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Surface temperatures of public buildings, built in 1880, 1970 and 2002, in Northern Greece

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Abstract. The purpose of this paper is to investigate the surface temperatures of the shelter of three public buildings in the city of Xanthi, in northern Greece. The buildings were built in different time periods and consequently they have different technical characteristics. Respectively, we survey the three following buildings that have been built in 1880 (Municipality Hall of Xanthi), in 1970 (Municipality Amphitheatre) and in 2002 (Bank offices building). Data have been gathered by the use of thermal camera and the survey has been conducted from January up to July. The data gathered regard measurements of the surface temperature of the exterior walls of the shelters, both inside and outside. The study aims at the evaluation of the thermal behavior of the shelter of buildings, which built in different time and under different regulations. The gathered data of the surface temperatures compare the different thermal behavior of the shelter. The analysis of the results and diagrams show that the thick masonry of the traditional Municipality Hall offers an insulation that is adequate. The building of 1970, which was constructed with the previous buildings regulation, has thermal losses due to inadequate insulation. The new building of 2002 has low thermal losses.

Keywords: thermal behavior; surface temperature; public buildings

1. Introduction

The energy saving in the buildings and the implementation of environmental and bioclimatic design solutions are contemporary subjects of analysis and research. The main aim of energy efficiency buildings is to reduce the energy consumption and to ensure comfort thermal conditions in the buildings.

A major number of the buildings of the Greek urban centers have been built at previous decades without specific constructive techniques for energy losses reduction of the building's shell. Nowadays, the new version of the contemporary technical regulations focuses upon the improvement of the energy efficiency of older buildings (change of frames, improve the insulation) and to design new buildings of low energy consumption.

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Buildings' construction has a major determining role on the environment through consumption of land and raw materials. It is also a significant consumer of non-renewable energy and an emitter of greenhouse gases. As environmental issues continue to become increasingly significant, buildings must become more energy efficient and the energy needs for their operation must decrease (Dimoudi and Tompa 2008).

Office buildings are classified amongst the buildings presenting the highest energy consumption (Kosmopoulos 2008). The annual energy consumption in European office buildings averages 100-1000 kWh/m^2 of conditioned floor area (Caccaveli and Gugerli 2002), depending on location, construction, HVAC and lighting installations, use and type of office equipment, operating schedules, etc. Typical annual total energy consumption in Hellenic office buildings averages 187kWh/m^2 (Spyropoulos and Balaras 2011).

The building sector accumulates approximately a third of the total energy consumption. Consequently, the improvement of the energy efficiency in buildings has become an essential instrument in the energy policies to ensure the energy supply in the mid to long term. During the last decade and being sensitive to this fact, many national governments and international organizations, have developed new regulations to achieve those targets (Gonzalez 2011).

The need of energy efficiency improvement of the building is of essential importance, so as to reduce the energy consumption and emissions of air pollutants, to achieve a better environmental footprint and restrict the thermal losses. These are important reasons because they are responsible for the degradation of the physical environment and of the urban microclimate.

The present paper studies the thermal behaviour of three buildings that have been built in different time (Building-1880, Building-1970, Building-2002), and thus under different regulations. The surface temperature of the wall, window and frames (aluminium or wood) are analyzed in relation to air temperature. For each material data have been gathered, regarded the thermal behaviour and reaction during the morning and midday time, and how the orientation effects in theirs surface temperature. The thermal behavior of shelter with different constructive characteristics is analyzed. Also, the study aims at pointing out problems to the shells of the three buildings and to come to conclusions and suggestions for improving their energy and thermal behaviour.

2. Materials and methods

In this study, a number of field experimental procedures were performed in three buildings, which were built in different period and with different construction methods. The selected buildings have been built in 1880 (Municipal Hall of Xanthi, Building-1880), in 1970 (Municipal Building, Building-1970) and in 2002 (Bank offices building, Building-2002).

For each case, it has been analyzed the design of the building, the construction materials, the thermal behaviour of the shell and the internal and external environmental conditions. The aim of the research is to observe the thermal behaviour of the buildings' shelter.

The field experimental procedures were performed in fixed points of the shells, in three orientations, in external and internal side of the buildings. For a specific construction material (frame, window and wall) the surface temperatures were measured in each site. The data were collected from January to July, two times a day, one at the morning and the second at the midday. The data were used to gather information and extract conclusions about the thermal surface behaviour and how the surface temperature varies during the day, the season and the orientation.

The measurements of surface temperatures are carried out by a thermal camera and of the environmental microclimatic conditions (air temperature, air velocity, humidity) by a polymeter.

2.1 Description of buildings

Three buildings have been selected according the decade of construction and the construction methods respectively.

2.1.1 Building constructed in 1880

The Building-1880 is a traditional building, built around 1880. In the early of the decade of 1990 a renovation of frames take place and an extension in southwest site. The surrounding space at the northeast side is a pebbled street dividing the Municipal Hall from the opposing, of same height building. At the northwest side there is a parking area and again a pebbled street between the Hall and the opposing building, while at the southwest side there is a small yard that is shadowed all the day by the neighbouring building.

The external wall is 90 cm thick and the interior wall is 60 cm. So, the wall thickness of northeast and northwest masonry is extremely thick. The southwest side, which is an earliest expansion, has a typical wall thickness of 40cm. The southwest wall is coated in both of the two sides, it is characterized by inadequate thermal protection and the externally side is in contact with the air. So, the factor U value is estimated as $1W/(m^{2}\cdot K)$, according to the National Regulation of Energy Performance of Buildings. The window at southwest orientation is single pane ($U_g = 5.70$ $W/(m^{2}\cdot K)$) and at the other facades, there is glazing with an air gap of 6mm ($U_g = 3.30$ $W/(m^{2}\cdot K)$). The wood frame in southwest has $U_f = 2.20$ $W/(m^{2}\cdot K)$) and in the other sides the aluminum frames have $U_f = 3.50$ $W/(m^{2}\cdot K)$).

During winter, offices use a central heating system and during summer, air-condition systems for cooling is used. The internal air temperature ranges from $19^{o}C$ to $30^{o}C$ and external one from $7^{o}C$ to $41^{o}C$.

2.1.2 Building constructed in 1970

The Municipal Building is located near the city square. At the North and South sides there is open space and trees that shadow the building.

This building has been constructed in 1970 and has been renovated in 2003. At the ground floor of the building there is the municipal amphitheater and above this there are five floors. The ground floor total area is $1100m^2$.

During the renovation of 2003, frames have been replaced by aluminum and plasterboards have been installed over the interior and external masonry. The U value for the north, south and west orientated walls, which are lined with marble slabs, is 1 $W/(m^{2}\cdot K)$. The windows in all orientations are glazing with an air gap of 6 mm ($U_g = 3.30$ $W/(m^{2}\cdot K)$) and the aluminum frames has $U_f = 3.50$ $W/(m^{2}\cdot K)$).

During the measurement procedures no heating or cooling system was in operation at the amphitheater. So, its operation profile doesn’t influence the measurements’ data gathered. The minimum internal air temperature in winter was $12{,}7^{o}C$ and the maximum at summer was $29{,}2^{o}C$. The external air temperature ranges from $11{,}1^{o}C$ in winter, to $40{,}3^{o}C$ in summer period.

2.1.3 Building constructed in 2002

The modern building has been built in 2002. At the ground floor there are bank offices. The facades of the ground floor examinated sides are glass with aluminum frames. The windows in south, southeast and southwest orientated facades are glazing with an air gap of 12 mm (U_g = 2 .80 W/(m^{2}·K)) and the aluminum frames has U_f = 3.50 W/(m^{2}·K)).

The main entrance has two doors and a hall, in order to minimize heat losses. The double glazing sides can be shadowed through internal metallic blinds.

Masonry at the north side consists of insulated brickwalls (U = 1 W/(m^{2}·K)).

For HVAC purposes, an inverter system is being used. The internal air temperature is constantly set at about 22-25^{o}C. This characteristic is useful during the analysis of temperature differences between the internal and external environment.

In Table 1, the thermal characteristics of the study materials are shown.

Table 1 Thermal characteristics of the study materials

	U value W/(m^{2}·K)					
	Wall		Window		Frame	
Building-1880	90cm thick	-	air gap 6mm	3.30	Aluminium	3.50
	southwest	1	single pane	5.70	Wood	2.20
Building-1970	1		3.30		3.50	
Building-2002	1		2.80		3.50	

2.2 Analysis method

The research aims at identifying the thermal behavior of materials in building shells, the fluctuation of surface temperatures during the morning and midday time. The experimental procedures took place in the internal and external side of the buildings. For each measurement point of the three buildings, the temperature differences between the internal and external surface temperature were investigated. Also, the effect of the orientation, of the air temperature and of the exposure in sunshine is investigated. The diagrammatic representations and the data analysis include:

• The fluctuation of the materials temperature differences between internal and external surface temperature, in comparison to the temperature difference of the air, internally and externally, respectively

• The fluctuation of the materials temperature differences between morning and midday surface temperature in comparison to the corresponding temperature difference of the air.

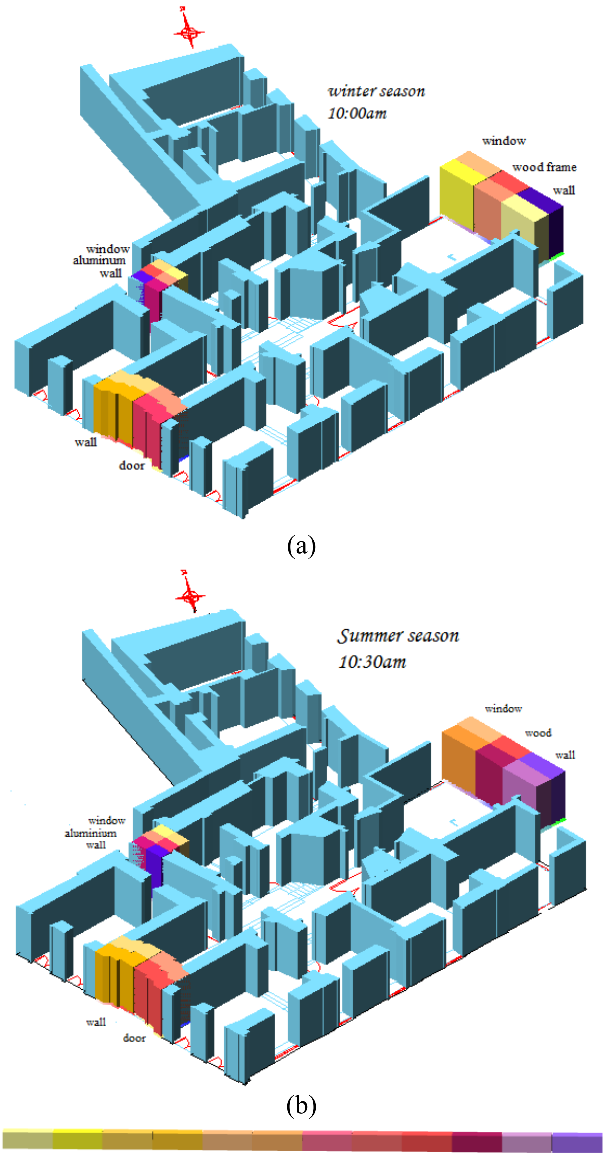
3. Results and discussion

3.1 Building -1880

During a typical winter season, all materials in Building-1880, in all orientations have greater temperature at the interior of the building, while during spring and summer months the temperature is higher externally.

The wall in all orientations is always cooler than the frame and window, while the window is warmer.

During the midday measurement, a temperature rise in all materials has been observed.



Color degradation of surface temperatures, from the warmer to the cooler

Fig. 1 Thermal behavior of materials, Building-1880, morning measurement, (a)Winter season and (b) Summer season

3.2 Building -1970

The wall in Building-1970, in each of the three investigated orientations, is always cooler than the aluminum frames and window, while the window is warmer. In the midday the surface temperature of all materials is rising.

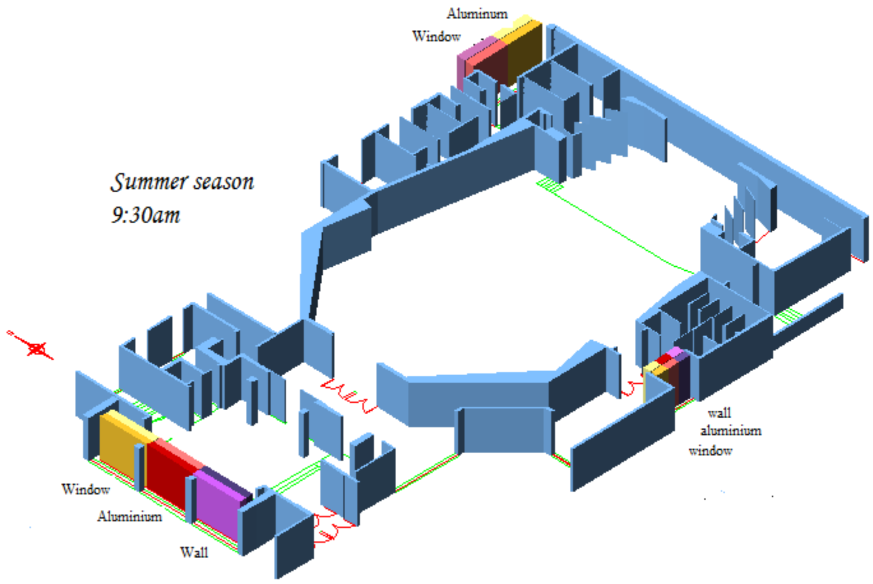
The internal window surfaces are warmer than the other materials during the morning measurement, in all orientations. In addition, the external window has higher surface temperatures than the wall, during both the morning and midday measurements.

At the north side of the Building-1970, the wall temperature is higher internally during winter and lower during summer.

As far as the temperature between window and aluminum frame is concerned, the external temperature of aluminum is higher in winter and lower in summer than the temperature of the window. The temperature of the window is influenced by the sunshine conditions and the external temperature. The surface temperature rises because of solar radiation and its thermal behavior is following the fluctuation of the air temperature.

In winter the internal temperature of the window is higher than the aluminum frame, while in summer, the temperature of the aluminum is higher.

In addition, the external temperature of the aluminum in the south side is higher than the window in summer. The south orientated façade has greater amounts of incident solar radiation. So, the thermal behavior of the aluminum frame is more influenced by the duration of sunshine than window itself.



(a)

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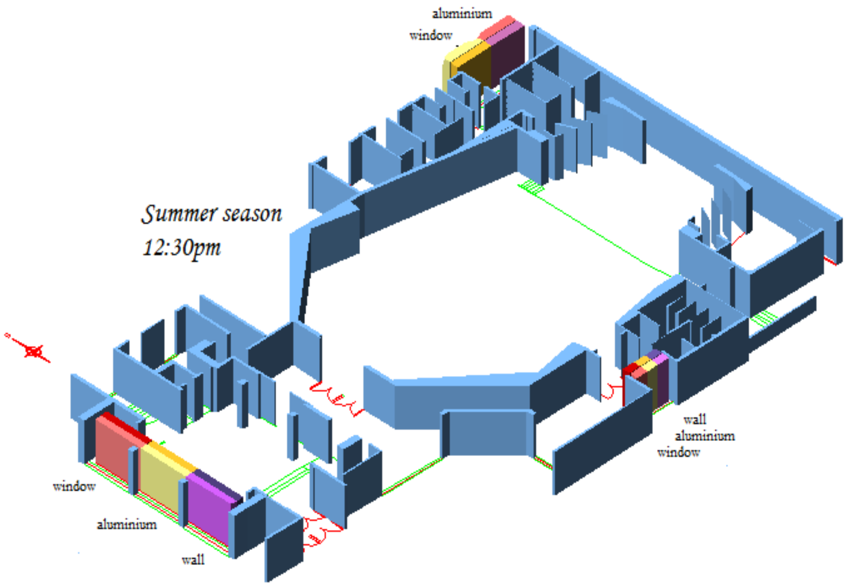

(b)

Fig. 2 Thermal behavior of materials, Building-1970, Summer season, (a) morning measurement and (b) midday measurement

3.3 Building -2002

Higher internal temperature has characterized the materials of Building-2002, in the investigated orientations, during a typical winter day. During spring- summer period, greater external temperatures have been observed. Also, the aluminum frame is always warmer than the wall and window surfaces.

In South-East orientation, the wall temperature rises during the midday measurement, while the aluminum temperature of the aluminum and window decreases compared to the morning measurement. The shadowing of the neighboring buildings affects the thermal behavior of different materials. Also, the orientation and the sun position on the midday time form the surface temperature. The window and aluminum emit easier the absorbed temperature than the insulated wall. In the South and South-West oriented facades, a temperature rise of the window and aluminum during the midday measurement, both at the interior and exterior of the building is observed.

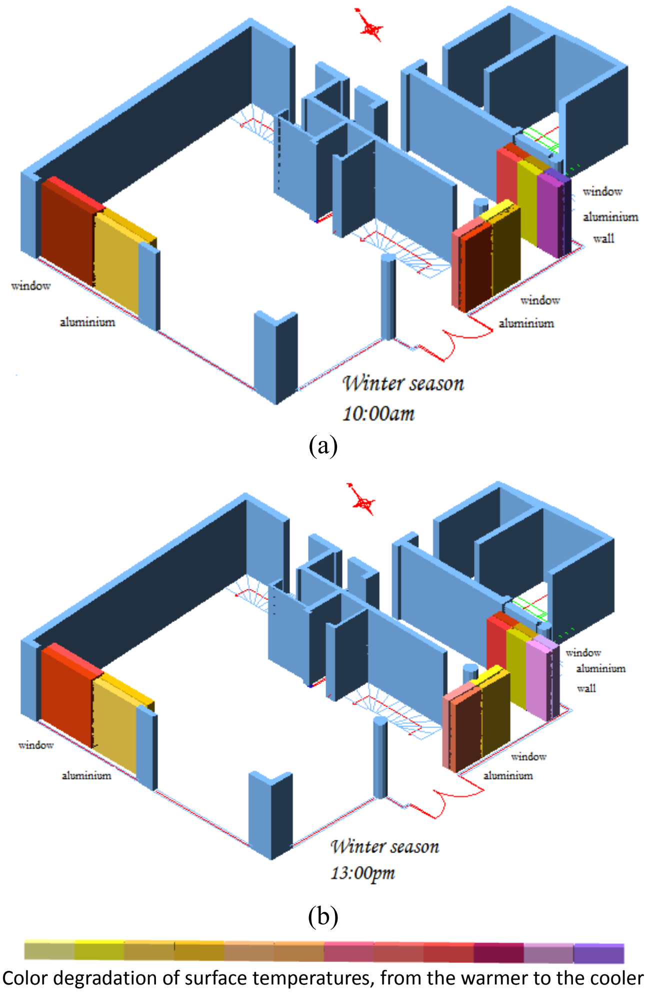

Fig. 3 Thermal behavior of materials, Building-2002, Winter season, (a) morning measurement and (b) midday measurement

3.4 Thermal behavior of materials

Material properties and characteristics affect the temperature fluctuation of the building shell. Also, the environmental factors such as the temperature of the internal and external air and the duration of sunshine are some important factors. The building's orientation defines the duration and the way that the building is thermally charged and discharged.

In particular, aluminum frame is greatly influenced by the duration of sunshine. In Figs. 4 and 5, a temperature increase of surface temperature in aluminum and window is observed. The temperature difference of aluminum between morning and midday measurement can reach the 3-5^{o}C, while of the window the 4-8^{o}C. The more the aluminum is exposed to sunshine, the more its temperature rises.

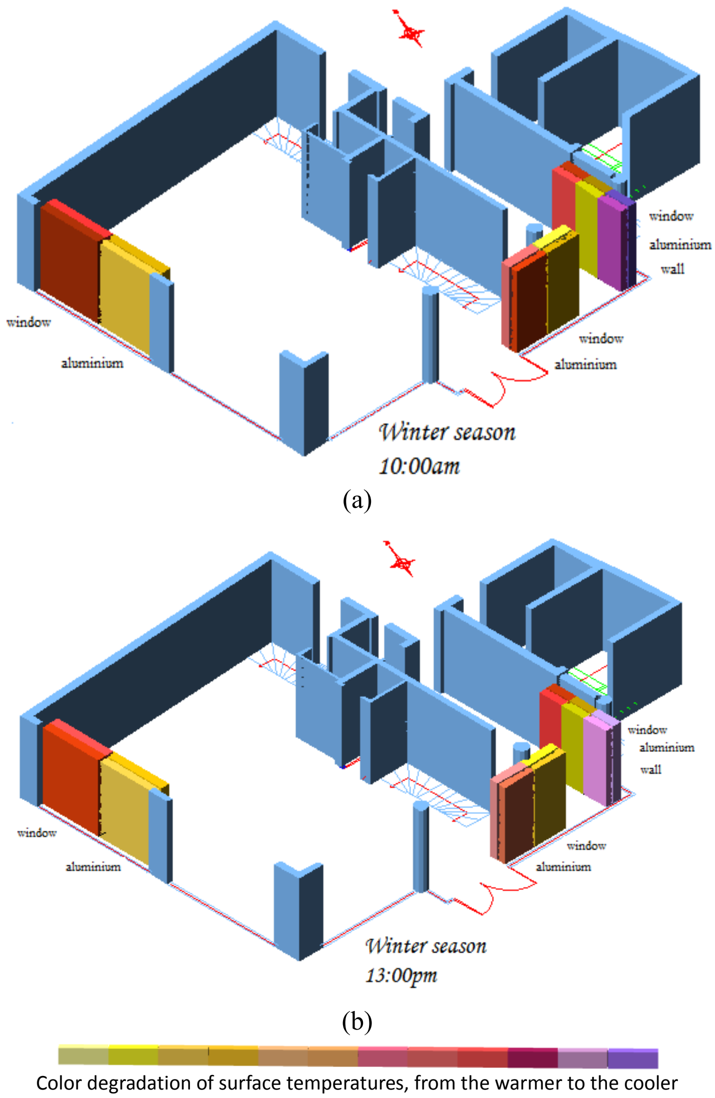

Fig. 3 Thermal behavior of materials, Building-2002, Winter season, (a) morning measurement and (b) midday measurement

At the thermophotographs in Fig. 4, the temperature of aluminum frame and window is observed. The thermal photos came from the Building-2002, during April, on south orientated façade. The left one is taken during the morning measurement and the right one during the midday measurement. The aluminum frame is the luminous line in the central of the thermal photo. The surface temperature of window increases at 5,2^{o}C, of aluminum at 4,1^{0}Cand the temperature of air has been raising by 8^{o}C.

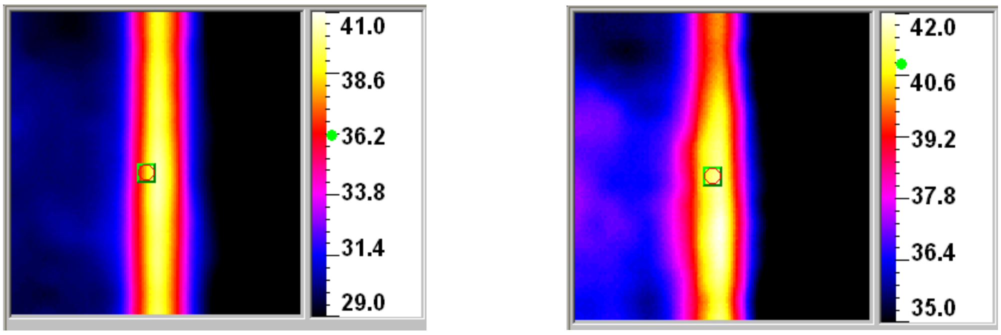

Fig. 4 Thermal photographs (23/4, *Building-2002*, south side). Temperature rise of the aluminum (luminous line) and the window after three hours

In Fig. 5, the surface temperature between morning and midday, in June, is observed. The temperature of the window has been rising at 7,6°C and of aluminium frame at 5,5°C. The air temperature has increased at 11,8°C, during measurement procedure.

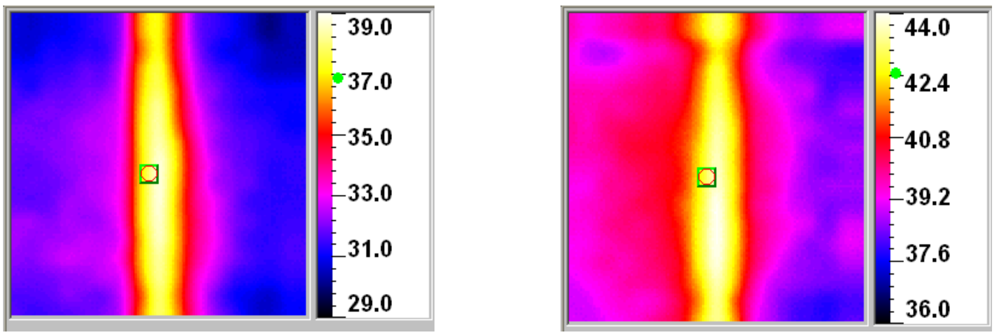

Fig. 5 Thermal photographs (4/6, *Building-2002*, South Side). Temperature rise of the aluminum (luminous line) and window after three hours

Contra wise, the thermophotographs in Fig. 6 indicate a decrease of surface temperature at the external South-East Side of Building 2002, in July. While the air temperature has been rising at 2,5°C, the surface temperature of window and aluminium frame has been decreasing for 1,1°C and 8,4°C, respectively. The sunshine conditions have influenced the thermal behaviour of window and aluminium. At the south-east side, the façade has been shadowed during the midday measurement.

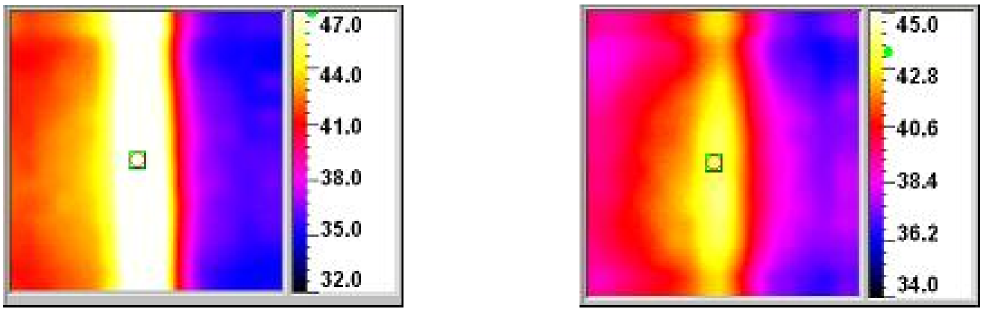

Fig. 6 Thermal photographs (16/7, *Building-2002*, External, South-East Side). Temperature decreasing of aluminum (luminous line) and window after three hours. There is a change in the sunshine conditions

In the diagrams below, the thermal behavior of the study materials is analyzed. The surface temperatures are measured by a thermal camera and air temperature by a polymeter. The differences between the external and internal temperatures are calculated by the gathered data. The abbreviations of the diagrams are in Table 2.

Table 2 Abbreviations of the diagrams

DT_{win}	Temperature Difference of window
DT_{al}	Temperature Difference of aluminium
DT_{wall}	Temperature Difference of wall
DT_{air}	Temperature Difference of Air
$DT_{material}$	Temperature Difference for each material
$DT_{(material)}$-1880	Temperature Differences for Building-1880
$DT_{(material)}$-1970	Temperature Differences for Building-1970
$DT_{(material)}$-2002	Temperature Differences for Building-2002
$DT_{(material)-(year)}$(in-out)	Internal Temperature minus (-) External Temperature
$DT_{(material)-(year)}$-in	Internal Temperature at midday minus (-) Internal Temperature at morning
$DT_{(material)-(year)}$-out	External Temperature at midday minus (-) External Temperature at morning

The thermal behavior of the window and the aluminum frame presents similarities regarding the temperature fluctuation in relation to the air temperature. In contrast, the wall's thermal behavior is characterized by different fluctuation, as the air temperature is increasing. The temperature of the wall in any case (regardless of the building, the constructive techniques, the orientation, the external or internal site, the morning or midday time of measurement), is lower than the temperature of the other materials (window, aluminum, wood).

In Fig. 7 the surface temperature differences of window, aluminum frame and wall masonry between internal and external façade of North side, in Building-1970, are observed.

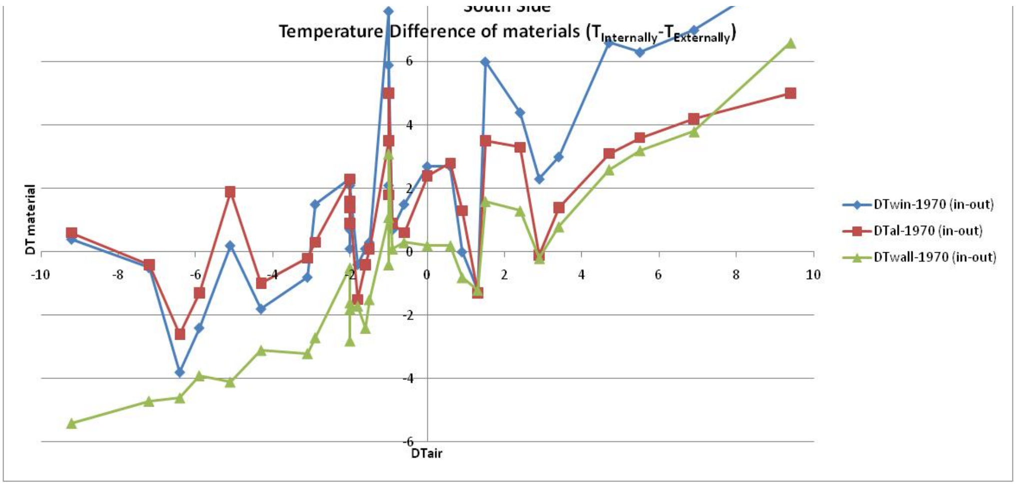

Fig. 7 Surface Temperature Differences of materials between internal and external facade, in relation to the Air Temperature differences, Building-1970, North Side

In Fig. 8, the surface temperature differences of window, aluminum frame and wall masonry between internal and external façade of North-West side, in Building-1880, are observed.

Great temperature differences between the internal and external temperature of the wall and no thermal bridges in thermographs are observed. These differences indicate the absence of thermal losses. There is no influence between the internal and external surface temperature. So, the very thick masonry of the Building-1880 provides adequate insulation to the building.

Thermal losses have observed in the Building-1970 at the West Side by the thermography. The analysis of the fluctuation of the surface temperatures (internal and external) of the building indicates inadequate insulation and thermal problems in the building's shell (Fig. 9). The differences between the internal and external wall temperatures are not great. Also, the thermal camera indicates thermal bridges. As a result, heat transfer is observed between the internal and external surface.

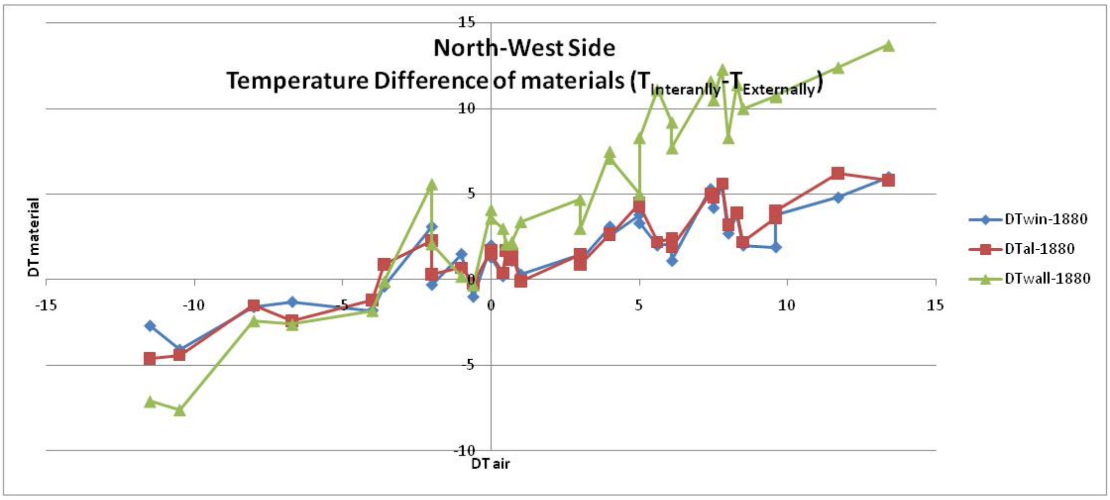

Fig. 8 Surface Temperature Differences of materials between internal and external facade, in relation to the Air Temperature differences, Building-1880, North-West Side

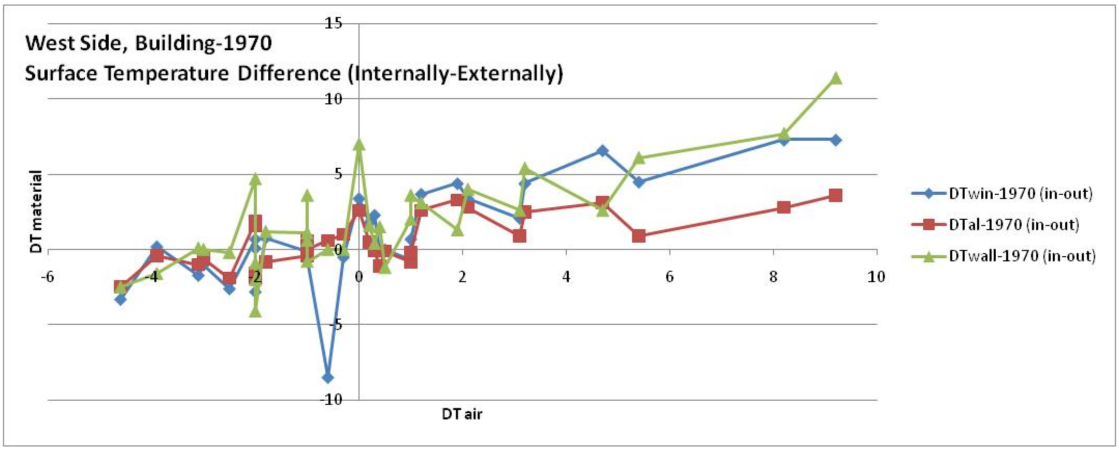

Fig. 9 Surface Temperature Differences of materials between internal and external facade, in relation to the Air Temperature differences, Building-1970, West Side

The masonry's internal temperature of Building-2002 does not show great temperature changes between the morning and midday measurement. Given that the air temperature at the interior of the building is steady at 20-22^{o}C with a standard operation program of the heating-cooling system, we conclude that the masonry insulation is adequate (Fig. 10)

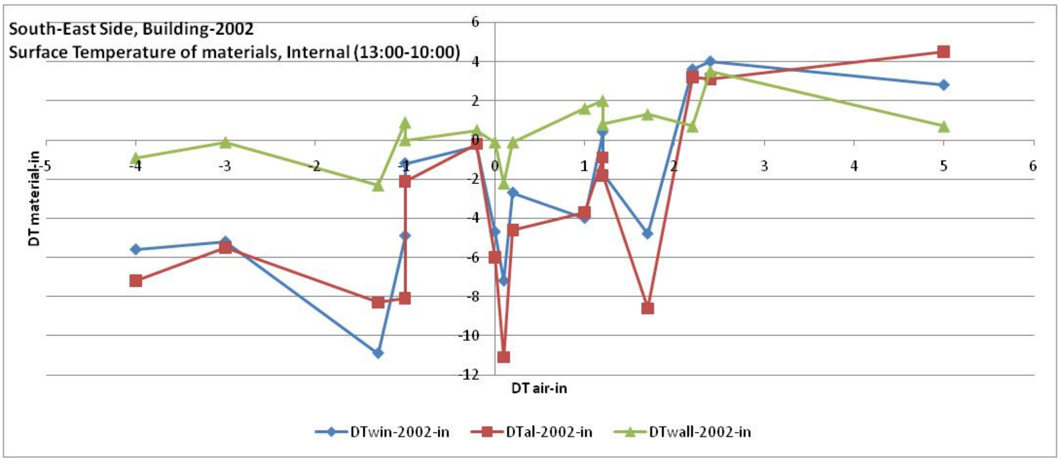

Fig. 10 Surface Temperature Differences of materials between 10:00 and 13:00 hours, in relation to the Air Temperature differences, Building-2002, South-East Side

Also, the surface temperatures in the South-East Side of Building-2002, are internally lower during the midday measurement (DT<0).The orientation and the overshadowing by the adjacent buildings affect the thermal behavior (Fig. 11).

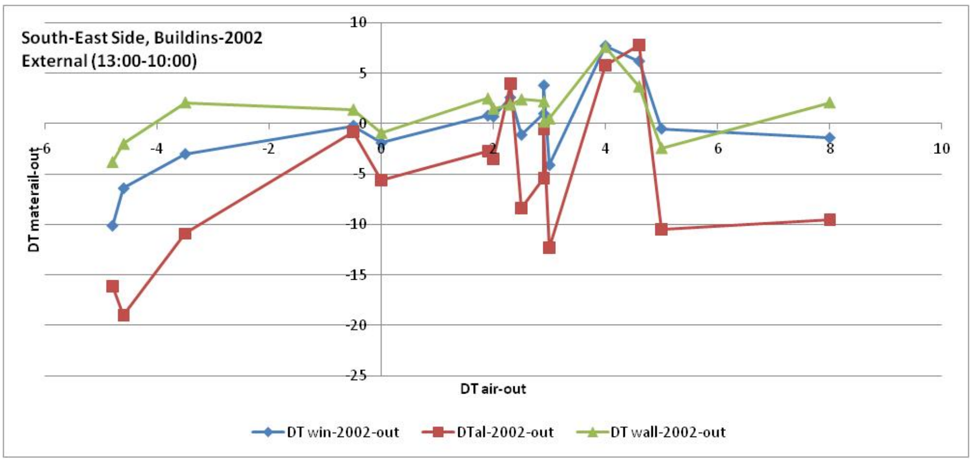

Fig. 11 Surface Temperature Differences of materials between 10:00 and 13:00 hours, in relation to the Air Temperature differences, Building-2002, South-East Side

The comparison of the three buildings indicates that in the Building-2002 greater temperature differences between external and internal surface temperatures of the construction materials are observed (Fig. 12). It can be concluded that the adequate insulation prevents the heat transfer between internal and external surface of the building's shell.

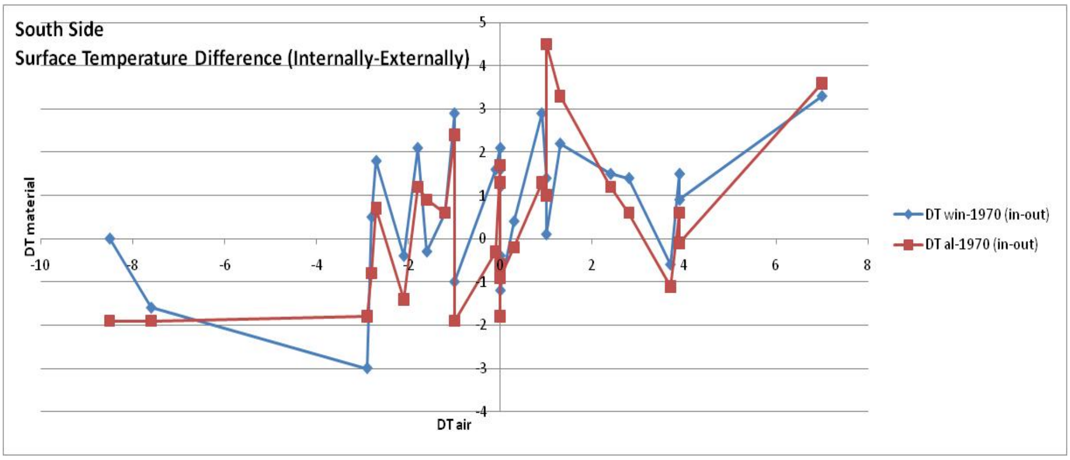

Fig. 12 Surface Temperature Differences of materials internally and externally, in relation to the Air Temperature differences, Building-1970, South Side

3.5 Suggestions for the improvement of buildings' thermal behavior

Aiming at improving the thermal behaviour of buildings with problems to insulation in their shell and to restrict the thermal losses, insulation of the internal wall can be placed, an improvement of the insulation and a replacement of the frames are suggested. Low U value induces the optimal thermal behavior, by the reduction of thermal losses and offers an optimal energy result.

In the Building-1880, it can be placed insulation to the internal of the masonry, in the newest and thinner South-West side. This side is a recent expansion. Thermal bridges were observed by thermograph. Also, the analysis of surface temperature differences indicates heat transfer between the internal and external surface. So, it is conducted that there are thermal losses from the South-West side of the shell. The suggestion refers to internal insulation, so as not to interfere in the external architecture of the building. The other sides are characterized by thick masonry. Because of the adequate insulation, it is preferable to avoid any intervention which might possibly change the thermo physical properties. The windows can be replaced by double glazing with low U value, e.g, twin glazing with 12 mm air gap, laminated with low emissivity (ε=0.10), with $U_{g\,=}$ 1.80 W/(m^2·K) and the frames can be replaced by metal frame with thermal break 24 mm with $U_{f\,=}$ 2.80 W/(m^2·K)

In the Building-1970, reinforcement both of the internally and externally insulation e.g., with extruded polystyrene of 3cm is suggested. The insulation will reduce the heat transfer between the external and internal surface. At the external side an additional marble layer can be placed for example to improve the thermal behaviour.

The properties of the double glazing window indicate low thermal losses from the building shell of the Building-2002. The internal protective grilles at the window panels offer thermal protection, prevent direct sunlight and ensure comfort conditions inside the building. Also, the double door in the entrance contributes to the avoidance of unpleasant comfort conditions and reduces the thermal losses.

The above interventions in the buildings (glazing with low U, reinforcement of the internal or/ and external insulation), can improve the thermal behaviour of the shelter and reduce thermal losses.

4. Conclusions

The masonry of 90 cm thickness in the Building-1880 offers an adequate and affective insulation. The thermal losses problems are due to the old frames and the lack of rational renovation and expansion in the South-West side.

In the Building-1970, heat losses have been observed due to the low temperature differences between the internal and external surfaces. The surface temperature of the window and the aluminium frame is affected by the orientation and the insulation conditions.

As for the structural characteristics of the Building-2002, double glazing with aluminium frame and adequately insulated masonry result in low thermal losses. The temperature differences between the internal and external temperatures of the materials are considerable, during the winter and summer period. The increased internal surface temperatures don’t influence the cooler external surface, in winter. Also, during summer season, the internal materials are cooler than the external. The orientation and shadowing affects the thermal behaviour of the materials. The window and the aluminium are more sensitive to the solar radiation. The protective grilles at the window panels prevent direct sunlight that could cause a temperature rise. The double door and the hall at the entrance contribute to the thermal protection of the space.

Different thermal behaviour is observed between different materials. The thermal properties and the orientation influence the surface temperatures.

The thick masonry offers adequate insulation and heat transfer isn’t observed between the internal and external surface.

Windows and aluminium or wood frames that are characterized by high U value have low temperature differences between internal and external surface. The use of materials with low U value improves the thermal behaviour and can reduce the thermal losses.

The temperature fluctuation of window and aluminium surfaces is more sensible to the solar radiation and the orientation of the façade.

The wall temperature is lower than the surface temperature of windows and aluminium or wood frames.

Finally, strict and pretentious thermal regulations regarding insulation (maybe according to the European directive 20/20/20) contribute to the low thermal losses from the buildings’ shell. The implementation of constructive methods in purpose to improve the thermal behaviour of the buildings’ shells is an urgent need. This is reflected by the attempts for adopting new and contemporary construction methods in national and global base, so as to achieve low thermal losses.

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