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UK hotel

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TITLE:

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

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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

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

10 Recent technological advancements have resulted in the availability of high performance, energy
11 efficient window and façade glazing systems that significantly improve thermal performance of
12 glazing. These advancements produce glazing with lower heat loss, less air leakage and warmer
13 window surfaces which enhance comfort and reduce condensation (Ander 2014). Also, modern
14 façade systems have been developed and advanced for greater thermal insulation, shielding from

15 solar radiation, improved thermal comfort and visual quality (Pasut and De Carli, 2012). The
16 Double Skin Façade (DSF) is one these improved façade systems (Pasut and De Carli, 2012; Kim
17 *et al.*, 2013).

18 The advantages of DSF systems, ranging from their aesthetic architectural benefits of increased
19 transparency, acoustic benefits and ability to decrease the heating demand of the internal
20 environment while serving as a protection from the external environment has increased their
21 popularity especially in Europe since the mid-1980s (Poirazis 2004; Chou *et al.* 2009). The main
22 feature of the DSF which provides it with this advantage is the cavity between the external and
23 internal glazed skin that acts as an insulating barrier against the undesirable effects of the external
24 microclimatic condition (Kaluarachchi *et al.* 2005; Yu *et al.*, 2017). This cavity (air gap) can be
25 naturally or mechanically ventilated, thus the attribute of the cavity space such as its ventilation or
26 shading strategies determines the performance of the DSF (Poirazis 2004; Ghaffarianhoseini *et al.*
27 2016). The application and role of DSF in a building fabric is complicated as it affects different
28 building parameters that usually interact with each other (such as ventilation, natural lighting,
29 internal air quality, thermal comfort and energy use), hence appropriate consideration must be
30 accorded to its design to ensure their possible advantages are not negated (Poirazis 2004, Yu *et al.*,
31 2017).

32 The DSF system in this case study hotel building adjoins a large central atrium to the east and
33 west, so the aesthetic benefit of multilevel glass façade which permits increased transparency and
34 unimpeded daylighting further enhances the atrium. The application of modern day atrium in
35 commercial builds (especially hotels, shopping malls and offices) became common during the late
36 1950s and early 1960s (Abdullah 2007). The aesthetic value of atria as a space organizer and
37 traditional environmental merits allowing sufficient natural lighting, passive cooling and heating

38 are now being exploited in temperate climate building designs in response to high building energy
39 consumption and energy security challenges (Abdullah 2007). Atria have the potential to improve
40 the thermal comfort of occupants by enabling solar radiation, natural heating and cooling which
41 can contribute to reducing lighting, heating and cooling energy demand (Jaberansari & Elkadi
42 2016). It is a common general assumption that atria automatically reduce the overall energy
43 consumption of a building, but this is a misconception if they are not designed appropriately
44 especially as the thermal behaviour of atrium remains difficult to predict (Abdullah 2007;
45 Aldawoud & Clark 2008).

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

58 The aim of this paper is the evaluation of the effect of extraction fans installed in the east and west
59 cavity of the DSF adjoining a central atrium on the thermal condition of the atrium and

60 consequently the impact on the overall energy consumption of an existing UK hotel building.
61 Hilton London Heathrow Airport Terminal 4 hotel is used as a case study for this evaluation.

62 The articulated aim is achieved with the following objectives:

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

76

77

78 **2.0 Literature Review**

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

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

98 Hoseggen *et al.*, (2008) and Gelesz & Reith (2015), both evaluated the application of DSF on
99 building energy performance in different climate of Europe with the aid of a building simulation

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

114 The works of Gratia and De Herde, (2004b) and Hien *et al.*, (2005), evaluated the effect of DSF
115 and the varied ventilation system on the energy performance of case study office buildings under
116 different climatic conditions, with the aid of building simulation software (TAS). Hien *et al.*,
117 (2005), investigated the impact of DSF ventilation strategies on energy consumption in a tropical
118 humid climate and their result indicated that naturally ventilated DSF could reduce energy
119 consumption and provide improved thermal comfort. Additionally, extraction fans could minimize
120 condensation induced by high humidity. It is worth noting that their work did not consider building
121 orientation. Whereas, Gratia and De Herde (2004b), investigated the energy performance of a DSF
122 with mainly natural ventilation coupled with the DSF orientation and wind speed in a temperate

123 climate. One of their key findings indicated that night ventilation is more effective than day
124 ventilation as it allows for considerable reduction of building cooling loads. Additionally, the use
125 of shading is relatively more effective in a single glazed building.

126 Fallahi *et al.*, (2010); Parra *et al.*, (2015), both worked on improving the thermal performance and
127 energy efficiency of DSF systems with the use of numerical modeling techniques. Fallahi *et al.*,
128 (2010) presented an approach of introducing thermal mass with the DSF and the energy
129 performance evaluation of its impact on adjacent study room was done using a verified numerical
130 model. Their parametric study result shows that the introduction of thermal mass in the cavity
131 space with mechanical ventilation gives significant energy reduction. Moreover, depending on
132 configuration, up to 26% summer energy saving and up to 59% winter energy saving is obtainable
133 relative to conventional DSF without thermal mass. Whereas Parra *et al.*, (2015), used
134 Computational Fluid Dynamics (CFD) to investigate the effectiveness of Venetian blinds (VB)
135 shading device on improving the performance of DSF. One of their key findings shows that VB
136 can reduce solar heat gain by up to 35%.

137 **3.0 Methodology**

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

142 The process that was employed to achieve the stipulated aim with the case study buildings can be
143 categorised into two distinct stages. The first stage involves estimating the energy consumption of
144 the building by developing holistic model reflecting the building fabric, systems and thermal

145 performance of the actual building. The predicted energy consumption is validated by comparing
146 against actual consumption data. The consumption data are collected from the electronic energy
147 meter reading of the hotel and the case study building is inspected to enable verification of
148 available data such as building fabric data (e.g. walls and windows), occupancy information to
149 ensure simulation assumptions are realistic, building usage to ensure zone grouping is as shown
150 on architectural plan and HVAC system characteristics. The second stage involves the integration
151 of the extraction fans into the model to evaluate their impact.

152 EDSL TAS software version 9.3.3 is employed as the dynamic simulation software to evaluate
153 energy performance for this study. The TAS software, designed by Engineering Development
154 Solutions Limited, is a set of application products with the capability to simulate thermal
155 performance of buildings and their systems which can be translated to energy consumption
156 estimates (Crawley *et al*, 2008). The software is also approved and fully accredited for the UK
157 building regulation 2013 and demonstrates compliance to various BS EN ISO standards (EDSL,
158 2015). It has a 3D graphic based geometry input interface (3D Modeller) that includes a CAD link
159 and can also perform daylighting calculations (Crawley *et al*, 2008). The core module is the TAS
160 Building Designer (TBD), it performs dynamic building simulation with integrated natural and
161 forced air flow (Crawley *et al*, 2008). TAS systems is the component of the software suite which
162 provides plant modelling capabilities to simulate systems such as Heating Ventilation and Air
163 Conditioning (HVAC) systems/control.

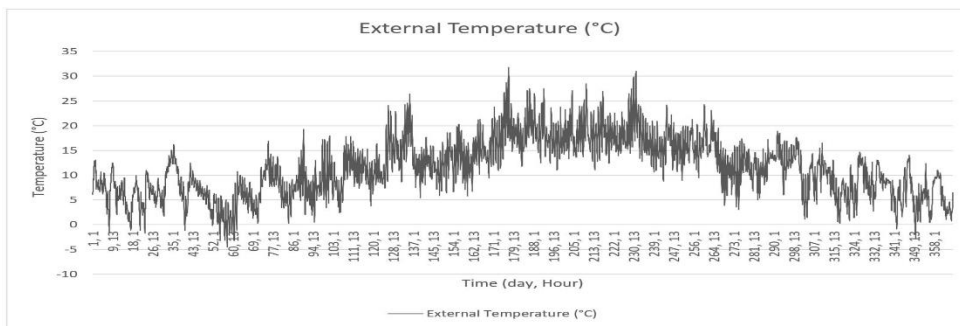
164 Weather data used for the simulation must be carefully chosen as it has considerable impact on the
165 result (Rotimi *et al.*, 2017). While engineers can only use the weather data of a year to perform
166 building simulations; the world metrological organisation defines climate as a 30-year period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

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

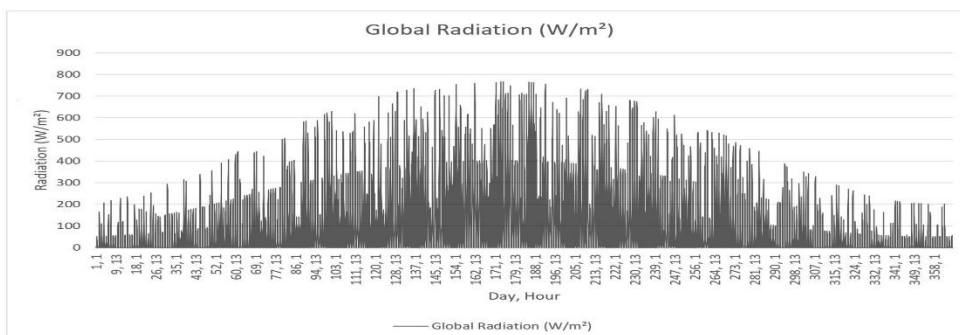
180 **3.1 Building description**

181 The case study building is a six storey hotel constructed in 1990, it is located in Heathrow and due
182 its closeness to the airport, the building is completely sealed for noise abatement. The building
183 consists of two wings situated either side of a central atrium that runs the entire building height
184 from the first floor and the east and west side of the atrium space is enclosed by DSF system. The
185 building is completely air-conditioned apart from the various plant rooms located on the ground
186 floor and sixth floor. The building has a total floor area of 20,881m², with the ground floor
187 containing the conference/meeting rooms, back of house offices and gym; the central atrium on
188 the first floor contains the restaurant, bar and reception area; while the 395 guest rooms are housed
189 in the first to fifth floors.

190 A 4-pipe FCU supplies treated air to individual bedrooms with the rooftop central Air Handling
 191 Unit (AHU) providing additional fresh air. Cooling is provided by three air cooled chillers whilst
 192 13 splits AC systems provides cooling for one of the large conference rooms, back of house and
 193 server room. The hotel has a Combined Heat and Power (CHP) unit which provides an onsite
 194 electricity generation and is sized to satisfy the domestic hot water demand along with a backup
 195 boiler. Since the hotel is in Heathrow, the weather data used for the building energy simulation is
 196 the current CIBSE London (TRY) weather file. To aid in the shadow calculation in the 3D
 197 Modeller, the latitude, longitude and time zone values of 51.46 degrees North, -0.44 degrees East
 198 and UTC +0.0 respectively were inputted to reflect the geographical location parameter of the
 199 hotel building. Figure 1 shows the hourly external temperature and global solar radiation of the
 200 weather data used for the simulation.



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

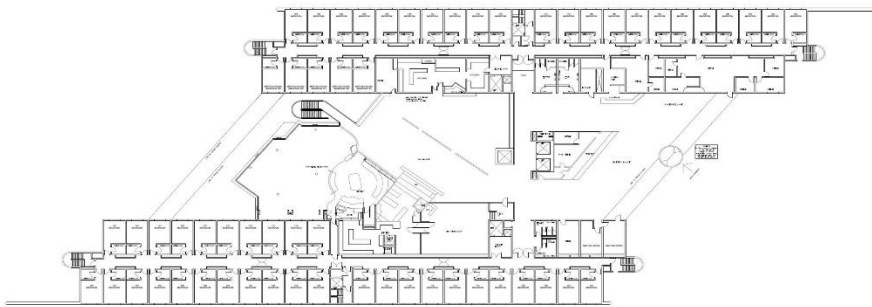


(b) Showing the hourly global solar radiation of the CIBSE TRY weather data used for the simulation

201
 202 Figure 1: Showing external temperature and global solar radiation of the simulation weather data

203 **3.2 Building 3D modelling process**

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



(a) First Floor Plan



(b) Second Floor - Fifth Floor Plan

210

211 Figure 2: Architectural plan of the hotel building

212

213

214

215

216 **3.3 Thermal simulation process**

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

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

222 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%

223

224

225 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

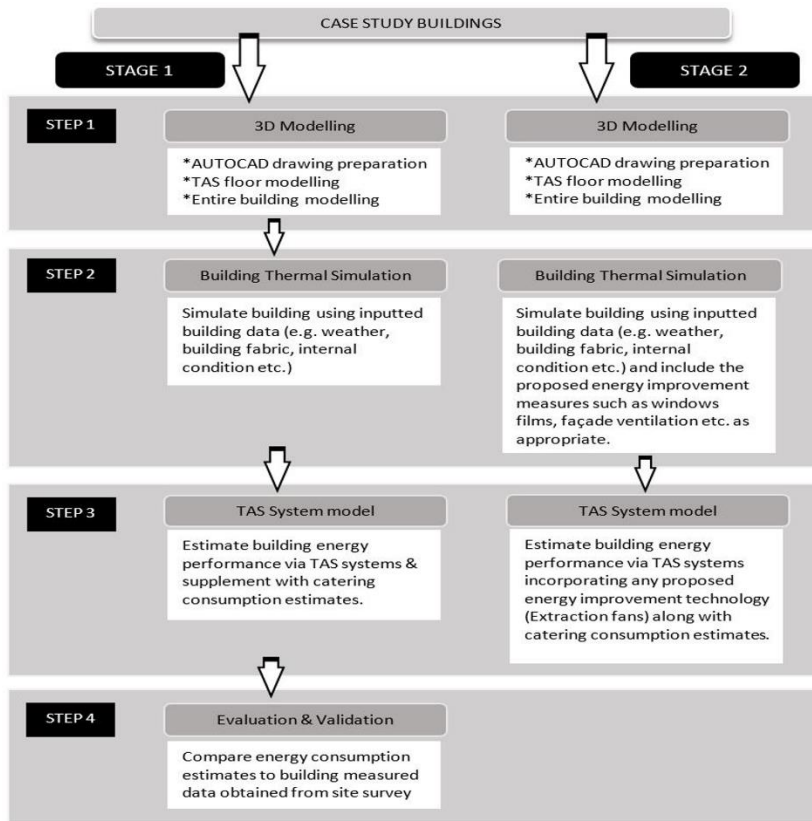
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227 3.4 Plant/systems modelling

228 TAS systems module of the software suite enables the thermal simulation result file referred to as
 229 (TSD file) to be directly attached to it. The systems module uses the TSD file to complete the
 230 simulation of the building’s plants consisting of (heating & cooling circuits, Air Handling Units,
 231 and energy sources) and produce energy performance results. However, the estimate does not

232 account for unregulated energy use such as catering which can be significant in a hotel building
233 and is therefore estimated in this work to augment the TAS systems result.

234 Figure 3 presents the summary of the case study process.



235

236 Figure 3: Summary of case study process

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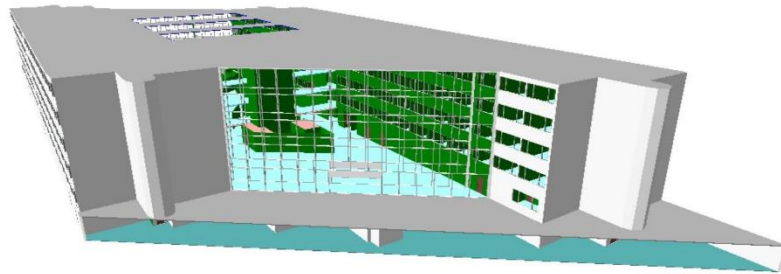
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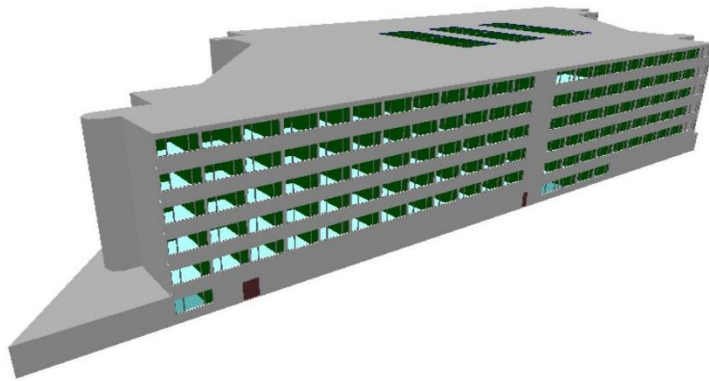
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244 **4.0 Results and Discussion of Result**

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



(a) Front view

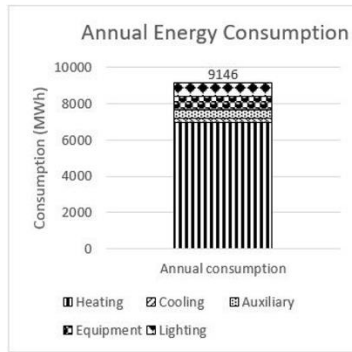


(b) Side view

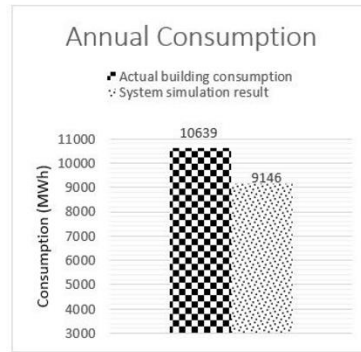
247

248 Figure 4: 3d modelling results

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



(a) TAS systems result showing annual demand and consumption



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

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

256

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

258 Figure 5(a) illustrates the annual energy consumption for the building obtained via plant/system
 259 simulation. It shows the breakdown of the energy consumption result which comprises: heating,

260 cooling, auxiliary, equipment and lighting. Auxiliary energy is the energy used by controls, pumps,
 261 and fans for the HVAC systems and the heating includes both space heating and DHW. In

262 computing the heating and cooling demands, there is a standard allowance for small power heat
 263 gains, which is from the equipment energy use. From figures 5(b) it is observed that the total

264 energy consumption predicted via the plant/system modelling is relatively lower compared to the
 265 actual building consumption data with a percentage error of -16% representing an underestimation.

266 Even though the building fabric and internal condition parameter was judiciously selected to
 267 ensure building simulation replicate real build operation, this discrepancy is still evident. The

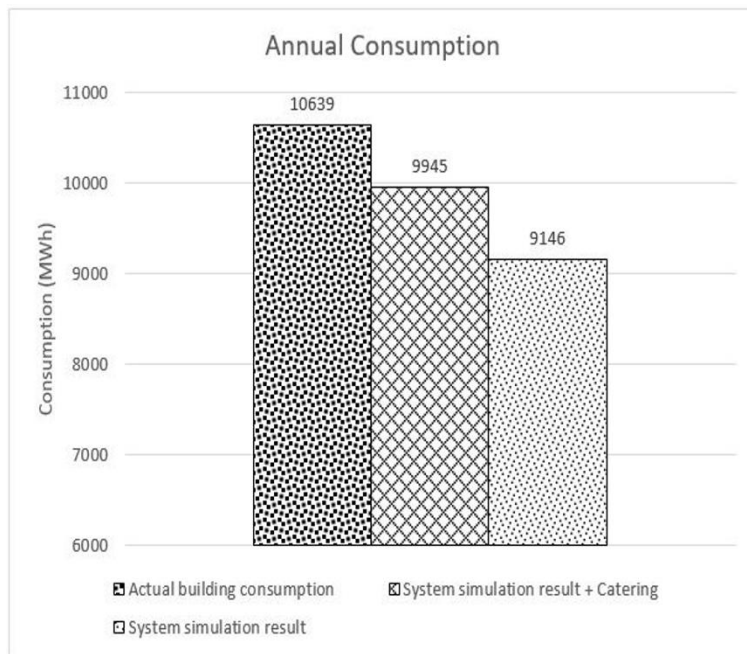
268 discrepancy is largely attributed to the fact that the estimated energy does not account for some
 269 energy use, referred to as (unregulated energy use) such as catering services which can be

270 significant in a hotel building. Additionally, deviation due to local microclimate of the building's
 271 location and the standard weather data used for building energy simulation can result in

272 discrepancy between predicted and actual energy consumption.

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

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



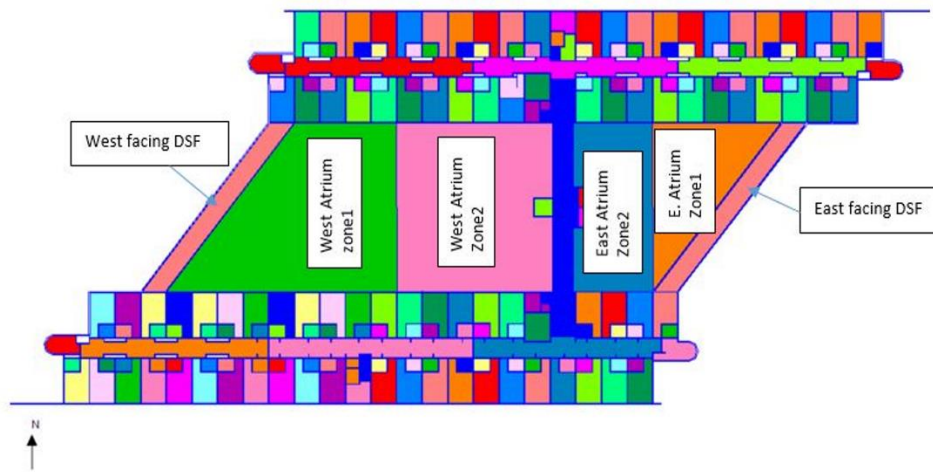
$$\text{Percentage Error} = \frac{(9945 - 10639)}{9945} * 100 = -7\%$$

283

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

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

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

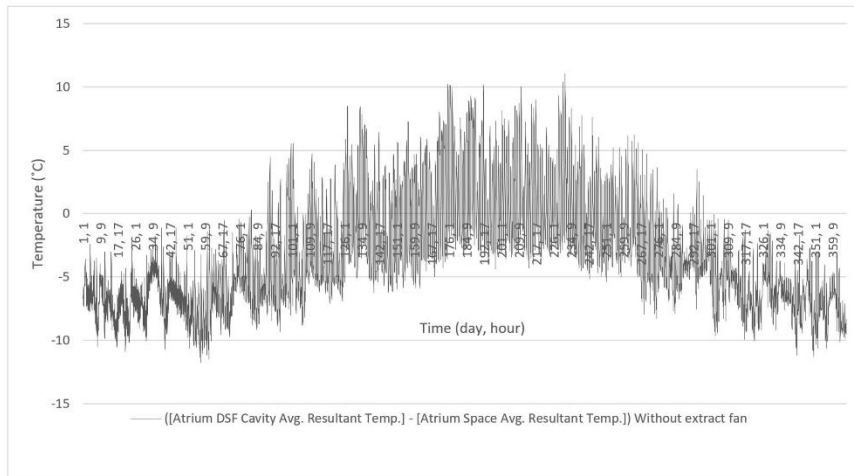


292
293 Figure 7: Showing zoning of atrium and adjoining double skin façade.

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

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

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



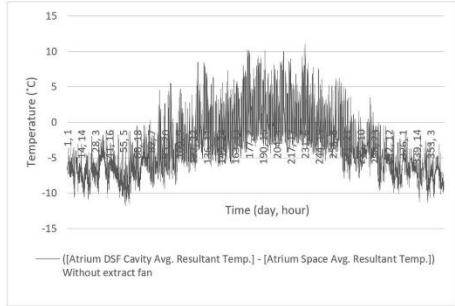
307
 308 Figure 8: Showing resultant temperature difference between the DSF cavity and central atrium
 309 (without extract fans)

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

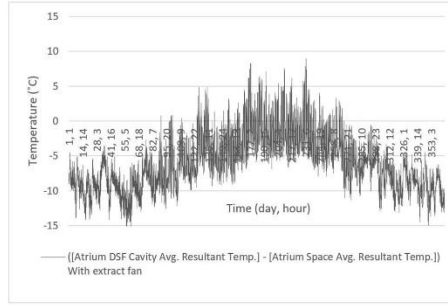
312 [Atrium DSF cavity avg. resultant temp. – Atrium space avg. resultant temp. (°C)] line on the
 313 graph is showing the plot of the value of (atrium DSF average resultant temperature) subtracted
 314 from (atrium space average resultant temperature). Hence, a negative (-) value implies that the

315 temperature of the (atrium DSF resultant temperature) is less than that of the (atrium space average
316 resultant temperature) and a positive (+) value implies the opposite.

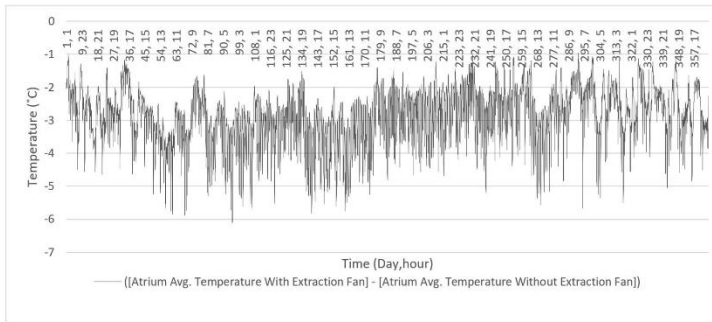
317 It can be observed from figure 8, that the prevailing resultant temperature in both the east and west
318 DSF cavity is largely significantly higher during the summer period than the prevailing resultant
319 temperature in the adjoining atrium space. Also, the DSF cavity temperature is generally lower
320 than that observed in the atrium space during the winter season. From critical analysis of the figure,
321 it can be observed that the temperature difference between the atrium's DSF façade cavity and the
322 central atrium is quite significant especially at the peak of the cooling and heating periods.
323 Temperature difference of between 10 °C to 11 °C is observed at the peak of the cooling period in
324 June and July. Similar trend is observed around the peak of the heating period, between October
325 and February where a temperature difference of -10 °C to -12 °C is obtained. The considerable
326 temperature difference observed from the simulation can significantly affect the heating and
327 cooling loads of the central atrium space especially in warmer weather scenarios, leading to
328 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)



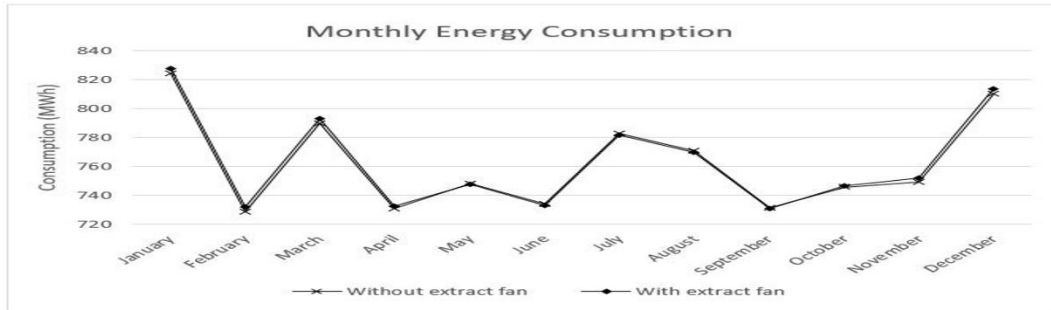
(c) Showing the difference in resultant temperature in the central atrium space due to the effect of installed extraction fans

329

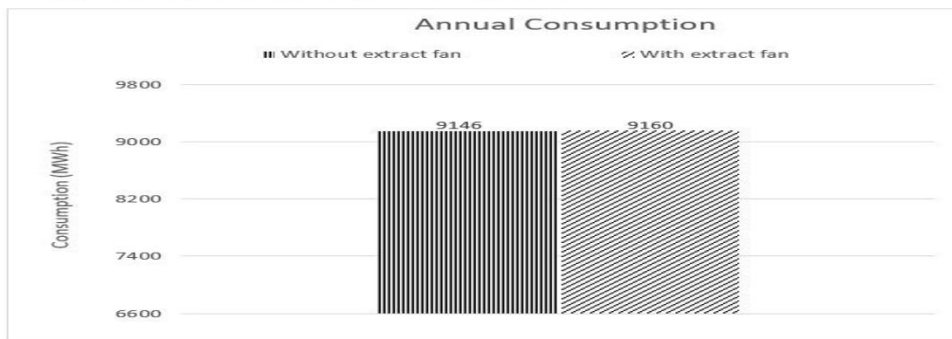
330 Figure 9: Showing resultant temperature result in the DSF cavity and central atrium (with and
 331 without extraction fan)

332 From figure 9(a) and (b) which presents the comparison of resultant temperature difference
 333 between the DSF cavity and the central atrium for the model simulation with and without
 334 extraction fan. The figure demonstrates that the installation of the extraction fans considerably
 335 reduces the temperature difference between the east and west DSF and the adjoining central atrium
 336 across the year. This helps to enhance the internal temperature of the central atrium especially
 337 during the summer period, thus reducing the risk of overheating and cooling demand. However,
 338 the reduced temperature difference is not favourable during the peak of the heating season as the
 339 warmer temperature in the DSF cavity is needed to reduce heating load. Furthermore, from figure
 340 9(c), the negative values (-) result from the subtraction of atrium resultant temperature with

341 extraction fan from the atrium resultant temperature without an extraction in the DSF cavity shows
 342 that the extraction fan generally reduces the atrium resultant temperature.
 343 The impact of the extraction fans on the overall energy consumption of the hotel building is
 344 presented in figures 10 to 12.



(a) Monthly overall energy consumption result



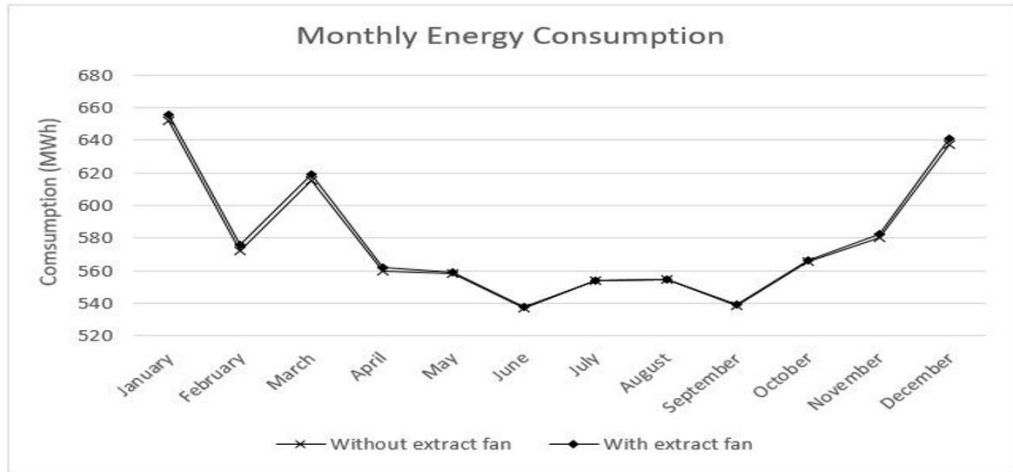
(b) Annual overall energy consumption result

345
$$\text{Percentage difference} = \frac{(9146 - 9160)}{9146} * 100 = -0.2\%$$

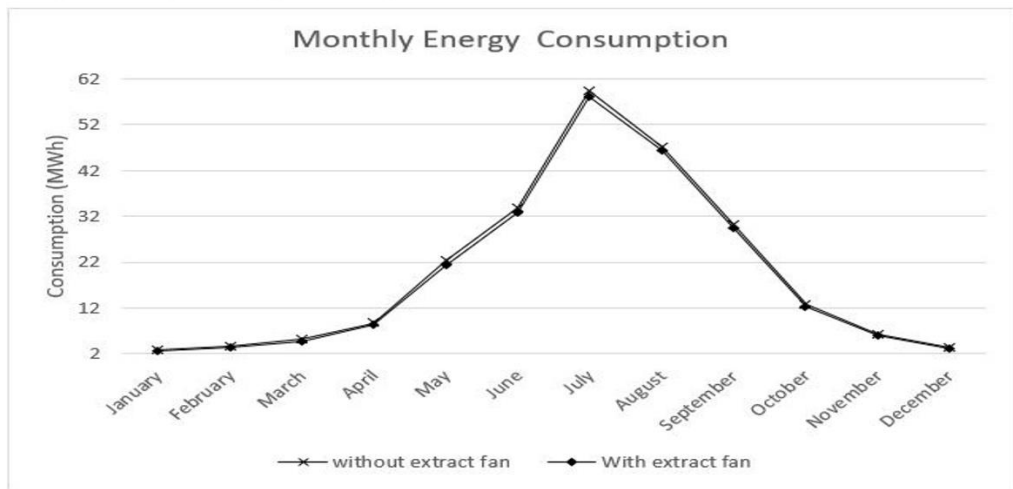
346 Figure 10: Overall energy consumption result for simulation with and without extract fan

347 Figure 10 illustrates the overall energy consumption result for the simulation evaluating the impact
 348 of the extraction fans in the DSF cavity adjoining the central atrium compared to the baseline
 349 model without extraction fans. From Figure 10(a) and (b), it can be observed that the operation of
 350 the extraction fan during throughout the year results in a 0.2% marginal increase in the overall
 351 energy consumption when compared to the energy simulation result of the model without the
 352 extraction fan. Though the impact of the extraction fans on the overall energy consumption is not
 353 substantial, it is insightful to analyse the effect of the fans on the components of the energy

354 consumption that they have direct influence on. This is helpful to deduce the optimum operation
 355 schedule for the extraction fans. Therefore, the energy consumption result for heating and cooling
 356 are presented figure 11.



(a) Heating energy consumption



(b) Cooling energy consumption result

357

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

359 From Figure 11(a), showing the heating energy consumption, it reveals that there is no energy

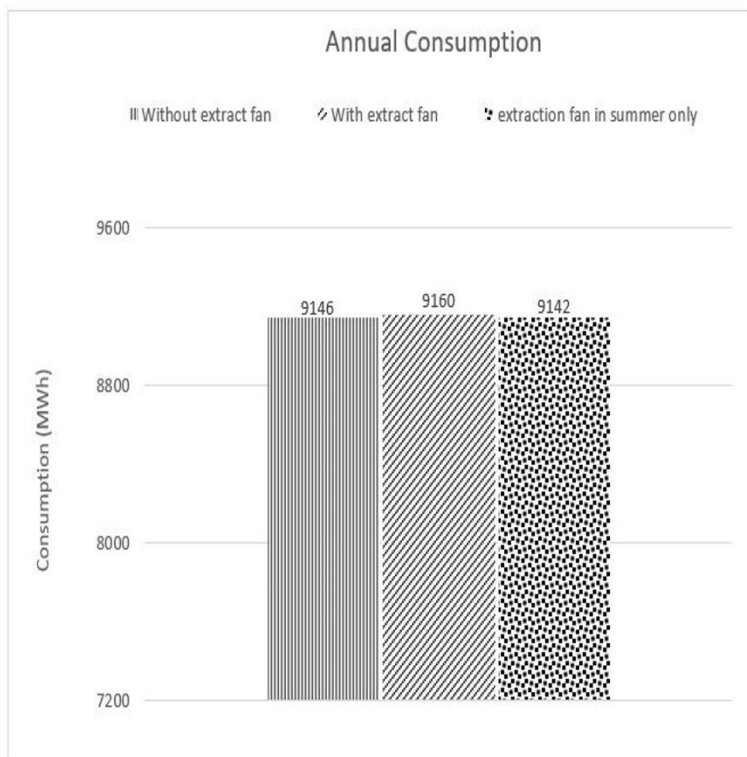
360 consumption savings accruing from the operation of the extraction fans in the DSF cavity. This is

361 because the heat gain from solar radiation in the façade is required during the heating season to

362 reduce the building's heating load. Moreover, the figure shows that there is a slight increase in
 363 heating energy consumption in October to April with the DSF extraction fans in operation.

364 However, from Figure 11(b) illustrating the cooling energy consumption, it is observed that the
 365 cooling energy consumption savings accruing from the operation of extraction fans in the DSF
 366 cavity is marginal. The maximum cooling energy consumption savings is observed in June to
 367 August during the summer period. Therefore, from analysis of the case study result, the optimum
 368 schedule of the extraction fan is during the cooling dominant period from May to September.

369 Figure 12 demonstrates this by comparing the overall energy consumption results of the building
 370 without the extract, with the extract fan in operation all year round and with the extract fan
 371 operating only during the summer period.



372

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

375 **5.0 Conclusion**

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

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

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

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

401

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