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Analysis of the thermal performance of a building design located at 2465 m: Antalya-Saklikent National Observatory guesthouse

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Abstract
This study is based on thermal performance analysis and evaluation of the National Observatory guesthouse with the software SUNCODE-PC. The study is unique owing to its high-altitude site (2465 m) in a remote area, harsh climate (with almost no data available), and functional restrictions of astronomical facilities. The design is thermally evaluated through different modes of application of insulation, materials, types of glazing, window/wall ratios, Trombe walls, winter night insulation, summer ventilation and shading.

1. Introduction
In 1994, Turkey's National Observatory and its guesthouse were proposed to be built in Bakirlitepe-Saklikent, (at 36.85°N latitude and 30.33°E longitude and 2465 m altitude) by the Basic Research Sciences Group of the Scientific and Technical Research Council of Turkey. It is one of the skiing resorts of Antalya with a deserted, massive rock crest. The site fulfilled the best observational criteria among four candidate sites, which were in turn chosen from 17 possible sites after one to two seasonal measurements [1].

The project consists of two observatory buildings for 40 and 150 cm diameter telescopes and a guesthouse for the accommodation of researchers. The factors described under the topic ‘Design Criteria’ governed the considerations of utilization of solar energy in the guesthouse. After the first phase of the design stage, thermal analysis and evaluation of the proposed building is conducted. The construction of the buildings was completed in 1997 and the building is in use from that time on (Fig. 1). The information given in this paper does not produce any new rules or guidelines for passively heated buildings built under normal climatic conditions and at moderate altitudes. It presents the design criteria, thermal analysis, and evaluation of the design of the guesthouse under very special conditions. The lack of previous studies for similarly harsh climates forced the authors to analyze extraordinary solutions like metal-Trombe walls. Different alternatives are discussed in comparative form. The authors hope that such a presentation will be a contribution to fill the gap for the prediction of the thermal performance of special-purpose buildings, under coarse climates at high altitudes.

Fig. 1. Guesthouse of TÜBTAK National Observatory.

2. Design criteria

The environmental and functional restrictions of the buildings due to the characteristics of astronomical observation can be summarized as follows:

• the astronomical observations require a completely clear, dark, stable and clean environment, and so the building needed to be specially designed not to produce any smoke, dust or light.

• The guesthouse should not radiate any direct electromagnetic wave in the thermal or visible range towards the observatory during the observation period. Hence, heat radiation at night time had to be strictly avoided.

• The guesthouse, when in use, has to serve as a comfortable building. During wintertime, snow closes the access roads and blocks out the site from the rest of the world. When the building is turned off during this season, the mechanical and electrical equipment may be adversely affected by harsh climatic conditions, hence, internal temperatures should be maintained above the freezing point.

• Due to the occasional usage of the building, manual control and maintenance should be minimized.

• The astronomers sleep and rest during daytime. Therefore, the bedrooms should not receive direct sunlight for the comfort of the occupants.

2.1. The functions and description of the building

The activities in the building are divided into three categories. The first one is technical, such as preparing and planning of the observation, data collection and analysis, which takes place through the day and nighttime. A computer room and a seminar/meeting room were provided for this function. The second is the accommodation of astronomers and technical staff, hence, seven bedrooms, dining room and rest rooms were proposed. A workshop was provided for the third activity, which is the maintenance and repairing of some parts of the telescope. Two-story building has a total area of 720 m2 (Fig. 2).

Fig. 2. Ground- and first-floor plan of TÜBTAK National Observatory guesthouse.

The highly insulated building is earth bermed from the northern side and has openings only on the southern façade. A sloped window, constructed in front of the south wall, forms a greenhouse on the ground floor. The glazing extends to the first floor with the same tilt angle in order to increase the amount of received solar radiation and the black painted wall runs parallel to it with an air gap in between. It is an isolated system Trombe wall, i.e., insulated Trombe wall permits only convective heat transfer to the interior space. In order to protect the building from overheating in summer, side vents are placed at the lower parts of the greenhouse. In this way, chilly and fresh outdoor air flows into the greenhouse and hot air is exhausted via roof vents (Fig. 3).

Fig. 3. Winter and summer operations of the building and detail from the isolated systems Trombe walls and greenhouse also showing the materials.

2.2. The climatic data

The necessary outdoor climatic data for thermal analysis of the building should contain the hourly values of outdoor air temperature (°C), outdoor dew point temperature (°C), wind velocity (m/s), direct normal radiation (kJ/m2), and horizontal total radiation (kJ/m2). The site has climatic data for the four months summer period only, during which astronomical observation is conducted [1]. The climatic data needed for thermal analysis of the building were incomplete; therefore had to be generated for the computation and analysis.

Outdoor air temperature, ground temperature, wind, and relative humidity data measured for periods of more than 6 years in six meteorological stations with altitudes varying from 1725 to 2400 m and latitudes ranging between 37.57°N and 40.30°N have been analyzed [2]. The most important geographical characteristics of Saklikent are its altitude and proximity to the Mediterranean Sea. The town named Van-Bakale that is close to Lake Van with an altitude of 2400 m and latitude 38.47°N, was selected among these candidate locations for use in the remaining period for the site. An hourly climatic data set of a typical winter day was produced by using the values of this town, and for the overheated period calculations, the available summer data of Saklikent has been used. In order to be on the safer side in the analysis, the mean of the minimum air temperature values of January and the maximum values of August for the hours 7:00, 14:00, and 21:00, were used. Furthermore, comparison of the cloudiness of Van-Bakale (i.e., 50%) with the number of clear nights in Bakirlitepe (i.e., 284 days [1]) indicated that the winter nights are probably colder in Bakirlitepe due to excess night-sky radiation. This led the authors to include the minimum value of air temperature of Bakale, which occurred once in 7 years, to the generated winter data set.

The relative humidity data were based on the winter values of Van-Bakale and summer values of Bakirlitepe and the dew point temperature data were obtained from this set. The hourly values of the wind velocities of winter are assumed to be the same and equal to the highest mean value for the specific month.

The solar radiation data were prepared by using the methods given by Hottel [3] and by Liu and Jordan [4]. The direct normal solar radiation and total radiation on a horizontal surface were calculated for a location at 36.85°N latitude and 2500 m altitude. Since the number of sunny days in Saklikent is high, the daily direct radiation values were calculated using atmospheric transmittance coefficients of the Hottel [3] method. For the calculation of total radiation on horizontal surface, however, the diffuse transmittance coefficients of [4] were used. Results are compared with the radiation data of Van-Bakale, which has a similar altitude, and they are found to be acceptable. Air and dew point temperatures, wind speed, and direct normal and total radiation of the produced data set for summer and winter are given in Table 1. The data represent the daily extreme values in winter and summer period.

Table 1. Hourly climatic data used in computer estimations

3. The analysis of the alternatives

The original design of the National Observatory guesthouse has been analyzed by the computer program named SUNCODE-PC, the microcomputer version of SERI/RES [5]. It is a general-purpose thermal analysis program for residential and small commercial buildings. The auxiliary heating load (Qaux), solar heating fraction (SHF) for the heating season and the hourly indoor air temperatures for both seasons, are computed. It is found out that, under worst case winter conditions, the indoor air temperature drops to −3°C at 7:00 and reaches 4°C as a maximum at 14:00 (Fig. 4). The daily Qaux of the original design is found to be 2.34 GJ.

Fig. 4. Hourly values of outside temperatures (Tout) and inside temperatures of original design (O).

The alterations tested for further thermal enhancement of the original design in accordance with the design criteria given in Section 2 are:

- changing the material of Trombe walls,
- increasing the thickness of insulation materials,
- changing the number of glazing in the Trombe walls and greenhouses,
- using different ratios of direct gain windows instead of Trombe walls and greenhouses,
- application of night insulation in winter time,
- application of shading and ventilation in summer time, and
- application of curtains to the direct gain windows of bedrooms at the first floor for day-time sleeping.

3.1. Final alternatives

The original design (abbreviated as O) does not fulfill the requirements of the Building Insulation Regulation [6] of Turkey for the coldest climatic region with its single glazing and insufficient floor insulation. Hence, all the alternatives that are presented below have been modified to have double glazing for vertical windows (4 mm×4 mm ordinary glass with 12 mm air gap in between), abbreviated as O+DG (original building with double glazing application only), and 5 cm extruded polystyrene (33.9 kg/m3) and 4 cm concrete layer between parquet and aerated concrete blocks as the floor material, abbreviated as O+FM (original building with floor insulation application only).

In summer, shading of the solar apertures with a curtain having a 0.2 shading coefficient value is applied in all proposals to prevent overheating. This curtain is assumed to be closed at the beginning of the cooling period and opened when heating is needed. Furthermore, natural ventilation would be obtained by opening the windows when the indoor air temperature exceeds 21°C.

After no less than 100 runs, three alternative building designs have been developed. The original design and the alternatives are given in Table 2. In the original design, an isolated gain system is chosen whereas, in the analysis, the effects of the alteration from an isolated system to indirect and direct gain systems have also been considered. Alternative 2 evaluates the different window/wall ratios of direct gain apertures at the ground floor (working space), instead of isolated Trombe walls and greenhouses. This alternative also includes metal Trombe walls at the first floor for examining the results of immediate response of the system. On the other hand, Alternative 3 has direct gain systems with changing window/wall ratios at both ground and first floors.

Table 2. The original design and the alternatives

Alternative 1A: Application of double glazing to the sloped glazing of greenhouses and Trombe walls with 6 mm tempered glass at the outer and 4 mm ordinary glass at the inner surfaces, with a 12 mm air gap in between.

Alternative 1B: Same as Alternative 1A, the only difference being the removal of the insulation from the aerated concrete isolated Trombe walls of O, hence, changing the system to an indirect one.

Alternative 1C: Same as Alternative 1B, the only difference being the change of material of Trombe wall from aerated concrete to reinforced concrete.

Alternative 2: Application of double-glazed direct gain windows at the ground floor, instead of the greenhouse and Trombe walls, with changing ratios from 20% to 100% by 20% increments, and vertical metal Trombe wall instead of the slanted aerated concrete Trombe wall at the first floor.

Alternative 3A: The ground floor being the same as Alternative 2, and application of double glazed direct gain windows with changing ratios from 20% to 100% by 20% increments instead of the slanted aerated concrete Trombe wall at the first floor.

Alternative 3B: Same as Alternative 3A, with curtain application to the direct gain windows at the first floor being considered due to the possibility of day-time sleeping of the personnel.

4. Results and discussion

Within the framework of the study, hourly indoor air temperatures, auxiliary heating and cooling loads, and SHF values are calculated. Hourly indoor air temperatures are given in figures for the comparison of the internal fluctuations of different applications. Minimum and maximum values of indoor air temperatures, Qaux, and SHF values are given in Table 3.

Table 3. Thermal evaluation data of the original and the alternatives

The daily Qaux values of O, with application of only 5 cm insulation to the floor of O (O+FM), and with application of only double glazing to O (O+DG) for the winter day are found to be 2.34, 1.99, and 1.95 GJ, respectively. The hourly temperature variations of these applications are given in Fig. 5. This illustration also includes the temperature variation of the building that has both double glazing and floor insulation (thus forming Alternative 1A). The insulation in the isolated system Trombe walls of O is removed, forming the Alternative 1B, to see the effect of the insulation material. As the next step, the performance of conventional Trombe walls with reinforced concrete rather than aerated concrete Trombe walls is examined, forming Alternative 1C. The hourly internal temperatures of 1A–1C are given in Fig. 6.

Fig. 5. Hourly values of inside temperatures of original design (O) and the proposed alternatives (Alternative 1A, original with addition of double glazing (O+DG), original building with the new floor material (O+FM).

Fig. 6. Hourly values of inside temperatures of the proposed alternatives, lA–1C.

The application of double glazing or floor insulation reduces the daily Qaux value of O by about 16 percent, solely. On the other hand, when both are applied (i.e., lA), Qaux decreases about 29 percent. The variation of O+DG is shown in Fig. 5. The temperature difference between O+FM relative to O, during the daytime, is due to increase of the heat storage capacity of the floor by the addition of concrete layer. Minimum and maximum indoor air temperatures of 1A have been estimated as −2°C and 3°C, whereas, corresponding temperatures are −1°C and 4°C, and 0°C and 4°C for 1B and 1C, respectively.

During winter, a fan may be applied to the greenhouse and to the Trombe walls of 1A to increase the convective heat transfer and the internal air temperature. The inside air temperatures of 1A are given in Fig. 7 in order to show the effect of the fan (1A+FAN). In the comparison of the alternatives, however, the fan is omitted because of any possibility of operation failure during the turned off period of the building.

Fig. 7. Hourly values of inside temperatures of Alternatives 1A, and 1A with the addition of fan (1A+FAN).

Alternatives 2 and 3 are very sensitive to night heat losses due to direct gain windows at the ground floor and direct gain windows or metal Trombe walls at the first floor; hence, these have been analyzed with and without night insulation application in winter. The hourly inside temperatures of Alternatives 2, 3A and 3B with the application of the double-glazed direct gain windows, 100% in ratio, are given in Fig. 8. The same figure includes O, 1A, 1B and 1C for comparison. For night insulation, a thick curtain having a 2.00 W/m2 K U-value has been applied. Table 3 includes the values only for the night insulated case since the calculated values of uninsulated case were poorer as expected. Table 3 also shows that, Qaux values have a striking difference between 3A and 3B. The Qaux value of 3A is 1.84 GJ, whereas this value reaches 2.36 GJ for 3B, with 100% ratio of fenestration to facade area (window/total), which is a 28% increase. This increase is about 6% for a 20% window/total.

Fig. 8. Hourly values of inside temperatures of Alternatives 1A–1C, and 100% ratio of fenestration to facade area (window/total) of Alternatives 2, 3A, and 3B, 2–100, 3A–100, and 3B–100.

5. Concluding remarks

During the process of improvement of the thermal performance of the original building design, the main criteria have been to decrease heating load, maintain the minimum indoor air temperatures above 0°C in winter, avoid overheating during summer, and accomplish the design restrictions. In the improvement process, different applications are considered and three main proposals are obtained. The indoor air temperatures, Qaux, and SHF values are estimated and presented in a comparative form.

Considering that the building will not be occupied during most of the time in a year, it is logical to minimize the manual control to operate the system. Hence, although Fig. 8 clearly shows that Alternatives 2, 3A, and 3B have higher thermal performances than Alternative 1, these solutions are not preferred because of manual operation of night insulation.

Furthermore, due to the difficulty of transportation, light construction materials are preferred. Also, due to the short construction season, it is not practical to construct the structural system by cast-in-place reinforced concrete. The building elements, therefore, should be modular to ease the construction, which eliminates Alternative 1C that has reinforced concrete Trombe walls.

Alternative 1B is also eliminated due to the possibility of the outgoing radiation from the building during the night time, since the insulation material is removed.

Hence, it is concluded that it is more appropriate to build Alternative 1A rather than the others for this specific building. During winter, to prevent reverse air circulation in the greenhouse and Trombe wall at night, it is proposed to add one-way lids to the vents that do not need any manual operation.

After the completion of the building, though long-term measurements are not taken apart from a two-day monitoring by the authors, it has been reported that there had been no frosting problems within the building since 1997. The astronomers and physicists, who stay in the building frequently for observation purposes (even during the severe winter months, which was not planned at the design phase of the building) point out that the inside temperature levels are just below the comfort temperature and use of electric heaters for a few hours is sufficient to keep the interiors comfortably habitable.

The two-day daytime monitoring, which may just give a vague idea about how the building responded to climate, showed that when outside temperatures varied between 6°C and 10°C, inside temperatures for the bedrooms on the first floor varied between 10°C and 18°C, for the greenhouse 15°C and 27°C, and surface temperatures of the Trombe walls between 23°C and 42°C.

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Figures & Tables

Fig. 1. Guesthouse of TÜBİTAK National Observatory.

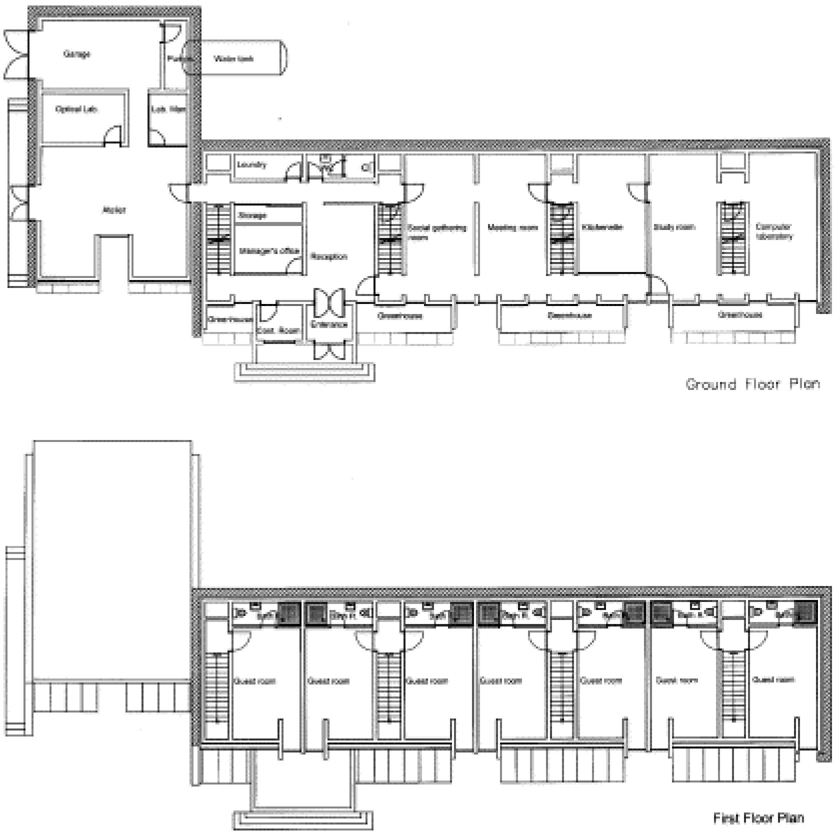


Fig. 2. Ground- and first-floor plan of TÜBİTAK National Observatory guesthouse

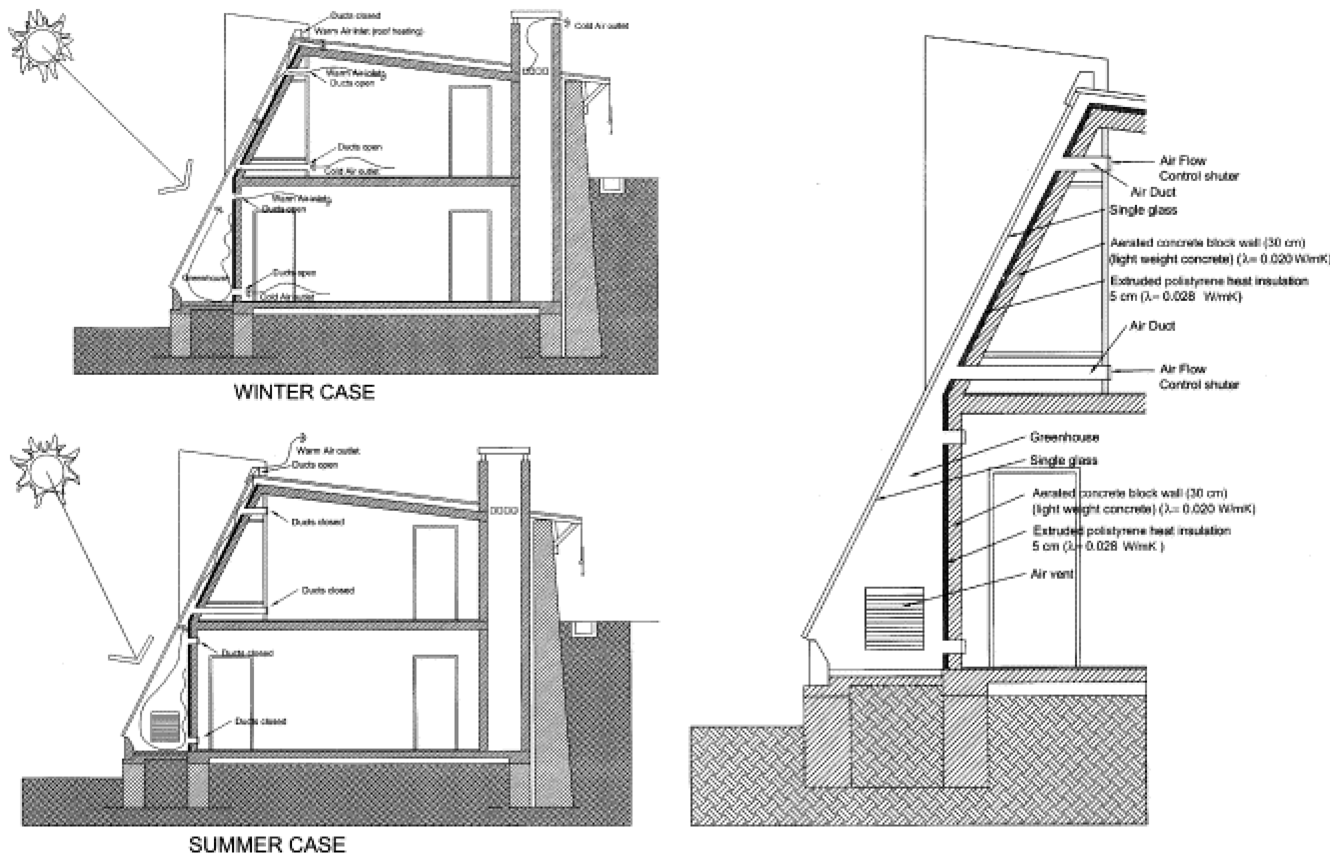


Fig. 3. Winter and summer operations of the building and detail from the isolated systems Trombe walls and greenhouse also showing the materials.

	Winter			Summer			Radiation (kJ/m²)			
							Winter		Summer	
Hour	Air temp. (°C)	Dewpt temp. (°C)	Wind speed (m/s)	Air temp. (°C)	Dewpt temp. (°C)	Wind speed (m/s)	Direct normal	Total	Direct normal	Total
1	−23.9	−26.8	4.0	14.0	3.8	2.0	0	0	0	0
2	−25.0	−27.8	4.0	13.9	3.7	2.0	0	0	0	0
3	−25.7	−28.5	4.0	13.9	3.7	2.0	0	0	0	0
4	−25.7	−28.5	4.0	14.0	3.8	2.0	0	0	0	0
5	−24.7	−27.5	4.0	14.1	3.9	2.0	0	0	0	0
6	−23.0	−25.9	4.0	14.4	4.1	2.0	0	0	48	70
7	−20.7	−23.8	4.0	14.7	4.4	2.0	0	0	574	689
8	−17.8	−21.1	4.0	15.3	5.0	2.0	0	0	1261	1421
9	−15.1	−18.8	4.0	16.1	5.7	2.0	393	495	1951	2139
10	−12.1	−16.1	4.0	17.2	6.7	2.0	930	1086	2559	2767
11	−9.4	−13.8	4.0	18.3	7.7	2.0	1383	1569	3029	3251
12	−7.0	−11.7	4.0	19.4	8.7	2.0	1670	1874	3321	3553
13	−5.3	−10.2	4.0	20.3	9.6	2.0	1670	1874	3321	3553
14	−4.4	−9.6	4.0	20.6	9.8	2.0	1383	1569	3029	3251
15	−4.5	−9.7	4.0	20.2	9.5	2.0	930	1086	2559	2767
16	−5.2	−10.1	4.0	19.3	8.6	2.0	393	495	1951	2139
17	−6.5	−11.2	4.0	18.1	7.5	2.0	0	0	1261	1421
18	−8.2	−12.5	4.0	16.9	6.4	2.0	0	0	574	689
19	−10.2	−14.2	4.0	15.8	5.4	2.0	0	0	48	70
20	−12.4	−16.2	4.0	15.0	4.7	2.0	0	0	0	0
21	−14.5	−18.1	4.0	14.4	4.1	2.0	0	0	0	0
22	−16.8	−20.1	4.0	14.1	3.9	2.0	0	0	0	0
23	18.9	22.2	4.0	13.8	3.6	2.0	0	0	0	0
24	−20.9	−24.0	4.0	13.7	3.5	2.0	0	0	0	0

Table 1. Hourly climatic data used in computer estimations

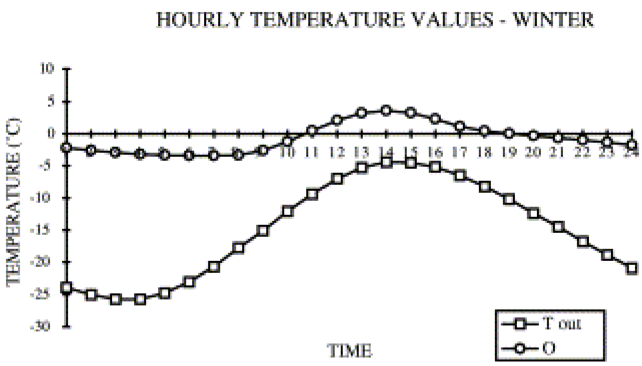


Fig. 4. Hourly values of outside temperatures (T_{out}) and inside temperatures of original design (O).

Alternative	Wall	Window glazing	Floor	Aperture type	
				Ground floor	First floor
O	Insulation and aerated concrete	Single	4 cm Concrete	ITW with GH and DGW with GH	ITW and DGW
1A	Insulation and aerated concrete	Double	5 cm Insulation 4 cm Concrete	ITW with GH and DGW with GH	ITW and DGW
1B	Aerated concrete	Double	5 cm Insulation 4 cm Concrete	TW with GH and DGW with GH	TW and DGW
1C	Reinforced concrete	Double	5 cm Insulation 4 cm Concrete	TW with GH and DGW with GH	TW and DGW
2	Insulation and aerated concrete	Double	5 cm Insulation 4 cm Concrete	DGW	Vertical metal TW
3A	Insulation and aerated concrete	Double	5 cm Insulation 4 cm Concrete	DGW	DGW
3B	Insulation and aerated concrete	Double	5 cm Insulation 4 cm Concrete	DGW	DGW with curtains

Table 2. The original design and the alternatives

		Winter				Summer	
Alternative	Window / total (%)	Maximum temperature (°C)	Minimum temperature (°C)	SHF (%)	Heating load, Q_{mz} (GJ)	Maximum temperature (°C)	Minimum temperature (°C)
O		4	−3	0.41	2.34	18	16
1A		4	−1	0.45	1.69	20	19
1B		3	−1	0.46	1.51	20	19
1C		4	−1	0.48	1.69	20	19
2–100%	100	11	−1	0.57	1.84	20	18
2–80%	80	10	−2	0.54	1.87	20	18
2–60%	60	6	−2	0.48	1.91	19	18
2–40%	40	3	−4	0.40	1.96	18	17
2–20%	20	−2	−5	0.31	2.01	17	17
3A–100%	100	12	0	0.60	1.84	20	18
3A–80%	80	10	−1	0.56	1.88	20	18
3A–60%	60	6	−2	0.48	1.92	19	18
3A–40%	40	2	−4	0.37	1.97	18	17
3A–20%	20	−4	−8	0.24	2.04	17	16
3B–100%	100	9	−4	0.50	2.36	20	18
3B–80%	80	7	−4	0.46	2.31	20	18
3B 60%	60	4	−5	0.39	2.25	19	18
3B–40%	40	−1	−7	0.30	2.21	18	17
3B–20%	20	−6	−9	0.19	2.17	17	16

Table 3. Thermal evaluation data of the original and the alternatives

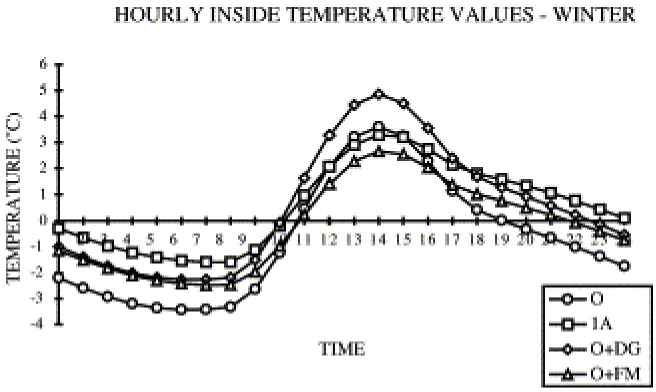


Fig. 5. Hourly values of inside temperatures of original design (O) and the proposed alternatives (Alternative 1A, original with addition of double glazing (O+DG), original building with the new floor material (O+FM).

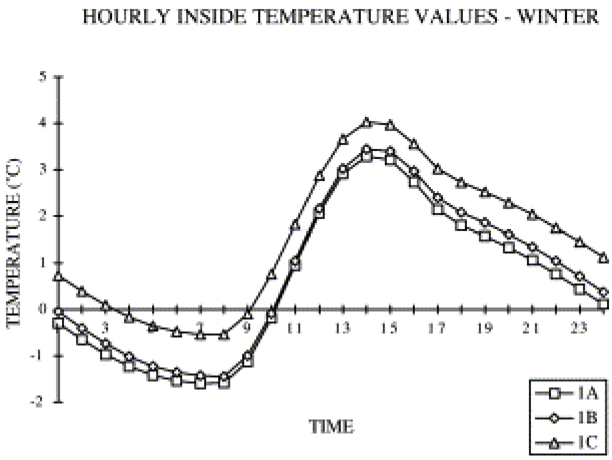
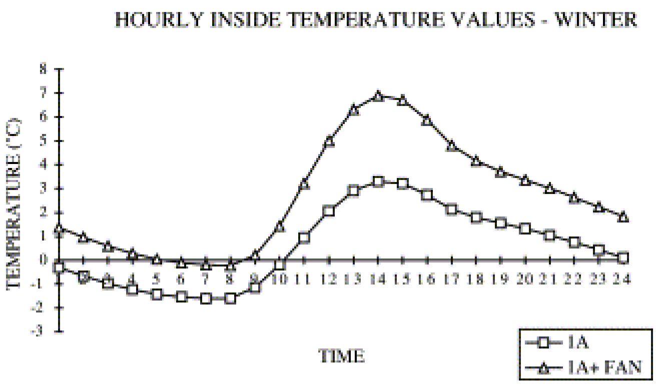


Fig. 6. Hourly values of inside temperatures of the proposed alternatives, lA–1C.



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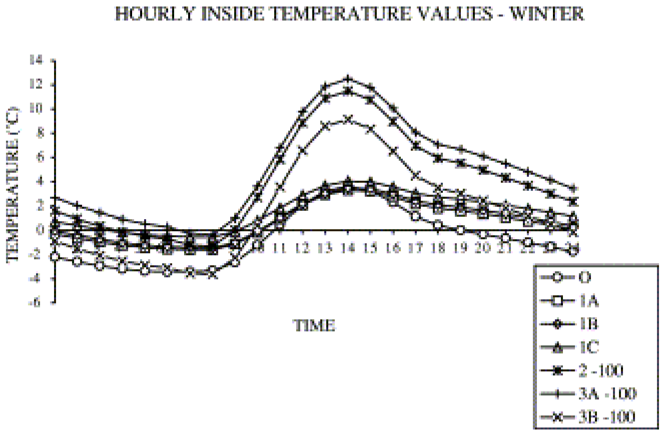

Fig. 8. Hourly values of inside temperatures of Alternatives 1A–1C, and 100% ratio of fenestration to facade area (window/total) of Alternatives 2, 3A, and 3B, 2–100, 3A–100, and 3B–100.