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Full Length Research Paper

Thermal comfort of multiple-skin facades in warm-climate offices

Halil Z. Alibaba and Mesut B. Ozdeniz*

Department of Architecture, Eastern Mediterranean University, Gazimagusa, TRNC, Via Mersin 10, Turkey.

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A multiple-skin facade is an envelope construction that consists of two transparent surfaces separated by a cavity. The extra skin can reduce both cooling demand in summer and heating demand in winter. Solar radiation entering through the outer skin on the south face of the building will heat the air in the cavity. Depending on whether there is a demand for heating or cooling, this preheated air can either be drawn into the interior spaces or ventilated out of the building.These kinds of systems can be varied, depending on the arrangement of the air cavity section. Some examples of variations are the shaft-box window, the corridor facade, the multi-storey double-skin facade, and the box-window facade. The advantages of the double-skin facade are that it provides acoustic insulation, thermal insulation, and reduction of the effects of wind pressure; this approach allows natural or fan-supported ventilation and the possibility of rehabilitating existing single-skin facades by the addition of a second skin. The disadvantages of the system are its higher cost, the lack of practical information on fire protection, reduction of available space for offices, and less room-to-room or floor-to-floor sound insulation. In this study, the authors chose to conduct a parametric study for warm climates to provide a design aid for architects and designers. The parameters studied were the width of the cavity between the double skins, the area of the openings, the height of the buildings, the height of the transparent chimney added to the top of the south double facade, and the arrangements of open and closed openings. The effects of these parameters on airflow within the building and levels of thermal comfort were studied.

Key words: TAS software, double-skin facade, natural ventilation, warm-climate building problems.

INTRODUCTION

Saelens (2002) defined the multiple-skin facade as “an envelope construction, which consists of two transparent surfaces separated by a cavity, which is used as an air channel.” The extra skin offers improved thermal insulation, which can reduce both cooling demand in summer and heating demand in winter. Solar shading systems can be integrated with the cavity, protecting the building from excessive sun. Solar radiation absorbed by the shading systems will also be connected into the air volume in the cavity. Depending on whether there is a demand for heating or cooling, this preheated air can either be drawn into the interior spaces or ventilated out of the building.

In the literature, a number of terms are used to describe a multiple-skin facade; for example, multiple-skin envelope, double-skin facade, twin skin, airflow window, and ventilated facade. A double-skin facade has many properties in common with an atrium or a glazed sun space (Wachenfeld and Bell, 2003). However, because the cavity in a double facade is used for ventilation, it does not offer occupiable space.

The main components of the multiple-skin facade system are external glazing, internal glazing, and an air cavity. The exterior glazing is usually a hardened single glazing. The interior glazing is an insulating double-glazed unit. Clear low-E coating and solar-control glazing can also be used. The air cavity between the two skins can be naturally or mechanically ventilated. The width of the cavity may vary from 200 mm to more than 2 m.

Double-skin facades can work as supply, exhaust, exterior air curtain or interior air curtain. These kinds of

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*Corresponding author. E-mail: mesut.ozdeniz@emu.edu.tr. Tel: +90 533 866 76 10. Fax: +90 392 630 23 65.

systems can be varied, depending on the arrangement of the air cavity section. Some examples of variations are the shaft-box window, the corridor facade, the multi-storey double-skin facade, and the box-window facade (Yellamraju, 2004). In a “shaft-box window”, the air space is divided into vertical compartments along the height of the facade with a tall ventilation shaft place near it. These box windows are connected to the vertical shafts on the facade, which provide a stack effect. This is suitable in high noise areas where a high level of sound insulation is required inside the buildings. In a “corridor facade”, the air space is divided into horizontal compartments, usually at the level of each storey. In some cases, vertical dividers are added for fire and sound protection. The corridor is accessible and is wide enough to be used as service platform. In a “multi-storey double-skin facade”, there is no horizontal or vertical partitioning between the two skins; instead, the air cavity is ventilated via large openings near the base and roof of the building. Normally, a multi-storey double-skin facade is used as a supply air facade in winter and as an exhaust air facade in summer. In a “box window”, the facade is horizontally and vertically subdivided. Thus, horizontal and vertical partitioning divides the facade into small, independent boxes and no shaft is used. It is suitable when a high level of sound insulation between the rooms is required. In this arrangement, the interior windows can be opened into the gap for ventilation, and the exterior facade includes openings for supply and exhaust air. Exhaust air from a lower element flowing into an element above can be avoided by offsetting the exhaust and supply openings from storey to storey.

The advantages of the double-skin facade are that it provides acoustic insulation, thermal insulation, and the reduction of the effects of wind pressure; this approach allows natural or fan-supported ventilation and the possibility of rehabilitating existing single-skin facades by the addition of a second skin. The disadvantages of the system are its higher cost, the lack of practical information on fire protection, the reduction of available space for offices, and less room-to-room or floor-to-floor sound insulation.

LITERATURE REVIEW

Faist et al. (1998) conducted a research work under the heading “Incidence of the Typology of Double-Skin Walls on their Energy Performance and Building Physics Behaviour” and wrote a report on this subject. Grabe (2002) studied both the airflow and temperature field of a double-skin facade specifically for energy consultants. Faggembau et al. (2003) proposed a new model for the study of the double-skin facade. This model allows advanced elements, such as phase-change materials, selective surfaces and improved glass, to be integrated into the facade. In a master’s thesis at Texas A&M University, Yellamraju (2004) studied double-skin facades in hot climates, especially in India. She concluded that double-skin facades in hot climates are effective only if used in combination with other materials, with the proper orientation and transparency. Gratia and Herde (2004) studied natural ventilation in a double-skin facade using a simulation program (TAS). They examined the impact of the orientation of the double-skin facade related to the wind direction and the degree of wind protection provided and concluded that air temperature rises during the day when blinds are positioned in the cavity. In a second paper, the same authors studied the optimal use of a south-facing double-skin facade and determined that its use should be dynamically controlled Gratia and Herde (2004).

Saelens et al. (2005) studied the performance of three different double-skin facades in Belgian climatic conditions. They discovered that both heating and cooling demands can be significantly improved by controlling the airflow rate and recovery of air returning from multiple-skin facades. Stec and Van (2005) studied the optimisation of an HVAC system with a double-skin facade. Using a simulation program, Hien et al. (2005) explored the energy consumption of a double-skin facade in a warm, humid climate and concluded that energy consumption is less than with a single-glazed facade. Ballestini et al. (2005) conducted another interesting study on natural ventilation by adding double-skin facades to historical buildings. Applying two different dynamic simulation models, these researchers found that the application of double-skin facade could save 12% of the ventilation energy in one year. With the use of a 1/25 scale model and a full-scale computational fluid dynamics model, Ding et al. (2005) studied the natural ventilation possibilities of double-skin facade with an added ventilation chimney above it. They concluded that the added ventilation chimney assured natural ventilation even when no wind was present in the vicinity of the building.

Poirazis (2006) conducted an extensive literature review of multiple-skin facades and recommended some new research topics. In another study, Poirazis (2008) analysed single- and double-skin glazed office buildings for Scandinavian climatic conditions. He concluded that, in a Scandinavian climate, the energy effectiveness of such an approach is poor unless the facade is designed very carefully.

Gratia and Herde (2007) also studied energy consumption with the addition of a double skin. They found that efficiency of the double skin depends on many factors, such as type and use of the building, its orientation, the level of insulation, the proportion of opaque and glazed surfaces of the inside skin, the operating mode of the double skin, and the type and position of shading devices. In another study, Gratia and Herde (2007) studied the greenhouse effect in double-skin facades and concluded that its effect is moderate and depends on the orientation of the facade. A commission of the European Council under the leadership of Blomsterberg (2007) prepared guidelines for the application of a double-skin facade. Hamza (2008) studied double-skin facades versus single-skin facades in hot, arid areas through a simulation program (IESVE). According to his research, a reflective double-skin facade can achieve better energy savings than a single skin with a reflective glazing in terms of cooling loads in hot, arid climates. Although the idea dates back to 1849 (Moezzi, 2009), recent attention has been given to the integration of natural ventilation into high-rise office buildings by means of multiple-skin facades. The Commerzbank in Frankfurt am Main (Germany) is an example of this approach.

Baldinelli (2009) looked at the effects of blinds in the south cavity of a building, with the aim of optimising the energy performance of the double-skin facade in both winter and summer. He found that over an entire year, the double-skin facade significantly improves a building's energy behaviour. Another interesting study was conducted by Chow and Hung (2006) on the behaviour of a double-skin facade in fire. They concluded that wider cavities might be safer in fire conditions to avoid breaking of the inner glass panels and that smaller glass panels would perform better than larger sheets. Chow and Hung (2006) also determined that it is safer to use tempered glass.

Despite the number of studies on multiple-skin facades, there is still a knowledge gap as far as their application, and architects still lack a comprehensive design tool. Hence, the authors chose to conduct a parametric study for warm climates to provide a design aid. The same approach can also be applied in other climates.

STUDY METHODOLOGY

In the first stage of the research, a test building was set up, and the accuracy of the simulation program was checked. The test house is 4.70 m wide, 12.20 m long and 3.53 m high. The length of the test house is on an east-west axis; thus, the long facades are facing south and north. It is a load bearing structure with 20 cm thick brick walls, plastered on both sides and 15 cm thick reinforced concrete ceiling slab with insulated low slope roof. Three 1.30 × 2.40 m box-type double-skin facades were fixed to the window openings on the south side, and one was fixed on the north side. The widths of the air cavities are flexible and can be adjusted between 30 and 120 cm. In the first run, a 30 cm width was tested as seen in Figures 1 and 2. Double windows were always placed on the inner side of the window opening, thus when the air cavity width is narrower than 120 cm, the opening cast shadow on the window. Each opening window, at the top and bottom of each floor and the cavity, can be opened up to a maximum of 1,800 cm². On the external surface, 6 mm-thick reflective type was used, and on the inner surface, 4+12+4 mm double glazing was used.

Reflective glass used has the following features. It was 6 mm thick silver grey and produced by pyrolitic (on-line) method. This reflective glass had solar transmittance as 0.160, external absorptance (external surface: 0.330, internal surface: 0.330). Internal solar absorptance (external surface: 0.330, internal surface: 0.330). Light transmittance: 0.890, light reflectance: 0.080, emissivity (external: 0.873, internal: 0.620). Conductance: 166.667 W/m²K. Time constant: 0.00, U-Value: 5.731 W/m²K. Total transmittance (G-value): 0.317. Pilkington shading coefficients (short wavelength: 0.184, long wavelength: 0.181, total: 0.364). No external or internal blind was used.

For the inner surface, 4+12+4 mm clear double glazing was used that has the following features. Solar transmittance as 0.498, external solar absorptance (external surface: 0.173, internal surface: 0.135). Internal solar absorptance (external surface: 0.227, internal surface: 0.097). Light transmittance: 0.760, light reflectance: 0.120, emissivity (external: 0.845, internal: 0.845). Conductance: 2.6 W/m²K. Time constant: 0.00, U-value as 1.808 W/m²K. Solar energy (EN 41 0): (direct transmittance: 0.498, direct reflectance: 0.193, direct absorptance: 0.308, total transmittance (G-value): 0.616). Pilkington shading coefficients (short wavelength: 0.573, long wavelength: 0.136, total: 0.709). No external or internal blind was used.

At various points both inside and outside the test house surface temperature, air temperature, relative humidity and air velocity were measured. These are outside air temperature and relative humidity in a shaded screen box at 3.5 m height, outside glass surface temperature, air cavity air temperature and relative humidity at the centre of the cavity, inside glass surface temperature, inside wall surface temperatures at six points, ceiling inside surface temperature at three points, air temperatures and relative humidity at 50, 150 and 250 cm heights at the centre of the test house, air velocities at four window openings.

Surface and air temperatures were measured with HOBO instruments with their own data loggers. The accuracy of the HOBO XT temperature probes is ±0.3 K in the measurement range of -5 to +37°C. The accuracy of HOBO U10-003 temperature and relative humidity probes is ± 0.4°C for temperatures in the range of 0 to 40°C and ±3.5% for relative humidity in the range of 25 to 85%. Air velocity was measured with an Omega HHF2005HW Hot Wire Anemometer with accuracy of ±5% of the reading in the range of 0.2 to 20 m/s. A number of important values like outside air temperature, cavity air temperature for windows 2 and 4, office air temperatures at the centre of the office at 10.00 h on 14th July, 2009 were given for comparison in Figure 6 as an example.

In the first attempt, a, c, f, and h apertures of all of the windows were opened. Each of the operable sliding windows was 325 cm² open. There were no blinds in the cavity. The results of the measurements at 10.00 h on July 14, 2009, were given in Figures 3, 4 and 5. The meteorological data on this day and time was as the following. Air temperature: 31.3°C, relative humidity: 47%, wind direction: south, wind velocity: 3.5 m/s, average daily cloud cover: 0.6, global radiation: 921.1 W/m².

On a typical summer day, without blinds, inside air temperatures during the day are slightly lower than the outside air temperatures, and during the night, temperatures are slightly higher inside. This shows that the double-skin facade contributes positively to thermal comfort during summer days and nights. As it is seen in Figure 4, relative humidity was also regulated, although this is not the result of the double-skin facade only. At night, relative humidity inside the test house was lower than outside, and during the day, relative humidity was higher inside than outside.

In the second stage of the study, the TAS simulation program was used for the same conditions. The results are in accordance with the experiments. As seen in Figure 6 the difference of the results on average varies between -2 and +2%, which is not significant. Hence, it was decided to continue with the simulation program to study the effects of various parameters on the performance of double-skin facades in warm climates.

First simulation experiments were carried out for multi-storey type double-skin facades. Parameter testing was done for an office building 20 m long and 10 m wide with a double-skin facade both on the long south and north facades. The tested buildings were two, five and ten floors; each floor was 3 m high. The width of the cavity

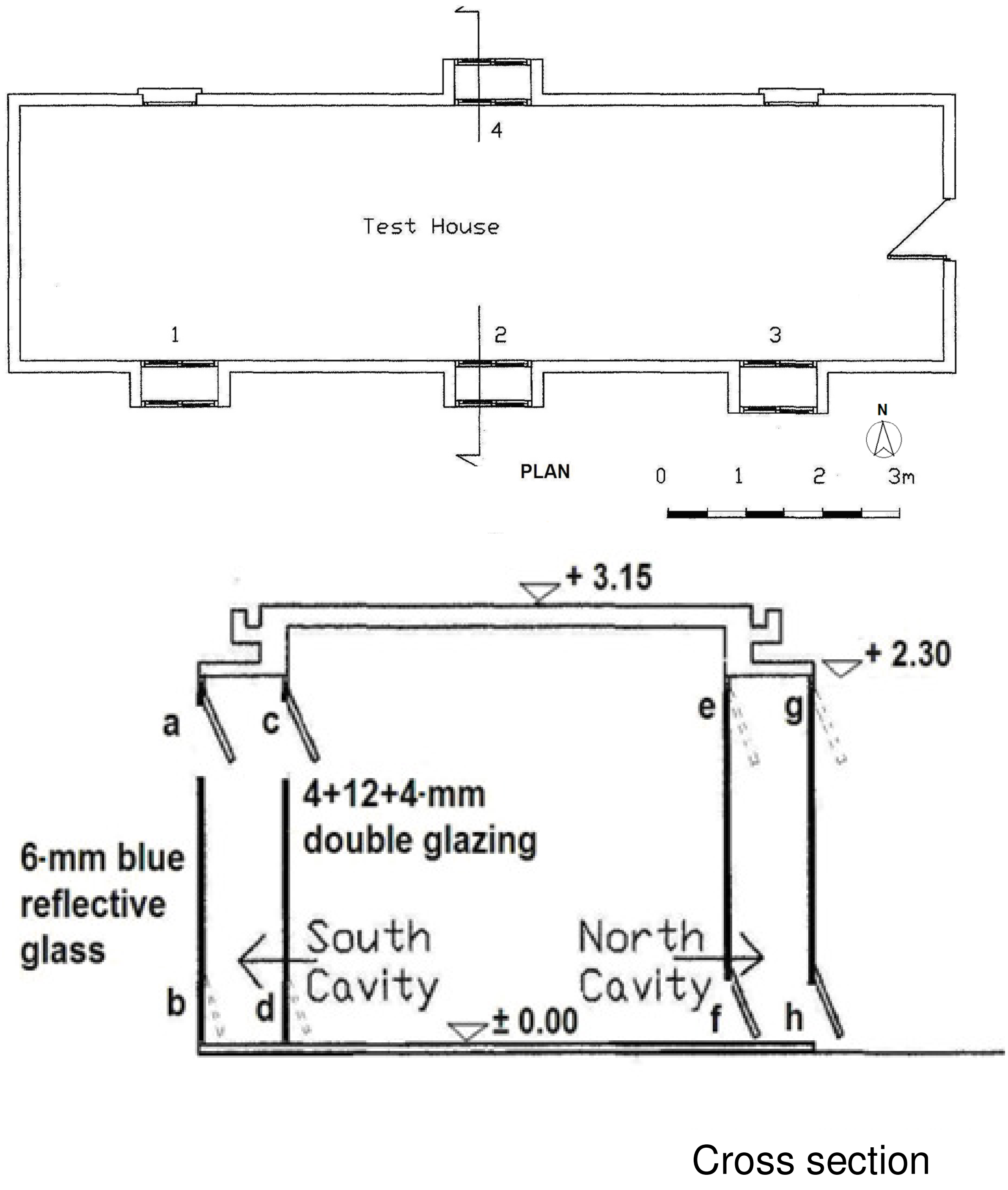

Figure 1. Plan and cross-section of the test house.

on the first simulations was 0.30 m. The simulation program uses hourly measured meteorological data and calculates hourly data of the building for the whole year. If any single day performance of the building is needed it starts to do the calculations fifteen days prior that day, in order to allow for the dynamic behaviour of the building. The continuously measured hourly meteorological data for the northern Cyprus town of Gazimagusa for the year 2009 used in the simulation program were provided by the North Cyprus Meteorological Office. The simulations were carried out for typical summer (June 21), spring (March 21), autumn (September 21) and winter (December 21) days.

For summer, spring and autumn days, how the system provided natural ventilation without any air-conditioning was checked. In this case, the upper external window of the south facade was open, and the lower external windows were closed. The upper windows of the inner surface of the south facade and the lower windows of the inner and outer surfaces of the north facade were open. All of the operable windows of 20 × 0.65 m size were 10% open. There was

Figure 2. Pictures from outside and inside of the south facade of the test house.

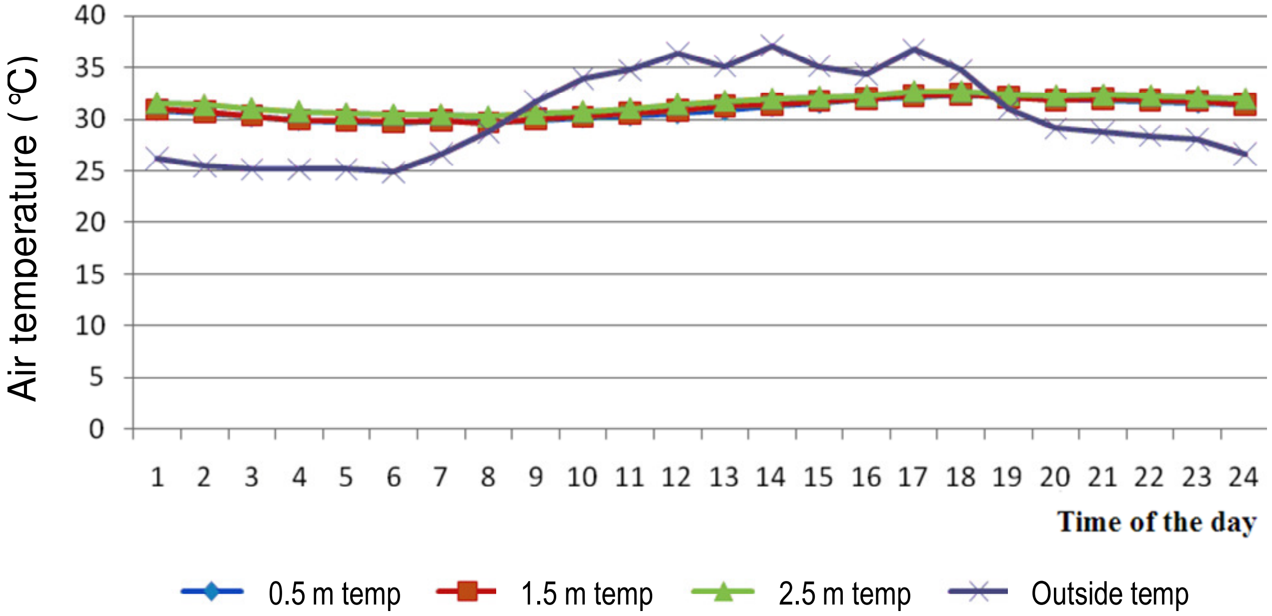

Figure 3. Air temperature measurements at various heights at the centre of the test house and outside on 14th July, 2009 (with no blinds).

no horizontal or vertical partitioning on the cavity of the south facade. However, on the north facade, the air cavity was divided into compartments by horizontal partitions at each floor level, as shown in Figure 7. In this position during summer days, some air at the top of the south cavity flows back into the upper floors because of the compression of the air at the top of the cavity. Increasing the size of the top window of the south cavity does not solve this problem. Thus, it was decided to increase height of the south cavity above the roof level. This feature, which has also been discussed by Ding et al. (2005), solved the problem.

When the height of the south cavity above the top floor was increased to 4.5 m, the return of hot air to the top floor was eliminated. However, in some cases, this height might not be acceptable. It was decided to determine how the height of this cavity tower could be lowered. When two 1.10 m-high windows were used on two opposing surfaces of the south tower, instead of only one, the height of the tower was reduced to 1.5 m. This condition was used for the rest of the simulations.

For winter, spring and autumn days, how the system provided heating without any mechanical heating system was determined.

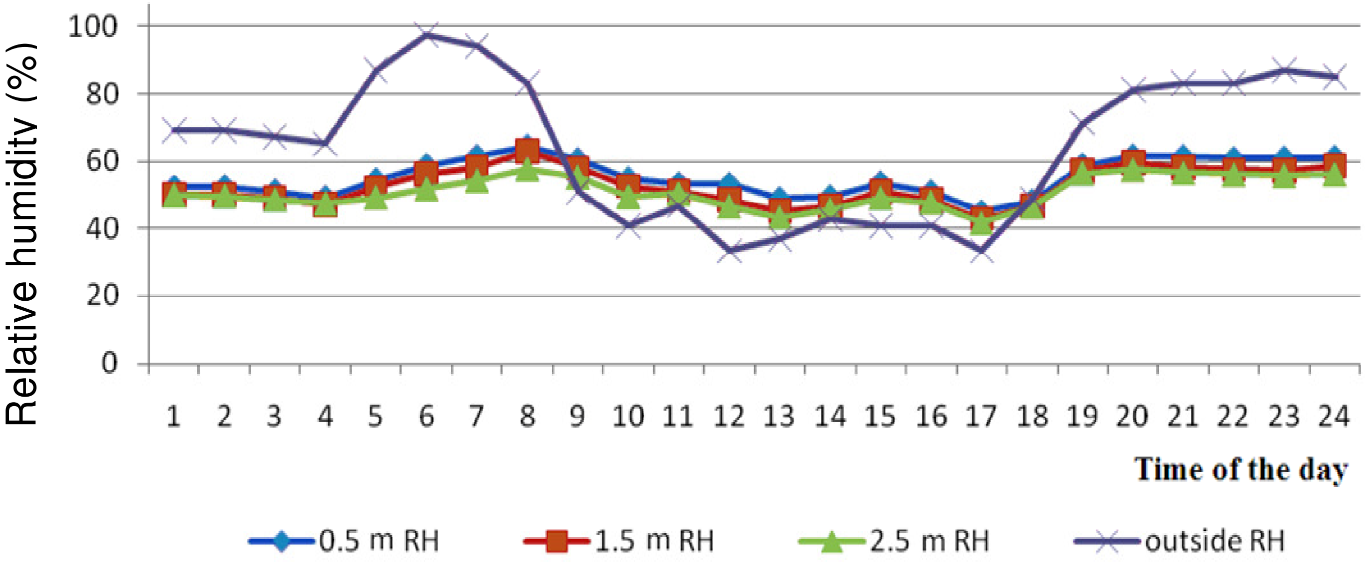

Figure 4. Relative humidity measurements at various heights at the centre of the test house and outside on 14th July, 2009 (with no blinds).

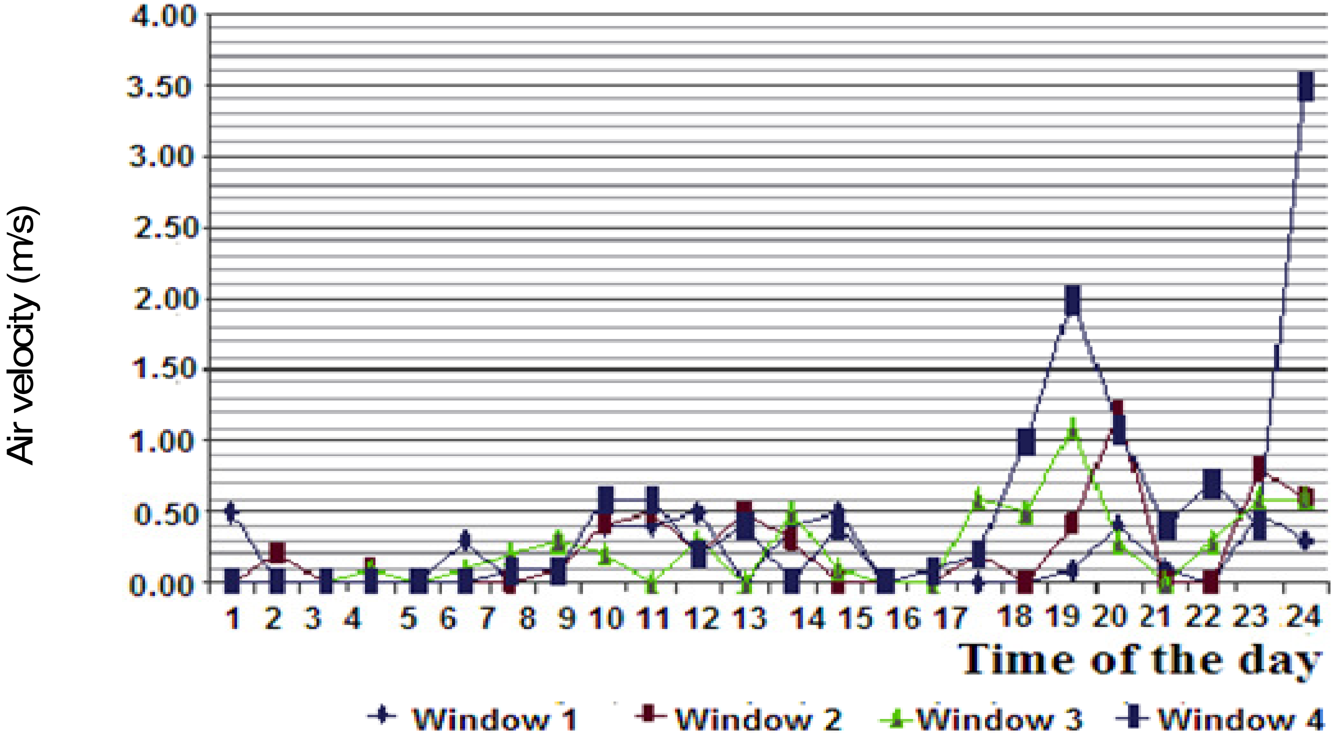

Figure 5. Air velocity (m/s) measurements at the openings of the windows on 14th July, 2009 (with no blinds).

This time, the external upper and lower openings of southern air cavity were closed. Both the inner lower and the inner upper windows of the south air cavity were 10% open at each floor level. All of the north-facing windows were 1% open for fresh air. For summer and also for spring and autumn days, how the system provided ventilation and how much the system contributed to thermal comfort without any mechanical system were checked.

The assumptions of some parameters for the calculation of predicted mean vote (PMV) and percentage of people dissatisfied (PPD) included the following: metabolic rate: 1.2 met, air speed: 0.150 to 0.300 m/s, external work: 0 W/m², clothing: 0.6 to 0.95 clo. A metabolic rate of 1.2 met is the rate of a standing and relaxed

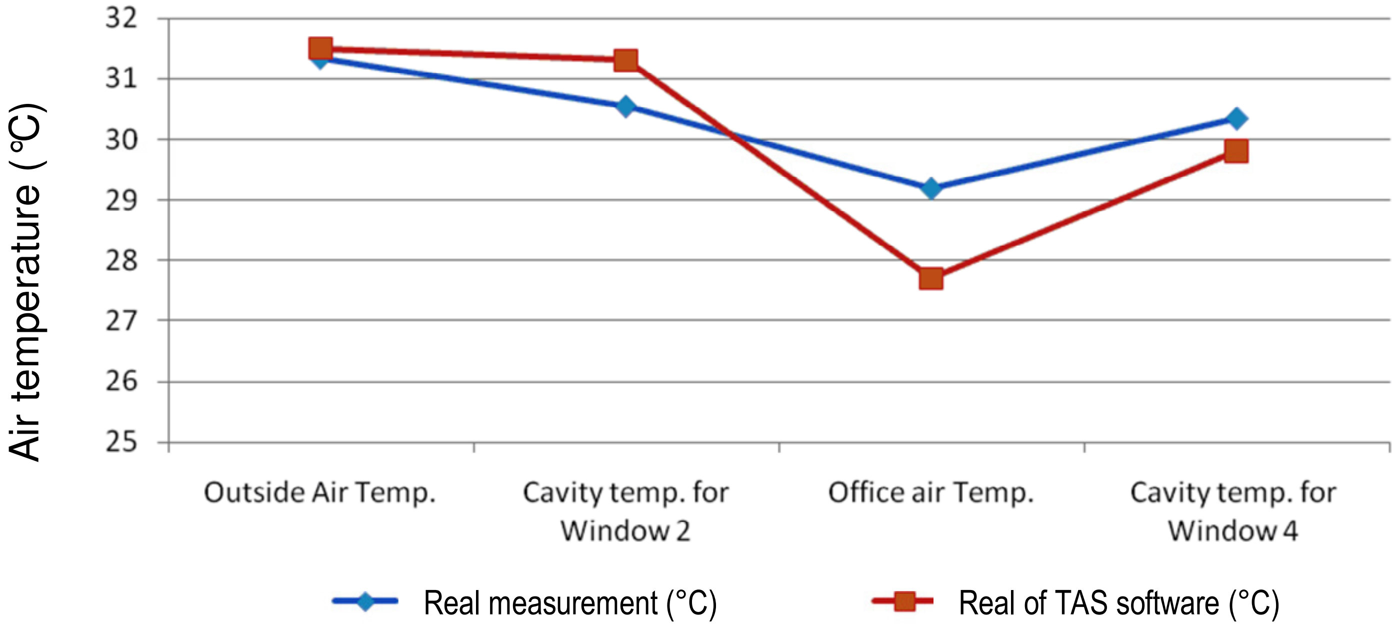

Figure 6. Comparison of test house measurements and TAS simulation results (14th July, 2009, at 10.00 h).

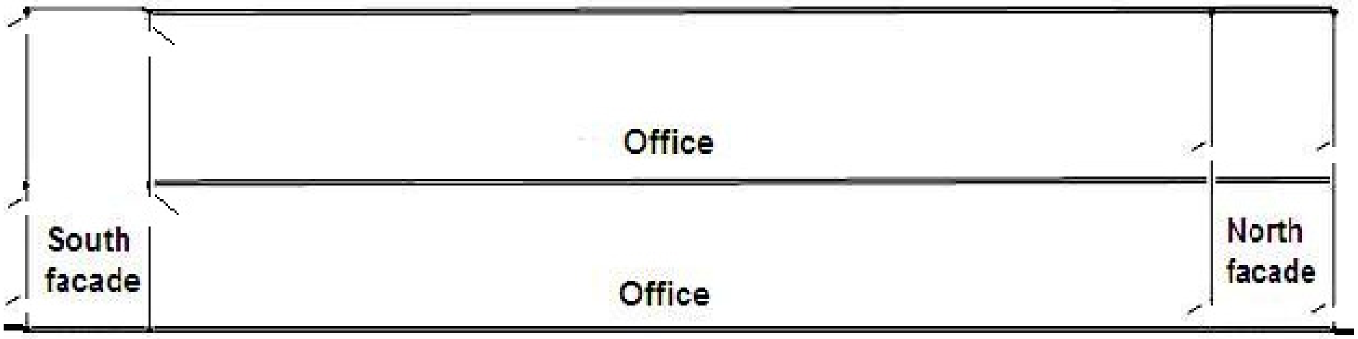

Figure 7. Section of the 2-storey office building showing window openings for TAS simulation.

average human. A clothing value of 0.6 to 0.95 clo corresponds to light indoor dressing. According to ASHRAE (2004) and ISO (2005), PMV is scaled as:

PMV thermal sensation scale:

+ 3 Hot
+ 2 Warm
+ 1 somewhat warm
0 Neutral
- 1 somewhat cool
- 2 Cool
- 3 Cold

A PMV of -0.5 to +0.5 or a PPD of 0 to 20% is considered the thermal comfort condition.

RESULTS

The results of the simulations for winter and summer were given separately.

Winter simulations

On December 21, a simulation was carried out for a 5-storey office building at 07:00 h. The cavity width was 0.3 m, and the tower height was 1.5 m. The external windows of the south cavity (1.1× 20 m in size) were closed, the upper internal south cavity windows on each floor level were 10% open, and the lower internal and external north

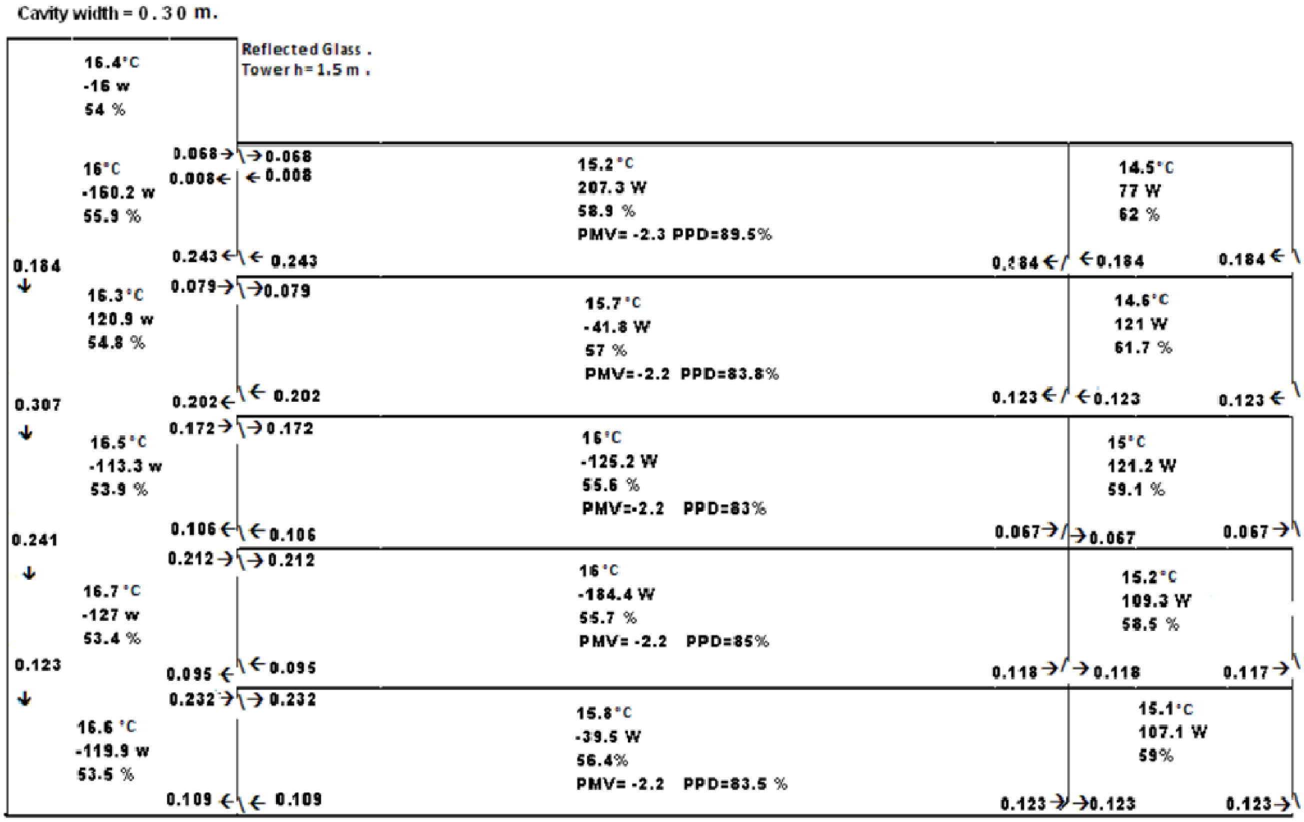

Figure 8. Airflows and the results on 21st of December in the morning, on a section of a 5-storey office (airflows are in kg/s).

cavity windows were 1% open. The wind speed at a height of 10 m was 6.9 m/s, and the wind direction was NNE. The outside air temperature was 14.5℃, and the relative humidity was 62%. Although it was early in the morning, with the first rays of sun, the temperature in the south facade increased two degrees above the outside air temperature. The ventilation between the south facade and the office increased the inside air temperature 1K. It was noted that the wind had a high velocity and came from a northerly direction. Parallel to the high relative humidity of the outside air, the relative humidity in the office was also high, although it was approximately 20% lower than outside. This indicates that the double-skin facade positively regulates relative humidity as well as temperature. The PMV was between -2.35 to -2.2, and the PPD was between 82.98 to 89.83% in the offices.

At noon, with an outside air temperature of 14.7℃, a wind speed of 4.3 m/s, a wind direction of N, and a relative humidity of 55%, the temperature of the south facade increased approximately to 28℃. Upper level temperatures of the south cavity were 2 K higher. This raised the office air temperature to approximately 22℃, which is a thermal comfort temperature. The relative humidity in the office was also within the comfort limits. The PMV was between -0.43 to 0.29, and the PPD was between 5.09 to 8.79% in the offices, which are considered thermal comfort conditions.

At 19:00 h, when the outside air temperature was 10.9℃ and the wind speed at a height of 10 m was 1.9 m/s from a WNW direction, air exchange between the south facade and the office kept the office air temperature 3 to 4 K higher than outside. These temperatures between 14 to 15℃ are lower than thermal comfort temperatures but still provide some heat if the offices are used at night as well. Similarly, the relative humidity is regulated during these hours as well. The PMV was between -1.68 to -1.55. The PPD was 6.55% at the uppermost floor, and on the rest of the floors, it was between 53.63 to 56.46% in the offices as in Figures 8, 9 and 10. These figures show air velocities in kg/s and the direction of the air flow, air temperatures in ℃, heat transfer in W, relative humidity in %, PMV and PPD in % at various zones.

In the same building on September 21 at 07:00 h, while outside air temperature was 21.90℃ and the wind speed was 2.2 m/s from an ESE direction, the double-skin facade raised the office air temperature to 28 to 29℃, well above the thermal comfort zone. Similar results were obtained for noon and evening hours.

On March 21, the windows in the same building were opened as for winter. At 07:00 h, when the outside air temperature was 12.4℃, the wind speed was 2.1 m/s

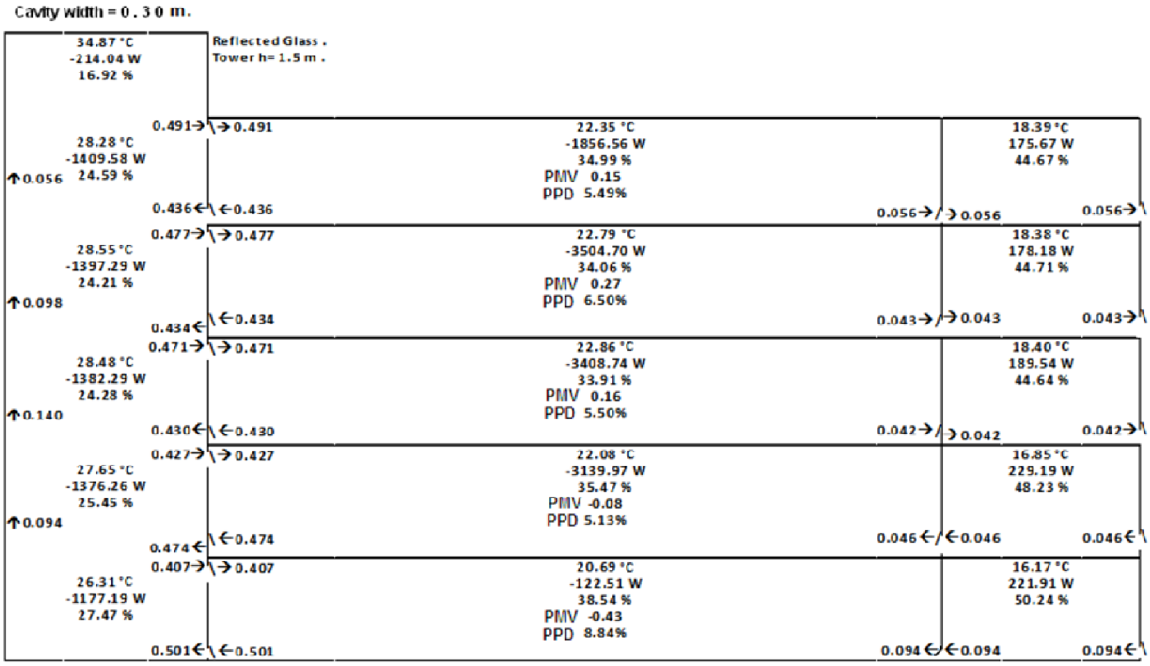

Figure 9. Airflows and the results on 21st of December at noon time, on a section of a 5-storey office (airflows are given in kg/s).

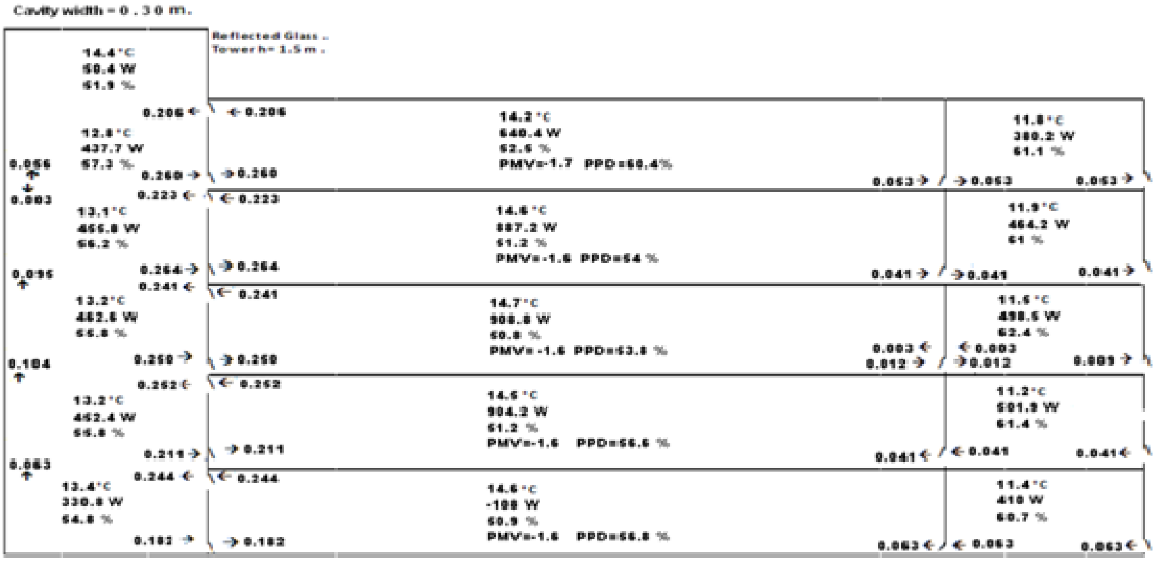

Figure 10. Airflows and the results on 21st of December at night time, on a section of a 5-storey office (airflows are in kg/s).

from the ESE and the relative humidity was 89%, the building performed similarly to winter conditions. In the morning and evening hours, the double-skin facade raised the indoor air temperature, thus contributing to the heating of the building, but did not provide full thermal comfort. At noon, the indoor air temperature was raised to a thermal comfort temperature. The PMV was between -0.55 to -0.93, and the PPD was between 11.35 to 23.2% in the offices, which is very close to thermal comfort conditions.

In another set of winter simulations, cavity widths of 0.60 m and 1.20 m were used. All of the cavity widths provided thermal comfort; however, a 30-cm-wide cavity provided a slightly better condition.

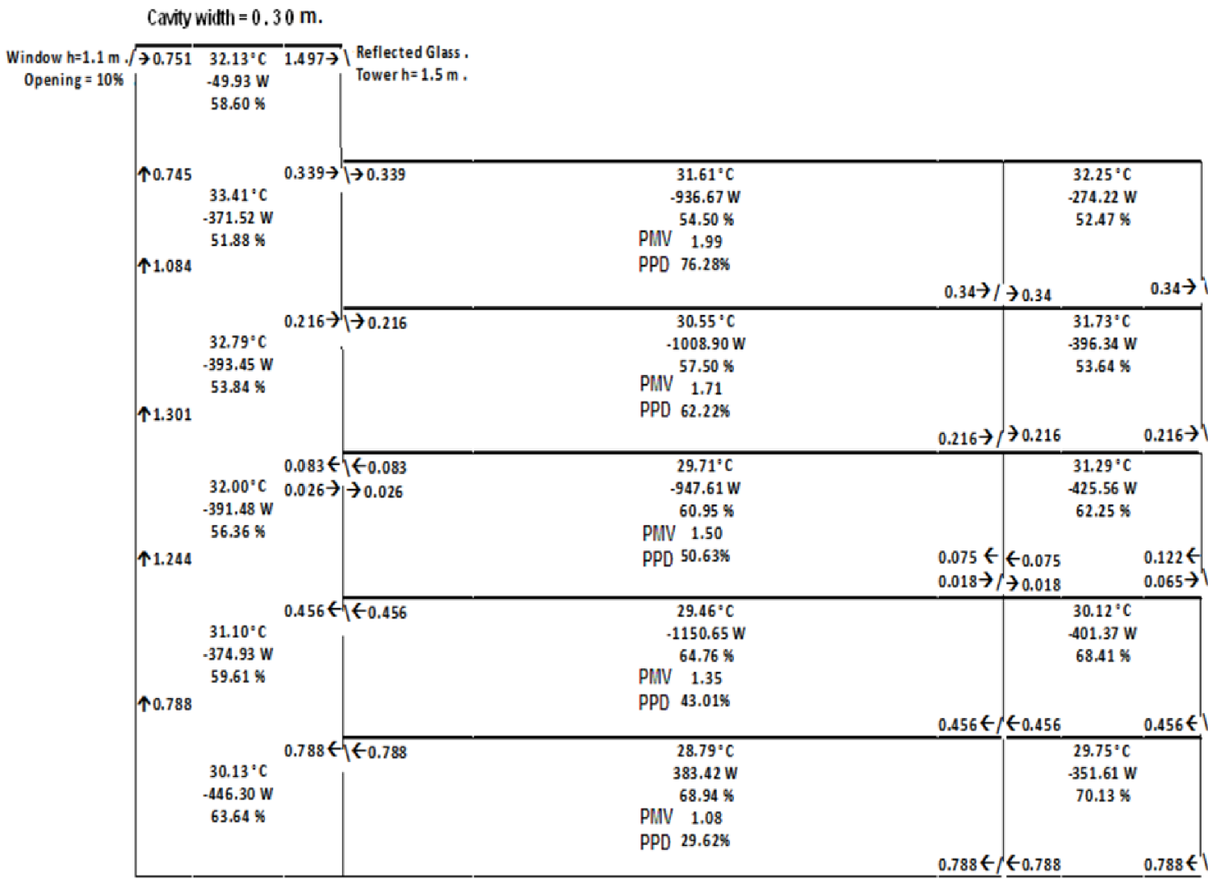

Figure 11. Airflow, PMV and PPD results on 21st of June at noon time on a section of a 5-storey office (airflows are in kg/s).

Summer simulations

Another simulation was conducted for June 21 at 07:00 h, when the outside air temperature was 26.4°C, the wind speed was 2.8 m/s from the NE and the relative humidity was 68%. As for the summer opening, all the windows were 10% open, including the opposing top windows of the south cavity tower. These windows were 1.1 × 20.0 m in size. The sizes of other opening windows were 20 × 0.65 m. The tower height was 1.5 m. The south cavity air temperature was around 28°C, and the office air temperatures were around 27°C. There was a very nice air intake from the north cavity at every floor level. The same results were observed in 2- and 10-storey high buildings. The PMV was between 0.79 to 1.43, and the PPD was between 18.29 to 47.13% in offices, which is not a thermal comfort condition.

At noon, when the outside air temperature was 28.9°C, the wind speed was 3.7 m/s from the E and the relative humidity was 74%, the south cavity temperature rose to 32°C. It did not rise more because of the very good ventilation achieved across the building. Office temperatures were between 29 and 31°C. This did not provide thermal comfort within the offices; thus, the air-conditioning should have come on. The PMV was between 1.05 and 1.96, and the PPD was between 28.25 and 75.03% in the offices as seen in Figure 11. This is felt as between somewhat warm and warm. At noon, the PMV and PPD did not indicate a thermal comfort condition.

In the evening, when the outside air temperature was 28.3°C, the wind speed was 1.9 m/s from SSW and the relative humidity was 72%, the south cavity temperature and that of the offices were approximately 28°C. The PMV was between 0.76 and 1.66, and the PPD was between 17.2 and 59.45% in the offices, which is not considered a thermal comfort condition.

On September 21 at 07:00 h, the PMV was between -0.14 and 0.65, and the PPD was between 5.01 and 13.98% in the offices, which is not considered a thermal comfort condition.

At noon, the PMV was between 0.84 and 1.99, and the PPD was between 19.71 and 76.24% in the offices, which is not considered a thermal comfort condition as seen in Figure 12.

In the evening, the PMV was between 0.24 and 0.75,

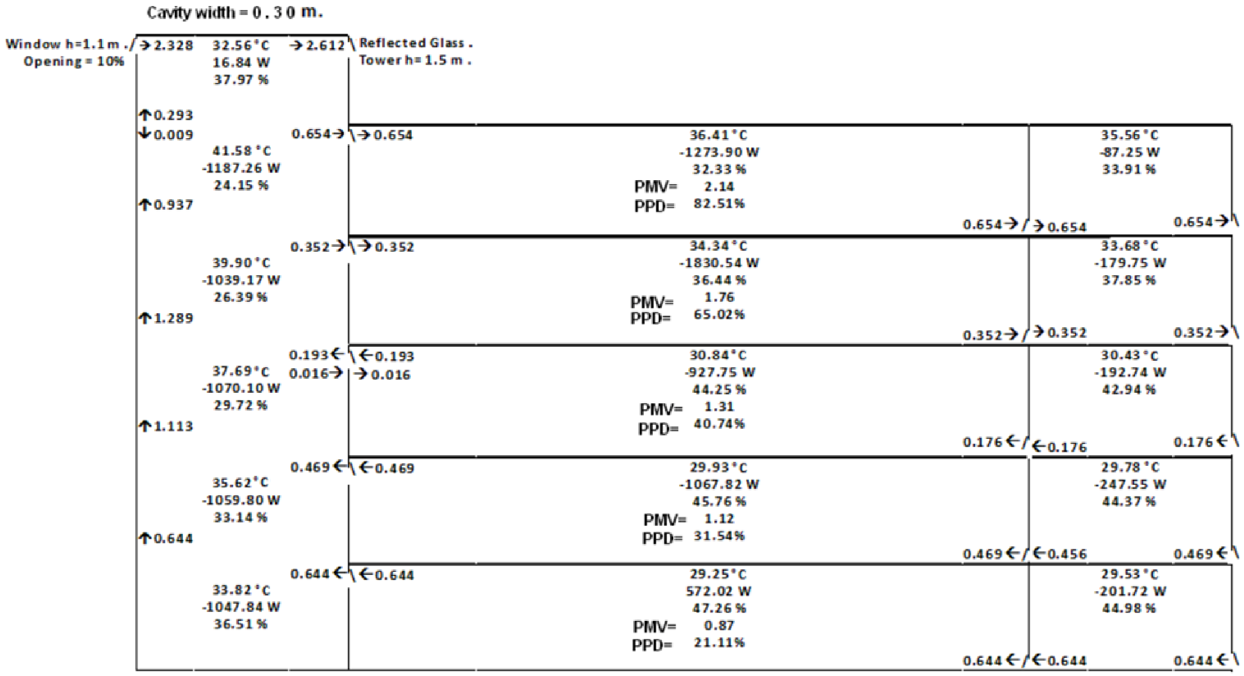

Figure 12. Airflow, PMV and PPD results on 21st of September at noon time, on a section of a 5-storey office (airflows are in kg/s).

and the PPD was between 6.17 and 16.69% in the offices. Thus, thermal comfort was achieved.

Thermal comfort has been achieved only during the morning and night hours. Because full thermal comfort cannot be achieved with the double-facade system, a number of alternatives have been tried. The cavity width was increased to 0.60 m. The height of the south cavity tower was again increased to 1.50 m with two 1.1 × 20 m opposing windows at the top, which were 10, 50 and 100% opened. Different kinds of roof insulations such as reverse and classical roofs have been applied. In a reverse roof, a non-wettable thermal insulation above the water insulation material obviates the need for a vapour retarder as in Figure 13. Both of the types of insulation provided better results in terms of PMV and PPD, but did not contribute to the full thermal comfort condition as in Figures 14 and 15. However, the results are very close to thermal comfort conditions, with the PMV being between 1.7 and 1.0 even on the hottest days of summer.

In another set of simulations for summer conditions, the cavity width was 0.30 m, the tower height was 1.5 m, the tower window size was 1.10 × 20 m, the tower windows were (10, 50 and 100%) open, and there was a solid brick wall on the upper back side of the tower instead of a glazed wall and a classical roof thermal insulation. These arrangements provided the same results as in Figure 15.

DISCUSSION

During the whole typical winter day (21st December), thermal comfort could be achieved only with the double-skin facade.

In winter, when the north cavity windows on all floors were 1% open, n (number of air changes per hour) ranged between 0.15 and 0.4. In summer conditions, when all of the windows were 10% open, n ranged between 1.5 and 3.6. All of these values are within acceptable limits, and even in winter, the north windows can be opened more according to the comfort standards of each country.

For conditions of Gazimagusa on September 21, the windows should be opened as during summer days to provide ventilation. When the windows were opened as during a summer day, natural ventilation was provided both in the morning and at night. However, at noon, this ventilation was not enough to cool the office, and it was necessary to start the air-conditioning system.

In summer, except during the morning and evening hours full thermal comfort cannot be achieved. Any thermal insulation on the roof provided better results, but did not achieve the full thermal comfort condition.

The number of floors did not change the thermal results; however, it changed the amount of airflow between the south facade and the office. As the height of the building increases, the amount of airflow increases, as expected. Opening the north cavity lower windows at each floor level in winter changes the direction of the fresh-air intake. Normally, fresh-air intake is through the north cavity. However, when wind speed is high, the fresh air in high-rise buildings is sent to the south cavity from the lower floors and from there to the upper floors. This

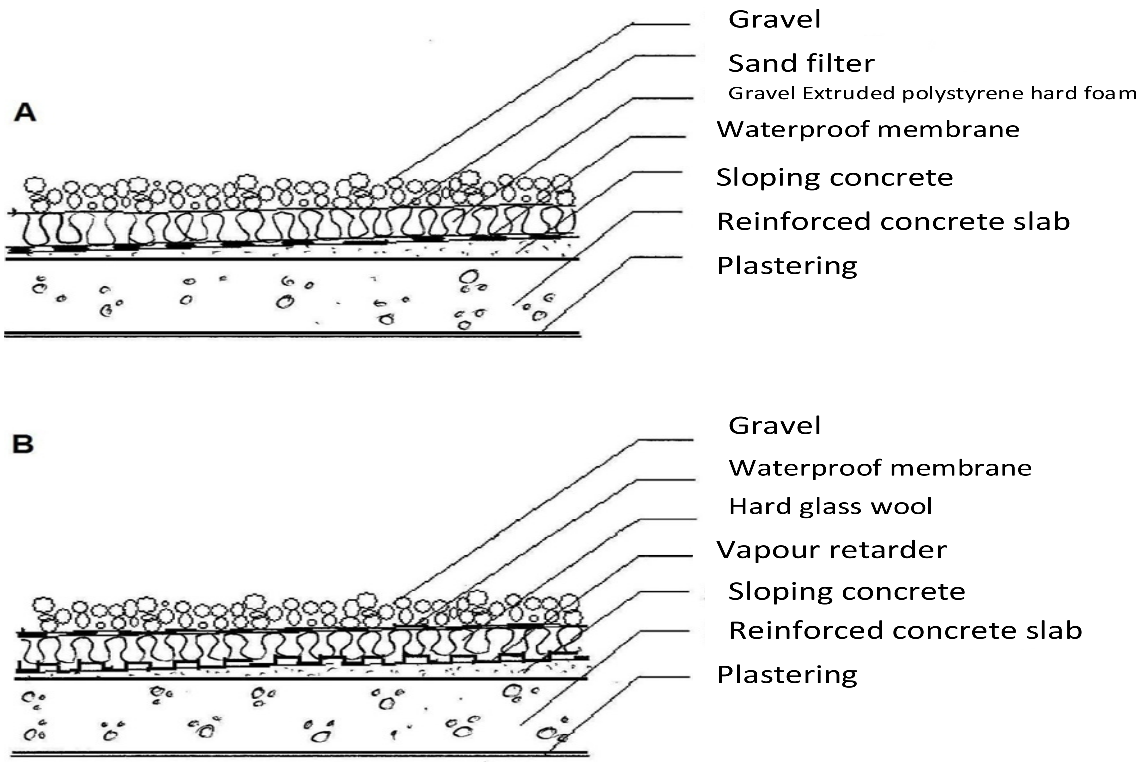

Figure 13. (A) Reverse, (B) classical roof thermal insulations.

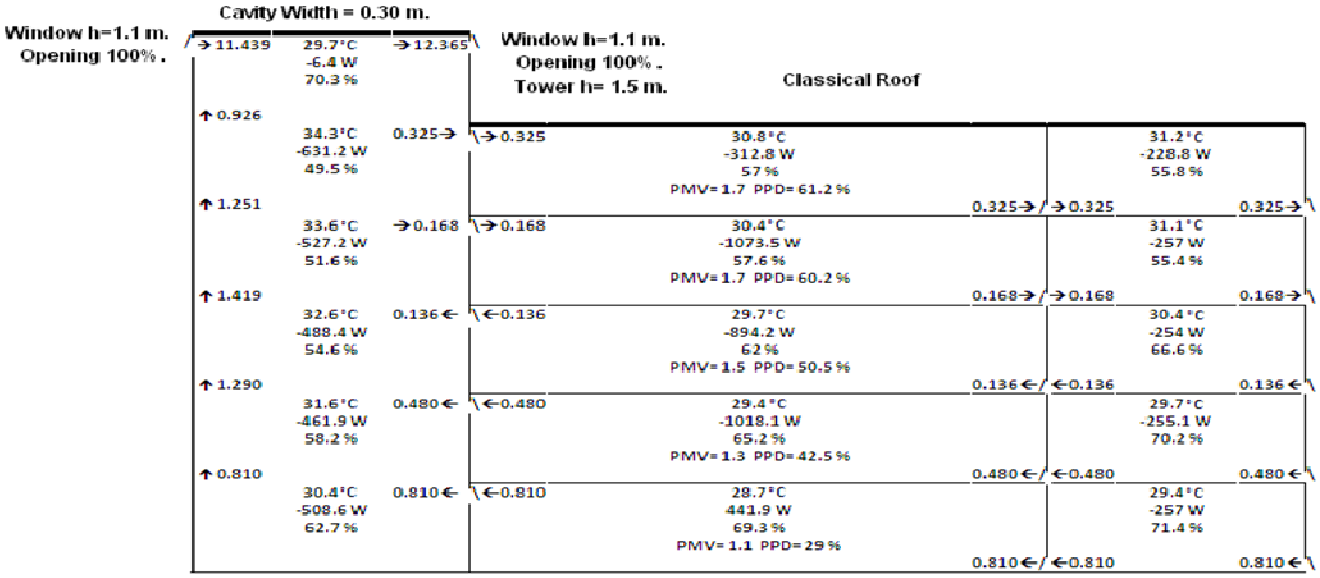

Figure 14. Airflow, PMV and PPD results on 21st of June (with a classical roof and top tower windows 100% open) at noon on a section of a 5-storey office (airflows are in kg/s).

issue will be addressed in future studies.

Reducing the office width to half or increasing it by two times did not change the PMV or PPD results. However if the office width is increased daylight factor should be checked in order not fall below the standards. Similarly, reducing and increasing the cavity width did not change

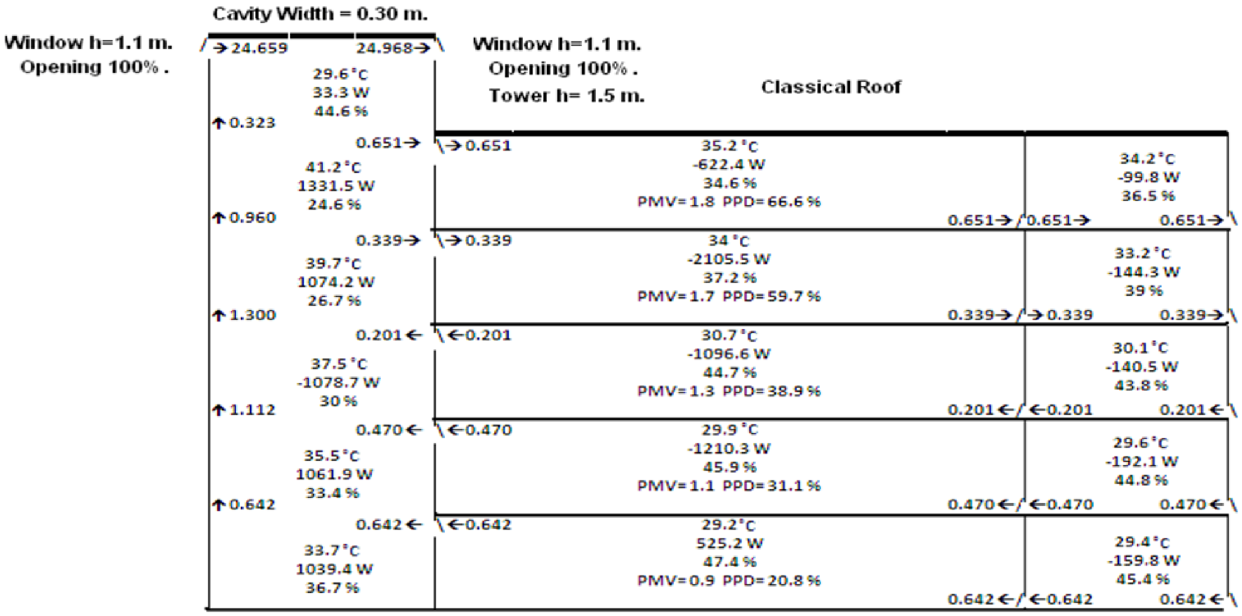

Figure 15. Airflow, PMV and PPD results on 21st September (with a classical roof and top tower windows 100% open) at noon on a section of a 5-storey office (airflows are in kg/s).

the results, as in the case of winter operations.

Conclusions

The measurements on the test house showed agreement with the TAS simulation program. To test as many parameters as possible within a reasonable time, it was decided to continue with the simulation program.

For year-around performance of the double-skin facade, it is necessary to open and close the windows according to the environmental conditions. This could be done manually. However, the best results are obtained when the windows are set to open automatically. In addition, the direction and velocity of the wind sometimes affect the results. Thus, a mechanism to open and close the windows that is connected to an environmental measurement centre will provide a better solution. However, the extra cost of this should be considered against the benefits.

Decreasing or increasing the office width does not change the PMV or PPD results, although it changes the amount of daylight in the office. Similarly, decreasing and increasing the cavity width does not change the results. However, a cavity width of 30 cm provides slightly better results.

Most of the time, a double-skin facade will provide thermal comfort during the winter. For the remaining time, a double-skin facade contributes to the heating of a building. In summer, the benefit of the system is limited because wind effects overcome the buoyancy effects on the south cavity except when the wind flows from the north. As long as the air temperature is less than the human deep-body temperature, which is 37°C for an average healthy adult, any ventilation will provide some cooling. When the air temperature exceeds this level, mechanical cooling is necessary. In Gazimagusa, the air temperature is lower than body temperature for most of the time in summer. To get better results for this time of the year in terms of thermal comfort, more research is necessary.

The authors plan to study more parameters in the future. Included in these parameters will be the effects of blinds in the south cavity, the effect of a corridor-facade type of double-skin facade and the effects of using different types of glass on the facades.

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REFERENCES

ASHRAE (2004). Standard 55-2004. Thermal environmental conditions for human occupancy. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
Baldinelli G (2009). Double skin facades for warm climate regions: Analysis of a solution with an integrated movable shading system. Build. Environ., 44(6): 1107-1118.
Ballestini G, Carli MD, Masiero N, Tombola G (2005). Possibilities and limitations of natural ventilation in restored industrial archaelogy buildings with a double-skin facade in Mediterranean climates. Build. Environ., 40(7): 983-995.
Blomsterberg A (2007). Bestfacade. Best practice for double skin

facades. EIE/04/135/S07.38652. WP5 Best Practice Guidelines. (Ed.). Energy and Building Design, University of Lund. Lund.

Chow WK, Hung WY (2006). Effect of cavity depth on smoke spreading of double-skin facade. Build. Environ., 41(7): 970-979.

Ding W, Hasemi Y, Yamada T (2005). Natural ventilation performance of a double-skin facade with a solar chimney. Energy Build., 37(4): 411-418.

Faggembau D, Costa M, Soria M, Oliva A (2003). Numerical analysis of the thermal behaviour of ventilated glazed facades in Mediterranean climates. Part I: Development and validation of a numerical model. Solar Energy Volume, 75(3): 217-228.

Faist AP (1998). Double-Skin Walls. Ecole Polytechnique Federale de Lausanne, Institute de Technique Du Batiment, Departement D'Architecture, pp. 1-44.

Grabe JV (2002). A prediction tool for the temperature field of double facades. Energy Build., 34(9): 891-899.

Gratia E, Herde AD (May 2007). Are energy consumptions decreased with the addition of a double-skin? Energy Build., 39(5): 605-619.

Gratia E, Herde AD (2007). Greenhouse effect in double-skin facade. Energy Build., 39(2): 199-211.

Gratia E, Herde AD (2004). Natural ventilation in a double-skin facade. Energy Build., 36(2): 137-146.

Gratia E, Herde AD (2004). Optimal operation of a south double-skin facade. Energy Build., 36(1): 41-60.

Hamza N (2008). Double versus single skin facade in hot arid areas. Energy Build., 40(3): 240-248.

Hien WN, Liping W, Chandra AN, Pandey AR, Xiaolin W (2005). Effects of double glazed facade on energy consumption, thermal comfort and condensation for a typical office building in Singapore. Energy Build., 37(6): 563-572.

ISO (2005). 7730, 2005. Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Geneva:International Standards Organisation.

Moezzi S (2009). Critical look to double skin facade systems. Msc Thesis. Eastern Mediterranean University, Gazimagusa, North Cyprus, pp. 6-7.

Poirazis H (2008). Single and double skin glazed office buildings. Analyses of energy use and indoor climate. Report EBD-T-08/8. Division of Energy and Building Design, Department of Architecture and Built Environment, Faculty of Engineering, Lund University, Lund, pp. 330-335.

Poirazis H (2006). Double skin facades, A Literature Review. Lund Institute of Technology, Lund, Sweeden, pp. 24-29.

Saelens D, Blocken B, Roels S, Hens H (2005). Optimization of the energy performance of multiple-skin facades. Ninth International IBPSA Conference. Montreal, Canada. pp.1059-1066.

Saelens D (2002). Energy performance assessment of single storey multiple skin facades. PhD Thesis. Laboratory for Building Physics, Department of Civil Engineering, Catholic University of Leuven, Belgium, p. 10.

Stec WJ, Van PAAHC (2005). Symbiosis of the double skin facade with HVAC system. Energy Build., 37(5): 461-469.

Wachenfeld BJ, Bell D (2003). Building integrated energy systems in smart energy efficient buildings - A state of the art. Sintef Report, Trondheim, Norway, p. 5.

Yellamraju V (2004). Evaluation and design of double skin facades for office buildings in hot climates. Master Thesis. Texas A&M University, Texas, pp. 20-25.