The influence of building design features on microclimatic modification in the warm periods of the year. Discussion based on temperature measurements

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ABSTRACT

The study of thermal environment around buildings is of great importance for residential microclimatic conditions. Temperature of external building surfaces, ground and outside air as well, affect the sense of thermal comfort for a person sitting outside a house.

The microclimatic components that can be modified through design and that strongly affect thermal comfort in the open areas close to the buildings is sun radiation and thermal radiation emitted by the surrounding objects. Many architectural design features of a building affect the exposure to the sun and the heat released to the environment.

In this paper is presented a preliminary study on how the external building surfaces, shading devices and materials commonly used in the building skin influence the thermal environment around the buildings.

The discussion is based on the results of a field experiment carried out in a single storey house in the surrounding area of Thessaloniki, Northern Greece (40^0N). A series of measurements were performed in order to explore the thermal effect of the fixed overhang and the various building materials to the creation of the microclimate close to the building. The potential of different design solutions, as how suitable are for creating thermal comfort conditions, is analysed for September, -a month at the boundaries of the cooling season-, when the air temperature is still high but pleasant as well, for a person to sit outside the building, all day.

1. INTRODUCTION

It is well documented that the microclimate attributes vary widely within any given part of the open-air habitable areas.

The most significant microclimatic variations next to each individual building are commonly created by differences in sun exposure of the several parts of the building, which in turn affect temperature, wind pattern, plant growth. Such differences in sun exposure have an immediate effect on the sensation of thermal comfort or discomfort experienced by sitting outside the building, as the main sources of energy available to heat a person in the landscape is radiation from the sun and radiation emitted from all objects around him. Therefore, the temperature of ground and building surfaces play an important role in the thermal environment around the buildings.

Orientation and shading conditions of building's external surfaces, building materials and colours of the walls, shading devices used and site landscaping are some of the architectural design features which modify forms of interaction between the building skin, the environment and the person sitting outside, such as the effective solar exposure, the rate of conductive, convective and radiant heat exchange between the building and the ambient air, the effective solar heat gain, the potentials for natural ventilation, etc. In other words, design decisions for the architectural elements in the façade of the buildings and the external finish can influence and affect the amount of solar and thermal radiation received by people sitting in the immediate environment of the building.

This paper reports on the results of measurements made in order to assess the effects of some architectural design features of the building such as the fixed compact overhang, and the materials used for walls, roof finishes and pavement, associated with their colour, on their environmental performance during the warm period of the year.

Measurements concerning the surface temperature of the building skin and the surrounding site were taken from various points of the external wall, roof, outside floor, and overhang, exposed to solar radiation and from shaded parts as well.

2. THE CONTEXT OF THE FIELD STUDY AND THE MEASUREMENT SYSTEM

In the Mediterranean area, hot period extends from May till October. The climate of Thessaloniki, Northern Greece (40^{0}N), is rather cold in winter, but fairly warm in summer. The highest temperatures appear in July and August. However, in the so-called transient period of the year (June and September), air temperature is still high but pleasant as well, in order to sit outside the building, all day.

The average daily temperatures for September range from 22.2^{0}C to 23.8^{0}C, with a maximum 27.7^{0}C. In June, peak ambient temperature often exceeds 29.5^{0}C. Average daily values of solar radiation on a horizontal plane range from 131 KWh/m^2 in September, with almost 239 hours of sunshine, in a total of 2429 hours annual. The relative figures for June are 186 KWh/m^2 and 293 hours of sunshine (Table 1).

To obtain an overview of the thermal environment created close to the building, a series of field measurements where carried out during September 2004.

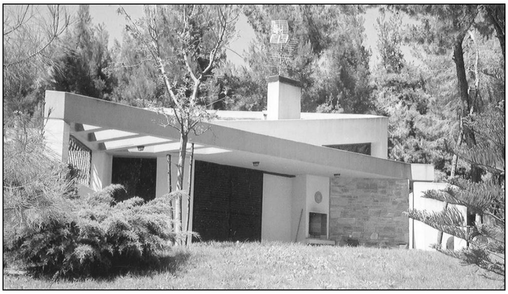

Figure 1: East facing elevation of the house.

A single-storey house with a garden, situated in the surrounding area of Thessaloniki, was used for the investigation. In front of the house a small courtyard -resting area- is created for outside sitting (Figure 1).

The east façade (SEE) of the building, which faces the courtyard, was chosen for the investigation, as the east facing surfaces are unfavourable, since they are exposed for long time and to a high intensity of solar radiation during the warm period.

A compact overhang in triangular shape is employed in the design to control solar penetration through the fenestration on the façade of the house. It is carefully designed in order to maximize shading during the summer months and to minimize heat gain while still letting direct sun into the interior during the winter season. It also shades the resting area and creates comfortable conditions in order to live outside. The overhang is partly perforated, to permit ventilation.

The building envelope is constructed with reinforced concrete used for columns, beams, slabs, and roof and with core thermal insulated brick walls. The outer skin is plastered with cement render and painted white.

The overhang is constructed with reinforced concrete, also plastered with cement render

Table 1: Thessaloniki: climatic data for the period May-October.

	Mean daily temperature (^{0}C)	Mean daily temperature during sunshine (^{0}C)	Mean daily maximum temperature (^{0}C)	Mean daily minimum temperature (^{0}C)	Monthly solar radiation (KWh/m^2)	Sunshine hours (hours/mo)
May	19.7	21.2	24.7	12.3	174	269
June	24.1	25.7	29.5	16.5	186	293
July	26.7	28.4	32.3	18.8	205	342
August	26.3	28.3	33.1	18.6	178	306
September	22.2	23.8	27.7	15.3	131	239
October	16.7	18.3	22.1	11.6	87	171

painted grey similar to the natural colour of the concrete.

The inclined roof is covered with slates, placed over a thick layer of extruded polystyrene. The external floor is paved with slates as well. A thin concrete slab is situated underneath, in order to create a firm basis to accommodate the slates.

A measurement system consisting of electronic thermistors (semi-conductors), mounted on different building elements, to record the surface temperature, was established. Sensors were placed against two external walls, the outside floor, the roof and the overhang, in such a way as temperatures from shaded and insolated parts of the same element to be recorded.

The outside air temperature (in shade) and the interior air temperature of the house was obtained as well.

During the measurement period, solar insolation data was collected from a nearby station.

The house was not in use during the measurement period. As a consequence thermal conditions in the several rooms behind the walls under investigation were similar. The inside temperature remained stable, 2-3^{0}C lower than the external temperature, and there was not different heat transfer from the various inside rooms to outside to influence the surface temperature of the building elements.

It was recorded:

- The surface temperature of the external SEE wall (sensor A), measured from a point, which was for a very long period shaded.
- The surface temperature of the external SSE wall (sensor B), measured from a point, always exposed in the sun. It has to be mentioned that the two walls under investigation are identical in construction.
- The surface temperature of the outside floor measured from two points, one being always in shade, the other exposed in the sun (sensors C and D respectively).
- The surface temperature of the roof, measured from a point in insolation (sensor E)
- The surface temperature measured on the upper side of the overhang (sensor F1, always under the sun), and also from a point on the bottom side (sensor F2, always in shade)

In the Figure 2 and 3, representing the shading patterns for a typical day in September (at 10.00 and 16.00), the measuring points are shown as well.

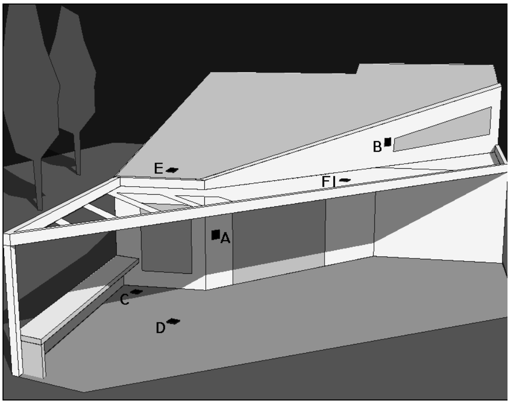

Figure 2: Shading pattern of the overhang for a sunny day at 10.00. Presentation based on shading analysis with the simulation programme ECOTECT.

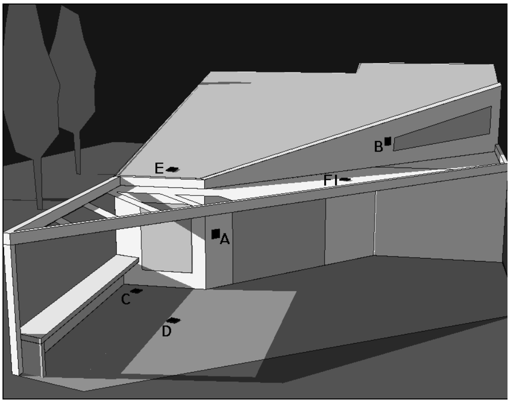

Figure 3: Shading pattern of the overhang for a sunny day at 16.00. Presentation based on shading analysis with the simulation programme ECOTECT.

This paper is based on the measurements made during September 2004, and focuses in more detail to the measurements collected during the week 12-19/9/2004, as they are considered representative and characteristic records for further discussion. The simulation programme ECOTECT was used for the study and visualization of the shading pattern created by the overhang.

3. SOLAR RADIATION

Solar radiation received by a person sitting outside the house is the direct, reflected and diffused solar radiation. In addition to these there exists another component of heat gain–radiant heat gain. Solar energy (direct or diffused) is absorbed by surfaces that face the space such as walls, floor, etc and the various objects. When these surfaces and objects become warmer than the surrounding air, some of their heat is transferred to the air by convection and re-radiation. It is well documented that the higher the temperature of the object, the more radiation is being emitted.

Energy conscious designed landscape around the building has to take into account the direct solar radiation striking the place and the heat emitted by the surrounding objects as well. The thermal radiation coming from building surfaces contribute to the development of the heat island phenomenon, created close to the building.

There are a number of ways to affect the exposure of a person sitting outside, to the solar radiation and to the heat emitted by the surrounding objects. Namely:

- to intercept sun radiation before it reaches him or a surface, by the means of shading devices
- to cause more or less radiation to be reflected by altering the material and the colour of the surface
- to change the amount that is absorbed by a surface and then released, by changing the absorptance and emittance of the material
- to carefully size the mass available to store the heat collected, especially in the days with high insolation

The amount of sun radiation, striking a given area, is predictable and its impact can be controlled by design. External building shading components are a passive design strategy that is employed in the design of buildings to control solar heat gain. Shading devices must be carefully designed and oriented in relation to the external surface and especially the fenestration

Many of the buildings that are designed in warm climates tend to use window overhangs. The overhang in the front façade plays a double role. It shades the fenestration and creates a shaded area outside the house.

In the house under examination, a compact overhang having a triangular shape is constructed. This overhang creates a shadow pattern, which reaches its biggest size during the measurement period, at 16.00.

4. SHADED AND EXPOSED ELEMENTS

The amount of solar radiation striking a given surface (wall, roof) changes constantly as a result of the sun changing position in the sky. Materials and the colour of the surface influence the absorption of solar radiation and the emission of thermal radiation. Their role to the creation of thermal environment have been underlined by various researchers (Axarli and Eumorfopoulou, 2002; Brown and Gillespie, 1995; Prado and Ferreira, 2005; Li et al., in press).

As it was mentioned before, the floor of the small resting area around the house, of approximate 30.0m^2, is paved with slates, 18mm thick. Slates are a heavy and "hard" material with an albedo of 0.1-0.3 and emittance of 0.96.

Figure 4 shows the temperature developed in the shaded and exposed parts of the floor, against the external air temperature. By observing the diagram the importance of shading the floor can be noticed.

The shaded part, even in days with no sunshine, has lower temperature than the exposed one. From 10.00, when insolation starts, the floor temperature starts to increase, reaching the maximum value at 14.00. Values up to 39^{0}C have been recorded. At that time, in periods with high sunshine, the difference in temperature, between exposed and shaded parts, reaches approximately 10^{0}C-15^{0}C, whilst during cloudy periods the difference drops to 4-6^{0}C. During night-time, the floor temperature is almost the same in all the measured points, usually not exceeding 22^{0}C. The lower temperature measured was 18^{0}C, as a result of a long cloudy period.

The same curve occurs with the shaded and exposed part of the wall. The wall rendered and painted white is characterized by an albedo of 0.34 (Figure 5).

In the figure above, the effect of the shading on the wall surface temperature, is clearly demonstrated. On exposure to solar radiation, the external wall's temperature rises above the ambient air level, in proportion to the absorbed radiation. It is clear that there is a temperature increase beginning at 10.00 when insolation of the wall starts, which reaches its peak at 14.00. During daytime, the solar radiation absorbed by the wall surface exposed to the sun, increases its temperature approximately 2^{0}C-4^{0}C more than the one occurred in the shaded part, while dur-

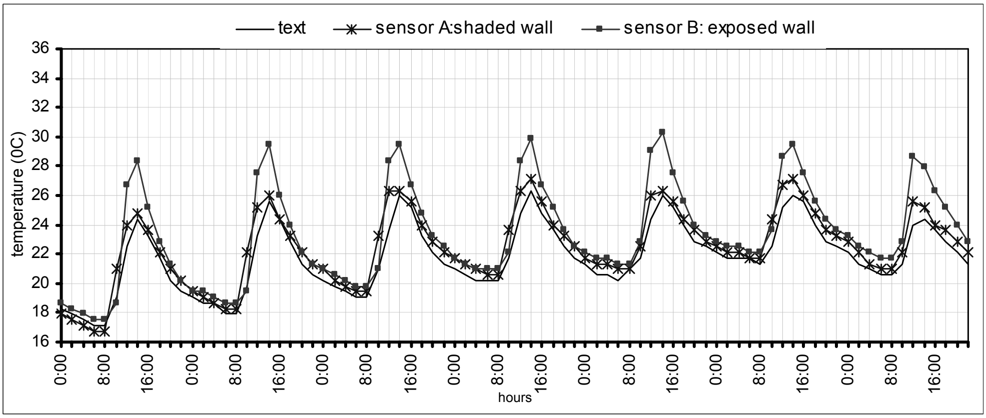

Figure 4**:** Air and surface temperatures developed on the shaded and exposed part of the floor, during the period 12-19/9/04.

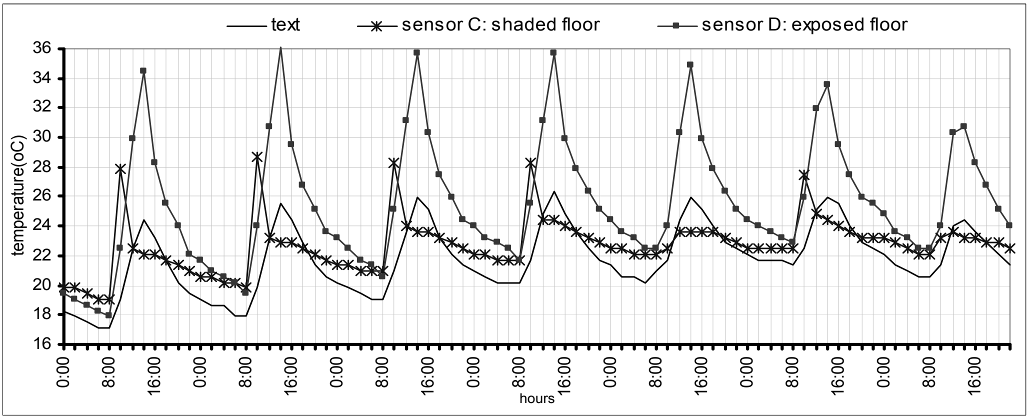

Figure 5: Air and surface temperatures developed on the shaded and exposed part of the wall, during the period 12-19/9/04.

ing night-time, both surface temperatures and the air temperature come close together.

On the contrary, the temperature pattern of the shaded wall tends to be near the outdoor air diurnal pattern. These findings are in agreement with findings recorded elsewhere (Axarli and Eumorfopoulou, 2002; Givoni, 1998; Papadakis et al., 2001).

As mentioned before, the floor covered with slates, either shaded or exposed, always develops, during day-time, higher temperature than the white painted wall. The opposite happens in night-time. The series of measurements demonstrate the expected strong correlation between solar reflectance and surface temperature in sunlight, and emittance and surface temperature in dark.

The albedo (or reflectance) of the materials is one of the variables responsible for their heat gain. The temperature elevation of the surface, caused by a given amount of solar radiation striking it, varies inversely with the lightness of the surface colour. Of course, the general idea of white washing structures to reject heat has known since antiquity.

The surface temperature is also associated with the emittance of the materials, since it determines the amount of thermal heat released to the environment.

5. THE SOLID OVERHANG

The most interesting remark refers to the overhang itself. The overhang, along with the roof,

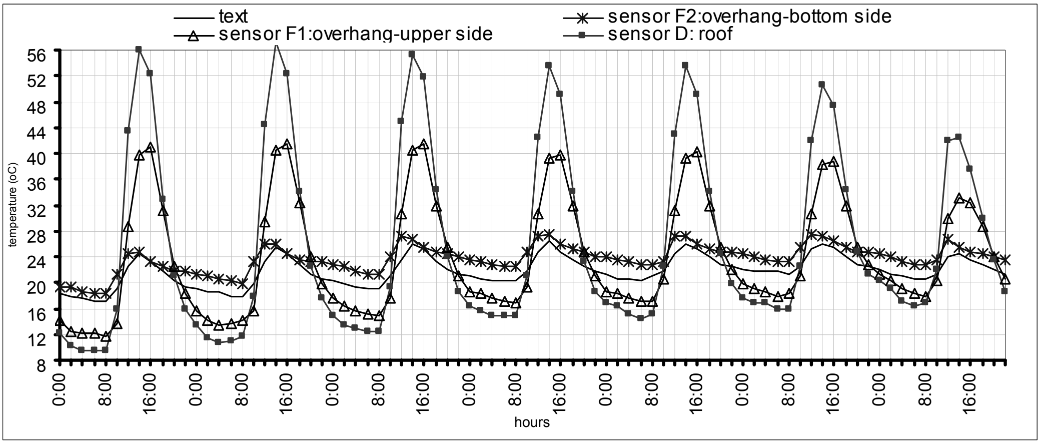

Figure 6: Air and surface temperatures developed on the upper and bottom side of the overhang and the roof, during the period 12-19/9/2004.

is the building's element most exposed to solar radiation in the warm periods of the year. It is therefore responsible for the great part of the heat flow transferred to the building and its environment (Kapur, 2004).

As it is constructed with concrete, a material with low thermal resistance, heat easily passes from one side to another. The upper side of the overhang receives solar radiation all the day. As it is expected, during day-time the surface temperature is much higher than the air temperature, while in the night time the situation is reverse. The highest temperatures occur between 12.00 and 16.00. Temperatures have been recorded as high as 42.46 ^{0}C, at 16.00 on 24th of September, a day with high insolation and air temperature around 27^{0}C. The corresponding temperature at the bottom of the overhang was 26.73^{0}C.

Usually during day time, the surface temperature of the bottom side of the overhang follows (with small deviation) the air temperature, while at night it is always higher than the air temperature, as it is shown in the Figure 6.

The concrete overhang made of material having high thermal mass and capacitance absorbs and retains short-wave solar radiation during the day. This stored heat is released or re-radiated to the atmosphere and its immediate surroundings later in the day as longwave radiation. During night-time, as the surface temperature of the bottom side of the overhang is higher than the air, it emits thermal heat to the environment; besides its dark colour increases the infrared emittance. Fortunately, the openings in the solid overhang, allow the generated warm air to escape.

The temperatures measured on the overhang's upper and bottom surfaces compared to those recorded on the roof, reveal the importance of thermal insulation.

The roof of the house, slightly inclined, is covered with slates in grey colour, which are placed over a layer of extruded polysterene.

While during day time, as there is no thermal mass under the slates to absorb the excess heat, the temperature on the roof reaches very high levels, during night the temperature drops quite low. It has been measured a maximum temperature of 57^{0}C at 14.00 and a minimum of 9.40^{0}C at 2.00. A difference of 40^{0}C in the diurnal thermal performance of the roof surface is often recorded.

Several studies have documented the role of thermal insulation beneath the roof finish material in limiting the flow of heat into the building. However, the temperature rise of the roof in the sun is significant, even for light-coloured roofs, and consequently the heat burden to the environment is high.

Comparing the thermal performance of the roof to the concrete overhang, it is expected that a solid overhang with thermal insulation on the bottom side, could perform better. Although detailed calculation concerning the proposed construction has not been done, the fact that the measured surface temperature of the roof finish during night is lower than the temperature of both surfaces of the concrete overhang, support the hypothesis that the addition of thermal insulation to the bottom side of the overhang will mitigate the thermal impact of the solid sunscreen.

During the day-time, the thermal mass of the concrete overhang will absorb the incident solar radiation, so the surface temperature will not be increased, while the thermal insulation layer will block the heat to escape from the bottom side. At night, the stored heat can be radiated back to the sky and not to the underneath open habitable space.

6. CONCLUSIONS

Taking into consideration that the sense of thermal comfort in an open air is the outcome of a combined effect of received solar energy, radiated thermal heat from the surrounding building surfaces (wall, floor, overhang) and the air temperature, the designer is expected to explore the potential of the different solutions for the materials used, and the color and type of the shading device as well.

Fixed solid shading devices are usually an integral part of the building's structure. Although they cast a distinctive shade pattern which, not always very effective, they protect to a great extent the building and the outside space from the incoming direct solar radiation. As it was mentioned, shading also helps in lowering the surface temperature of the shaded elements. However, little consideration is given to the impact of radiant heat exchange of the solid shading devices on the adjacent building surfaces and the environment.

It must be pointed out, as the measurements revealed, that when an opaque sun screen is used to shade the wall and the floor, its temperature during daytime usually becomes several degrees higher than the surrounding air, and thus there is an additional radiation thermal load to the environment. Even worse, during night-time the heat collected in the shading device and radiated, thermally burdens the wall, the floor and the outside air, and the sense of thermal comfort is lower.

The heat capacity of the overhang determines the diurnal swing of the temperature in the surrounding area of the building, while the addition of a thermal insulation layer is expected to determine the extent to which heat stored in the mass can be released to the environment.

Also, the type and properties of the materials of the building skin, affect the heat exchange between the building and the surrounding open air. As the reduction of the building elements' surface temperature contributes directly to a better local climate, increasing the albedo of the materials used, it could effectively mitigate the heat islands phenomenon created close to the buildings.

In conclusion, the recorded temperatures stress the role of the shading, the colour and the thermal insulation of the several elements of the building shell, on the modification of the microclimate in the areas close to the buildings.

Since the design features for the façades of the buildings and the various materials used as finishes have no uniform attributes and there are significant interactions; so that the quantitative effect of one feature may greatly depend on the design details of other features, systematic and full scale monitoring of different cases need to be carried out to establish applicable data.

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