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ESTABLISHING A SIMPLIFIED CORRELATION BETWEEN A PROPOSED DOUBLE SKIN FAÇADE AND A THERMALLY EQUIVALENT SINGLE SKIN FAÇADE FOR DYNAMIC BUILDING ENERGY MODELLING

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ABSTRACT

Advanced façade systems such as double skin facades are increasingly common. However, evaluation of performance in terms of energy and comfort is not always possible. Limitations and constraints of current design tools lead to the introduction of a number of necessary simplifying assumptions. In-depth understanding of both software tools and the function and the performance of double skin façade systems are essential in solving these problems. The paper presents a case study and starts to develop a methodology for establishing an appropriate correlation. An energy simulation model of a commercial high rise building in London was created for the purpose of a Building Regulations compliance check. An extremely high number of thermal zones in conjunction with the need to represent double skin façades (DSF) in the simulations, significantly increased the complexity of the simulation model. Moreover, the Building Regulations (specifically 'Part L' which deals with energy performance) do not permit sufficient reduction in the number of modelled zones to scientifically ease the process. Consequently, a correlation between the proposed DSF and a thermally equivalent single skin facade (SSF) was established with the aim of reducing simulation time and - more importantly - facilitate the modelling process for the building. In order to derive this correlation, a study was carried out of the impact of the ventilation rate through the DSF cavity and the position of the shading device (between inner and outer skin); subsequently, a thermally equivalent SSF was defined. The correlation agreement was evaluated for results obtained for the heating and cooling demand on an hourly, monthly, and annual basis. The modelling of the building was carried out in 'IES'software, which was also used for assessing the achievable correlation between the simulated single and double façade performance. Additional tools were also used in order to achieve the correlation as mentioned below.

INTRODUCTION

For a couple of decades there has been a strong interest in 'transparent architecture'. Since the achievable energy efficiency and quality of indoor thermal environment in highly glazed buildings is often questioned, detailed modelling is often required. The intrinsic complexities of such building designs can, however, often be an issue, increasing the required modelling effort to such an extend that it can become restrictively time consuming if not practically impossible. Simulating buildings with double skin façades is an example of such a case. The mode of the double skin façade (standard type or airflow window), its function throughout the seasons (e.g. naturally ventilated during summer for heat extraction and closed off during winter for increased thermal insulation), the position of shading devices within the façade cavity, the dimension and position of ventilation openings and possible damper control set points are all parameters that influence both the resulting façade performance and the modelling complexity. In order to significantly reduce both the complexity and the simulation time, a study was carried out, aiming to define a correlation between a double skin façade model and an 'energy equivalent' single skin façade model. The study was carried out for a specific high rise, mixed use building in London, UK.

OBJECTIVE

The present paper describes the method and the steps involved in achieving a satisfactory correlation between a double skin façade (DSF) model and an equivalent single skin façade model. The purpose of the study was to correlate the physical (energy) properties of a project-specific DSF and an equivalent SSF for building performance simulations utilising the IES software. Since IES typically handles the DSF cavity as a separate zone, detailed DSF modelling applied throughout the entire building (in this case 72 floors) would prove prohibitively time consuming, if not practically impossible. In the specific case, a DSF/SSF correlation can reduce the simulation time and facilitate the building modelling process. This paper describes the methodology and evaluates the correlation through discussion of selected results.

At this point, it has to be noted that accurate energy and thermal performance predictions of buildings with double skin façades is often a complicated task, mainly due to the complexity of the system and the lack of DSF models' validation. In this case, IES, which is a building regulations accredited software, was selected for the energy assessment of the studied building. This paper aims at meeting a performance agreement between the proposed DSF and an equivalent SSF. Further investigation of the accuracy of the IES DSF model was not a part of the study.

BACKGROUND

General background on Double Skin Façades

One of the main characteristics of any double skin façade system is its ability to regulate the façade thermal properties throughout the year, potentially enhancing the building performance. Two basic modes are described in literature (Poirazis, 2004): the 'standard' double skin façade (where the cavity is ventilated with outdoor air) and the airflow window (where the cavity is ventilated with return air from the indoor space). The ventilation mode for the 'standard' double façade can be natural, mechanical or hybrid, while for the airflow window it is always mechanical. In general, depending on the mode, the use, the geometry and the type of panes and shading devices used, the double façade can either expel excess heat through the ventilated cavity during the cooling season, or function as a thermal buffer, increasing the thermal insulation during the heating season (naturally ventilated case). At other times, the façade can serve to preheat fresh air achieving energy savings during winter (mechanically ventilated cases). For the specific project, the cavity is naturally ventilated throughout the year.

Correlation of single skin and double skin façades

Correlating a single skin façade and a double skin façade is a complex task, since their performance characteristics are different and vary throughout the year, depending on the environmental conditions. Initially, the study focussed on two aspects in order to match the simulated performance: the effect of DSF cavity ventilation and the effect of the shading device position on the secondary transmittance. These two aspects are described in more detailed in the following.

Cavity ventilation and secondary transmittance

The main aim of a naturally ventilated DSF is to control the air temperatures inside the cavity, especially when solar shading is deployed. In order to assess the effect of ventilation on the secondary transmittance, a comparison of a closed and open cavity was carried out (Figure 1). For the closed cavity (which is equivalent to a triple glazed window with intermediate shading), the air temperatures are higher than when ventilated; a more absorbing shading device leads to higher cavity air temperatures. Increased temperatures between the shading and the 2nd pane will affect the pane temperatures. Likewise, the temperature of the 3rd pane is going to be higher, ultimately affecting the longwave radiated and convective heat transfer to the indoor side. In terms of resulting secondary transmittance, the difference between the closed and open cavity depends on the ventilation efficiency, the glass type (e.g. low emissivity panes would reduce the impact of ventilation, since the longwave heat transfer is reduced) and the gas type in the inner skinned double glazing unit (DGU).

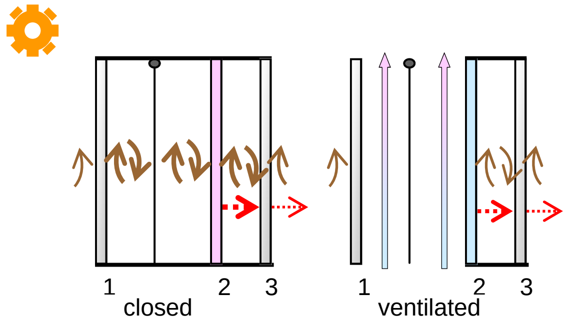

Figure 1 Difference in secondary transmittance between a closed and a ventilated cavity

Shading position and secondary transmittance

The IES software offers no option for intermediate shading devices for a closed cavity configuration (triple pane window). The way around this is to introduce an equivalent pane including the effect of the shading. This approach, however, does not allow for modelling of controls, so the effect of shading remains constant throughout the year. Another possible way could have been to apply either internal or external shading instead of the intermediate one; while the direct solar transmittance of internal or external shading would be similar to that of intermediate shading, the secondary transmission will differ and vary throughout the year, depending on climatic conditions. In order to address this aspect, the study was based on the introduction of equivalent simultaneous internal and external shading. The methodology is explained in the following.

THE DOUBLE SKIN FACADE

The (storey high) double skin façade is designed as a bespoke unitised curtain walling system, which is modelled as two layers without detailed assessment of the framing details. The glazing is build up with a single glazed outer skin and a double glazed inner skin (insulating glazing units). The outer skin is a low iron laminate incorporating solar control, while the inner skin is a double glazed unit, low iron glass, with a low-emissivity coating and a 16 mm air-filled cavity. A 210 mm deep ventilated cavity separates the two skins (as displayed in Figure 2).

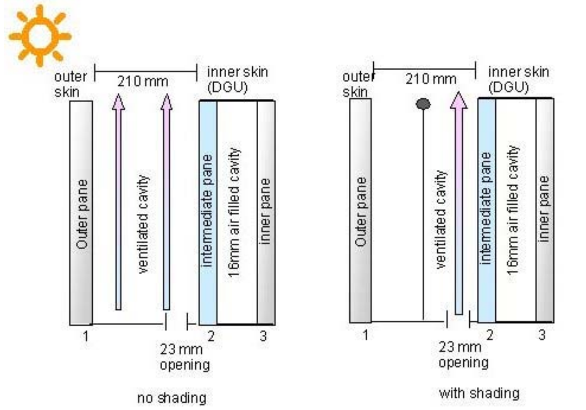

Figure 2 Section of the Double Skin Façade

The pane properties considered are given in Table 1.

Table 1
Double Skin Façade pane properties

	OUTER SKIN	**INNER SKIN**	
	OUTER PANE	**INTERM. PANE**	**INNER PANE**
thickness (mm)	16	8	10
emissivity (int)	0.84	0.05	0.84
emissivity (ext)	0.84	0.84	0.84
transmittance (shortwave)	0.64	0.6	0.8
absorptivity (shortwave)	0.15	0.14	0.12

An automatically controlled fabric roller blind is located within the ventilated cavity. The assumed properties are: 5% openness factor; 0.11 shortwave transmittance; 0.65 absorptivity. The linear ventilation slots between the ventilated cavity and the outside are 23 mm wide.

CORRELATION METHODOLOGY

The study was carried out in four steps: (i) defining the DSF system performance and evaluating the sensitivity to the modelled ventilation opening size on the heat extraction for steady state boundary conditions, (ii) adjusting the modelled pane properties of the equivalent SSF (thermal, total solar and direct solar transmittance) throughout the year for cases without shading devices, (iii) investigating the impact of the interstitial shading device on the DSF performance and suggesting an equivalent shading model and (iv) once the final tuning of the equivalent SSF has been carried out, its all year round performance was evaluated for four different orientations (as in the actual building) in a dynamic thermal software (IES). The agreement between the DSF and the equivalent SSF performance was then investigated. The study only considers thermal buoyancy as the driving force for the naturally ventilated cavity (i.e. wind effects) was not taken into account due to the increased model complexity.

Evaluation of the DSF performance

The first step of the study was to investigate the impact of the ventilation openings on the heat extraction efficiency of the ventilated façade. Initially, a 210 mm deep façade with linear 23 mm wide openings was considered. A discharge coefficient of 0.55 was then assumed, reducing the Equivalent Leakage Area (ELA) to 12.7 mm. The airflow rate within the ventilated cavity, the temperatures in each of the layers and the systems properties were calculated for steady state boundary conditions. The study was carried out by means of the WIS 3.0 software. WIS 3.0 is software tool based on European standards aims to assist in determining the thermal and solar characteristics of window systems (glazing, frames, solar shading devices, etc.) and window components.

Adjustment of SSF pane properties

Once the properties of the proposed double skin façade system were calculated, the pane properties of an equivalent single skin façade (triple glazing) were adjusted, to match the double skin performance (including the effect of natural ventilation). The glazing performance was matched in terms of monthly average thermal, total solar and direct solar transmittance values (Hellström et al., 2007). The system was modelled without shading devices. The modelling was carried out by means of the Parasol software. Parasol is a design tool based on dynamic energy simulations and provides monthly results for the total and direct solar energy transmittance (g-and T-values) of the sunshade and the combination of sunshade and window system.

Definition of shading device properties

Once the panes properties were adjusted so that the equivalent single skin glazing (without shading devices) matched the performance of the double skin facade, an equivalent single skin model with shading devices was defined. The U, g and T_{dir} (thermal, total solar and direct solar) values of the double skin system were calculated, this time including the shading device within the ventilated cavity. Starting from the equivalent SSF (of which the pane properties were defined in the previous step) internal and external shading devices were introduced in order to match the performance of the DSF. The process included the following the steps:

1. Initially, only the internal shading was considered in order to match the thermal transmittance (U-value).
2. External shading was added and the properties were adjusted in order to match the total solar energy transmittance (g-value).
3. Both internal and external shading properties were further modified in order to match the ratio between the direct and secondary transmittance as calculated by means of WIS 3.0 in Step 1. The

simulations at this step were carried out in WINDOW software (BEANS).

4. Once these properties of the equivalent glazing system were defined, a further round of minor adjustments followed in IES in order to improve the match between the SSF and the DSF alternative in terms of simulated performance. For this comparison, a set point of 200 W/m^2 on the outer pane was considered in order to deploy the shading devices. All year round simulations initially on a zone level were carried out using the IES software. For each of four orientations, (similar orientations as for the real building) a zone was modelled surrounded by identical zones (Figure 3). The simulations were carried out for the proposed double skin façade design and the derived equivalent single skin façade model. The simulations were carried out without internal loads and with low thermal mass.

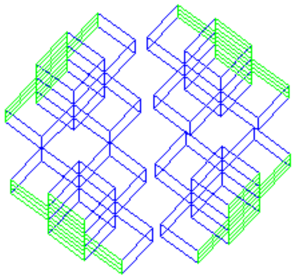

Figure 3 Zone level study.

For the double skin façade case the façade was divided into three compartments as shown in Figure 4. Since the IES double skin façade model is a single node model, this division into compartments allowed for approximation of the stratification of air within the cavity. The linear ventilation openings of the cavity were modelled as 12.7 mm deep.

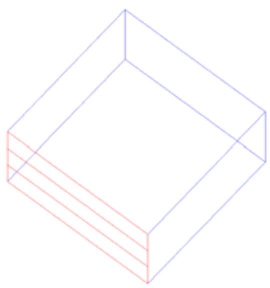

Figure 4 Facade of the zone model.

Once a reasonable agreement on a zone level was achieved, a simulation for a closed and open back scenarios on a floor level was carried out. The final results on a floor level were compared and are presented and discussed below.

RESULTS AND DISCUSSION

Evaluation of the DSF performance

The double skin façade properties (U, g and T_{dir}) were calculated for three different cavity cases: (i) closed, (ii) naturally ventilated through 23 mm wide linear slots, and (iii) ventilated with an Equivalent Leakage Area opening (ELA) of 12.7 mm. The calculations were carried out for several steady state boundary conditions; The resulting properties for a 'typical summer day' (outdoor air temperature of 20°C, indoor air temperature of 24°C and direct solar radiation of 500 W/m^2) are presented in Table 2.

Table 2
Double skin façade properties

		U-value [W/m^{2}K]	**g-value [-]**	**T_{dir} [-]**
no shading	Closed	1.0	0.4	0.3
	12.7 mm opening	1.0	0.4	0.3
	23 mm opening	1.1	0.4	0.3
with shading	Closed	0.8	0.2	0.03
	12.7 mm opening	0.9	0.1	0.03
	23 mm opening	1.0	0.1	0.03

The impact of ventilation is most significant in cases where solar shading is applied. For cases without shading the only ventilation results in a slight reduction in the total solar energy transmittance, while for the cases with shading the g-value is reduced by one third. This effect can be seen also in the Figures 5 and 6 below.

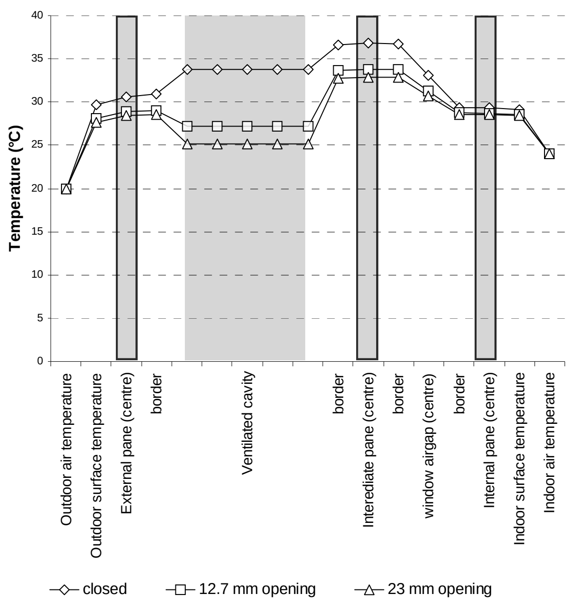

Figure 5 Temperatures at the horizontal and vertical centre of the DSF cavity alternatives (no shading).

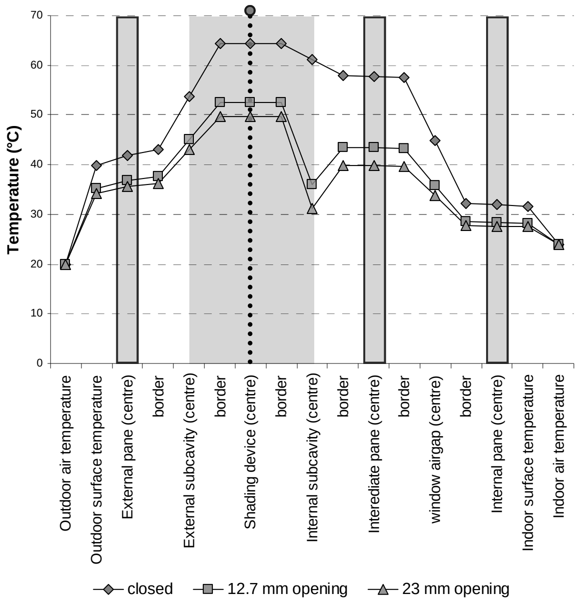

Figure 6 Temperatures at the horizontal and vertical centre of the DSF cavity alternatives (with shading).

Adjustment of the pane model

The adjustment of the pane properties was carried out for the case without shading devices. The monthly average thermal, total solar and direct solar transmittance values (Hellström et al., 2007) of the DSF were calculated (with the Parasol software) and an equivalent SSF was defined.

Table 3
DSF and the SSF properties before and after the adjustments of pane characteristics

	U-value [W/m²K]	**g-value [-]**	**T_{dir} [-]**
DSF	1.14	0.41	0.33
SSF	1.09	0.45	0.37
Properties changed	Emissivity of coating in DGU changed from 0.048 to 0.08	Transmittance of the outer pane changed from 0.64 to 0.57	Reflectance of the outer pane changed from 0.21 to 0.28
Equivalent SSF	1.14	0.41	0.33

Adjustment of solar shading device model

In order to match the characteristics of the single and double skin cases (U, g and T_{dir}) when shading is applied (inner and outer shading for the single and interstitial shading in a ventilated cavity with 12.7 mm ventilation openings for the double skin facade), simulations were carried out in FABRIC and WINDOW software (BEANS). The pane properties of the equivalent single skin case were kept unchanged from the previous step. The properties of the inner and outer shading devices of the single skin façade were adjusted as described below, in order to match the performance of the double skin façade with an interstitial roller blind.

- The properties of the inner shading device properties (of the single skin façade) were adjusted to match the thermal transmittance of the double skin façade.
- The outer shading properties (of the single skin façade) were adjusted to match the total solar energy transmittance of the double skin façade.
- The inner and outer shading adjusted further in order to match the ratio between the direct and secondary transmittance as calculated by means of WIS 3.0.

The properties of the layers are set out in Table 4.

Table 4
Properties of glazing and shading (FABRIC and WINDOW software (BEANS)).

	OUTER BLIND	**OUTER PANE**	**CAVITY**	**INTERM. PANE**	**CAVITY**	**INNER PANE**	**INNER BLIND**
				INNER SKIN (DGU)			
Transmittance	23	57		60		80	40
Absorptivity (inside)	23	15		14		12	40
Absorptivity (outside)	50	15	210 mm	14	16 mm	12	40
Emissivity (inside)	50	84		8		84	84
Emissivity (outside)	84	84		84		84	84

Comparison of the results for simulations of double skin façade and equivalent single skin façade

A comparison of the heating and cooling demand of the zones as modelled in IES show a reasonable agreement both on an hourly and monthly basis. The following results show the agreement for the correlation between two IES simulations: one incorporating a double skin façade (DSF) model and one introducing an equivalent single skin façade (SSF) model, which is proposed for use in the Building Regulations (Part L) compliance check model. The comparison was carried out on a single office floor for both 'open and closed back' scenarios (open back: open plan office space, closed back: cell type office space, as shown in Figures 7 and 10). In each case, the appropriate national calculation method templates were modelled. The results are presented for heating and cooling demand on a monthly and annual basis.

- **Open back scenario**

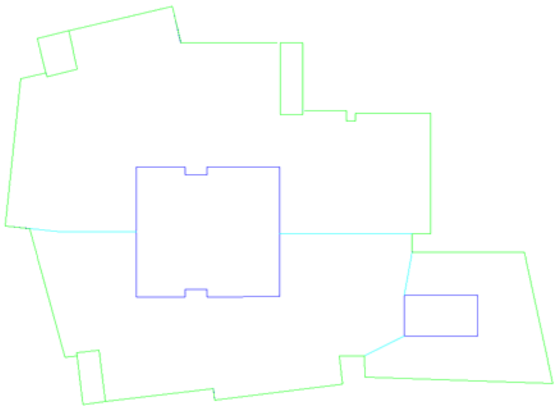

Figure 7 Open back scenario

The heating demand for the open back scenario is presented in Figure 8 and in Table 5.

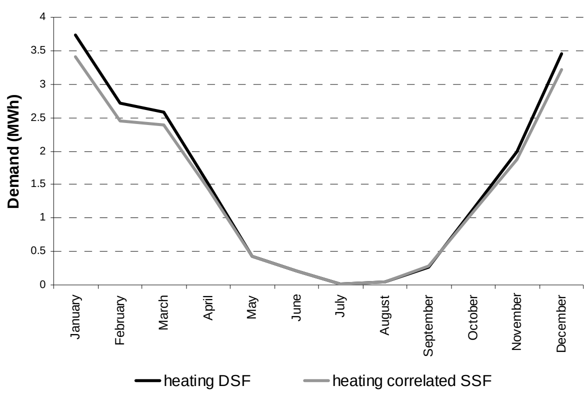

Figure 8 Heating demand for the open back scenario

Table 5
Heating demand for the open back scenario

	DSF	CORRELATED SSF	DIFFERENCE
Date	MWh	MWh	%
Jan	3.7	3.4	8.8
Feb	2.7	2.5	9.3
Mar	2.6	2.4	7.2
Apr	1.5	1.4	4.5
May	0.4	0.4	1.8
Jun	0.2	0.2	-3.3
Jul	0.0	0.0	-5.6
Aug	0.1	0.1	-15.8
Sep	0.3	0.3	-2.1
Oct	1.1	1.1	3.8
Nov	2.0	1.9	6.2
Dec	3.5	3.2	6.9
Total	18.1	16.8	6.8

DSF CO_2 emissions = 18.06 x 1000 x 0.19 = 3431.4 $kgCO_2$/annum

SSF CO_2 emissions = 16.83 x 1000 x 0.19 = 3197.7 $kgCO_2$/annum

SSF under prediction = 233.7 $kgCO_2$/annum

Zone area = 3140.3 m^2

SSF under prediction = 0.07 $kgCO_2/m^2$/annum

The heating demand for the open back scenario is presented in Figure 9 and in Table 6.

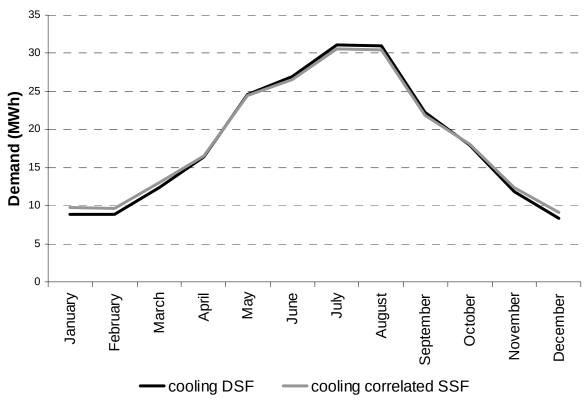

Figure 9 Cooling demand for the open back scenario

Table 6
Cooling demand for the open back scenario

	DSF	CORRELATED SSF	DIFFERENCE
Date	MWh	MWh	%
Jan	8.9	9.7	-9.5
Feb	8.9	9.6	-8.1
Mar	12.4	13.1	-5.7
Apr	16.4	16.5	-0.9
May	24.6	24.5	0.4
Jun	26.9	26.6	1.2
Jul	31.1	30.6	1.7
Aug	31.0	30.4	1.9
Sep	22.2	21.9	1.2
Oct	18.0	18.1	-0.9
Nov	11.9	12.3	-3.7
Dec	8.3	9.2	-10.2
Total	220.5	222.5	0.0

DSF CO_2 emissions = 220.51x 1000 x 0.422 = 93055.2 $kgCO_2$/annum

SSF CO_2 emissions = 222.53 x 1000 x 0.422 = 93908.2 $kgCO_2$/annum

SSF over prediction = 854.3 $kgCO_2$/annum

Zone area = 3140.3m^2

SSF over prediction = 0.27 $kgCO_2/m^2$/annum

Combining the open back heating and cooling results shows that the correlated SSF over predicts the carbon emissions by 0.20 $kgCO_2/m^2$/annum. A guideline Target Emissions Rating (TER) for an air conditioned/mechanically ventilated buildings is approximately 35-40$kgCO_2/m^2$/year. Given this, a 0.20 $kgCO_2/m^2$/annum discrepancy would represent a less than 1% error.

- **Closed back scenario**

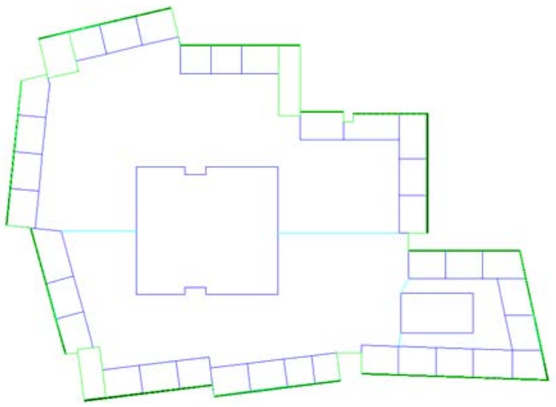

Figure 10 Closed back scenario

The heating demand for the open back scenario is presented in Figure 11 and in Table 7.

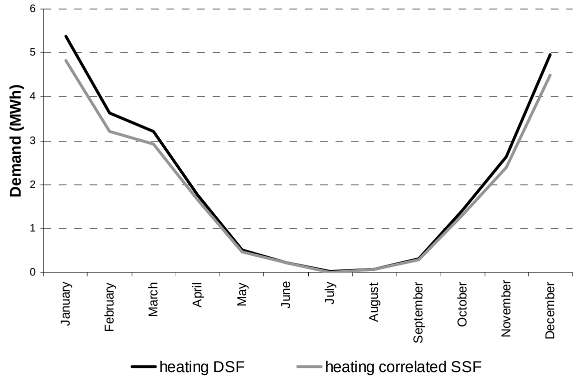

Figure 11 Heating demand for the closed back scenario

Table 7
Heating demand for the closed back scenario

	DSF	CORRELATED SSF	DIFFERENCE
Date	MWh	MWh	%
Jan	5.4	4.8	10.4
Feb	3.6	3.2	12.1
Mar	3.2	2.9	9.3
Apr	1.8	1.7	7.0
May	0.5	0.5	7.4
Jun	0.2	0.2	3.0
Jul	0.0	0.0	9.1
Aug	0.1	0.1	4.5
Sep	0.3	0.3	4.7
Oct	1.4	1.3	6.7
Nov	2.6	2.4	9.1
Dec	5.0	4.5	9.6
Total	24.2	21.9	9.5

DSF CO_2 emissions = 24.16 x 1000 x 0.19 = 4590.4 $kgCO_2$/annum

SSF CO_2 emissions = 21.86 x 1000 x 0.19 = 4153.9 $kgCO_2$/annum

SSF under prediction = 436.2 $kgCO_2$/annum

Zone area = 3140.3m2

SSF under prediction = 0.14 $kgCO_2/m^2$/annum

The cooling demand for the open back scenario is presented in Figure 12 and in Table 8.

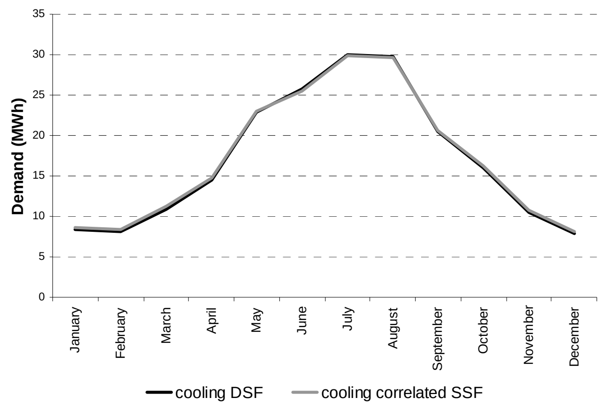

Figure 12 Cooling demand for the closed back scenario

Table 8
Heating demand for the closed back scenario

	DSF	CORRELATED SSF	DIFFERENCE
Date	MWh	MWh	%
Jan	8.4	8.7	-3.4
Feb	8.1	8.4	-3.4
Mar	10.9	11.3	-4.0
Apr	14.5	14.7	-1.6
May	22.9	22.9	-0.2
Jun	25.7	25.5	0.7
Jul	30.1	29.9	0.6
Aug	29.7	29.6	0.4
Sep	20.6	20.7	-0.5
Oct	16.0	16.3	-1.6
Nov	10.6	10.8	-2.0
Dec	7.8	8.1	-3.4
Total	205.1	206.7	-0.8

DSF CO_2 emissions = 205.11 x 1000 x 0.422 = 86556.4 $kgCO_2$/annum

SSF CO_2 emissions = 206.74 x 1000 x 0.422 = 87244.1 $kgCO_2$/annum

SSF over prediction = 686.2 $kgCO_2$/annum

Zone area = 3140.3m^2

SSF over prediction = 0.22 kgCO2/m2/annum

Combining the closed back heating and cooling results shows that the correlated SSF over predicts the carbon emissions by 0.14 $kgCO_2/m^2$/year. A guideline Target Emissions Rating (TER) for an air conditioned/mechanically ventilated buildings is approximately 35-40 $kgCO_2/m^2$/year. Given this, a 0.14 $kgCO_2/m^2$/year discrepancy would represent an error of less than 1.0%.

CONCLUSIONS

This paper describes the steps followed to define a correlation between a double skin façade (DSF) and a equivalent single skin façade. The purpose of the study was to develop a methodology for assimilation of the physical properties of the proposed double skin façade for a prominent high rise building (300m+) in central London. A hypothetical single skin façade (SSF) was defined, in order to substantially reduce the complexity and the workload associated with building energy performance simulations using the IES modelling software. A correlation between the DSF and SSF can significantly reduce the simulation time and - more importantly - ease the process of modelling a building, which features an extremely high number of thermal zones. The paper suggests a methodology and presents examples of results that allow for the evaluation of the resulting correlation.

The main issues that were studied in order match the SSF and DSF performance are the ventilation of the DSF cavity and the effect of the interstitial shading device. The study was carried out in three steps: (i) defining the DSF system performance for steady state boundary conditions, (ii) adjusting the modelled SSF pane properties (thermal, total solar and direct solar transmittance) throughout the year for cases without shading devices, and (iii) investigating the impact of the interstitial shading device on the DSF performance and suggesting a SSF modelling solution that would match the simulated DSF energy performance.

The results have shown a reasonable agreement between the double skin façade and an equivalent single skin façade both on hourly and monthly basis. However, it is a personal opinion of the author that for other DSF configurations (i.e. cavity geometry, panes and shading used) and building location this correlation methodology would not necessarily be as accurate.

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WINDOW (part of Building Environmental Analysis Suite (BEANS)) ARUP in-house software

WIS 3.0 software (Window Information Systems) Webpage: http://www.windat.org/wis/html