GLASS PARTITIONS, VENTILATION AND THERMAL MASS AS RETROFITTING MEASURES IN AN ATTACHED SUNSPACE

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ABSTRACT

In this paper the effectiveness of retrofitting strategies in a sunspace attached to a one-storey building has been investigated. Natural and hybrid ventilation, air-tight glass partitions, awnings and increased thermal mass retrofitting scenarios were implemented, mainly for the Greek climate. Window openings and sensor-controlled fans were used to create a controllable and secure environment. Combined ventilation and thermal simulation were applied, taking into account all the related physical phenomena, such as ventilation, infiltration and solar radiation. The thermal and air tightness characteristics of the building's envelope and the built environment were also simulated. The results are presented in the form of hourly temperature variations for typical winter and summer period in three Greek and one U.S. city and outcomes and comparisons have been derived for the retrofitting scenarios.

KEYWORDS

Attached sunspace, hybrid ventilation, flow through large openings, retrofitting scenarios.

1. INTRODUCTION

Sunspaces are one of the most widespread types of passive solar systems that are used both as a solar collecting system and an additional pleasant living space. Sunspaces can also be constructed as part of the retrofitting of an existing building, forming a glazed envelope on a balcony or a new building extension. The main function of an attached sunspace should be twofold: to reduce the auxiliary energy demand for the building and to create a comfortable and secure living area. The first function should comprise a reduction in the heating energy demand during the heating period and a reduction in overheating problems during the cooling period, especially in southern latitudes. The role of the sunspace during the heating period is threefold: to act as a buffer zone by reducing conduction losses, to supply pre-heated ventilation air and to exploit direct solar gains through conduction. The main role of the sunspace during the summer period is to be serve as an open air space, preventing overheating and thermal charge in the attached building, through implementing effective solar control and passive cooling techniques as night ventilation, hybrid ventilation etc. In this paper the thermal behavior and the potential of indoor climate control in a one-storey building with an attached sunspace are examined, through the implementation of various strategies:

- Shading devices on the roof and the vertical glazed surfaces to control sunspace overheating and to reduce the direct solar gains on the south façade of the main building.
- Night ventilation techniques, by implementing the use of top windows and inclined half-opened doors, in order to maintain security and to control access.

- Hybrid ventilation by implementing ventilators activated by temperature sensors to reduce overheating.
- Thermal mass consisting of heavy concrete walls between the house and the sunspace.
- Retrofitting of the glazed envelope of the sunspace by implementing airtight windows and doors. The occupant behavior related to the use of the sunspace openings is also simulated.

2. RETROFITTING STRATEGIES AND THERMAL PERFORMANCE

The influence of the sunspace on the thermal behavior of the building and the comfort conditions inside the sunspace, for the strategies mentioned in the previous paragraph, is investigated through implementing the Suncode and Comis simulation programs [1, 2, 3], which are coupled by implementing the sequential coupling technique. The under examination house is a single-storey heavy-structure building, which is heavily insulated and connected to the attached sunspace at the southern façade (Fig 1.). The ground floor is treated as a uniform zone of 64 m^2 and the sunspace as an autonomous zone of $16m^2$. The thermal performance of the above building has been simulated for three cities in Greece at different latitudes: Athens (lat. 37.58^o, long. 23.4^o), Thessaloniki (lat. 40.39^o, long. 23.1^o), and Chania on Crete (lat. 35.1^o, long. 24.1^o). Simulations are also performed for a southern-latitude and mild-climate US city: Los Angeles (lat. 33.56^o, long. 118.2^o), in order to compare the results and to focus on the effectiveness of the implemented strategies in combating winter and summer overheating problems.

Two typical days in the cold and warm period are examined, January 21st and July 21st. Hourly values of the typical reference years (TRY AND TMY2) in the four cities have been used for the calculations: global horizontal radiation (KJ/m^2 h), direct normal radiation (KJ/m^2 h), ambient air temperature (^oC), dew point temperature (^oC), wind speed (m/s), wind direction (degrees), humidity ratio (g/kg) and atmospheric pressure (kPa).

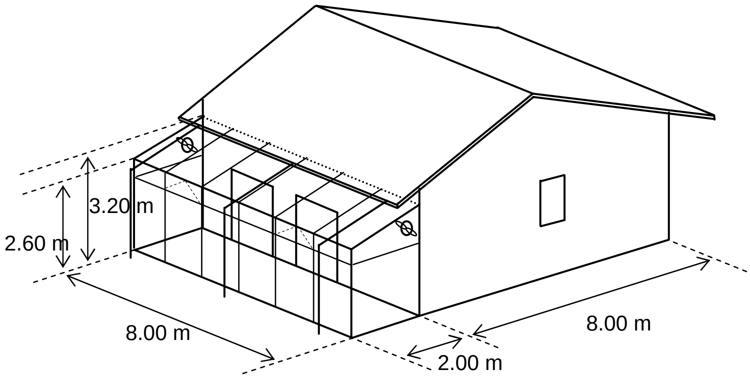


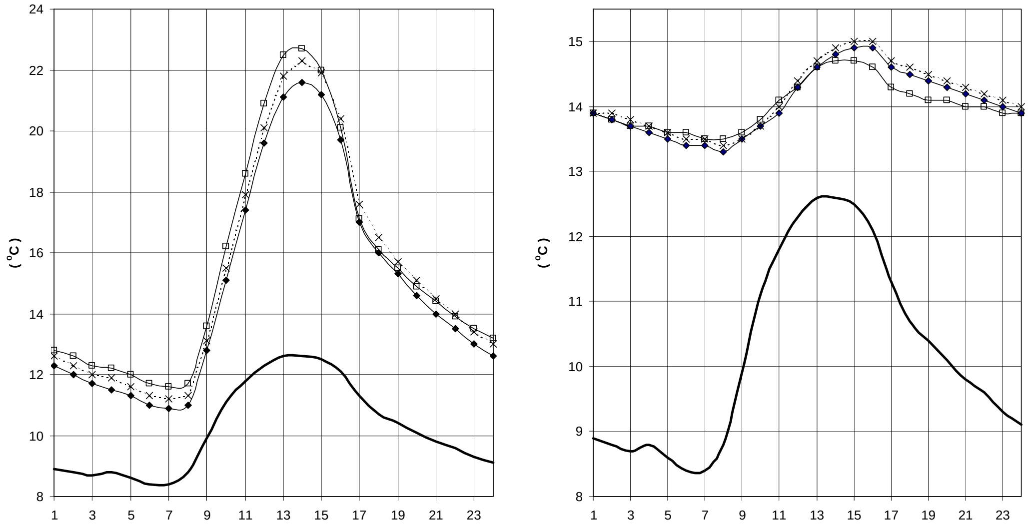
Fig. 1. The simulated attached sunspace and the building

2.1 Winter period

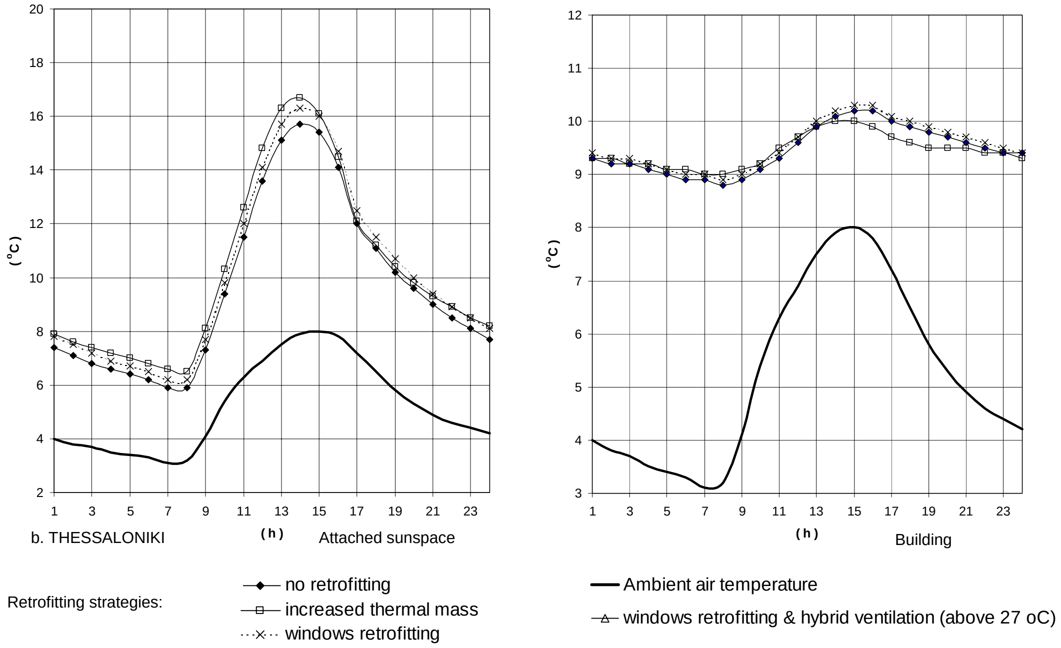
In Figs. 2 a to d the hourly variations in the ambient and zone air temperatures are presented for the sunspace and the building for the abovementioned cities. The examined retrofitting strategies for the heating period include the following scenarios:

- No retrofitting: the sunspace remains with a non-airtight glazing envelope, no shading and venting devices, while user behavior is taken into account by simulating the use of the large openings for 5-minute opening periods. Thermal mass is relatively low, including a 15cm-thick concrete floor covered with marble flagstones and a20cm-thick common brick wall on the southern façade.

- Increased thermal mass: the brick wall is replaced by a 40cm-thick concrete mass wall. All other features remain unchanged.
- Window retrofitting: the glazed envelope of the sunspace is replaced by a more airtight one, by implementing leakage specifications of existing products in the Greek and E.U. construction market. The mean air change values in the sunspace are visibly affected by this retrofitting scenario which reduces the air change rates from 1.7 ach to approx. 0.5 ach for the examined cases and configurations. All other features remain as in the "no retrofitting" scenario.
- Window retrofitting and hybrid ventilation: the above "window retrofitting" scenario is changed by implementing hybrid ventilation with two ventilators placed at the top of the lateral surfaces of the sunspace (500 m^3/h nominal total ventilation rate). The ventilators are sensor-controlled at a set point of 27^oC and the mean air change rates inside the sunspace were between 9 ach and 11 ach. This strategy has been implemented in practice in the warmer cities (in this paper Los Angeles), where sunspace overheating also occurs during the winter period. This strategy is most useful during the summer period.



a. ATHENS Attached sunspace Building



Figs. 2 a and b. Temperature distributions of the ambient and zone air temperatures for the sunspace and the building in the cities of Athens and Thessaloniki, for the retrofitting strategies of the winter period.

In order to achieve a detailed and credible simulation of all the natural phenomena involved such as ventilation, infiltration and solar radiation, the airflow around the building and through the large openings and the effect of the neighboring buildings were taken into account. The simulation technique has been analyzed and validated in previous publications [3, 4, 5].

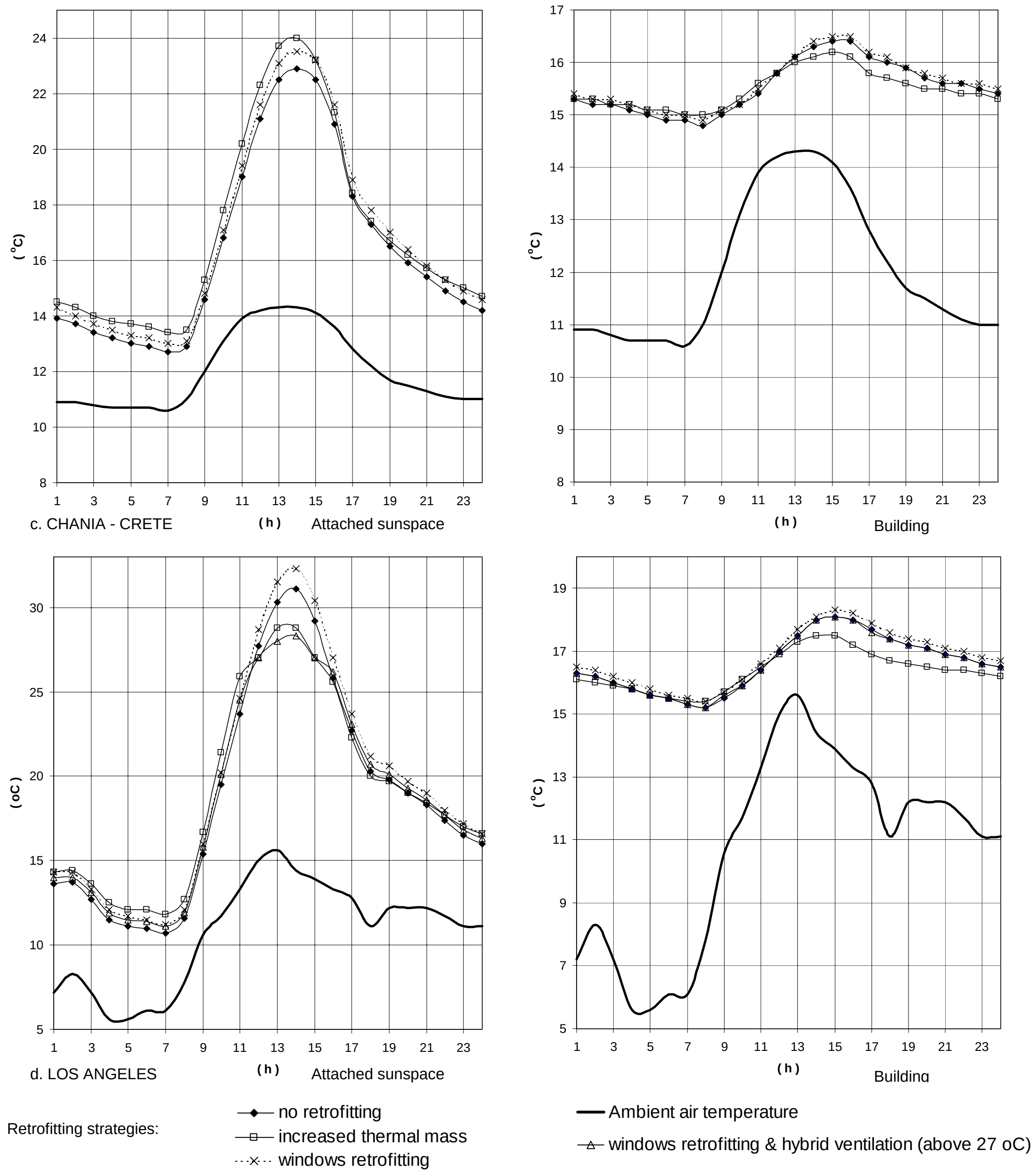


Fig. 2 c and d. Temperature distributions of the ambient and zone air temperatures for the sunspace and the building in the cities of Chania (Crete) and Los Angeles (CA), for the retrofitting strategies of the winter period.

From Figs. 2 a to d, outcomes regarding the effectiveness of the retrofitting scenarios may be derived for the winter period. Increased thermal mass and window retrofitting appeared more effective for the Greek cities where no overheating appeared and the temperature variations between day and night were greater. The temperature on a typical January day in the Greek cities varies from 8.5 to 12.6 ^{o}C in Athens, from 3.1 to 8.0 ^{o}C in Thessaloniki and from 10.6 to 14.3 ^{o}C in Chania. The maximum indoor air temperatures in the sunspace in the increased thermal mass scenario, are 22.8 ^{o}C, 16.7 ^{o}C and 24.0 ^{o}C for the cities of Athens, Thessaloniki and Chania respectively. The maximum indoor air temperatures in the sunspace in the window retrofitting scenario appeared approximately 0.5 ^{o}C higher in the abovementioned cases. The values for the non retrofitting scenario were 0.9 to 1.1 ^{o}C lower compared to the thermal mass scenario. This pattern also occurs in the night temperatures. The temperature variations in the sunspace were more than two times greater compared to the ambient air temperature.

Inside the building, the thermal mass scenario leads to less divergent temperature variations due to thermal inertia. Window retrofitting leads to higher temperatures: during the early morning hours the building air temperature is 0.2 ^{o}C higher and during the early afternoon hours 0.4 ^{o}C lower, compared to the window retrofitting scenario. Nevertheless the mean air temperature inside the building is about 3 ^{o}C higher compared to the mean ambient temperature and adequately steady, due to the combination of sunspace, thermal mass and heavy insulation.

On the other hand, for the mild climate of Los Angeles, hybrid ventilation appeared more effective and reduced the overheating phenomena at noon even without shading devices. The peak values of the air in the sunspace were reduced by about 4^{o}C. Overheating was almost eliminated for the mild oceanic climate of Los Angeles.

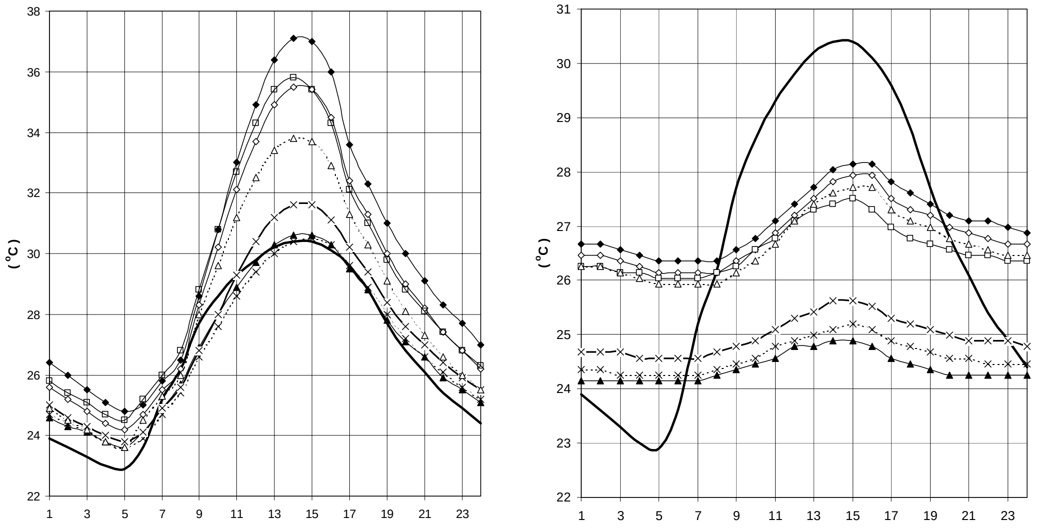
2.2 Summer period

The examined retrofitting strategies for the summer period include the following scenarios:

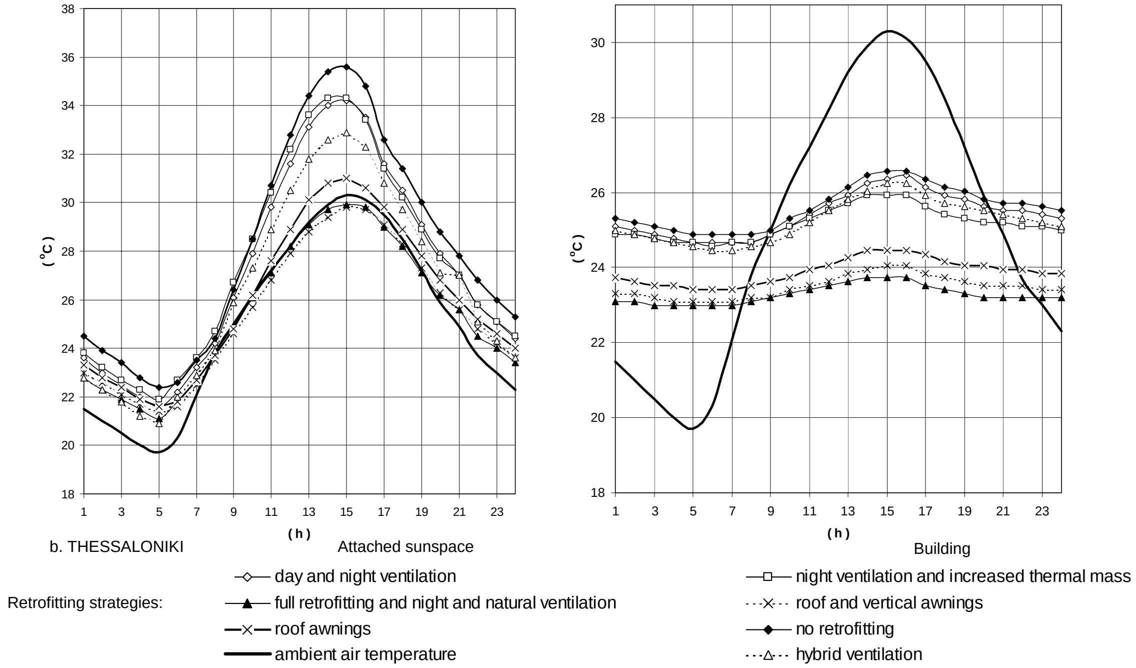
- No retrofitting: includes all the features of the corresponding “no retrofitting” scenario for the winter period.
- Day and night ventilation: this is based on the “no retrofitting” scenario implementing extensive natural ventilation during the day and passive cooling ventilation during the night.
- Night ventilation and increased thermal mass: the brick wall is replaced by a 40cm-thick concrete mass wall. All other features remain as in the “no retrofitting” scenario.
- Roof awnings: awnings are placed at the top of the sunspace during daytime. All other features remain as in the “no retrofitting” scenario.
- Roof and vertical awnings: awnings are placed vertically on the external vertical surface during the daytime. All other features remain as in the “roof awnings” scenario.
- Full retrofitting and day and night ventilation: includes window retrofitting, increased thermal mass, night and day ventilation and hybrid ventilation and roof and vertical awnings.
- Hybrid ventilation: hybrid ventilation in the form of two ventilators placed at the top of the lateral surfaces of the sunspace, sensor-controlled at a set point of 27^{o}C as described in the winter period strategies.

From Figs 3 a to d, outcomes regarding the effectiveness of the retrofitting scenarios may be derived for the summer period. Of the summer retrofitting scenarios implemented, solar shading proved to be the most effective retrofitting factor, followed by night and hybrid ventilation. Thermal mass did not appear to be significantly effective and therefore is not presented as an individual strategy, but is combined with night ventilation in order to exploit the benefits of thermal mass and time lag in the temperature variations.

In the case of the sunspace the main aim is to reduce indoor air temperature variations an make them match ambient air temperature variations as closely as possible. The “no retrofitting” scenario results in unacceptably high temperatures during almost all hours for all the examined cities, with peak values reaching 37.1 °C, 35.7 °C and 36.1°C, for the cities of Athens, Thessaloniki and Chania respectively. These peak values are about 6 °C greater than the respective ambient air temperature peak values. In the Los Angeles case the sunspace air peak value is 29.8 °C, almost 7 °C greater than the respective ambient temperature. The “hybrid ventilation” scenario led to a reduction in these temperature differences of about 50% in all cases. The full retrofitting scenario could achieve the abovementioned aim, bringing the temperature variations in the indoor and ambient air close to each other, as presented in Figures 3 a, b and c for the Greek cities. The abovementioned target is partially achieved in the case of Los Angeles, where the temperatures inside the sunspace are from 0 to 2 °C greater than the respective ambient temperatures.

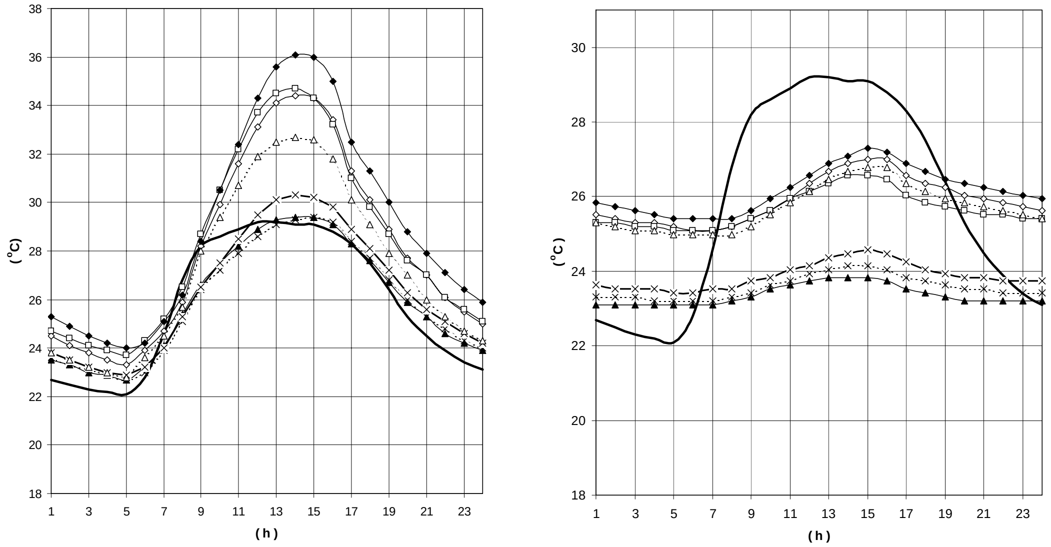


a. ATHENS Attached sunspace Building

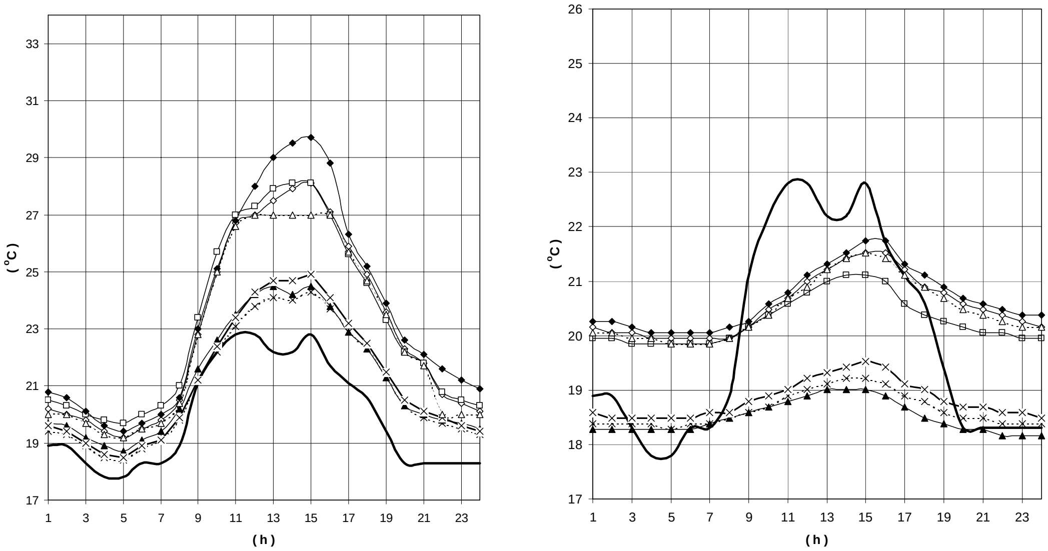


Figs. 3 a and b. Temperature distributions of the ambient and zone air temperatures for the sunspace and the building in the cities of Athens and Thessaloniki, for the retrofitting strategies of the summer period.

In the case of the main building the basic aim is to reduce indoor temperatures by implementing the shading devices of the attached sunspace and hybrid ventilation to gain the benefits of the thermal discharge of the south mass wall.



c. CHANIA - CRETE Attached sunspace Building



d. LOS ANGELES Attached sunspace Building

Figs. 3 c and d. Temperature distributions of the ambient and the zone air temperatures for sunspace and the building in the cities of Chania (Crete) and Los Angeles (CA), for the retrofitting strategies of the summer period.

In the case of main building the shading scenarios proved significantly effective, reducing the building's indoor temperature by approximately 1.5 to 2^{o}C in all cities, compared to the "no shading" scenarios. Therefore, two groups of temperature variations were formed in the main building's summer diagrams with a temperature shift of 1.5-2 ^{o}C, one for scenarios including shading and one for no shading. In each group the scenarios which include increased thermal mass and night ventilation were more effective than the others. Another advantage of these scenarios is that their effectiveness is increased during noon and afternoon hours due to the time lag of thermal inertia, as seen in Figs. 3 a to d. The same phenomenon appeared during the winter period, as can be seen in Figs. 2 a to d, but its effectiveness is rather undesirable for winter.

Overall, the implementation of retrofitting scenarios during summer appears to be positive in both the sunspace and the main building. If the complete retrofitting scenario is implemented, the air temperature variations in the sunspace are very close to the respective ambient variations and even slightly lower in the morning and early noon hours. In the main building the combination of shading and increased thermal mass leads to acceptable thermal comfort conditions, with a maximum air temperature lower than 25 ^{o}C in all cities.

3. CONCLUDING REMARKS

The effectiveness of the retrofitting strategies in a sunspace attached to a one-storey building was investigated in three representative Greek sites and a southern-altitude U.S. city, throhgh implementing combined thermal and ventilation modeling. Special emphasis was given to the simulation of ventilation phenomena and the investigation of thermal performance during both the winter and summer periods. From the results it has been concluded that the sunspace could significantly help to reduce heating loads demand during the winter. Retrofitting strategies such as renovation of the glazed envelope with more airtight windows and thermal mass increase the energy benefits, while hybrid ventilation diminishes the sporadic overheating problems during the winter period. The retrofitting techniques also appeared effective in reducing summer overheating problems. Solar shading devices combined with hybrid and natural night ventilation achieve acceptable indoor temperatures in most cases in both the sunspace and the house, reducing the cooling energy demand even in relatively warm climates.

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