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Double skin facade for Ljubljana's climate - Applicability studies

Grega Zrim and Rosa Schiano-Phan

MSc Sustainable Environmental Design, Architectural Association School of Architecture, UK, grega.zrim@aaschool.ac.uk

Abstract
Ventilated double skin facades have been in the architectural world for a few decades now. The work done in scope of master studies of sustainable environmental design at the Architectural Association School of Architecture brings new data on the applicability of the dynamic facade concept to the climate of Ljubljana, Slovenia. The work consisted of: fieldwork executed in Ljubljana; parametric analysis of specific environmental strategies and finally the performance analysis of an office unit from the thermal comfort and energy demand perspective, tested against climatic data for Ljubljana. The findings from dynamic thermal simulation indicate that the considered typologies of ventilated double glazed facade (single storey and multi storey) will not ensure long term comfortable conditions in free-running mode, but they will reduce energy demand for both heating and cooling while providing comfortable conditions in comparison with single skin facade in supported mode.

Keywords: double skin facade; thermal modelling;

1 Introduction
From its beginnings, considerable criticism was directed to the dynamic facade concept arguing that its influence on indoor conditions and energy demand for cooling is not entirely beneficial and that its use can lead to high risks of overheating and occupants' discomfort. This is exemplified in a widely cited article by Gertis (1999) in "A Critical Review of Double-Skin Facades" (Lee et al, 2002). On the contrary, the recent findings from the "BestFacade" project claim that a properly designed double skin facade will lower the risks of having uncomfortable thermal and visual conditions in comparison with traditional glazed facade (Blomsterberg Ed., 2007). Therefore, the aim of the presented research work was to explore how ventilated double skin facade concept would perform in the context of Ljubljana, analysing elements, processes and results.

2. Methods

2.1 Study case building and fieldwork
The office building with a ventilated multi storey double skin facade on Ljubljana outskirts, designed by Janez Lajovic (Figure 2) was chosen as a precedent from the analysed context. Measurements of indoor dry bulb temperature and internal surface temperature in the middle of a shaded inner glazing pane were undertaken at the building and subsequently used for the calibration of thermal simulation model presented in Figure 4. The figure includes the results of the particular simulation run, which confirmed the method of modelling to be appropriate. The properties and characterisitics of the thermal simulation model (Figure 3), (e.g. orientation (8° clockwise from south), geometry, volume, height from the ground, height of windows

and the window sill) were taken after the study case building (Figure 1). The choice of materials is the same for primary structure (reinforced concrete), alteration is made in selection of thermal insulation and its thickness, giving the U-value 0,35 W/m^2.K for the opaque part of the external wall. The main parametric steps of the performed simulations comprise of different facade typologies and variation in window to floor ratio as presented in Table 2. The type, thermal and optical properties of glazing were determined with study of precedent research and are given in Table 1. Apertures in the facade stretch over the whole width of the office space and are 0.45m high. Manually controlled venetian blinds are used as shading device.

Table 1. Glazing properties

Internal skin glazing	
Light transmittance	0.797
Light reflectance	0.144
Total g-value	0.637
Direct transmittance	0.497
Direct absorptance	0.328
Direct reflectance	0.175
U-value	1.51 W/m^2.K
External skin glazing	
Light transmittance	0.87
Light reflectance	0.08
Total g-value	0.763
Direct transmittance	0.7
Direct absorptance	0.23
Direct reflectance	0.07
U-value	5.6 W/m^2.K

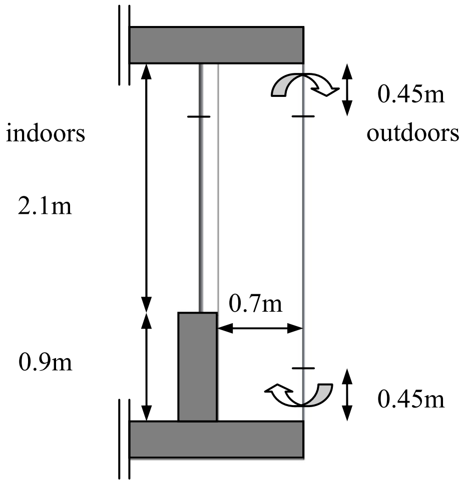

Fig. 1. Facade geometry

Fig. 2. SOP Krško building

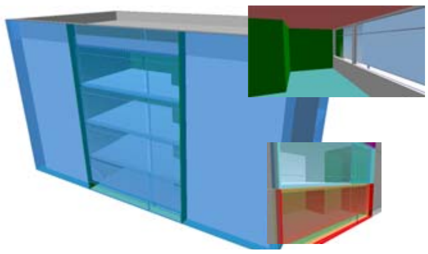

Fig. 3. Illustration of double skin facade thermal model and its zoning

2.2 Climate and thermal comfort

The Ljubljana yearly weather data, used for thermal simulations and determination of overheating potential, were taken from the weather database software Meteonorm 6.1., categorizing the climate as temperate (Atkinson, 1953 cited in Szokolay, 2008, p.34). A deeper dry bulb temperature analysis shows that Ljubljana's climate is heating predominant but even so free-running summer conditions would be hard to achieve. The benchmark operative temperature for overheating was established with determination of upper boundary of adaptive comfort band according to EN 15251:2007, calculated at 29°C. Data for day 190 (9th July) were used in the detailed hot day performance analysis.

2.3 Tools

The measurements at the building were carried out with data loggers, left at the building for 3 days in free-running mode. The thermal simulations were performed with EDSL Tas thermal simulation software.

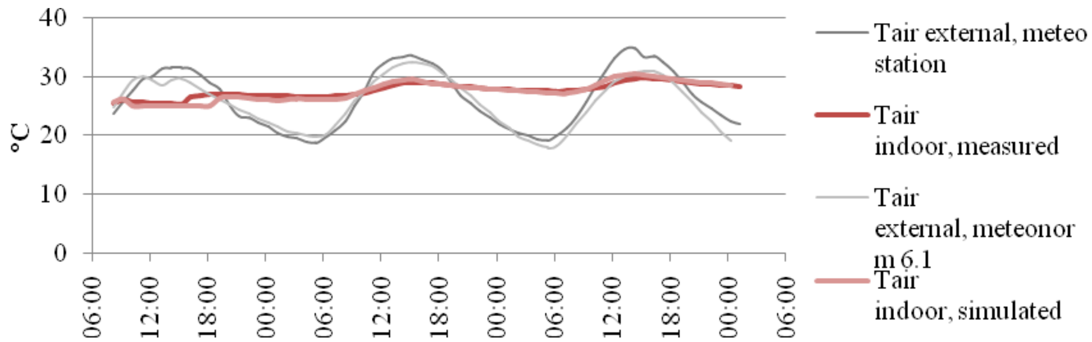

Fig. 4. Comparison of measured (from 8th to 10th July) and simulated indoor air temperature (from 18th to 20th August – weather file)

3. Results

Table 2. Description of parametric analysis steps

Case		Typology	W/F	Shading device	Glazing type	NVC
Type 1	SSF	-	0.38	yes	Table 1	yes
Type 2	DSF	single-storey	0.38	yes	Table 1	yes
Type 3	DSF	single-storey	0.54	yes	Table 1	yes
Type 4	DSF	multi-storey	0.38	yes	Table 1	yes
Type 5	DSF	multi-storey	0.54	yes	Table 1	yes

3.1 Heating demand

The influence of double glazed facade with closed air cavity, presenting a thermal buffering effect, has proven to be an efficient environmental strategy for lowering the heating demand over the heating period from November to February, as shown in Figure 5. The analysed cases assumed the shading devices to be lifted and no obstacles present preventing the solar access. Infiltration was set at 0.5 ach and ventilation for fresh air at 0.64 ach.

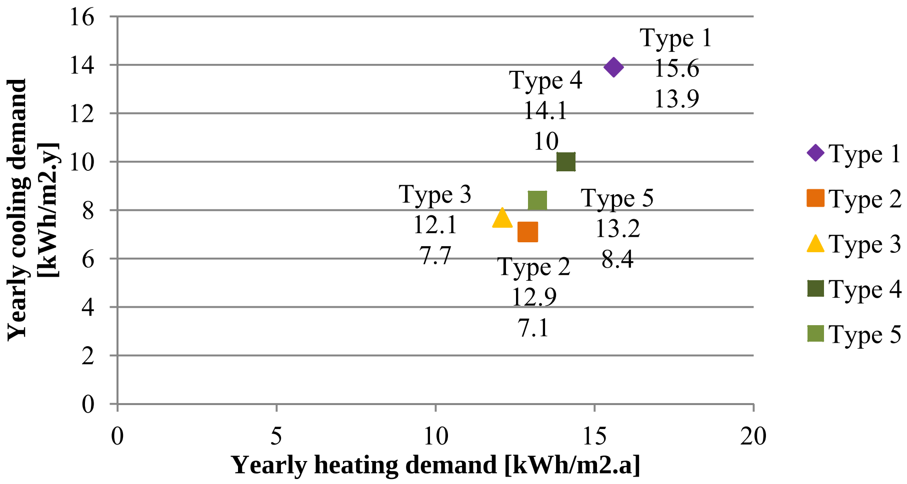

Fig. 5. Yearly heating and cooling demand [kWh/m2.y]

3.2 Free-running mode and potential of overheating

The main criterion used for the assessment of overheating potential was the frequency of operative temperature above the upper limit of adaptive comfort band. Results show that the operative temperature would exceed the benchmark of 29°C, established according to EN 15251:2007, more than 1% of the occupied hours in all studied cases of facade typology. Apertures of same size were predicted to be open all day. A separate single skin case with all apertures open was run, showing that even if the size of opening is increased to maximum, the conditions would not be sufficiently comfortable. Thus, auxiliary cooling was assumed to be necessary in order to achieve thermally comfortable indoor conditions. No strategy of supplying passively pre-cooled air or air from cooler thermal zones by natural ventilation was predicted.

3.3 Cooling demand

In accordance with the findings on indoor conditions for free-running mode the yearly cooling demand, is higher for the single skin facade in comparison with all the considered cases of double skin facade (Figure 5).

The analysis of cooling demand, mean radiant temperature, internal surface temperature of inner glazing pane and amount of solar gain that the observed pane, oriented 8° from south, receives over a hot summer day (Figures 6 to 9) points toward

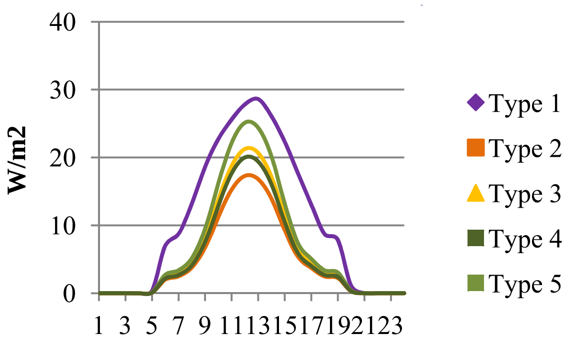

Fig. 6. Solar gain of observed glazing pane on hot summer day (9th July)

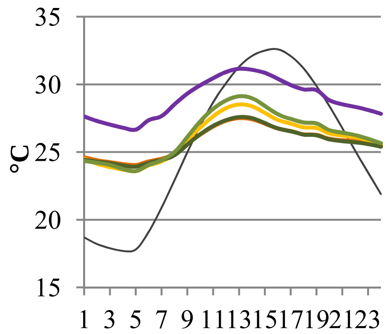

Fig. 7. Mean radiant temperature on hot sumer day (9th July)

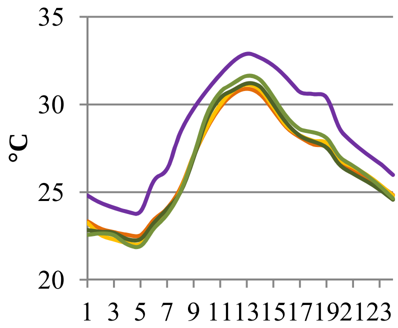

Fig. 8. Internal surface temperature of inner glazing on a hot summer day (9th July)

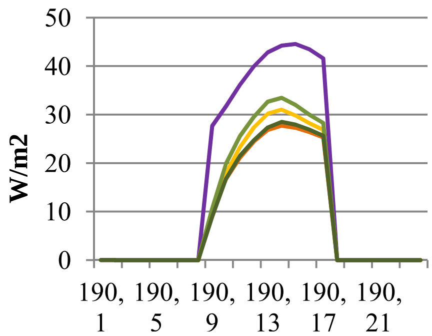

Fig. 9. Cooling demand on a hot summer day (9th July)

the conclusion that the amount of solar radiation penetrating the single skin facade is higher than in the cases of double skin facade. This is reflected in higher mean radiant temperature of the office. While being unable to dissipate the extra heat outwards during the day (windows are closed) and providing sufficient air change rate by natural ventilation during the night, the cooling loads are respectively higher.

3.4 Thermal comfort considerations on a hot summer day

The thermal comfort analysis was executed according EN 15251:2007 using the Fanger's thermal comfort model for heated and cooled buildings, representing supported conditions similar to the ones in study case building (Table 3). The outcomes show that in case of single skin facade, the conditions in the office space would be quite uncomfortable almost the entire day (Figure 10), classifying the building as category IV (PPD > 15%). On the contrary, the double skin facade typologies 2, 3 and 4 would fulfil the criterion for category II building (PPD < 10%), which is the category for new buildings with normal level of expectations. Only the type 5 would fall into category III building.

Table 3. Thermal comfort parameters for supported mode analysis

Conditions	A
CLO	0.46
MET	1.1
v	0.1
RH	50
DBT	26
MRT	hourly

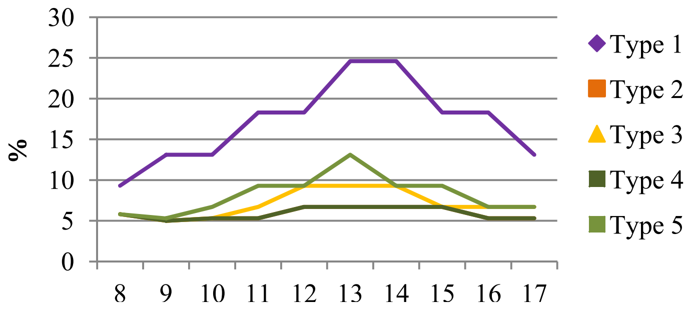

Fig. 10. PPD index for types 1-5, occupied hours (9th July)

The raise in level of clothing in accordance with CIBSE (2006) guidelines would push the PPD index well over 20%, therefore none of the facade concepts would be in compliance with the category II building criterion, PPD of less than 10%. The rise in air velocity to 2m/s would sufficiently improve the indoor conditions only for double skin facade typologies, lowering the PPD to 9.5%. Thus the reduction of mean radiant temperature was identified as the main strategy for improving the thermal comfort conditions.

An additional aspect of thermal comfort and radiant environment is the surface temperature asymmetry. The CIBSE (2006) recommends that the thermal asymmetry should not contribute more than 5% to predicted percentage dissatisfied. For warm wall that means difference in temperature of 23K. Even though the inner surface temperature of the internal glazing rises above 30°C there is no other surface cool enough to cause discomfort above 5% PPD.

4. Discussion

The original design of the Ljubljana case study building precedent predicted the combination of the building's atrium and double skin facade as an environmental strategy for reducing the cooling demand, which was confirmed in one of the reviewed design performance reports (Novak et al, n.d.). A positive effect of thermal mass on daily temperature development was also indentified in the same review. The thermal simulations in the scope of this research, did assume the use of thermal mass in combination with night time ventilative cooling, but did not include the study of atrium and double skin facade combined performance. Nevertheless, the analysis has indicated that the application of double skin facade may be beneficial for reducing heating and cooling load.

A precedent research on double skin facade performance in the Belgian context (Gratia, E. et al, 2007), has shown that the buildings should be thermally well insulated even if double skin facade is applied. The energy demand analysis of Gratia's study case, presenting a well insulated building, with main facade oriented towards south and double skin applied demands cumulatively slightly less (2.7%) energy for heating and cooling than the case without the double skin, which instead shows an increase of 41% in cooling demand and decrease of 15.8% in heating demand respectively.

Comparing the findings of another vast double skin facade research (Blomsterberg et al, 2007) with the ones obtained in this research, noticeable differences can be found. Firstly, the application of double skin facade in context of Paris, would result in 26.2 % reduction in cooling demand and 35 % reduction in heating demand. For the same typology of double skin facade in context of Ljubljana (type 3), the reduction of 44,6

% in cooling demand and only 22.4 % in heating demand would be obtained. Secondly, in Ljubljana, the energy demand for cooling is lower than the heating demand in all studied cases, which is just the opposite to the findings in context of Paris, where regardless of glazing type, window to floor ratio and facade typology alterations the cooling demand is higher. The main cause for these dissimilarities might be the different glazing properties, lower ventilation rate (infiltration and fresh air supply) and very high window to floor ratio (0.83) in Paris study case.

5. Conclusions

The outcomes of the presented research, gained with study of research and built precedents, climate study, fieldwork and a series of computer simulation, point towards the applicability of the double skin facade to office buildings in the context of Ljubljana. As the analytic work presented here shows, the building with a double skin facade with carefully chosen properties would perform in benefit of the building occupants (PPD < 10% for DSF types 2,3 and 4) and yield energy savings of 9.7 $kWh/m^2.y$ compared to a single skin building of similar specification. However, before final confirmation of its applicability is put forward, further research of how microclimatic and indoor conditions influence the thermal and energy performance of a building with double skin applied needs to be done and more long term energy as well as environmental monitoring data obtained.

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