Energy Performance and Thermal Comfort of Double-Skin and Single-Skin Facades in Warm-Climate Offices

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Abstract

The energy performance and thermal comfort of an office building with single and double skin facades, in a warm climate was studied using TAS software. A double-skin facade is an envelope construction that consists of two transparent surfaces separated by a cavity. The extra skin can reduce cooling demand in summer and heating demand in winter. It is concluded that in a warm climate office, a double skin facade can perform better than a single skin facade. In a warm climate a double skin facade fully provides heating and thermal comfort in winter. In a warm climate however its benefit in summer is limited. Further studies are needed to increase the performance of double skin facades in summer.

Keywords: double-skin facade; single-skin facade; thermal comfort; energy performance; TAS software

1. Introduction

It is necessary to do research on energy saving in buildings by using different measures. A suitable selection of site, building orientation, building transparent surface ratios, building forms, elements and materials are some of these measures. In this paper, energy performance and thermal comfort by using a double and single skin for offices in a warm climate was studied. Saelens (2002) defined the double-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 within the cavity. Solar radiation absorbed by the shading systems will also be transmitted 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 this paper, the authors tried to find how efficient the double and single skin facades can be in terms of energy performance and thermal comfort throughout an entire year.

In the literature, a number of terms are used to describe a double-skin facade; for example, multiple-skin envelope, twin skin, airflow window, and ventilated facade. A double-skin facade has many properties in common with an atrium or a glazed sunspace (Alibaba and Ozdeniz, 2011; Poirazis, 2006). However, because the cavity in a double facade is used for ventilation, it does not offer an occupied space.

The main components of the double-skin facade system are the external glazing, the internal glazing, and the air cavity. The exterior glazing primarily consists of a hardened single glazing. Various types of clear low-E coating and solar-control glazing can also be used. The interior glazing is an insulating double-glazed unit. The air cavity between the two skins can be naturally or mechanically ventilated and 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 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-e 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 façade with a tall ventilation shaft placed near it. These box windows are connected to the vertical shafts on the façade, 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 a 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. 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 in storeys.

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.

2. Literature Review

Faist (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 published a report on this subject. Grabe (2002) studied both the airflow and temperature field of a double-skin facade specifically for energy consultants. Faggembauu 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 De Herde (2004a) studied natural ventilation and the impact of orientation related to the wind direction in a double-skin facade using the simulation program (TAS). They concluded that air temperature rises during the day when blinds are positioned in the cavity. In a second paper, they studied the optimal use of a south-facing double-skin facade and determined that its use should be dynamically controlled (Gratia and De Herde 2004b).

Yılmaz and Çetintaş (2005) studied the performance of double-skin facades of office buildings in winter, in Istanbul, Turkey. They concluded that for this condition, the double-skin facade had a great advantage in reducing the heating energy consumption significantly.

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 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 a 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 a 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.

Another 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 the inner glass panels and that smaller glass panels would perform better than larger sheets. They also pointed out that it is safer to use tempered glass.

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. The study concluded that, in a Scandinavian climate, the energy effectiveness of such an approach is poor unless the facade is designed very carefully.

Gratia and De Herde (2007a) also studied energy consumption with the addition of a double-skin. The result showed that the 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 of Gratia and De Herde (2007b) it was concluded that if blinds are used they should be positioned at the centre of the south cavity, and in summer when the south facade cavity windows are opened the cooling requirement will be less. Gratia and De Herde (2007c) also 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 Waldner et al. (2007) prepared guidelines for the application of a double-skin facade. Saelens et al. (2008) studied the performance of three different double-skin facades in Belgian climatic conditions. The study concluded that the energy efficiency of the
double-skin facade depends on its typology. Double-skin facades may reduce transmission losses in winter and gains in summer. They also concluded that both heating and cooling demands can be significantly improved by controlling the airflow rate and recovery of air returning from multiple-skin facades. Hamza (2008) studied double-skin facades versus single-skin facades in hot, arid areas through the simulation program (IESVE). According to this 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, recent attention has been given to the integration of natural ventilation into high-rise office buildings by means of double-skin facades (Moezzi, 2009). The Commerzbank in Frankfurt am Main (Germany) is an example of this approach.

Stigge and Adibi (2008) studied the payback time of double-skin facades. They concluded that in Las Vegas, USA based on 2003 prices, a conventional curtain wall facade with low-e glass would cost £300/m², and for a simple, flat, double facade with operable vents, blinds and windows for a large building, manufactured in a factory would cost £800/m². "The same facade installed in New York might cost 50% more, in the UK 40% more and in Germany 20% more" (Stribling et al. 2014). The building model studied was a four-storey high office building with only one double-skin facade. The other three sides were solid walls and in the simulations the double-skin facade was oriented to different directions. This is not the most efficient way of using double-skin facades. Normally, they are used on south and north orientations so that the system can provide ventilation of cool air from the north side in summer. However, their conclusions were interesting because for London as a mild, cloudy climate, Las Vegas as a hot, dry sunny climate, and Winnipeg, Canada as a cold climate the annual energy saving for a building with south facing double-skin facade will be respectively 23%, 27%, 12%. The payback period according to their assumption ranges between 100 to 240 years. This does not seem feasible so new calculations are necessary for more efficient double-skin facade systems.

Another comprehensive study on the double-skin facades has been done by (Shameri et al. 2011). They concluded that more research is needed on the behaviour of double-skin facades in warm and humid climates. Despite the number of studies on double-skin facades, there is still a knowledge gap, as far as their efficiency in warm seasons and the degree of contribution to the heating and cooling loads of the buildings are concerned.

3. TAS Software Simulations

TAS is a software package for the thermal analysis of buildings. TAS has a 3D modeler, an energy analysis module and a 2D CFD package for reports. It is a powerful and user-friendly thermal simulation program and design tool for buildings (Gratia and De Herde, 2004c; EDSL, 2012). It can calculate temperatures, effect of shading, heat flows, air flows, thermal comfort values like PMV and PPD. Thus, it is more useful than programs based on static equations in studying the cooling effect in summer. The outline of the calculation method of building thermal behaviour and natural ventilation for TAS has three sections. Firstly, in a 3D modeler, geometry with zone(s) should be created, then secondly a building simulator, where expected internal gains, infiltration and ventilation rates, heating and cooling set points, building materials, zone groups, apertures, substitute elements, feature shading, bulk inter-zone air movement and occupation patterns should be entered, while the third step is to read the results viewer section for outputs as a series of hourly snapshots. TAS uses the response factor method for the transient analysis of the building structure, which is more accurate than finite difference methods and can be up to ten times quicker in computational speed. TAS has completed all the building envelope and HVAC equipment performance tests as required, and has been verified by a number of sources.

3.1 A Preliminary Study to Test the TAS Software

According to the previous study conducted by Alibaba and Ozdeniz (2011), a test house 4.70 m wide, 12.20 m long and 3.53 m high with multi-storey type double-skin facades was built in Gazimagusa, as seen in Figs.1.-6. The long sides of the building were 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 an insulated low slope timber roof. At various points both inside and outside the test house surface temperature, air temperature, relative humidity and air velocity were measured for the whole year. Surface and air temperatures were measured with HOBO instruments with their own data loggers. Air velocity was measured with an Omega HHF2005HW Hot Wire Anemometer.

Figs.3.-5. show the results of measurements on the test house. Air temperature measurements do not change at different heights. Relative humidity measurements vary slightly with height. It is more towards the floor. Air velocity entering the test house from windows 1, 2 and 3 of the south facade are very close to each other. However, air entering the test house from window 4 of the north facade is more because of the north wind.

Thereafter, these measurements were compared with the same virtual building created in TAS software. As seen in Fig.6., the results were either similar or the same, hence, validating the TAS simulation results. Temperature differences are between 0.5 to 1°C, which cannot be defined as significant for this kind of work. Therefore, the current study has used this software (Alibaba and Ozdeniz 2011).
3.2 Simulation Study on a Virtual Office Building

The simulation program uses hourly measured meteorological data and calculates hourly data of the building for the whole year. The program also calculates the heating and cooling demand for each month and also at any time. Gazimagusa was selected as a climatically average town in Northern Cyprus. It has a yearly average temperature of 19°C.

The continuously measured hourly meteorological data for Gazimagusa for the year 2009 was obtained from the North Cyprus Meteorological Office. This year was selected because the averages of this year were very close to the overall average. The simulations were carried out for the whole year. The parameters obtained were air temperature, humidity, air flow, heat flow through the office building, PMV and PPD in the offices. The Thermal Sensation Scale can be summarized as; -3 cold, -2 cool, -1 slightly cool, 0 neutral, 1 slightly warm, 2 warm and 3 hot ASHARE (2013) and ISO (2005). A PMV of -0.5 to +0.5 or a PPD of 0% to 20% is considered as the thermal comfort condition. Moreover, PMV of -1 to -0.5 covers slightly cool and +0.5 to +1 covers slightly warm.

The building studied in this article is a virtual office building in Northern Cyprus which is located in a warm climate. It is 20 m long and 10 m wide with glazing both on the long south and north facades. The narrow sides of the building have rendered 20 cm thick brick walls. The roof consists of 5 cm gravel, filter, 4 cm of hard glass wool, vapour retarder, sloping concrete (3 cm thick minimum), 12 cm reinforced concrete, 1 cm gypsum plaster, from top to bottom. It is a reinforced concrete building. The tested virtual buildings had five floors, each of them being 3 m high. The south double-skin facade was of a multi-floor type without any horizontal division. The north double-skin...
façade has horizontal partitions on each floor level. The width of the air cavity was 0.30 m. The south double-skin facade was extended 1.5 m as a solar chimney above the flat roof and two opposite side windows were used at its top. This feature prevents the hot air at the top of the double-skin facade going down to the offices in summer. In Figs.7. and 8., the plan and the sections with window openings for under-heated (cool) and over-heated (warm) periods of single and double-skin facades can be seen.

3.2.1 Single-Skin Facade Glass Features

For the single-skin glass facade surface, 4 + 12 + 4 mm clear double glazing is 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. It should also be mentioned that no external or internal blinds were used.

3.2.2 Double-Skin Facade Internal and External Glass Features

On the external surface of the double-skin facade, the reflective glass used had the following features: It was 6 mm thick silver grey and produced by a pyrolytic (on-line) method; this reflective glass had a solar transmittance of 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; Moreover, no external or internal blinds were used.

On the inner surfaces of the double-skin facade, the glass used had the same features as the single-skin facade glass and no external or internal blinds were used.

4. Comparison of Double-Skin and Single-Skin Facades

Thermal simulations for five storey double-skin and single-skin facade office buildings were conducted in order to compare them in terms of energy performance and thermal comfort. The simulations were made when there is no heating and cooling throughout the year in order to understand the benefits of the double-skin facade and single-skin facade. According to the logic of the programme, if the heat flow is negative the temperature is rising and vice versa if the heat flow is positive the temperature is falling. Tables 1-4 recording the results on specific times of the year were detailed.

The under-heated (cool) period in Gazimagusa is between the 1st of November and 30th of April. For this period 21°C was accepted as the thermal comfort room temperature. For the single-skin facade, all the windows on the south facade were closed, but the lower windows of the north facade were 1% open as shown in section A-A (Fig.7.). For the double-skin facade, the upper and lower external windows of the south facade were closed. Both the lower and upper windows of the inner surface of the south facade were also 1% open. The entire upper and lower operable windows are 0.65 x 20.0 m in size. In this condition, the aim was to find out what the contributions of the double- and single-skin facades were to the heating of the offices as shown in section B-B.

Table 1. confirms that the under-heated (cool) period averages of indoor room temperatures, PMV and PPD are within an acceptable range in the double-skin facade. However, it is out of the comfort range in the single-skin facade. As a result, the double-skin facade will provide full thermal comfort during the under-heated (cool) period in Gazimagusa. Single-skin facade offices get quite warm at noontime, while double-skin facade offices exhibit more balanced results.
The over-heated period (warm) in Gazimagusa as seen in Fig.8. is between the 1\textsuperscript{st} of May and 31\textsuperscript{st} of October. 24°C was accepted as the thermal comfort room temperature. For single-skin facades, the upper external windows of the south facade were 10% open. Upper external windows were 0.65 x 20.0 m in size. Both the inner and outer skin windows of the north facade were 1% open as shown in section C-C. Moreover, for the double-skin facade, the upper and lower external windows of the south facade were 100% open. Upper and lower external windows were 1.1 x 20.0 m. The windows of the inner surface of the south facade had lower and upper windows that were 10% open. Both the inner and outer skin windows of the north facade were 1% open as shown in section D-D. In this way, it was possible to find out the contributions of the double- and single-skin facades to the room temperature, relative humidity, wall surface temperatures, heat flow, PMV, PPD, air flow in and out for natural ventilation.

As shown in Table 2., on typical days of under-heated (cool) periods, average heat loss of a single-skin facade office is approximately three times more than the double-skin facade. Moreover, as shown in Table 4., single-skin offices gained five times more heat than the double-skin offices during over-heated (warm) periods.

Table 3. shows that in comparison to single-skin, double-skin facade offices will have lower indoor air temperatures during the over-heated (warm) periods. Air flow in double-skin facade offices is more, which provides more cooling. However it is not enough to provide full thermal comfort. In another set of simulations, cavity widths of 0.60 m and 1.20 m were used. All of the cavity widths provided similar results; however, a 30-cm-wide cavity provided a slightly better result.

Hourly variations of surface temperatures can be seen on specific days in Figs.9. to 12. In Fig.9., hourly variations of surface temperatures for double- and single-skin facades on the 21\textsuperscript{st} of March can be seen. Surface temperatures were measured at the midpoints of the internal surfaces of the windows as well as the last floor ceiling (the Roof).

The inside surface temperatures of south windows for the double-skin facade are much higher than the single-skin facade south window, contributing to the heating of the offices in winter daytime. During night time, the figures are almost the same. Because of the reinforced concrete roof construction of the fifth floor which stores heat, the internal ceiling surface temperatures are higher than the other surfaces at night time. Only the top floors benefit from this behaviour.

In Fig.10., the hourly variation of inside surface temperatures for double- and single-skin facades on the 21\textsuperscript{st} of June can be seen. The double-skin façade's internal surface temperatures can reach 50°C, while the single-skin temperature stays fairly low. This high temperature of the south double-skin reduces the effect of ventilation cooling in summer. However, this cooling effect can be seen when the surface temperatures between the months of June and December are lower.

In Figs.11. and 12. the hourly variation of inside surface temperatures can be seen on the equinox days. In contrast to December, the building behaves as a summer day on the 21\textsuperscript{st} of September, thus the windows should be opened as in summer. This is why it was considered as the over-heated (warm) period.
5. Conclusions

Simulation programs are necessary to test as many parameters as possible within a reasonable time. For year-round 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 but the best results are obtained when the windows open automatically. In addition, the direction and velocity of the wind sometimes affect the results. Thus, a window mechanism that is connected to an environmental measurement centre will provide a better solution. Clearly costs need to be considered against benefits.

The under-heated (cool) and the over-heated (warm) period simulations show that the double-skin facade performs better than the single-skin facade in a warm climate. The double-skin facade helps to heat up the building in the under-heated (cool) period and helps natural ventilation during some part of the over-heated (warm) period.

During the whole year the average PMV in double-skin facade offices is mostly around 0.5, while in single-skin facade offices it is mostly around 1.5. PPD averages are 4% and 50% respectively. 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.

The performance of double-skin facade depends much on the climatic conditions. The results discussed here are for the Mediterranean town of Gazimagusa at 34ºN latitude. In this town, a double-skin facade will mostly provide thermal comfort during the under-heated (cool) period. For the remaining time, a double-skin facade contributes to the heating of the building.

In the over-heated (warm) period, some solar heat entering through the roof also affects the performance at the top floor. Thus thermal insulation on the roof is very necessary. In this period a double-skin facade contributes on average 25% to the cooling of the office spaces which is not enough to provide full thermal comfort.

The double-skin facade provides full thermal comfort during the under-heated (cool) period in this warm climate. For year round benefit it is more suitable for northern climates.
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