural setting.
- Demand for both permanent and seasonal occupation.
- Private and public interior zoning.
- Smooth transition between interior-exterior spaces.
- The residences to be part of a unified morphological complex.
- The achievement of thermal and visual comfort.
- The minimization of buildings' energy consumption for heating and cooling.
- Design to comply with the very tight Greek Building Regulation.
- Commercial viability.

2. ARCHITECTURAL DESIGN STRATEGY

The architectural design strategy is given below:

- Bungalows organised in two levels in order to be adapted to the site's topography.
- SW orientation for the buildings to be merged with the landscape following the site's contours.
- The use of local materials such as stone and wood (Picture 1). Wherever render coating is used is mixed with earth colours.
- Reduction of openings' surface (<30% elevation surface, based on Greek Building Regulation).
- Night ventilation with the use of clerestories on the NE face.
- Air flow throughout the building with the use of openings on N/S direction.
- Use of SE and SW shading devices (wooden pergolas).

Picture 1: 3D representation of the residential buildings.

3. HEATING AND COOLING LOADS

3.1 Input Climatologic Data

In order to evaluate thermal and cooling loads, hourly values of global solar radiation and diffuse solar radiation on the horizontal, air temperature, relative humidity, wind speed and wind direction were used. The required inputs are representative for Tirintha' s region.

3.2 Thermal zones

The complex consists of eleven residential buildings and that can be seen in Figure 1 and Picture 2. There are three building types A, B, C.

In order to estimate the energy consumption for each residence, each one of the three building types (A, B, C) was separately studied.

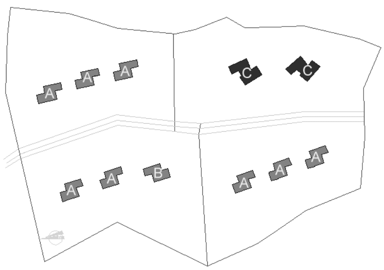


Figure 1: Topographic plan showing the three building types.

Picture 2: 3D representation of the eleven residential buildings.

Table 1: The thermal zones for each building type.

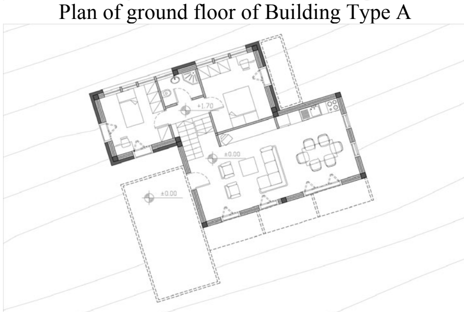
Zone	Use
Z1	General Use
Z2	Living room
Z3	Master Bedroom
Z4	Bedroom
Z5	Bathroom
Z6*	Entrance, hall

*Thermal zone Z6 exists only to building type C.

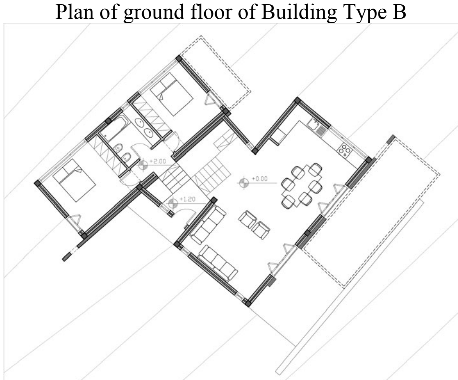
Each building was separated in five or six thermal zones (Table 1, Fig. 2). It has been assumed that all the zones are heated and air-conditioned.

Figure 2 illustrates the architectural plans of

Plan of ground floor of Building Type A



Plan of ground floor of Building Type B



Plan of ground floor of Building Type C

Figure 2: Architectural plans of the ground floor.

Table 2: Set point temperatures for heating and cooling.

	Temperature (^0C)	Schedule
Heating	20	00: 00– 24:00
Cooling	26	07:00 – 23:00

the ground floor of each building type and the thermal zones that each one is separated.

3.3 Set point temperatures

Table 2 illustrates the comfort temperatures during the summer and the winter.

The internal gains were assumed negligible, as the objective is the optimisation of the building skin concerning its energy performance.

The infiltration has been assumed 0.8ACH, in order to meet the Greek building insulation code. The U – values of the building elements in the base case are in accordance with the requirements of the Greek building insulation code too.

3.4 Heating and cooling loads

The residences' thermal and cooling loads have

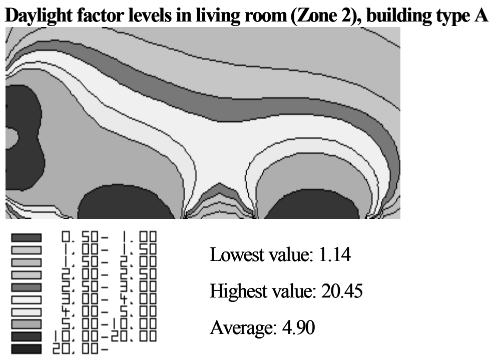


Figure 3: Spatial distribution of the daylight factor for the living room of residential building A.

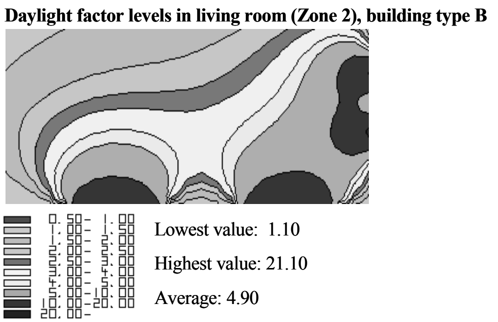


Figure 4: Spatial distribution of the daylight factor for the living room of residential building B.

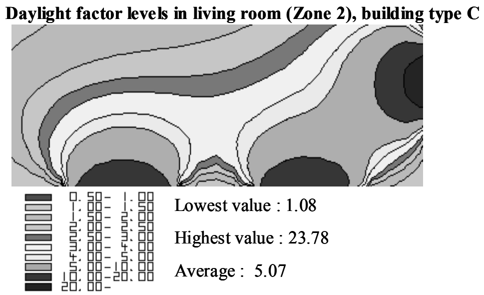


Figure 5: Spatial distribution of the daylight factor for the living room of residential building C.

been calculated for the scenarios that are given in Appendix A.

The calculated scenarios concern the insulation, the glazing type, external shading, the ability of natural ventilation, the opening size, the possibility of installation of ceiling fans and a heat recovery system.

The annual values of heating and cooling load for each scenario are given in Appendix B.

4. QUALITY OF DAYLIGHT

The levels and quality of daylight within the interior of the buildings has been studied for the following areas:

1. The living room of each residence (Figs. 3, 4, 5).
2. The master bedroom of each residence.
3. The bedroom of each residence.

The calculation of daylight distribution has been calculated with the use of the software tool DAYLIGHT. For the specific tool an overcast sky has been used and the results are the spatial distribution of the daylight factor. For the calculations it has been assumed that the reflectivity for the wall, floor and ceiling surfaces is 0.5, 0.2 and 0.7 respectively.

Suggestively, the daylight factor distribution contour diagrams that correspond to the living rooms of each residential building are given. Also the luminance and illuminance values corresponding to the living room of type B are given too. The luminance calculations (Pictures 3, 4, 5) have been done with the RADIANCE software assuming clear sky, while the illuminance calculations (Pictures 6, 7, 8) have been done with the same software assuming a totally overcast sky.

The calculations have been done for scenario K13 (Appendix A).

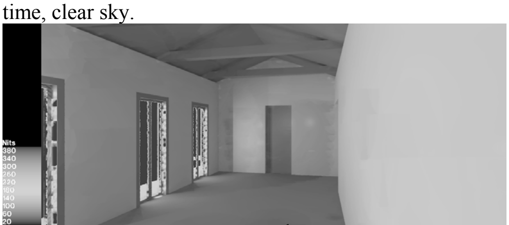
As it comes from the calculation results quality of daylighting is acceptable even with the worst ambient conditions.

5. CONCLUSIONS

As a general conclusion we could say that the architectural design aims, are in coordination with those of the energy assessment study, while the architectural proposal was part of a typical architectural study without exceptional applications.

The final architectural design as well as the buildings' high thermal mass determines the

Picture 3: Luminance levels, 21st of June, 12:00 solar time, clear sky.



Picture 4: Luminance levels, 23rd of September, 12:00 solar time, clear sky.

Picture 5: Luminance levels, 21st of December, 12:00 solar time, clear sky.

Picture 6: Illuminance levels, 21st of June, 12:00 solar time, totally overcast sky.

Picture 7: Illuminance levels, 23rd of September, 12:00 solar time, totally overcast sky.

Picture 8: Illuminance levels, 21st of December, 12:00 solar time, totally overcast sky.

usefulness of night ventilation and ceiling fans' installation during the summer, since the energy consumption for cooling is reduced. Also, the external shading and Low E glazing result to lower energy consumption for cooling too. The reduction of cooling load compared to the base case scenario, which is referred to a typical construction, is approximately 65% or 24 kWh/m^2.

Also, the building skin allows the right use of solar gains and the reduction of thermal losses during the winter, since the energy consumption for heating is minimized. More specifically, the improved thermal insulation, the usage of a waste heat recovery ventilator and Low–E glazing reduce the heating load by 30% or 18.5 kWh/m^2 approximately.

Finally concerning the quality of daylight, the calculation results show that daylight levels are high enough even with the worst ambient conditions (totally overcast sky), while the calculated luminance levels have a small spatial variation even assuming a clear sky.

REFERENCES

TRNSYS (Version 15), A Transient System Simulator Program, Solar Energy Laboratory, University of Wisconsin, Madison, USA.

RADIANCE, Synthetic Imaging System, Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley, USA.

APPENDIX A. TABLE OF SCENARIOS

Scenario	Description	Comments	Type A	Type B	Type C
K1	Basic Scenario	The U – values of the building skin elements has been assumed that are in accordance with Greek thermal legislation code. The opening frame has been assumed as wooden and the U – value as 3.5 Watt/m^2/^{0}C. The frame has been assumed as 15% of each opening. The glazing has been assumed as clear, double with gap of 10mm filled with air. The relative technical data are: Visual transmissivity: 82% Solar transmissivity: 73% U value: 2.7 Watt/m^2/^{0}C g – value: 0.77	✓	✓	✓
K2	External shading	External shading of master bedroom openings – shading factor 50%	✓	✓	
K3	Increased roof insulation	Thickness of roof insulation: 10cm of extruded polystyrene (thermal conductivity: 0.030 Watt/mºK).	✓	✓	✓
K4	Increased wall insulation	Thickness of brick wall insulation: 6 cm of extruded polystyrene (thermal conductivity: 0.030 Watt/mºK). Thickness of concrete element insulation: 4 cm extruded polystyrene (thermal conductivity: 0.032 Watt/mºK).	✓	✓	✓
K5	Combined scenario (K3 & K4)	Increased roof and wall insulation	✓	✓	✓
K6	LowE glazed units	The glazing has been assumed as clear, double with gap of 12 mm filled with air. The relative technical data are: Visual transmissivity: 75% Solar transmissivity: 54% U value: 2.1 Watt/m^2/^{0}C g – value: 0.60	✓	✓	✓
K7	Combined scenario (K3 & K4 & K6)	Increased roof and wall insulation and Low – E glazing	✓	✓	✓
K8	Night ventilation	5 ACH, in bedroom and master bedroom	✓	✓	✓
K9	Reduction of openings’ surface	Reduction of west openings’ surface by 10%.	✓	✓	
K10	External shading	External shading of west openings – shading factor 50%	✓	✓	
K11	K2&K7&Ceiling fans		✓	✓	✓
K12	K2&K7&K8&Ceiling fans		✓	✓	✓
K13	K12&dormer windows		✓	✓	
K14	K13&Heat Recovery		✓	✓	✓
K15	K13& increased walls’ thermal insulation		✓	✓	
K16	K6&K8&Ceiling fans& increased walls’ thermal insulation				✓

APPENDIX B. HEATING – COOLING LOADS

Results are given in kWh/m^2.

Scenarios	Building type A		Building type B		Building type C	
	Heating Loads	Cooling Loads	Heating Loads	Cooling Loads	Heating Loads	Cooling Loads
K1	53.30	33.86	53.16	38.30	67.15	36.85
K2	55.31	31.08	55.66	34.88		
K3	48.24	32.55	47.33	36.62	61.03	34.58
K4	48.74	33.55	48.04	38.14	60.86	36.43
K5	43.62	32.09	42.21	36.46	54.67	34.20
K6	50.53	26.75	51.36	30.64	65.46	29.85
K7	40.73	24.58	40.35	28.55	52.94	26.97
K8	53.30	28.84	53.16	31.52	67.15	31.27
K9	53.39	32.71	53.25	37.15		
K10	56.16	31.32	57.62	32.03		
K11	40.72	13.25	42.27	15.26	52.93	19.73
K12	53.30	9.12	42.27	10.13	52.94	14.13
K13	40.75	13.84	41.97	13.64		
K14	28.76	11.09	32.59	13.79	40.85	13.73
K15	37.30	9.44	35.11	13.47		
K16					45.77	13.54
	Percentage of energy reduction	Percentage of energy reduction	Percentage of energy reduction	Percentage of energy reduction	Percentage of energy reduction	Percentage of energy reduction
K1						
K2	3.77%	-8.23%	4.70%	-8.92%		
K3	-9.49%	-3.87%	-10.97%	-4.38%	-9.11%	-6.16%
K4	-8.55%	-0.94%	-9.63%	-0.40%	-9.36%	-1.13%
K5	-18.15%	-5.23%	-20.59%	-4.81%	-18.59%	-7.20%
K6	-5.19%	-21.01%	-3.38%	-20.01%	-2.51%	-18.99%
K7	-23.58%	-27.43%	-24.10%	-25.45%	-21.16%	-26.80%
K8	0.00%	-14.83%	0.00%	-17.69%	0.00%	-15.13%
K9	0.17%	-3.42%	0.18%	-2.99%		
K10	5.38%	-7.51%	8.39%	-16.37%		
K11	-23.60%	-60.88%	-20.48%	-60.14%	-21.17%	-46.47%
K12	0.00%	-73.06%	-20.48%	-73.54%	-21.16%	-61.66%
K13	-23.55%	-59.12%	-21.05%	-64.39%		
K14	-46.03%	-67.26%	-38.68%	-64.00%	-39.16%	-62.74%
K15	-30.01%	-72.14%	-33.94%	-64.84%		
K16					-31.84%	-63.24%

APPENDIX C. GRAPHS

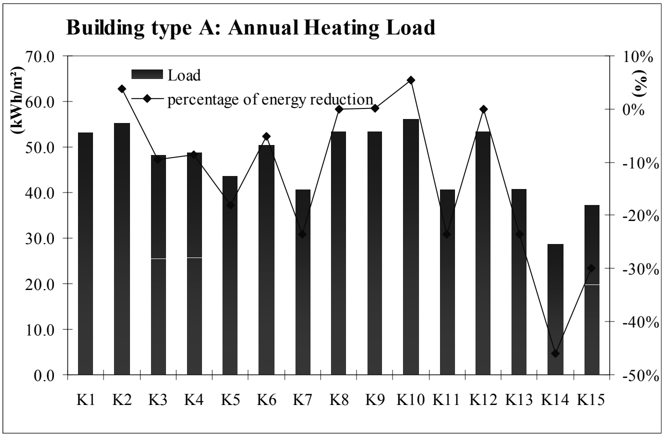


Figure 6: Impact of each scenario on the heating load of building type A.

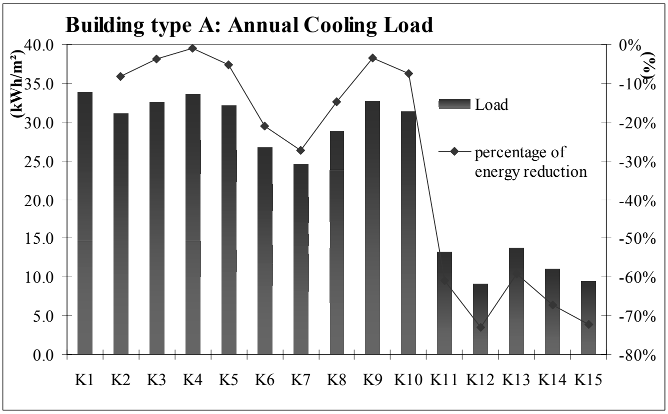


Figure 7: Impact of each scenario on the cooling load of building type A.

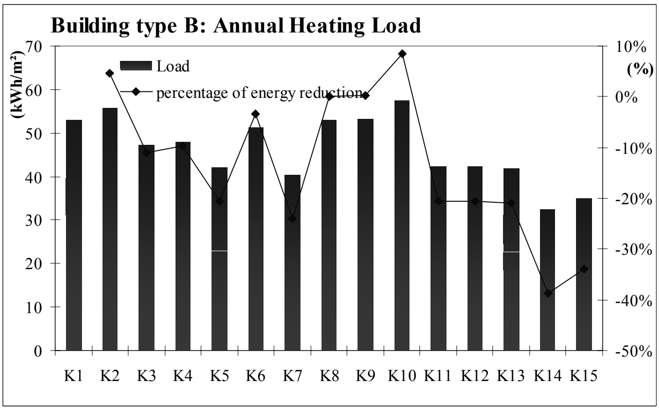


Figure 8: Impact of each scenario on the heating load of building type B.

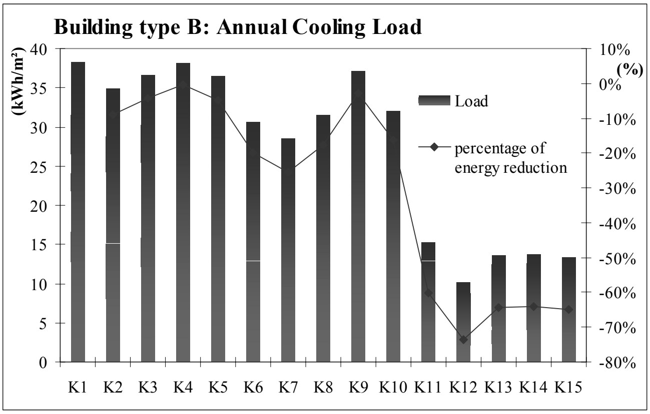


Figure 9: Impact of each scenario on the cooling load of building type B.

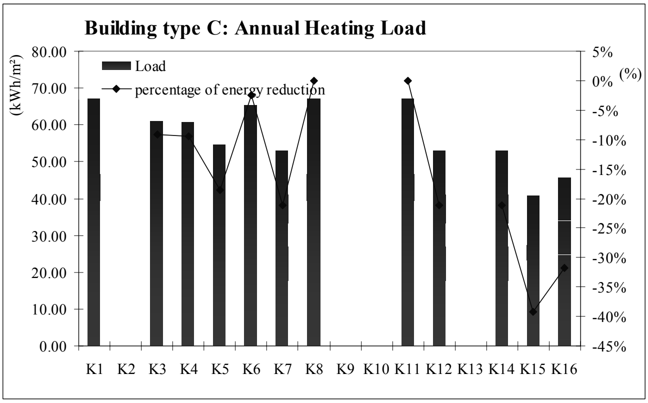


Figure 10: Impact of each scenario on the heating load of building type C.

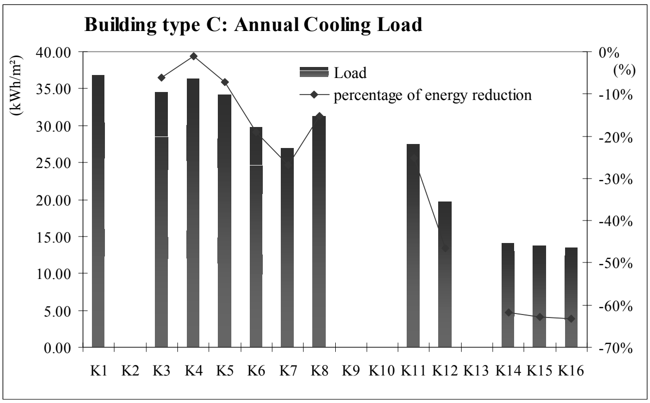


Figure 11: Impact of each scenario on the cooling load of building type C.