Design and retrofitting of a hybrid building in Athens

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ABSTRACT

This paper's aim is to present a building design case study in a Mediterranean urban environment using as main assessment tool, a comparative dynamic thermal and daylight computer simulation.

The scope is to describe the methodology based on which the simulation was undertaken, to analyse the results and provide conclusions for the evaluation of the design as well as the credibility of the estimated future building behaviour concerning the passive cooling strategies.

1. INTRODUCTION

1.1 Climate, Site and Project parameters

The site is situated on a middle density suburb, 10 km north of the Athens city center and next to one of the busiest and most significant Roads, Kifisias Avenue.

In general the climate is characterized by warm summers and mild winters, limited but strong rainfalls of short period and relative humidity levels ranging from 42% to 78% on average. Winds are in majority bi-directional, coming from either south, south – west or north, northeast.

The yearly climate concerning the dry bulb temperature can be divided into 3 different periods:

- The cold period, December, January, February and March with temperature minimum 3^oC and maximum 21^oC (average 8 to 15^oC).
- The free-running period, including April, May, October and November, with temperature minimum 7^oC and maximum 30^oC. (average 13 to 22^oC).
- The warm period, which is the summer season and September when temperature reach minimum 16^oC and maximum 38^oC (average 22 to 30^oC).

The site of 1520 m^2 in total area, includes at the present a 2-storey building with basement of 200 m^2 (Net internal area) on each floor which is used as a modern furniture store. The project outline proposes the design of a new building of 1250 m^2 total net internal area (including retrofitting of the existing) and maximum 4 storeys to accommodate office and commercial spaces.

Concerning the general characteristics of the site, the existing building is detached and totally unobstructed regarding overshadowing from all neighboring buildings. The area is polluted due to heavy vehicle traffic in every day basis, while

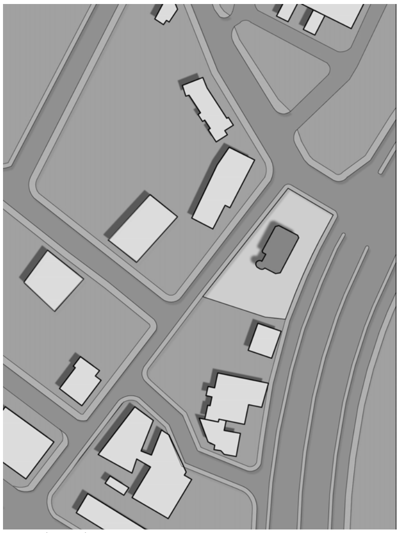

Figure 1: Site plan.

the average noise levels are quite high (70-90 Db). The most common land uses on the area are offices, commercial, few public green spaces and recreational spaces such as bars and restaurants.

2. EXISTING BUILDING

2.1 Monitoring and problem definition

The first step towards the understanding of the existing building's problems, were on site observations and measurements. The equipment was a data logger recording dry bulb temperature, a Lux-meter and a wind velocity meter. The thermal monitoring had a total duration of 7 days, while wind and daylight levels were measured daily to record the interaction between external and internal conditions.

2.1.1 Thermal properties

- Large daily temperature fluctuation, due to the increased areas (65% window to wall ratio) of low quality and high u-value (5.2 W/m^2 K) single glazing, unless if HVAC system is switched on during the majority of occupational hours.
- 60 % of total glazing area is oriented towards east-west, therefore contributing less in passive solar heating during winter.
- The solid external envelope parts have insufficient insulation and in combination with cracks and thermal bridges, result increased heat loss or gain, according to the season.
- Negligible internal heat gains from occupants and appliances.

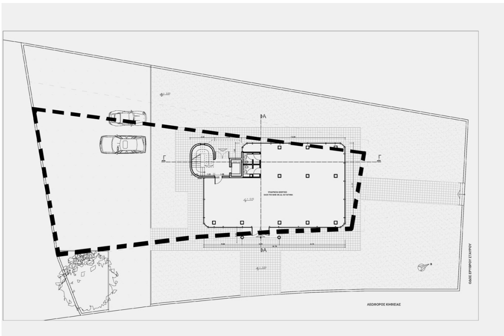

Figure 2: The existing ground floor plan and indication of the buildable area.

Figure 3: The existing building as seen from the avenue. (East elevation).

2.1.2 Daylight availability

Adequate daylight levels on the perimeter of the building, but poor in the centre, which indicates that there is insufficient distribution of diffused daylight due to:

- Low height of apertures compared to the total floor to ceiling height.
- Internal demonstration panels of 2 m height.
- Bad quality and maintenance of the single glazed elements.

2.1.3 Air quality and noise pollution

Poor quality of indoor air and high noise levels in the building obstructing the stuff and the visitors due to:

- Proximity of the polluted and heavy traffic avenue.
- Main entrance oriented towards the road.
- High air infiltration but almost not any natural ventilation due to lack of openable parts on the existing windows. Ac/h are not sufficient to provide the required air mass replacement.
- Lack of sound buffers such as noise insulation or vegetation.

3. HYPOTHESIS

3.1 Establishing the standards

The first step towards an effective simulation is to define the acceptable standards for the aspects that concern the occupant comfort and building behaviour.

Internal Temperature Thermal comfort band:

- Winter season 18-23^{o}C.
- Summer season 22-28^{o}C.

Internal Relative Humidity: 45-65 %.
Luminance levels:

- Distribution: 100-200 Lux
- Work: 200-300 Lux
- Display: 500 Lux minimum
- Kitchen –Bathrooms: 200-300 Lux

Recommended rates of outdoor air supply:

- Offices: 25.5 - 42 m^3/hr/person
- Commercial: 20.5 - 30 m^3/hr/person

According to the Greek building regulations for offices, the recommended rate is 2 – 4 ac/h.

3.2 Establishing the methodology criteria

The next step is to define the targets of the design process on which the methodology will be based.

- Maximising the positive potential of solar availability the site provides.
- Production of a simple as possible building that deals with the external conditions using as main feature its external envelope.
- Reduce the annual energy consumption for HVAC, hot water and artificial lights.
- Provide as more as possible of the total energy need through building integrated renewable – based means.
- Resultant internal temperature should be kept as possible within the predefined comfort band limits depending as less as possible to mechanical heating or cooling.
- Natural daylight should reach the standards in different zones according to the use, as many of the occupational hours annually as possible.
- Avoidance of glare or contrast between over-illuminated and dim working areas as well as direct solar radiation during occupational hours.
- Application of natural cross ventilation during the day in order to adjust the temperature fluctuation and renew the air mass.
- Application of night ventilation during summer and occasionally mid-season to cool down the building.
- Use of low embodied energy local materials.
- Provision of an envelope which will buffer the noise levels in conjunction with the actual architectural elements.

4. SIMULATION PROCESS

The main use of the simulation is to test the efficiency of the systems and methodologies that were applied at the design and concern solar control, natural and night-time ventilation and thermal comfort.

The simulation process took part in conjunction with the architectural design and was used as the main evaluation tool. The software for the thermal simulation was TAS version 8.50 by EDSL Company and the one for daylight performance was Radiance version 4.2 having as platform Ecotect 5.2.

The daylight analysis was used mainly to define parameters such as aperture sizes and levels of light comfort which affect the majority of the thermal properties as well.

4.1 Validation of the process

As starting point for this procedure, it was necessary to define the optimum level of thermal 3D model simplification and data input, in order to provide a sufficient estimation of the building behaviour. The tool for that process was to use the weather data of the days that the existing building was monitored and its free-running performance in direct comparison with weather data input in TAS and the simulation of its thermal performance.

According to TAS weather data for Athens, the week between 7-13 April during 1979 and the actual weather had the most similar properties concerning external temperature fluctuation, solar radiation, wind direction and speed. Those conditions in conjunction with the rest of input such as material properties, internal heat gains and occupancy pattern were defined in TAS for a 7 day simulation. After a gradual and staged process, the simulated building’s performance presented similar characteristics with the real one:

- The daily fluctuation on the free-running days (day 3-7) is of almost same amount of degrees Celsius (Days 1-2 had HVAC support).
- The lowest night-time temperatures, when the building is unoccupied, are proportional compared to the given outdoor temperature.
- During sunny days the internal temperature is affected equally in both cases from solar gains.

- The heat loss and gain ratio is similar judging from the rising and falling rate of temperature during early in the morning and late in the evening.

This comparison proves that the building was simulated relatively accurately, so the next step, which is the annual thermal performance, would be expected to be indicative of the proposals problems and advantages.

4.2 Daylight simulation

4.2.1 Methodology

In order to draw useful conclusions and present accurate and also realistic results, it was necessary to limit the size of simulation and concentrate in only one floor as an example for the rest of the building. Therefore, the selected zone was the 2nd floor. All building materials have been simulated and given their real colors, while the position of the basic furniture and working spaces has been defined. Due to alteration on the use of different parts of the building it was necessary to provide zoning in similar way that would be done in the thermal simulation, in order to meet with the real demands for daylighting. Moreover, since the predominant use is office space, a satisfactory illuminance level is 300 Lux.

4.2.2 Choice or representative scenarios

The simulation was done for five prevailing situations throughout the year according to a daily study of Athens Meteorological Station annual data, about the cloud cover factor and solar availability:

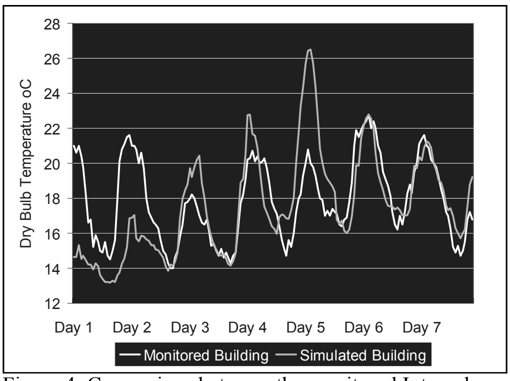

Figure 4: Comparison between the monitored Internal Temperatures and the simulated ones.

- Summer: 92% sunny days/hypothesis: 100% sunny.
- Autumn or Spring day: 64% intermediate without sun/36% sunny.
- Winter: 78% overcast day/22% sunny.

4.2.3 Interactive simulation

According to the latter procedure, the following results have been produced:

The manipulations of the five different occasions are trivial since the envelope of the building deals with the majority of the external conditions. During summer, with higher solar altitude, the folded skin prevents the direct solar radiation and the moveable louvers or the Venetian blinds on east and west elevation diffuse the incoming light, while the skylight provides adequate natural light levels throughout the day on the 2nd level.

- During mid-season on a usual intermediate or cloudy day without sun, due to higher levels of global luminance, the daylight provided is adequate during the most occupational hours. The general illuminance levels are between 1000 Lux near apertures to 200 Lux on the core of the plan, with the exception of isolated service rooms. In the case of a sunny day, similarly to the summer, the louvers and blinds are adjusted according to the wish for provision of direct sunlight or not.
- During Winter, whenever it is overcast, the simulations indicate that except of the areas close to the windows, the rest of the space has relatively acceptable but low daylight levels. As a result the use of artificial light is necessary in case of special task. The louvers are rotated to allow maximum sky view and the blinds are up.
- Whenever it is sunny, on a typical winter day, in the case that the occupants desire it and it doesn't negatively affect working areas, either during morning or afternoon the direct solar radiation is heating up the building fabric and internal surfaces. Each user is able to manipulate the personal environment and shade its working space. Due to direct sun light and the high reflectance of the internal surfaces, the light levels are satisfactory, though glare might be resulted.

4.3 Dynamic thermal simulation

Following the latter test, the proposed building design was modelled, according to the proper window sizes and positions, divided in zones by floor and orientation, estimated the new internal heat gains from occupants, lights and appliances, and building properties per element. Three different pattern strategies were applied according to the season. The main aim was to adjust the internal space properties by using trivial manipulations on the envelope of the building which is considered the main buffer against the external conditions using passive cooling techniques.

A very important decision was to perform the thermal simulation by using only one zone and modify one parameter every time in order to be able to monitor the results without risking mistakes from misinterpretation. In the particular situation, the 2nd floor of the new building was selected.

During winter season, by reducing infiltration rate and limiting natural ventilation to the minimum required which is 1 ac/h, all zones are within the comfort band during the majority of the occupational hours, while the heating need remains in low levels. In this case, the strategy includes passive solar heating. The apertures are not shaded and the incoming solar radiation contributes drastically to the space heating by being stored on the internal thermal mass such as the floor and the external walls.

On the free-running period, natural ventilation levels are increasing to 2ac/h, during occupational hours since the outdoor conditions are comfortable. With limited use of the HVAC system only during few days, the energy consumption is at the lowest throughout the year. In the case of warmer days that might be observed during April, May, and October, appropriate shading is applied to reduce direct solar radiation that will cause possible overheating and 5 ac/h of night ventilation is used to reduce the mean radiant temperature of the exposed thermal mass. For that purpose all windows are equipped with openable upper parts, in order to allow cross ventilation close to the building elements.

During summer, in the case that the external temperature is at maximum 30 to 32 ^{O}C, variable natural ventilation of 5-10 ac/h is applied through infiltration points at low level and outlets at higher points. Consequently, the occupants are not disturbed by excessive air movement. In conjunction with ceiling fans over the working areas, air movement is produced resulting conditions closer or within thermal comfort band.

In the case of days when the ambient temperature is far above the pre-mentioned conditions, the interior is partly isolated, by reduction of the infiltration rate and 0.5 ac/h basic ventilation rate, to allow the HVAC to be more efficient.

In both latter cases, total shading is applied to all possible apertures on the south, east and west side according to the time of the day. Simultaneously, the double façade system which comprises the external solid building elements, having air cavity between the marble panels and the main wall, allows air movement in-between and therefore reduces the effect of heat produced by the direct solar radiation being transferred through walls to the interior via conduction.

5. CONCLUSIONS

Through this procedure of building design methodology and evaluation, the following conclusions have been derived:

- The thermal simulation demonstrated that the full solar availability of the site was the main reason for excessive gains and therefore the most important disadvantage.
- The simulated zones without any support from mechanical cooling, presented a temperature rise not more than 4 to 5 ^{O}C higher or lower from the desired comfort band. Furthermore, TAS was not able to simulate ac-

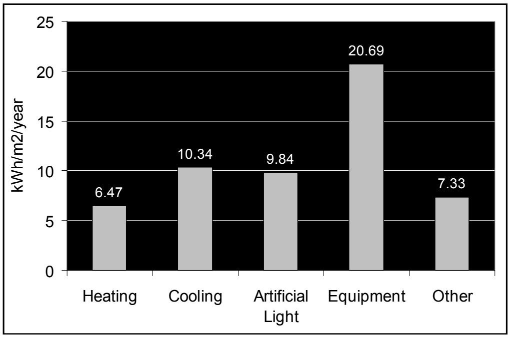

Figure 5: Energy consumption breakdown per annum.

Figure 6: The front elevation of the designed building.

curately the ceiling fan effect on the extension of comfort band, thus presenting a worse case scenario.

- The combination of a light colored external layer material and the ventilated air gap between the latter and the rest of the structure provides a useful sun protection shield against overheating. The possibility of stopping the air movement during winter could be beneficial for passive solar heating through conductivity.
- By modifying each passive cooling technique individually, night time ventilation proved to lower internal temperature by an approximately 20% of the total daily temperature fluctuation.
- Window types that allow low infiltration rates are very important during very cold or hot days, due to the fact that they provide a certain amount of internal air mass renewal but not so, that the internal temperature is significantly affected.
- Fixed position external louvers versus moveable ones would result a less effective thermal performance but easier for the occupants to use and less energy consuming for their operation.
- In general, the simulated zones present a 60% of the occupational hours within the comfort band while overheating and underheating vary from 15 to 17% each during free-running mode.
- The application of solar control in collaboration with natural and night time ventilation reduce the need for HVAC support by approximately 30%.

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