# Non-Uniform Double Skin Façade Cavities:

## An exploratory study on cavity heat stratification and daylight levels indoors

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*ABSTRACT: Between 1990 and the beginning of the 21st century, double skin facades had uniform cross sectional air shafts that could be extended over a number of floors. Recently, there is an increasing interest in the architectural design community to explore the configuration of the uniform double skin facades (DSF) realized in different climatic regions. The external facade layer is starting to present itself as an architecturally engaging surface. Contemporary examples head towards changing the norm of a smooth transparent glazed outer surface into inclined or faceted surfaces. Experimentation also extends towards changing the inner façade massing into staggered levels. The function of the air shaft in DSF is shifting from a solar chimney, sound barrier or for introducing natural ventilation indoors into break out spaces for gatherings. Varying the aesthetic expression of the facade, the depth between the double skin layers has uncertain effects on the air flow, thermal performance and daylight levels indoors. This paper presents and exploratory study using thermal and daylight modelling for three different façade DSF façade configurations in the North East of England. Results indicate that thermally the staggered internal massing while raking the façade might experience less thermal stratification as the internal façade shades itself from direct solar radiation but the lack of appropriate daylight levels may render this solution as energy extensive due to the need for artificial lighting. Future research needs to integrate findings from this study to look deeper into the impact of less thermal stratification in the staggered facade on the buoyancy effect and possibility of natural ventilation*

*Keywords: Double Skin Facades, thermal stratification, daylight, temperate climate*

**INTRODUCTION**

In the main, double skin facades (DSF) are designed as two glazed facades separated by an air cavity of uniform cross-section. It is widely accepted that if properly designed it could have a beneficial impact on improving indoor thermal, visual and acoustic conditions in perimeter areas, while increasing the provision of natural ventilation and acceptable levels of internal surface temperatures. Acting as a stand-alone solar chimney or coupled with mechanical systems for mixed mode ventilation of deep plan environments [1] or in extreme climates as hot arid climates; double skin facades with an external reflective glazed surface are predicted to lead to a substantial reduction in cooling loads [2].

As a thermal buffer zone around a building, double skin facades have precedents in vernacular architecture worldwide, such as the Japanese traditional house and multiple window glazing units in the Swiss alpine houses. It is widely recognized in its contemporary form and mainly deployed in office buildings. The latter requiring a corporate image (usually conveyed through extensively glazed facades) and high levels of energy use to maintain thermal comfort. Contemporary examples include the Willis, Faber and Dumas building (Foster and Partners, 1975), Occidental Chemical Centre in New York (Canon Design 1980) Commerz bank (Fosters and Partners, 1991-1997, Strador in Dusseldorf (Petzinka, Pink and Partners), Swiss Re Building in London (2002-Fosters and Partners) and the Leicester John Lewis Store. Interestingly this technology is now extended to being used in other high occupancy buildings such as courthouses such as the Magistrates court in Manchester and 'supreme audit court' in Tehran.

Recently, there is an interest within the architectural design community to explore changing the configuration of glazing properties and cultural reflections of the external layer of the double skin façade. For example (Figure 1) the John Lewis store in Leicester in the UK (Foreign Office Architects, 2008), uses patterns of local cultural significance itched on both glazed surfaces to refract direct solar radiation through the double skin façade to conserve merchandize indoors [3]


*Figure 1: John Lewis Store in Leicester, 2008 by FOA where the external pattern is reflective and the internal pattern is matt itched on the glass. Both patterns directly face each other and this is to refract direct solar entry which is incident at an angle while allowing shoppers to*

There is an increasing understanding of how the buoyancy effect is generated in the cavity and its effect on decreasing heating and cooling loads.
Figure 2, shows the external layer constructed as a folding textile such as the Health Department building in Bilbao, Spain by Coll-Barreau Arquitectos in 2008 and to reflect the historic surroundings of the centre of Bilbao, Spain. The function of the air shaft in the DSF is shifting from a solar chimney, sound barrier or for natural ventilation into a social place and for break out time

*Figure 2: external folded double skin façade (left),social break out space in the cavity of the DSF (right)*

## THE IMPACT OF NON-UNFORM FACADES ON TEMPERATURE STRATIFICATION IN THE CAVITY

Double-skin facades are constructed of an external glazed surface and separated from the internal façade of the building by an air cavity acting as a shaft to trap heated air as a cloak around the building in winter, while reducing direct solar radiation on the inner façade. In summer natural buoyancy lifts the warmed up air that stratifies in the cavity. Thermal stratification in the cavity is influenced by a number of design and climatic parameters including solar radiation levels, building orientation, shading devices use and their colour, opaque wall/window ratios of the interior facade, depth of the cavity of the double-skin, glazing types on both façade layers and design of inlets and outlets in relation to prevailing wind direction and speed. Reviews of simulation studies on double skin facades in hot arid areas [4],[5],[6] and in moderate climates [7],[8],[9] claim that the outer glazed surface is warmed up and experiences much higher temperatures than ambient more than the inner surface facing the cavity. However, the elevated temperatures of the air within the cavity, augmented by convection transfers leads to trapping heat in the cavity and inducing the buoyancy effect.

Gomaa, etal [6] conducted a three dimensional Computational Fluid Dynamics on a uniform double skin façade (1m) in a hot arid climate on an East orientation. The purpose of the investigation was to analyse the effect of solar radiation through the intermediate air cavity and how it augments mixed convections in the cavity driving buoyancy. A conjugate heat transfer model was creating combining a finite discretization method with SIMPLE solution Algorithm of the velocity pressure coupling involving the low turbulence $k$-$\varepsilon$ model was used and is coupled with a ray tracing solar model to solve the complete solar and radiation fields as well as the convection and conduction fields. The model is different than this current investigation as it involves an East oriented façade and has a total height of 19m in a hot arid area. However, similar to other studies in temperate climate, Figure:3 results indicated that the temperature on the inner surfaces of the outer skin are higher than the inner façade surfaces facing the cavity and the mid cavity temperatures are substantially lower (15C) than the surfaces of the exterior façade layer facing the cavity). The drop in air velocities at the top of the cavity also contributes to higher thermal stratification. The mid cavity temperatures are generally the ones reported in literature and indicate the possibility of introducing natural ventilations indoors.

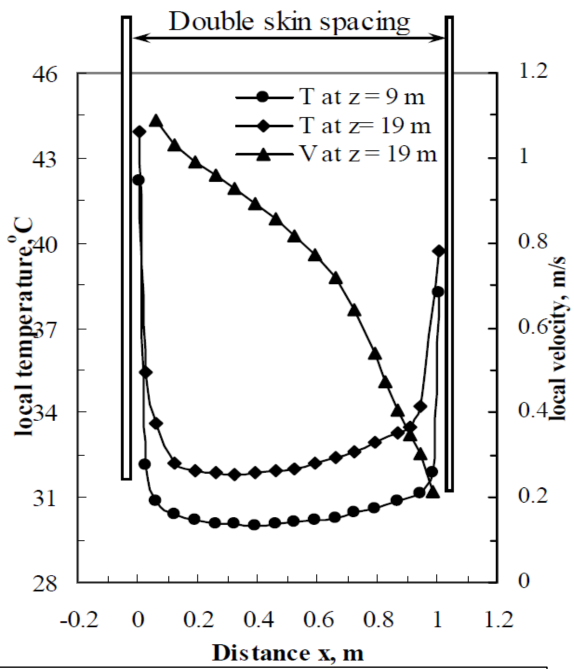


*Figure 3: Thermal stratification profile in a DSF cross section and air velocities at the top of the cavity*

The disadvantage of using CFD simulations to simulate DSF is its limited ability to include the orbital sun movement on surfaces over an annual duration and thus results stating possible heating and cooling reductions are only valid for the CFD simulation temporal settings. The strength in running simulations using dynamic thermal modelling is the coupling of direct solar radiation and its effect on cavity surface temperatures but there is a need for due vigilance in building the model in a way to capture temperature stratification in mid cavity. The double skin façade has to be built as compartments separated at each floor level and connected by holes representing the actual opening between floors taking away allowances for meshes. However, the limitation of the latter is its incapacity to show air velocities or air movement patterns in the cavity.

Hashemi, etal [10] monitored the thermal behaviour of a ventilated double skin façade in the hot arid climate of Tehran on an 11 storey high building of the 'supereme audit court' in Tehran. Simulation results agree well with measurements and indicate that the cavity temperatures are higher than ambient temperatures and vary by orientation and floor height. The Double skin façade is divided every two storeys During summer because of the cavity's poor ventilation on the seventh floor, its temperature is 2–10 °C more than the outside, whereas on 11th floor, which has good ventilation the difference is only 2–4 °C. The DSF in winter preheats the interior spaces and decreases the heating load. In the case building the cavity temperature on seventh floor is 5–12 °C and on 11th floor 7.5–10.5 °C more than the outside temperature in winter. Interestingly temperature differences between the cavity and ambient were higher in simulations than monitored data. In summer, it was up to 14.5° for simulations and 5–10° for monitoring. During winter it was up to 9.5° for simulations and 5–12° for monitoring. This shows that simulations for winter conditions are more accurate. Discrepancies between simulation results and measurements are expected. Simulation results can be used as a comparative analytical tool to look at the thermal stratification and daylight levels of various possible architectural configurations.

A study on three DSF buildings in Germany shows that $T_{cav}$ in Siemens building (a box-window DSF) is 10 °C more than $T_o$, in Victoria Insurance Co. (a multi-storey DSF) 8 °C and in RWE Tower (a box-window DSF) 15 °C [11].

Hamza etal [12] modelled the performance of non-uniform double skin facades within three different DSF configurations, a straight, raked and necked configuration using CFD in a temperate climate to study the effect of the mass flow rate and possibility of coupling the cavity with indoor natural ventilation in occupied office spaces. Results indicated that there were minor differences in the cavity temperature stratification and natural ventilation air change rates introduced indoors. However, this research departs from the previous study in staggering the interior façade massing.

**MODEL GEOMETRY**

The room plan is a construction bay of 6m*6m*3.5m facing the West Orientation. The weather profile is a synthetic average annual profile of weather conditions in Newcastle Upon Tyne, UK 55$^o$ North.

Pressure tends to drop significantly with façade cavity height after the second floor The buoyancy effect is

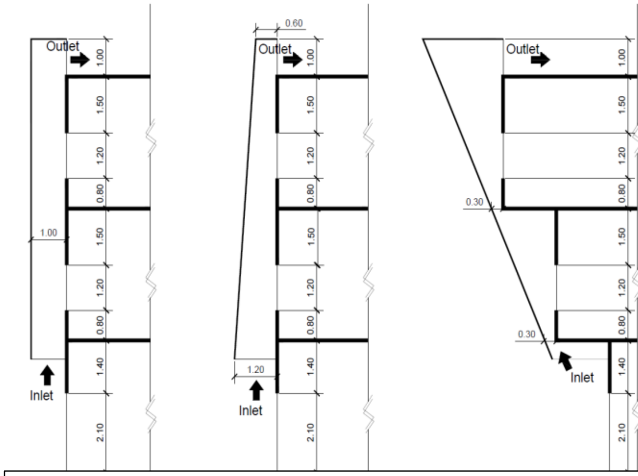


*Figure 4: Straight DSF (left), Raked DSF (middle, Staggered DSF (right)*

naturally driven by the increase in surface temperatures and if not controlled in DSF configurations for upper floors can increase the greenhouse effect around the building. Ding etal [13] studied varying the height of the solar chamber on top of the double skin facade and found that increasing its height has a beneficial effect on substituting for lost pressure in the cavity .when ventilating upper floors. They recommend that the cavity height is a minimum of 2 storeys high above the top floor. In this research, the parapet height on the roof level was substituted by the solar chamber(Figure: 4), this means that is only 1m above the roof height and placed vertically above the double skin cavity which is seen as more practical in architectural and construction costing terms.

In this study the double skin facade extends over the first and second floors. The double skin inlet is 3m above ground level and is assumed to have no obstructions or walkways to decrease the effective inlet opening area thereby minimizing thermal exchanges with the ground and providing better air quality intake. The flow domain in this case is the double skin facade cavity, where temperatures at inlet are assumed equal to outdoor temperatures

Walls: U-value 0.35 W/m$^2$K
Floors: U-value 0.25 W/m$^2$K
Roofs: U-value 0.25 W/m$^2$K
Floors/Ceilings: Carpeted 100mm reinforced-concrete ceiling U-value 2.3 W/m$^2$K

Windows: low-e double glazing (6mm+6mm) (2002 regs) U-value 1.6786 W/m$^2$K
Double skin façade glazing: PILKINGTON K 10mm U-value 5.0 W/m$^2$K

IESVE is dynamic thermal modelling software that incorporates RADIANCE for daylight modelling. It is widely used in both practice and research as a validated tool. IESVE version 6.4.0.12 is used for thermal and daylight modelling to study the impact of direct solar radiation on buoyancy in the DSF.

## RESULTS AND DISCUSSION

Figure 5,below, shows that the impact of direct solar radiation is more pronounced than convective and conductive thermal transfer in the double skin façade cavity. A consistent trend of the three façade configurations indicates that the inner cavity temperatures are consistently higher than ambient conditions. In January where the sky conditions are mostly heavily cast and daylight hours are from about 8.30-4p.m. the differences between the three façade configurations is minimal and consistently about 3$^o$C higher than ambient. In the summer month the straight and raked configurations show an almost identical thermal behaviour with temperatures rising sharply (7-8 $^o$C) above ambient during direct incident solar radiation hours. In summer the staggered configuration is predicted to follow the ambient profile more closely as it overshadows itself by the projection of the massing of the internal façade.

Figure 5, also presents predictions of the relative humidity conditions in the cavity between the three configurations. Newcastle upon Tyne experiences down pours and heavy rain almost year round. The study of the relative humidity level also indicates whether the air in the cavity can be introduced for natural ventilation. It is a consistent pattern between the three configurations that the second floor has less relative humidity as the thermal stratification leads to higher temperatures in the second floor cavity. The direct incident solar radiation combined with the buoyancy effect also plays a role in decreasing the relative humidity on the cavity in summer as it elevates the cavity temperatures above ambient in the second floor.
Second floor cavity temperatures are about 2C higher than the first floor which further limits the possibility of natural ventilation especially when the cavity air is introduced to areas with high internal heat gains and there is a need for cooler air.

Figure 6 , presents a comparative daylight study between summer and winter conditions of the three façade configurations. It shows that the straight and raked configurations are almost similar in creating areas of higher daylight levels with the possibility of glare near the perimeter zones. It is argued that in practice the provision of maintenance walkways and see through nets can alleviate this problem in summer afternoon periods or in times of clear sky conditions. However, the staggered configurations exhibits a very dark indoor environment that even on a clear summer day may need topping up of natural daylight levels with extensive use of artificial lighting which is another internal gain and energy consumer as lux levels range between 50-150 Lux.

## CONCLUSIONS

As in many preliminary investigations; this investigation raises more questions and warrants the need for further research. It is an attempt to give architects and professionals engaged in using double skin facade technology some evidence that enables robust design decisions. Interest in the potential of double skin facades as an architectural configuration while harnessing its benefit as a buffer for climatic and noise external conditions is manifesting itself in an increasing number of buildings. The bulk of building thermal and daylight performance simulation work is currently on-uniform cavity cross sections. There is a need to extend this research into more challenging architectural configuration and to study how this has an impact on the volume flow rates inside the cavity, pressure drops and the possibilities of natural ventilation indoors
Thermal conditions indicate that the first floor has a lower temperature distribution and average temperatures than the second. This is expected due to the reduced buoyancy driving force on the upper floor.

The thermal performance of the straight and raked cavity is almost similar this is in line with previous simulations using CFD [12].

For the staggered configuration although maintaining a lower thermal stratification profile the overshadowing reduces the penetration of daylight substantially. The opening between the two floors is a 0.3m and changing this opening to other dimensions and its impact on the air flow rate and air quality in the cavity needs to be investigated.

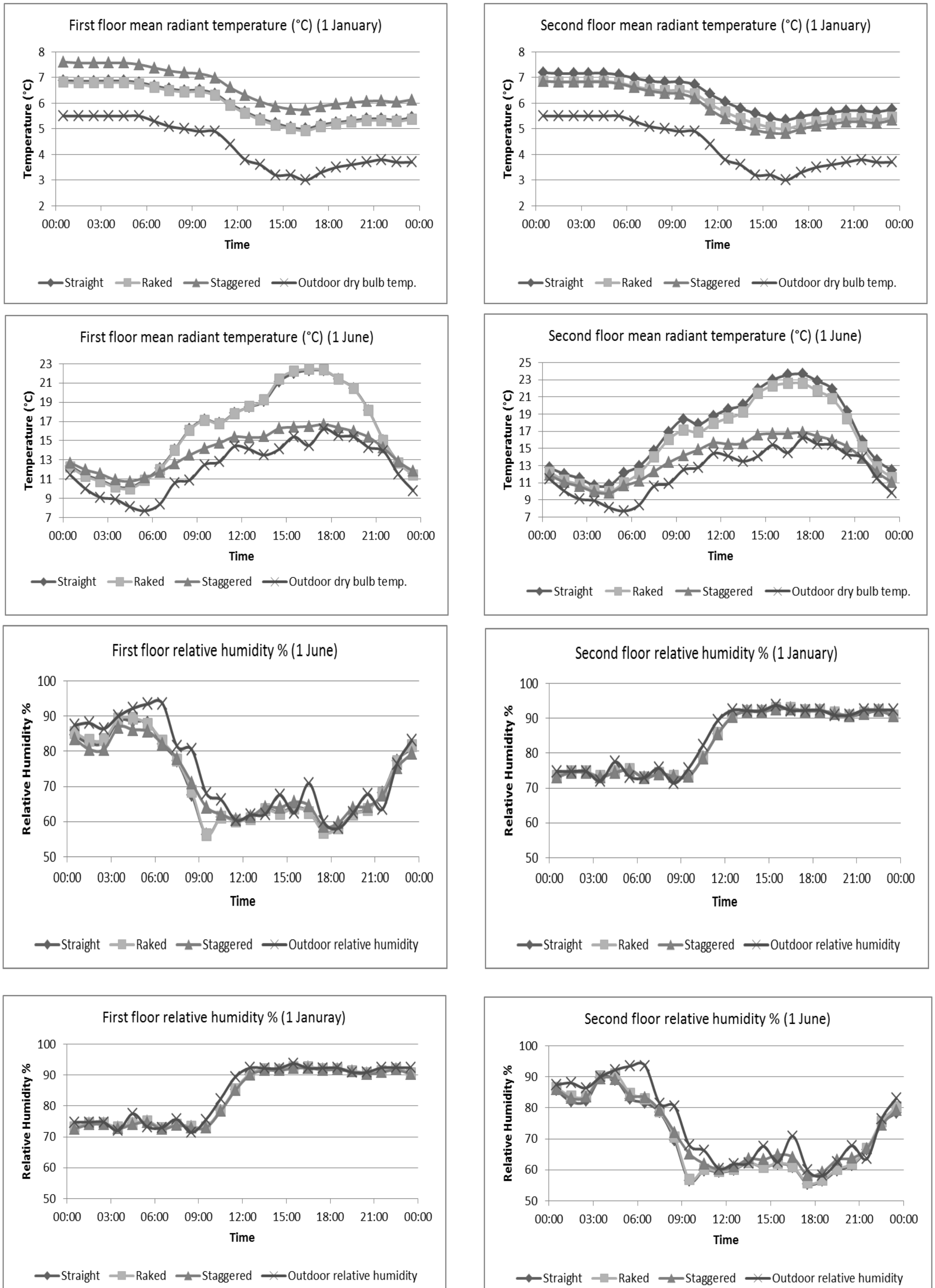


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*Figure 5: comparative analysis of the three DSF configurations between summer and winter by floor level*

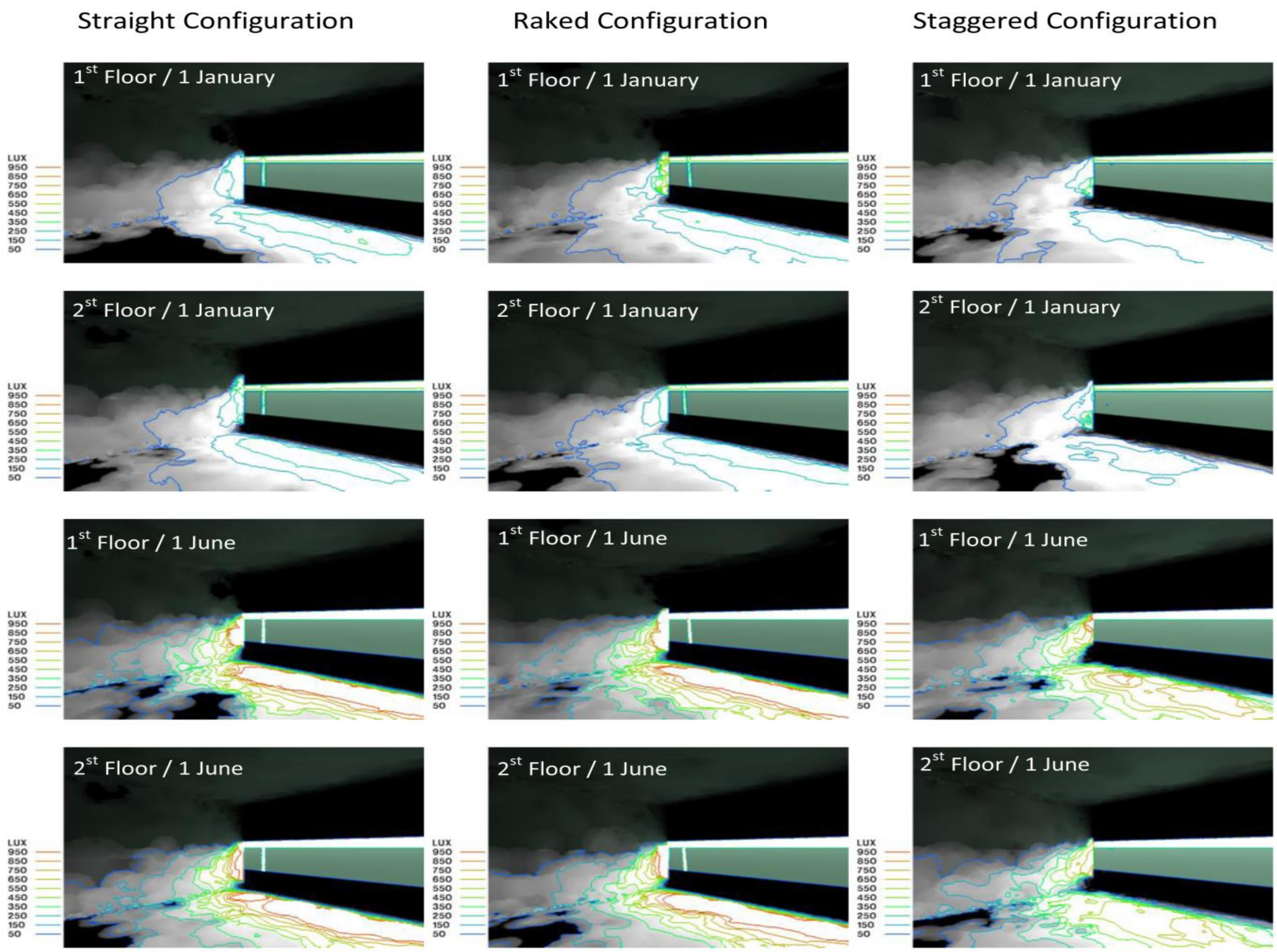


*Figure 5: shows the impact of the three different façade configurations on daylight levels between winter and summer*

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