Impact of cavity extraction fans on thermal and energy performance of existing UK hotel

Rotimi, Abdulazeez, Bahadori-Jahromi, Ali ORCID: https://orcid.org/0000-0003-0405-7146, Mylona, Anastasia, Godfrey, Paulina and Cook, Darren (2017) Impact of cavity extraction fans on thermal and energy performance of existing UK hotel. Proceedings of the ICE - Engineering Sustainability, 172 (2). pp. 76-86. ISSN 1478-4629

http://dx.doi.org/10.1680/jensu.17.00017

This is the Accepted Version of the final output.

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ABSTRACT

The advantages of Double Skin Facade (DSF) systems, ranging from their aesthetic architectural benefits, acoustic benefits and ability to decrease the heating demand of the internal environment has increased their popularity in Europe since the mid-1980s. However, appropriate consideration must be accorded to its design to ensure their possible advantages are not negated.

This work evaluates how the effect of extraction fans installed in the cavity of the DSF adjoining a central atrium impacts the thermal condition of the atrium and consequently, the overall energy consumption of an existing UK hotel building.

The results of the investigation demonstrated that the DSF extraction fans improve the internal temperature and condition of the adjacent central atrium, especially in the summer. The fans result in a marginal increase in the overall energy consumption when operated throughout the year, hence, the optimum schedule for operation of the extraction fans is during the cooling-dominant period.

Impact of cavity extract fans on the thermal and energy performance of existing UK hotel

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1.0 Introduction

The quest for improved energy efficiency and thermal comfort in existing buildings most often involves an all-encompassing approach, incorporating enhanced cost-effective building fabric and retrofit. In the building envelope, façade and especially the glazing has significant impact on the thermal and energy performance of a building (Kaluarachchi *et al.* 2005; Hee *et al*. 2015). Currently, the use of highly glazed facades is widespread in high-rise and commercial buildings due to the short application time, low maintenance, lightweight, aesthetic value and durability (Cetiner & Özkan 2005). However extensive glass curtain wall can result in significant energy consumption due to high solar thermal gains or considerable night heat loss in cold climate (Ghaffarianhoseini *et al*. 2016).

Recent technological advancements have resulted in the availability of high performance, energy efficient window and façade glazing systems that significantly improve thermal performance of glazing. These advancements produce glazing with lower heat loss, less air leakage and warmer window surfaces which enhance comfort and reduce condensation (Ander 2014). Also, modern façade systems have been developed and advanced for greater thermal insulation, shielding from solar radiation, improved thermal comfort and visual quality (Pasut and De Carli, 2012). The Double Skin Façade (DSF) is one these improved façade systems (Pasut and De Carli, 2012; Kim *et al.*, 2013).

The advantages of DSF systems, ranging from their aesthetic architectural benefits of increased transparency, acoustic benefits and ability to decrease the heating demand of the internal environment while serving as a protection from the external environment has increased their popularity especially in Europe since the mid-1980s (Poirazis 2004; Chou et al. 2009). The main feature of the DSF which provides it with this advantage is the cavity between the external and internal glazed skin that acts as an insulating barrier against the undesirable effects of the external microclimatic condition (Kaluarachchi *et al.* 2005; Yu *et al.*, 2017). This cavity (air gap) can be naturally or mechanically ventilated, thus the attribute of the cavity space such as its ventilation or shading strategies determines the performance of the DSF (Poirazis 2004; Ghaffarianhoseini et al. 2016). The application and role of DSF in a building fabric is complicated as it affects different building parameters that usually interact with each other (such as ventilation, natural lighting, internal air quality, thermal comfort and energy use), hence appropriate consideration must be accorded to its design to ensure their possible advantages are not negated (Poirazis 2004, Yu *et al.*, 2017).

The DSF system in this case study hotel building adjoins a large central atrium to the east and west, so the aesthetic benefit of multilevel glass façade which permits increased transparency and unimpeded daylighting further enhances the atrium. The application of modern day atrium in commercial builds (especially hotels, shopping malls and offices) became common during the late 1950s and early 1960s (Abdullah 2007). The aesthetic value of atria as a space organizer and traditional environmental merits allowing sufficient natural lighting, passive cooling and heating are now being exploited in temperate climate building designs in response to high building energy consumption and energy security challenges (Abdullah 2007). Atria have the potential to improve the thermal comfort of occupants by enabling solar radiation, natural heating and cooling which can contribute to reducing lighting, heating and cooling energy demand (Jaberansari & Elkadi 2016). It is a common general assumption that atria automatically reduce the overall energy consumption of a building, but this is a misconception if they are not designed appropriately especially as the thermal behaviour of atrium remains difficult to predict (Abdullah 2007; Aldawoud & Clark 2008).

The study was necessitated due to the challenge of prevailing high temperature identified in the cavity of the DSF resulting in high temperature in the atrium, thus increasing the cooling demand. Therefore, the option of installing DSF extraction fans was evaluated by this study as an alternative to increasing the chiller capacity which will have considerable impact on the overall energy consumption. It considers the holistic effect of the DSF cavity space ventilation on the total energy consumption. The paper contributes to existing body of knowledge, as most studies in this area use either commercial office building or prototype building as case study or computational fluid dynamic modelling of the DSF cavity alone. Furthermore, it highlights the optimum operational schedule for the extraction fans to ensure increased energy consumption resulting from the installation is neutralized. Moreover, the features of this case study hotel which has a large central atrium and enclosed by DSF to the east and west justifies the need for it to be studied especially as the effect of both features on the energy and thermal performance is difficult to evaluate.

The aim of this paper is the evaluation of the effect of extraction fans installed in the east and west cavity of the DSF adjoining a central atrium on the thermal condition of the atrium and consequently the impact on the overall energy consumption of an existing UK hotel building. Hilton London Heathrow Airport Terminal 4 hotel is used as a case study for this evaluation.

The articulated aim is achieved with the following objectives:

- Collection of all necessary data such as (Architectural plans, building fabric makeup, plants/system information and operating energy consumption), site survey is also undertaken to verify collected data.
- Development of holistic hotel model in the dynamic simulation software using the data obtained.
- Estimation of the annual overall energy consumption of the hotel via system modelling of the dynamic simulation software.
- Improvement of the system modelling result by including estimation of unregulated energy use (catering energy use). Subsequently, validation of model results and comparison against actual building operational energy consumption.
- Incorporation of extraction fans in the DSF cavity of the hotel building model and comparison to hotel model without the extraction fans to evaluate their impact on thermal condition of the atrium and overall energy consumption.

2.0 Literature Review

Evaluation of existing state of the art indicates that there are considerable and varied amount of literature on the impact of DSF on the energy and thermal performance of building envelopes. Some of these works are presented.

Gratia and De Herde, (2004a) and Chou *et al.*, (2009), investigated the effectiveness and behaviour of different glass façade systems. Gratia and De Herde, (2004a) investigated the impact of a south DSF on the thermal behaviour (heating and cooling demand) of a case study office in Belgium using a building simulation software (TAS). Critical periods of the seasons for the DSF corresponding to sunny and cloudy spring, summer, autumn and winter days were analysed. Their case study result illustrated that the application of DSF reduces the winter heating loads and increases the cooling loads during summer. However, their result did not investigate the effect of the DSF on the overall energy consumption. On the other hand, Chou *et al.*, (2009), studied the impact of DSF on the solar heat gain, the envelope thermal transfer value (ETTV) and consequently the building's energy management. This was done using a systemic approach of computer simulation and laboratory experiment and their work considered the impact of influencing parameters like, wall-to-window ratios (WWR), shading coefficients, (SC) and building orientation. Their results indicated that SHGC values of the DSF are considerably higher in the East and West facing façade compared to the North and South facing façade. Additionally, the study indicated that a DSF having WWR of 0.3 reduces the solar heat gain by up 45% with this potential diminishing as the WWR approaches 0.9.

Hoseggen *et al.*, (2008) and Gelesz & Reith (2015), both evaluated the application of DSF on building energy performance in different climate of Europe with the aid of a building simulation software. Hoseggen *et al.*, (2008) investigated the implementation of DSF in Norway (heating-dominant climate); where the DSF was applied to the east façade to optimise energy consumption reduction. The key findings of their work demonstrated that, even though the heating was 20% higher for a single façade with basic window attributes, the use of improved U-value windows with the single façade produced energy performance closely comparable to that of the DSF solution. Hence, the predicted DSF energy savings are marginal, making the application of the DSF unprofitable. Similarly, Gelesz & Reith (2015), evaluated the energy performance of a DSF compared to that of a double and triple glazed single façade in Hungary, which is a Central European moderate climate region. The DSF evaluated is characterised by a buffer mode window and a naturally ventilated outdoor air curtain box type window for winter and summer period respectively. The main finding of the study indicated that outdoor air curtain mode DSFs have promising prospect of reducing energy consumption compared to the single skin façade substitutes in Central-Europe, though, the observed energy savings is marginal with a cooling energy saving of 7%.

The works of Gratia and De Herde, (2004b) and Hien *et al.*, (2005), evaluated the effect of DSF and the varied ventilation system on the energy performance of case study office buildings under different climatic conditions, with the aid of building simulation software (TAS). Hien *et al.*, (2005), investigated the impact of DSF ventilation strategies on energy consumption in a tropical humid climate and their result indicated that naturally ventilated DSF could reduce energy consumption and provide improved thermal comfort. Additionally, extraction fans could minimize condensation induced by high humidity. It is worth noting that their work did not consider building orientation. Whereas, Gratia and De Herde (2004b), investigated the energy performance of a DSF with mainly natural ventilation coupled with the DSF orientation and wind speed in a temperate climate. One of their key findings indicated that night ventilation is more effective than day ventilation as it allows for considerable reduction of building cooling loads. Additionally, the use of shading is relatively more effective in a single glazed building.

Fallahi *et al*., (2010); Parra *et al.*, (2015), both worked on improving the thermal performance and energy efficiency of DSF systems with the use of numerical modeling techniques. Fallahi *et al*., (2010) presented an approach of introducing thermal mass with the DSF and the energy performance evaluation of its impact on adjacent study room was done using a verified numerical model. Their parametric study result shows that the introduction of thermal mass in the cavity space with mechanical ventilation gives significant energy reduction. Moreover, depending on configuration, up to 26% summer energy saving and up to 59% winter energy saving is obtainable relative to conventional DSF without thermal mass. Whereas Parra *et al.*, (2015), used Computational Fluid Dynamics (CFD) to investigate the effectives of Venetian blinds (VB) shading device on improving the performance of DSF. One of their key findings shows that VB can reduce solar heat gain by up to 35%.

3.0 Methodology

The aim of this study is to examine the impact of extraction fans installed in the east and west cavity of the DSF on the thermal performance of enjoining central atrium and overall energy consumption of a case study Hilton hotel building located in the south east of the UK. The evaluation is conducted with the aid of an approved dynamic simulation software.

The process that was employed to achieve the stipulated aim with the case study buildings can be categorised into two distinct stages. The first stage involves estimating the energy consumption of the building by developing holistic model reflecting the building fabric, systems and thermal performance of the actual building. The predicted energy consumption is validated by comparing against actual consumption data. The consumption data are collected from the electronic energy meter reading of the hotel and the case study building is inspected to enable verification of available data such as building fabric data (e.g. walls and windows), occupancy information to ensure simulation assumptions are realistic, building usage to ensure zone grouping is as shown on architectural plan and HVAC system characteristics. The second stage involves the integration of the extraction fans into the model to evaluate their impact.

EDSL TAS software version 9.3.3 is employed as the dynamic simulation software to evaluate energy performance for this study. The TAS software, designed by Engineering Development Solutions Limited, is a set of application products with the capability to simulate thermal performance of buildings and their systems which can be translated to energy consumption estimates (Crawley *et al*, 2008). The software is also approved and fully accredited for the UK building regulation 2013 and demonstrates compliance to various BS EN ISO standards (EDSL, 2015). It has a 3D graphic based geometry input interface (3D Modeller) that includes a CAD link and can also perform daylighting calculations (Crawley et al, 2008). The core module is the TAS Building Designer (TBD), it performs dynamic building simulation with integrated natural and forced air flow (Crawley et al, 2008). TAS systems is the component of the software suite which provides plant modelling capabilities to simulate systems such as Heating Ventilation and Air Conditioning (HVAC) systems/control.

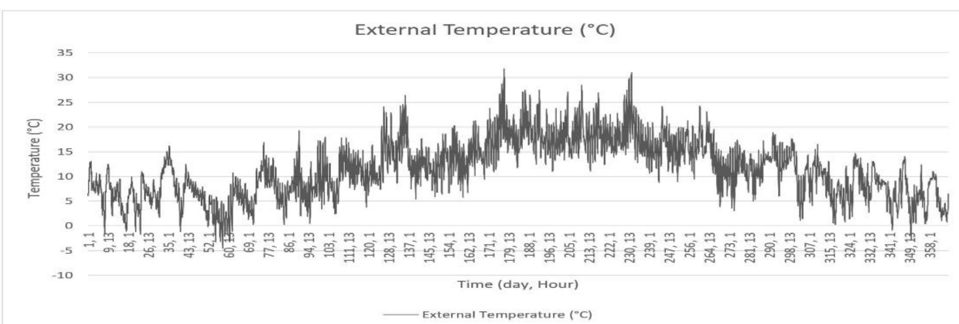
Weather data used for the simulation must be carefully chosen as it has considerable impact on the result (Rotimi *et al.*, 2017). While engineers can only use the weather data of a year to perform building simulations; the world metrological organisation defines climate as a 30-year period to reduce the effect of natural inter-annual differences in the weather data (Holmes and Hecker 2007).

This poses a question of which year's weather data should be used. Generally, the weather data employed in building simulation models contain hourly records of the core weather variables (like temperature, solar radiation, relative humidity and wind speed) at a location in proximity to the modelled building (Eames 2016). Typically, two different types of weather files are used to run building simulation in the UK; these are the Test Reference Year (TRY) and Design Summer years (DSY) (CIBSE 2017). The weather file of a year that is representative of the weather over certain number of years is referred to as the (TRY) which differs as different countries employs different methods in choosing their TRY (CIBSE 2009a; Amoako-Attah and B-Jahromi, 2016). The weather file comprises of average months chosen from baseline of historical data (Virk & Eames 2016). The updated CIBSE TRY files are developed using a baseline period of 1984 to 2013 as opposed to the previous TRY using a baseline of 1984 to 2006, therefore, they account for the effect of climate change (Mylona 2017).

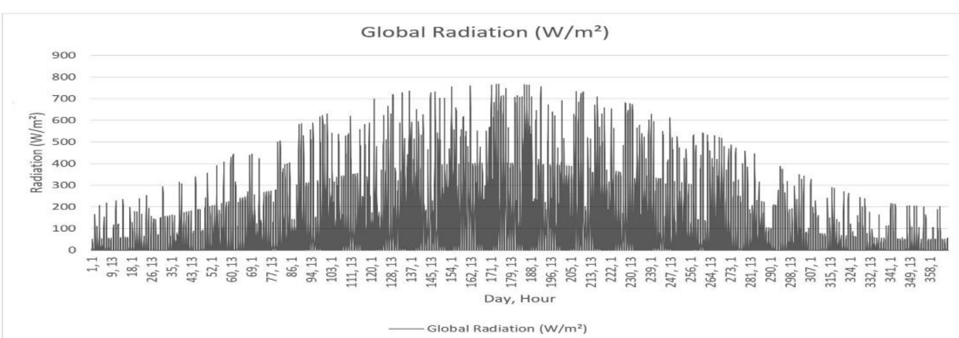
3.1 Building description

The case study building is a six storey hotel constructed in 1990, it is located in Heathrow and due its closeness to the airport, the building is completely sealed for noise abatement. The building consists of two wings situated either side of a central atrium that runs the entire building height from the first floor and the east and west side of the atrium space is enclosed by DSF system. The building is completely air-conditioned apart from the various plant rooms located on the ground floor and sixth floor. The building has a total floor area of 20,881m^2, with the ground floor containing the conference/meeting rooms, back of house offices and gym; the central atrium on the first floor contains the restaurant, bar and reception area; while the 395 guest rooms are housed in the first to fifth floors.

A 4-pipe FCU supplies treated air to individual bedrooms with the rooftop central Air Handling Unit (AHU) providing additional fresh air. Cooling is provided by three air cooled chillers whilst 13 splits AC systems provides cooling for one of the large conference rooms, back of house and server room. The hotel has a Combined Heat and Power (CHP) unit which provides an onsite electricity generation and is sized to satisfy the domestic hot water demand along with a backup boiler. Since the hotel is in Heathrow, the weather data used for the building energy simulation is the current CIBSE London (TRY) weather file. To aid in the shadow calculation in the 3D Modeller, the latitude, longitude and time zone values of 51.46 degrees North, -0.44 degrees East and UTC +0.0 respectively were inputted to reflect the geographical location parameter of the hotel building. Figure 1 shows the hourly external temperature and global solar radiation of the weather data used for the simulation.



(a) Showing the hourly external air temperature of the CIBSE TRY weather data used for the simulation



(b) Showing the hourly global solar radiation of the CIBSE TRY weather data used for the simulation

Figure 1: Showing external temperature and global solar radiation of the simulation weather data

3.2 Building 3D modelling process

The 3D modeler component of the TAS software allows data on the building geometry and fabric such as (floors, wall types, windows and doors dimensions etc.) to be inputted. It also enables the grouping of the floor areas into different zones based on their usage, all these data are used to generate the 3D model as close to reality as possible. The data used for the 3D modeling are obtained from the AUTOCAD drawings of the hotel which show plans for individual floors, is presented in figure 2.

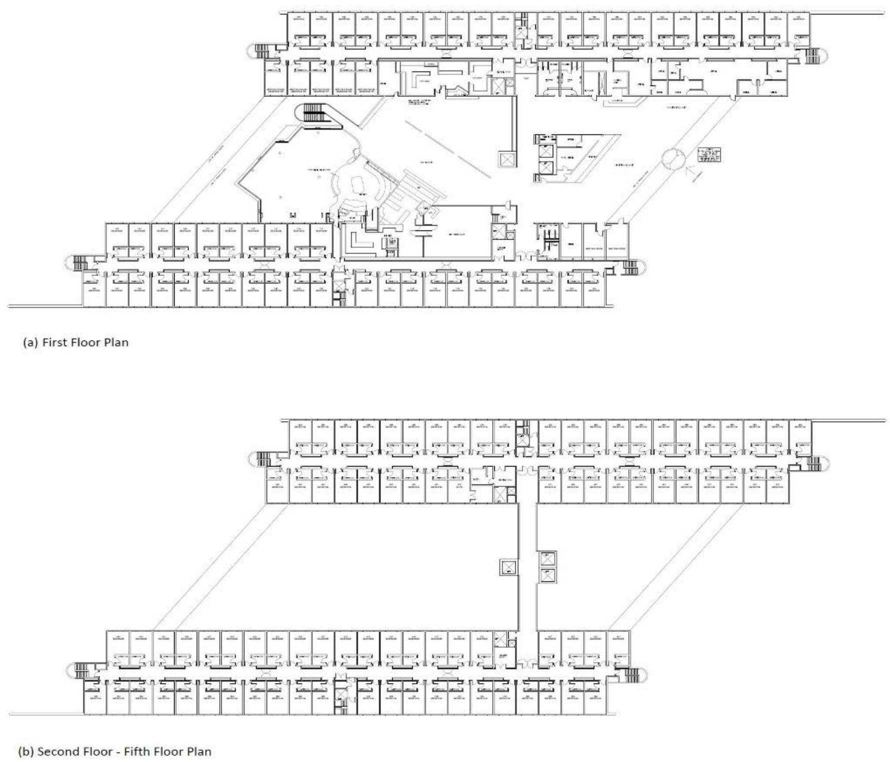


Figure 2: Architectural plan of the hotel building

3.3 Thermal simulation process

The thermal simulation of the building is performed by the TBD component of the software which is the core part of the software suite. Appropriate choice of modelling parameters and assumptions are required to execute the building performance simulation.

Tables 1 and 2 shows the modelling simulation parameters and assumptions based on the case study building characteristics.

Table 1: Modelling and simulation assumptions based on characteristics of the case study building

Building fabric		
Calculated area weighted average U-values	Wall	0.61 W/m^2 K
	Floor	0.84 W/m^2 K
	Roof	0.42 W/m^2 K
	Windows	2.52 W/m^2 K
	Doors	2.47 W/m^2 K
	High usage entrance door	2.53 W/m^2 K
Average U-values		0.98 W/m^2 K
Calendar	NCM Standard	
Air permeability	5 $m^3/(h.m^2)$ at 50 Pa	
Average conductance	14558 W/K	
Alpha values	6.59%	

Table 2: Modelling and simulation parameters and assumptions

Construction data base	NCM Construction v5.2.tcd	
Occupancy levels; people density; lux level	Restaurant	0.2 person/m^2, 150 lux
	Changing room	0.119 person/m^2, 100 lux
	Circulation area	0.115 person/m^2, 100 lux
	Bedroom	0.094 person/m^2, 100 lux
	Gym	0.140 person/m^2 150 lux
	Food prep/kitchen	0.108 person/m^2, 500 lux
	Hall	0.183 person/m^2, 300 lux
	Office	0.106 person/m^2, 400 lux
	Plant room	0.11 person/m^2, 200 lux
	Reception	0.105 person/m^2, 200 lux
	Store	0.11 person/m^2, 50 lux
	Swimming pool area	0.140 person/m^2, 300 lux
	Toilet	0.118 person/m^2, 200 lux

Fuel source	Natural gas	CO_2 factor – 0.198 Kg/kWh
	Grid electricity	CO_2 factor – 0.4121 Kg/kWh

3.4 Plant/systems modelling

TAS systems module of the software suite enables the thermal simulation result file referred to as (TSD file) to be directly attached to it. The systems module uses the TSD file to complete the simulation of the building's plants consisting of (heating & cooling circuits, Air Handling Units, and energy sources) and produce energy performance results. However, the estimate does not account for unregulated energy use such as catering which can be significant in a hotel building and is therefore estimated in this work to augment the TAS systems result.

Figure 3 presents the summary of the case study process.

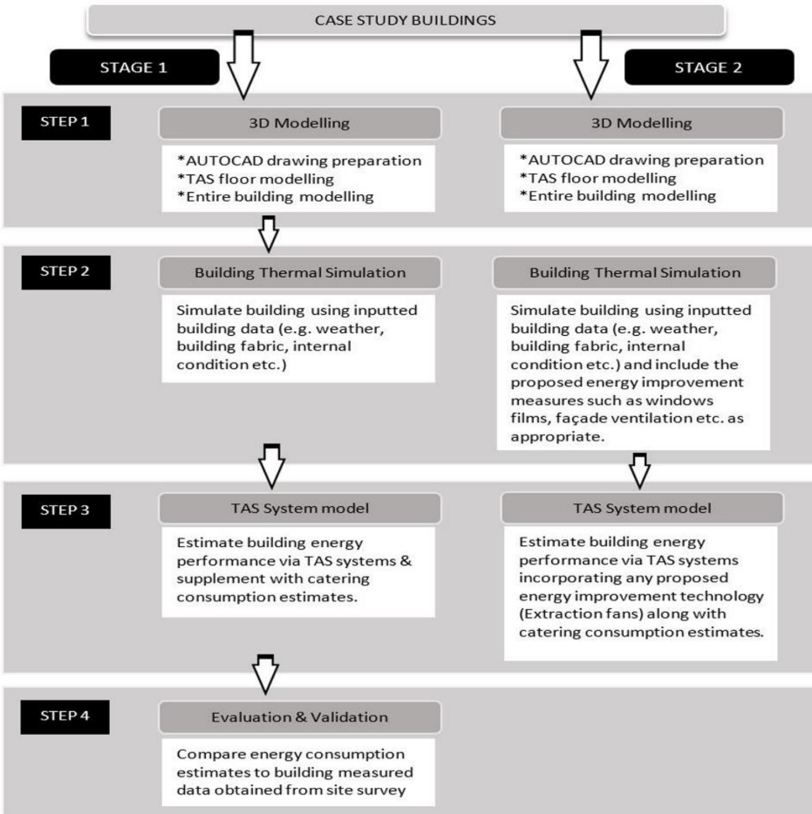


Figure 3: Summary of case study process

4.0 Results and Discussion of Result

The result and discussion for the case study hotel building is presented in this section. Figure 4, presents the result of the 3d modelling process.

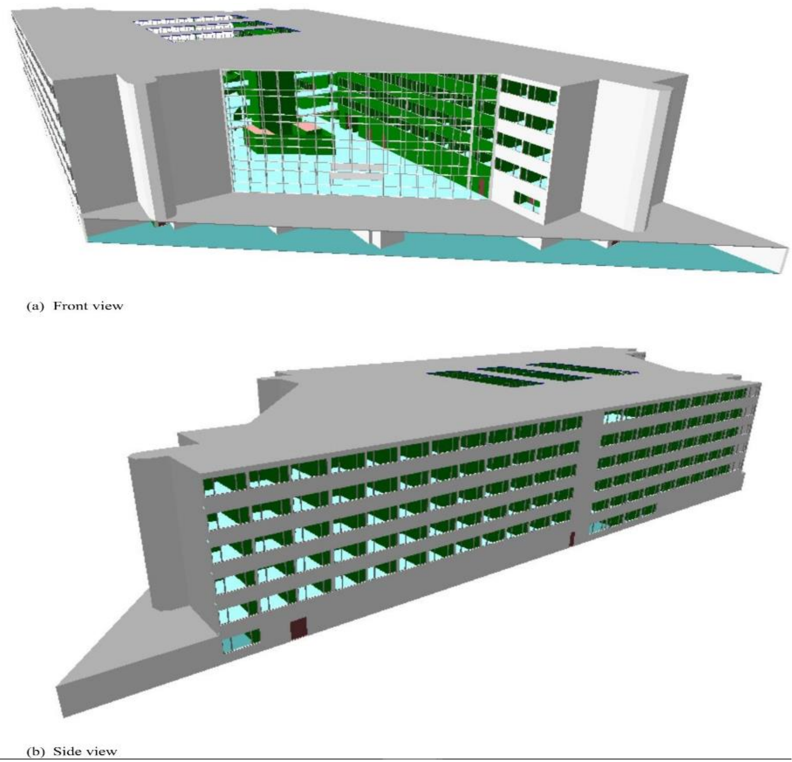
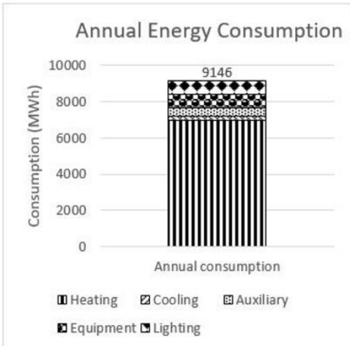
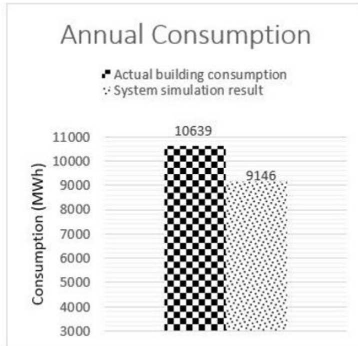


Figure 4: 3d modelling results

The TAS TBD component of the software is populated appropriately and simulated to reflect the characteristics of the building operating without extraction fans installed in the east and west facing DSF. The simulated TBD file is attached to the system and plant modeling component of the software to obtain energy performance results of the building. Typical results which includes reports of annual energy consumption, monthly energy consumption simulation of the case study hotel building is presented. The energy consumption estimate comprises of heating, cooling, auxiliary, lighting and equipment energy use.



(a) TAS systems result showing annual demand and consumption



(b) Annual TAS Systems result vs. Actual building consumption

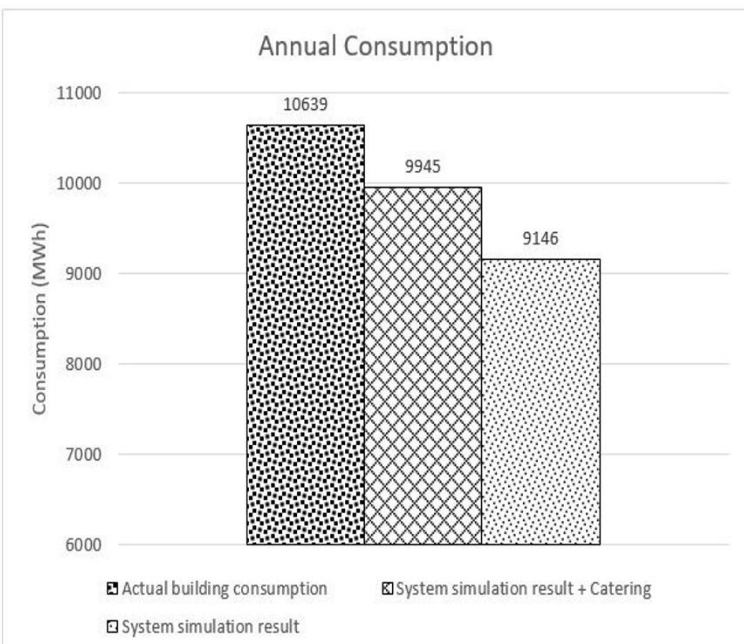
$$Percentage\ Error = \frac{(9146 - 10639)}{9146} * 100 = -16\%$$

Figure 5: Showing energy performance result from plant/system simulation

Figure 5(a) illustrates the annual energy consumption for the building obtained via plant/system simulation. It shows the breakdown of the energy consumption result which comprises: heating, cooling, auxiliary, equipment and lighting. Auxiliary energy is the energy used by controls, pumps, and fans for the HVAC systems and the heating includes both space heating and DHW. In computing the heating and cooling demands, there is a standard allowance for small power heat gains, which is from the equipment energy use. From figures 5(b) it is observed that the total energy consumption predicted via the plant/system modelling is relatively lower compared to the actual building consumption data with a percentage error of -16% representing an underestimation. Even though the building fabric and internal condition parameter was judiciously selected to ensure building simulation replicate real build operation, this discrepancy is still evident. The discrepancy is largely attributed to the fact that the estimated energy does not account for some energy use, referred to as (unregulated energy use) such as catering services which can be significant in a hotel building. Additionally, deviation due to local microclimate of the building's location and the standard weather data used for building energy simulation can result in discrepancy between predicted and actual energy consumption.

Energy use for catering services is estimated and used to augment the result. This is undertaken to further enhance the result and make the baseline model much more acceptable for evaluation of the impact of the extraction fans on the thermal condition of the adjoining atrium and the overall energy consumption of the building. Since simple and reliable calculation estimates for catering energy use are difficult to come by, the catering energy use is estimated using the CIBSE TM 54 benchmark for commercial kitchen (CIBSE, 2009b).

The operational energy benchmark of (2.54 kWh for fuel and 1.46 kWh for electricity) for a good practice business/holiday hotel building type was used along with the hotel data of number of meals served. Figure 6 presents the results for systems simulation plus catering energy consumption estimate.



$$Percentage\ Error = \frac{(9945 - 10639)}{9945} * 100 = -7\%$$

Figure 6: Annual systems simulation result + Catering energy use vs. Actual building consumption

It can be seen from figure 6 that the system simulation result supplemented with catering energy use estimate still underestimates the overall annual energy consumption compared to actual building data. However, the result of the overall energy consumption estimate is significantly improved giving an underestimation of 7%.

The next phase of the analysis involves the simulation of the case study building with extraction fans installed in the east and west facing DSF adjoining the central atrium. The result and analysis of this simulation are presented in figures 7 to 12.

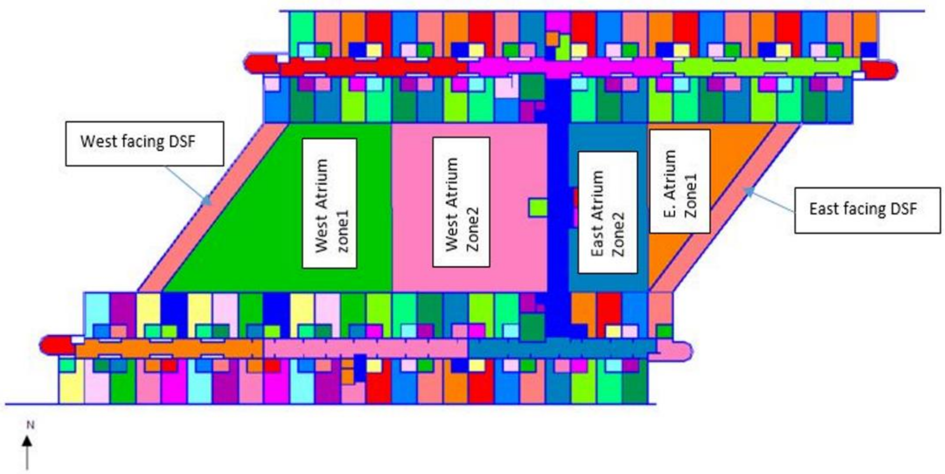


Figure 7: Showing zoning of atrium and adjoining double skin façade.

Figure 7 shows the different zoning of the central atrium space and façade along with their respective orientation (i.e. west or east). The central atrium space to the east and west are sub-divided in zone 1 & 2 with a null line because of the size of the space. The division with null lines does not act as a wall in the simulation, it is only employed to divide large spaces into smaller units to facilitate the analysis process and improve the output.

The internal condition applied to the west and east DSF façade cavity space is 'unoccupied unconditioned' which implies that no cooling or heating is used in that space. Whereas, the main atrium space is simulated as internal circulation space where heating or cooling is applied.

The simulation results of the baseline model with unventilated DSF cavity showing the temperature difference between the east & west façade space and the main central atrium is presented in figure 8. The temperature result analysis is presented to provide an understanding of the prevailing temperature in the façade cavity and its influence on the operating temperature of the atrium space.

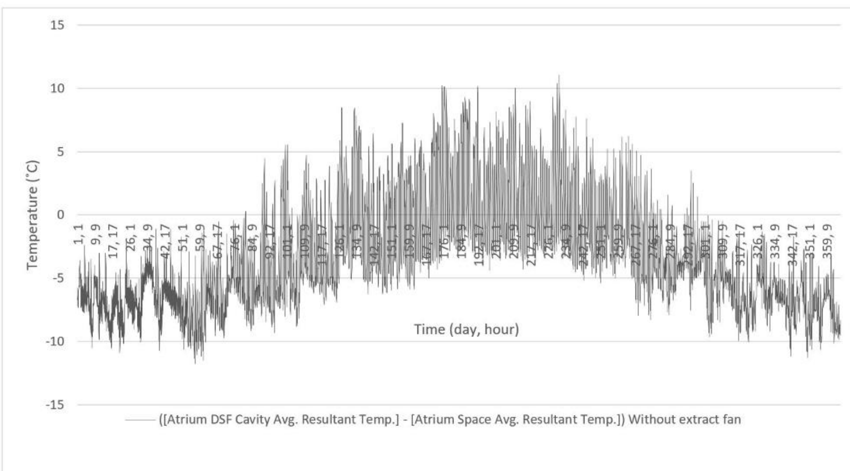
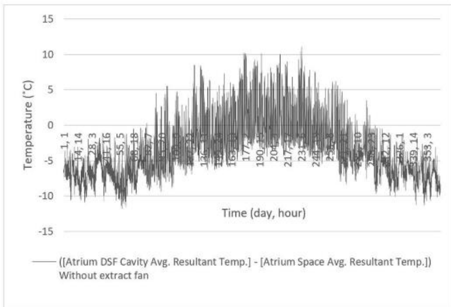


Figure 8: Showing resultant temperature difference between the DSF cavity and central atrium (without extract fans)

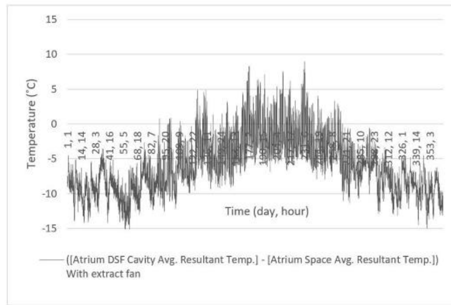
Brief description of the line on the graph presented in figure 8 is given to aid in the comprehension of the subsequent critical analysis of the figures.

[Atrium DSF cavity avg. resultant temp. – Atrium space avg. resultant temp. (^{o}C)] line on the graph is showing the plot of the value of (atrium DSF average resultant temperature) subtracted from (atrium space average resultant temperature). Hence, a negative (-) value implies that the temperature of the (atrium DSF resultant temperature) is less than that of the (atrium space average resultant temperature) and a positive (+) value implies the opposite.

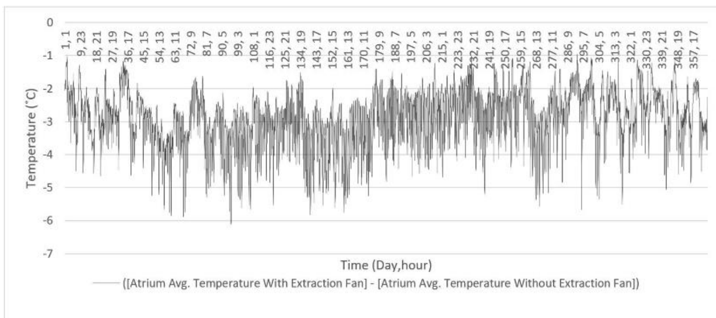
It can be observed from figure 8, that the prevailing resultant temperature in both the east and west DSF cavity is largely significantly higher during the summer period than the prevailing resultant temperature in the adjoining atrium space. Also, the DSF cavity temperature is generally lower than that observed in the atrium space during the winter season. From critical analysis of the figure, it can be observed that the temperature difference between the atrium's DSF façade cavity and the central atrium is quite significant especially at the peak of the cooling and heating periods. Temperature difference of between 10 ^{o}C to 11 ^{o}C is observed at the peak of the cooling period in June and July. Similar trend is observed around the peak of the heating period, between October and February where a temperature difference of -10 ^{o}C to -12 ^{o}C is obtained. The considerable temperature difference observed from the simulation can significantly affect the heating and cooling loads of the central atrium space especially in warmer weather scenarios, leading to increased risk of overheating and adverse effect on the thermal comfort of the atrium space.



(a) Showing result temperature difference between the Atrium DSF cavity and central atrium (without extraction fan)



(b) Showing result temperature difference between the Atrium DSF cavity and central atrium (with extraction fan)

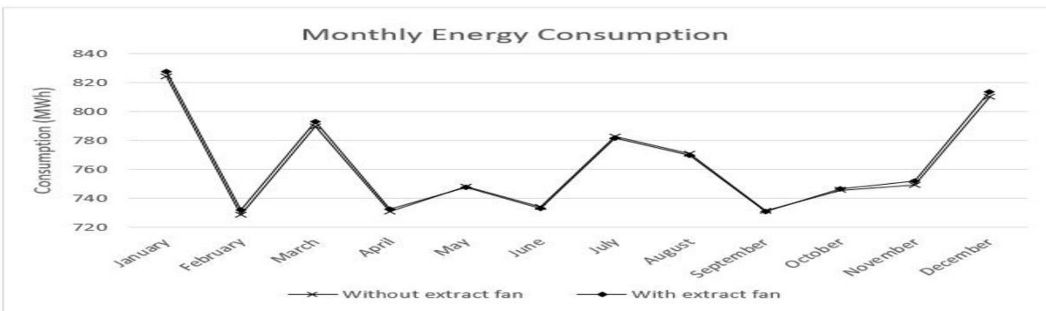


(c) Showing the difference in resultant temperature in the central atrium space due to the effect of installed extraction fans

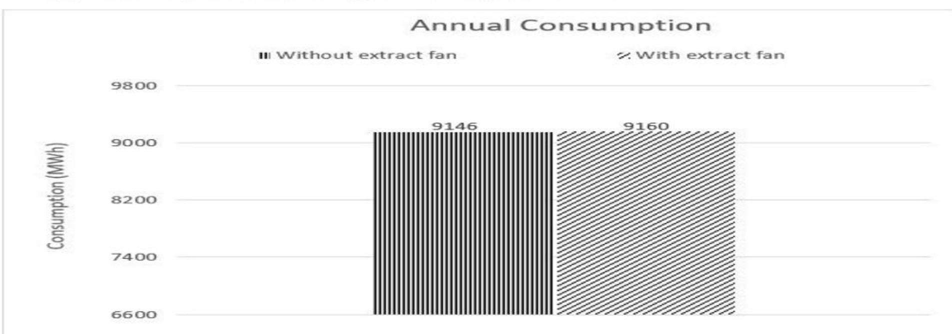
Figure 9: Showing resultant temperature result in the DSF cavity and central atrium (with and without extraction fan)

From figure 9(a) and (b) which presents the comparison of resultant temperature difference between the DSF cavity and the central atrium for the model simulation with and without extraction fan. The figure demonstrates that the installation of the extraction fans considerably reduces the temperature difference between the east and west DSF and the adjoining central atrium across the year. This helps to enhance the internal temperature of the central atrium especially during the summer period, thus reducing the risk of overheating and cooling demand. However, the reduced temperature difference is not favourable during the peak of the heating season as the warmer temperature in the DSF cavity is needed to reduce heating load. Furthermore, from figure 9(c), the negative values (-) result from the subtraction of atrium resultant temperature with extraction fan from the atrium resultant temperature without an extraction in the DSF cavity shows that the extraction fan generally reduces the atrium resultant temperature.

The impact of the extraction fans on the overall energy consumption of the hotel building is presented in figures 10 to 12.



(a) Monthly overall energy consumption result

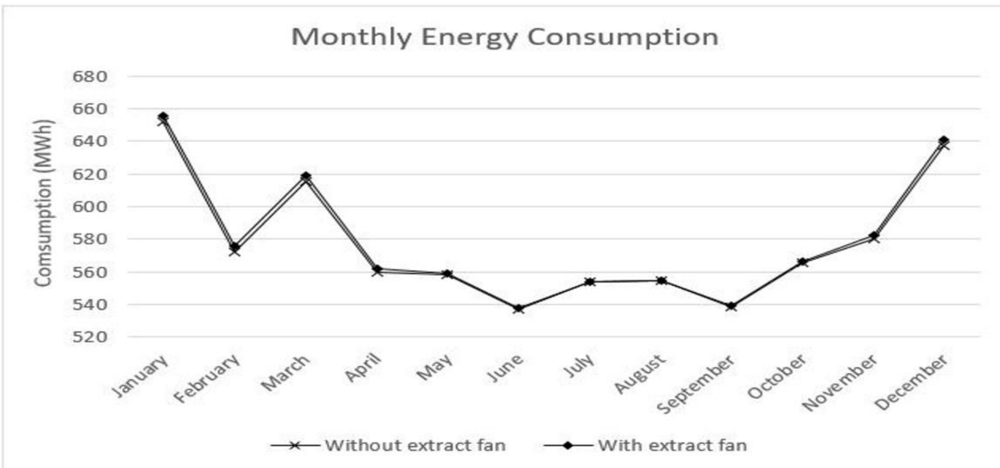


(b) Annual overall energy consumption result

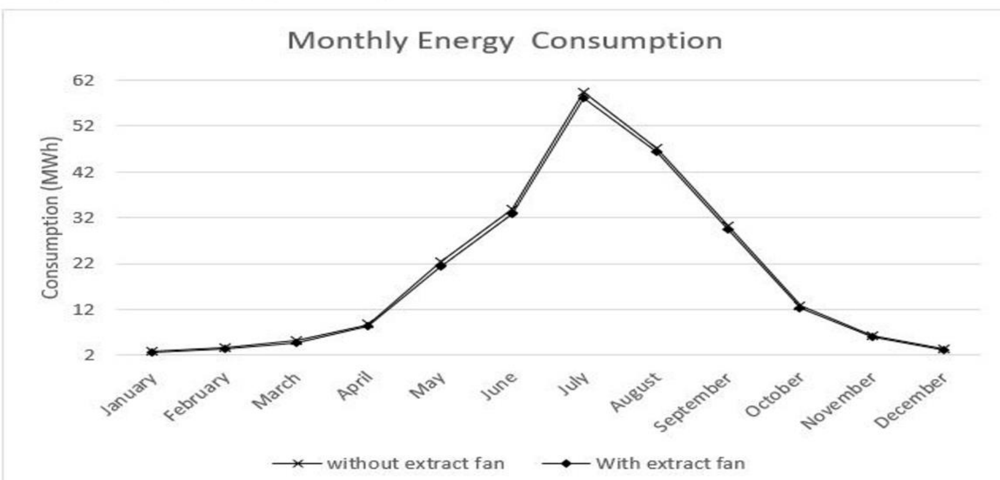
$$Percentage\ difference = \frac{(9146 - 9160)}{9146} * 100 = -0.2\%$$

Figure 10: Overall energy consumption result for simulation with and without extract fan

Figure 10 illustrates the overall energy consumption result for the simulation evaluating the impact of the extraction fans in the DSF cavity adjoining the central atrium compared to the baseline model without extraction fans. From Figure 10(a) and (b), it can be observed that the operation of the extraction fan during throughout the year results in a 0.2% marginal increase in the overall energy consumption when compared to the energy simulation result of the model without the extraction fan. Though the impact of the extraction fans on the overall energy consumption is not substantial, it is insightful to analyse the effect of the fans on the components of the energy consumption that they have direct influence on. This is helpful to deduce the optimum operation schedule for the extraction fans. Therefore, the energy consumption result for heating and cooling are presented figure 11.



(a) Heating energy consumption



(b) Cooling energy consumption result

Figure 11: Impact of DSF cavity extraction fan on the heating and cooling energy consumption

From Figure 11(a), showing the heating energy consumption, it reveals that there is no energy consumption savings accruing from the operation of the extraction fans in the DSF cavity. This is because the heat gain from solar radiation in the façade is required during the heating season to reduce the building's heating load. Moreover, the figure shows that there is a slight increase in heating energy consumption in October to April with the DSF extraction fans in operation.

However, from Figure 11(b) illustrating the cooling energy consumption, it is observed that the cooling energy consumption savings accruing from the operation of extraction fans in the DSF cavity is marginal. The maximum cooling energy consumption savings is observed in June to August during the summer period. Therefore, from analysis of the case study result, the optimum schedule of the extraction fan is during the cooling dominant period from May to September. Figure 12 demonstrates this by comparing the overall energy consumption results of the building without the extract, with the extract fan in operation all year round and with the extract fan operating only during the summer period.

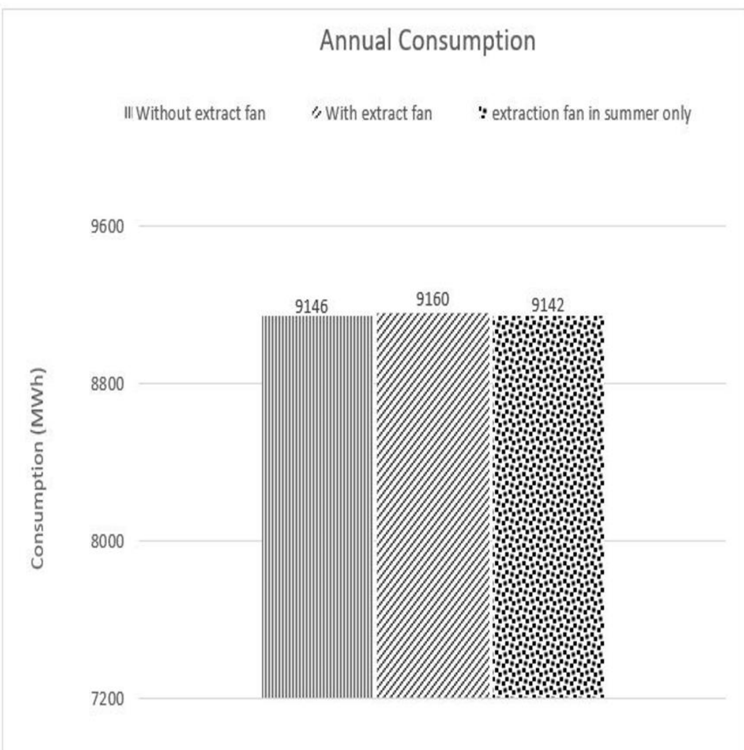


Figure 12: Annual overall energy consumption result (without extract fan vs. with extract fan vs extract fan in operation in summer only)

5.0 Conclusion

The case study investigated the impact of extract fans installed in the DSF cavity adjoining a large central atrium to the east and west on the thermal performance of the atrium and consequently, the overall energy performance of the hotel building. The case study building is an existing UK hotel building (Hilton London Heathrow Airport) and the simulation was conducted using a building energy simulation software. The software's energy estimate and thermal performance results were validated with actual building consumption data before simulation and evaluation of the effect of the installed façade extract fans on the energy performance of the case study building.

The case study results demonstrated that the resultant temperature of the façade cavity adjoining the central atrium is substantially high. Temperature difference between the DSF cavity and the atrium space of up to 11^{o}C is observed in summer times and similarly, temperature difference of up -12^{o}C is observed during the winter. This significant temperature difference between the façade cavity and the atrium space and poses the risk of overheating and occupant discomfort especially at during the summer.

The result of the model simulation incorporating extract fans in the façade cavity indicates that the resultant temperature difference between the DSF façade cavity and the central atrium reduces significantly relative to the model without extraction fans. This reduced temperature difference results in improved internal temperature of the atrium space, marginally reducing the cooling demand during the summer but also slightly increasing the winter heating requirement. The result of the overall energy consumption shows that there is a marginal increase of 0.2% in the annual energy consumption when the extraction fans are in operation throughout the year.

However, the annual energy consumption result of the simulation with the extract fans operating from May to September and off from October to April demonstrates that the 0.2% marginal energy consumption increase is neutralized. Therefore, to improve the internal condition of the atrium space without an increase in overall energy consumption, the optimum schedule of the extraction fan is during the cooling dominant period from May to September.

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