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EFFICACY OF DOUBLE SKIN FAÇADE ON ENERGY CONSUMPTION IN OFFICE BUILDINGS IN PHNOM PENH CITY

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ABSTRACT

The use of glazed façades for office buildings in Phnom Penh city has been increasing these days, and those conventional façades lead to a high energy demand especially for cooling purpose in the buildings. Almost fifty percent of the overall annual energy has been consumed by the commercial sector in Cambodia, and it keeps growing year after year. Pertaining to the matter, the use of double skin façade (DSF) as one of the approaches to improve building energy performance has been studied. The objectives of this study are, to assess the potential of DSFs on building energy efficiency, and to propose its optimum configurations for office buildings in Phnom Penh city. To do so, the different DSF parameters consisted of cavity depth, glass materials for interior and exterior layer and shading device for DSFs were investigated by using the whole building energy simulation program, EnergyPlus™. The primary result shows that DSF is a good technique to achieve building energy efficiency in Phnom Penh city, but it does require a proper design to avoid unexpected issues such as excessive solar radiation and thermal transfer into the building through the building's façade. The optimum parameters of DSF found in the study are 500 mm cavity depth, bronze laminated glass for the internal, and external layers of DSF, and external blind louvre. The combination of all optimum parameters could potentially reduce about 34% of the annual energy demand.

1. INTRODUCTION

These days, the concern on the sustainable building development is growing around the world, and one among major elements is energy saving in buildings (Chan et al., 2009). In a typical commercial building, air-conditioning system is the main electricity consumer which accounts for more than 40% of the entire electricity consumption of a building, and one of the principal thermal

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loads in the building façade heat gain is the heat transfer through window glazing of the building's exterior wall (Chan et al, 2009). Consequently, various energy saving methods have been introduced to block solar radiation in the buildings (Hong et al., 2013). Double skin façade (DSF) is one of the approaches used for solving the issues of energy performance in the buildings. It is a pair of walls or glass skins separated by air cavity which can be expanded from 20 cm to several meters, where the internal skin is normally a conventional façade, while the external layer is normally covered up the main layer (typically glazing) to create cavity space for insulation purpose (Uuttu, 2001). In addition, the ventilation mode used in the cavity of DSFs could be passive, active or hybrid ventilation system (Streicher et al., 2005). Over the last 10 to 15 years, the practice of DSFs has significantly increased, primarily due to the profits attributed to them regarding the improved energy efficiency and enhanced day lighting (Author & Pollard, 2000).

The vast majority of DSFs have been built in Europe, especially Northern Europe, principally because of their huge heating requirements, the high cost of energy, and the desire for improved natural light (Author & Pollard, 2000). However, Streicher et al. (2005) stated that DSFs is mostly used in Europe because it contributes to the architectural trend which is commonly known for aesthetic of transparent glass, improvement, and stabilisation of the internal environment, acoustic quality protection, and decreasing of energy consumption.

Nowadays, the potential of using DSFs for buildings in climates other than Europe has also been found. For instance, Wong et al. (2008) found that a substantial energy saving is possible, if passive ventilation can be exploited by using DSFs in hot and humid climate region. Moreover, based on the study on the effect of double glazed facade on energy consumption, thermal comfort, and condensation for a typical office building in Singapore by Hien et al. (2005), double glazed facade is a good approach to improve thermal comfort in a multi-storey office building. However, the potential of using the system in other climates has not been fully investigated yet. Besides, the climatic condition, and local characteristics such as temperature, solar radiation etc., need to be considered in the design of DSFs to achieve reduction in energy consumption (Azarbayjani, 2014). Also, Rahmani et al. (2012) stated that accurate planning strategies must be followed to reduce overheating, and get more benefit out of DSF layering. Therefore, DSFs need to be designed based on the specific climatic behaviour of a location.

In a hot climate, the building could have high external heat loads to deal with for the whole or part of the year. For the conventional building systems, natural or low energy systems such as shading and fans are usually used to provide comfort cooling. Nevertheless, the nature of current buildings, and various user expectations can make it hard to implement these strategies, thus the high external and internal loads encourages the necessary need of air-conditioning system to provide cooling for all or a major portion of the year (Author & Pollard, 2000).

For a hot and humid climate country like Cambodia, the energy demand for the air-conditioning system in buildings accounted for the main proportion of energy consumption in the operation of the buildings. About 48 percent of total annual energy was consumed by commercial sector in Cambodia, and the demand of energy keeps significantly rising every year (Cambodia National Energy Statistics, 2016). At present, the conventional façades of office buildings in Phnom Penh city allow extreme thermal transfer through the building envelope, and cause unsatisfied atmosphere in the buildings. Due to the architects' desire, conventional glass materials are still preferably used for the skin of the buildings even though it causes significant heat gain into the space.

Various energy efficiency strategies have been introduced by many literature (Hong et al., 2013). DSF is one of the potential strategies that can be adopted to improve the energy performance of the buildings. Hence, this study was conducted with the objectives to assess the potential of DSFs on building energy efficiency, and to propose its optimum configurations for office buildings in Phnom Penh city.

2. LITERATURE REVIEW

2.1 DEFINITION

DSFs are characterised inversely by the most critical researchers to explain the performances of the system. Outer façade, a halfway air space, and internal façade are included in the DFS system. Ventilation is applied, and permitted in the cavity space, while the climate, and acoustic are protected by the external layer, which also provides the thermal resistance. In addition, a movable shading gadget is typically used for better performance (Oesterle et al., 2001). Arons (2000) described DSF as a façade having two separated planar components that grants internal or external air to travel through its structure, in which it is also called a twin skin.

According to Safer et al. (2005), DSF is a special type of envelope, where a second skin, usually a transparent glazing, is placed in front of a regular building facade. The air space in between or the channel, can be between 0.8 to 1.0 m, where it is ventilated naturally, mechanically, or using a hybrid system to diminish overheating problems in summer, and to contribute to energy savings in winter.

Chan, et al. (2009) on the other hand termed DSF as a building facade covering one or several storeys with multiple glazed skins, where the skins can be air tight or naturally/mechanically ventilated. The outer skin is usually a hardened single glazing, and can be fully glazed, whereas the inner skin can be insulating double glazing, and is not completely glazed in most applications. The width of the air cavity between the two skins can range from 200 mm to more than 2 m. An air-tightened double skin facade can provide better thermal insulation for the building to reduce the heat loss in winter. On the other hand, moving cavity air inside a ventilated double skin facade can absorb heat energy from the sun-lit glazing, and reduce the heat gain as well as the cooling demand of a building.

Even though there are some unique definitions among the distinctive sources of writing, DSF has a common meaning i.e. a system of building that consists of two facades or skins, constructed in such a way that air flows in the intermediate space in between or cavity.

2.2 PERCEPTIONS ON DOUBLE SKIN FACADE

In architecture, DSF plays an important role in exterior design. Its transparency provides good aesthetic, and daylight for buildings, and protects the interior space by giving the opening between two layers a ventilation system, which can be operated passively, actively or a combination of both. DSF not only provides a better visualisation, but also improves the indoor thermal comfort, visual comfort, natural lighting, and energy savings. According to Hendriksen et al. (2000), the transparency is frequently observed as the principle architectural purpose behind a twofold skin exterior, since it makes close contact with the environment. Transparent view to the outside, and sunshine levels are expanded when twofold skin exteriors are utilised instead of customary window surfaces.

For engineering, DSF has its main roles and benefits regarding technical constructions and physical environment. According to Lee et al. (2002), the chief advantage of DSF is acoustics. In active areas such as the air terminal or high activity urban regions, DSF is utilised to decrease sound level by its second layer of glass screen in front of a traditional façade. Then again, if the air space in the outside layer is big enough to empower tolerable natural ventilation, operable windows behind this all-glass layer will bargain this acoustic advantage predominantly. Other than the acoustics, sun based extraction, and sun radiation load are controlled by shading framework situated in the moderate space between the outside glass façade and inside façade. It is like outside shading framework that sun-powered radiation load is obstructed before entering the building, while heat consumed by the cavity is drawn off through the outside skin by normal or mechanical ventilation framework.

Basically, the primary purposes of DSF as characterised by Arons (2000) are aesthetics, passive ventilation, cost saving, sound diminishment, client control and comfort, occupant productivity related to surrounding environment, and additional security for buildings.

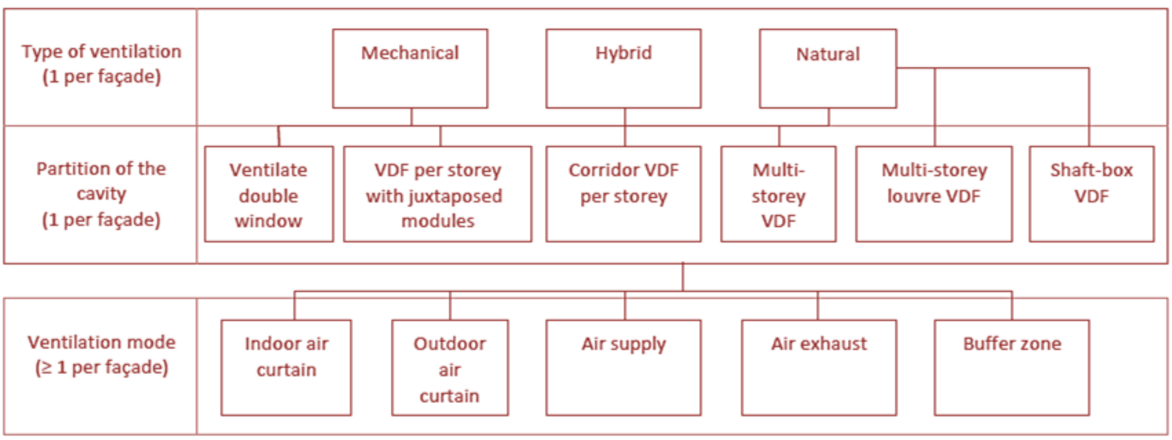

Figure 1: Classification of DSF (VDF means DSF) (BBRI, 2005)

2.3 CLASSIFICATION OF DOUBLE SKIN FACADE

Classification of DSFs can be made according to the Ventilated Double Façade (VDF) classification (BBRI, 2005), that is based on the ventilation type, partitioning of the cavity, and mode of ventilation as summarised in Figure 1.

Referring to the above classification, Streicher et al. (2005) explained that the type of ventilation refers to the driving forces at the origin of the ventilation of the cavity located between the two glazed façades, in which each ventilated double skin façade concept is characterised by only a single type of ventilation. The ventilation mode refers to the origin, and the destination of the air flowing in the ventilated cavity. It is independent of the type of ventilation applied. The partitioning of the cavity gives the information on how the cavity situated between the two glazed façades is physically divided.

There are other strategies for classification of DSF as well. Most of them are dependent on the design principle, for instance, the direction of air flow inside the intermediate space, the façade design and the arrangement of cavity system (Regazzoli, 2013). Similarly, Oesterle et al. (2001), classified the DSFs mostly by considering the geometry of the cavity. According to Poirazis (2004), the most well-known one is to categorise the façade according to its geometry. The four types mentioned are Box Façade, Corridor Façade, Shaft-Box Façade and Multi-Storey Façade as shown in Figure 2.

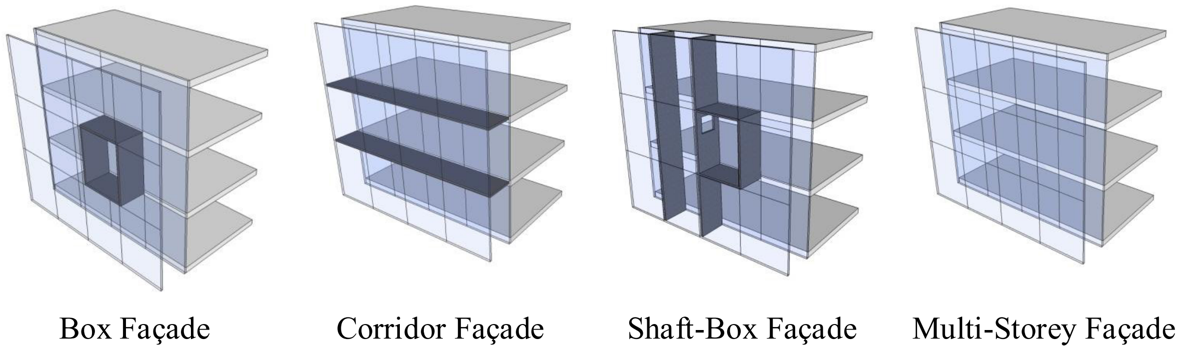

Figure 2: Types of double skin façade (after Regazzoli (2013)).

2.4 Technical Aspects of Double Skin Façade System

2.4.1 Cavity

The depth of the cavity can be varied according to the different concept of utilising DSFs, in which it can be between 10 cm to more than 2 m. On the other hand, the width of the cavity affects the physical properties of the façade, and the way that façade is sustained. The parameters of DSFs including the aesthetics, types of shading device, the access for maintenance, and the ventilation modes is determined to consider the depth of the cavity (Sinclair et al., 2009 as cited in Ghaffarianhoseini et al., 2016).

The results from the study conducted on office buildings in a temperate climate by Regazzoli (2013) show that the most efficient façade construction combination is the 1000 mm Multi-Storey Double-Skin Façade with a regulating cavity. This combination managed to achieve an annual energy saving of about 16% as compared to the base model using a conventional single skin façade.

According to Rahmani et al. (2012), who conducted their study in a fully air-conditioned office building in the tropical climate, the recommended cavity for DSF system is 1000 mm as it enhances the performance of DSF in lowering the solar heat gains. However, the system does not work efficiently if the cavity is more than 1000 mm. Aksamija (2009) also found that the ventilation of air cavity is essential in reducing the cooling loads, in which the 1000 mm cavity is the better parameter of DSF that increases the performance of DSF.

2.4.2 Glass Type

Streicher et al. (2005) stated that the typology of the façade is the first consideration for the choice of the glass type for the internal and external walls of DSFs. If outdoor air is used to ventilate the façade, the internal wall is normally equipped with an insulating pane (thermal break), while the external wall is equipped with a single glazing. The opposite will be applied in case of indoor air is used for façade ventilation.

On the other hand, Sinclair et al. (2009) mentioned that the glazing system design for a DSF depends on the climatic conditions of the project site, preferred ventilation and blind operating modes, and internal space requirements. Besides, Haase & Amato (2006) found in their study that the amount of heat gain through the building envelope can be reduced significantly by designing a ventilated DSF using two clear glazing in the internal and external layers with natural ventilation in the cavity. Similarly, Aksamija (2009), stated that the location of double glazing on the exterior skin improves the overall energy consumption, with high-performance e-glazing glass is the better parameter that enhances the performance of DSF.

2.4.3 SHADING DEVICE

According to Oesterle et al. (2001), determining the effective characteristics of the sun shading in each case poses a special problem at the planning stage since the properties can vary considerably, according to the type of glazing and the ventilation of the sun shading system. They added that the sun shading provides either a complete screening of the area behind it or, in the case of the louvres it may be in a so-called “cut-off” position. Hence, for large-scale projects it is worth investigating the precise characteristics of the combination of glass and sun shading, as well as the proposed ventilation of the intermediate space in relation to the angle of the louvres.

Regarding DSFs and shading devices, heat gain into buildings can possibly be reduced when the blinds are placed in the accurate location, and it is found that the blinds with light color are likely to offer more light into the facades (Baldinelli, 2009). Haase & Amato (2009) conducted an experiment on DSFs by placing blinds, and shading devices inside the cavity between the two layers to provide the shield against intrusion, direct sunlight, and glare. The results show that the exterior or mid pane types offer the decrease in solar heat gain. A proper control and adjustment of the blind could lead to a considerable amount of energy saving.

In addition, Gavan et al. (2007) investigated the effect of ventilated DSF with venetian blinds on its energy performance. They found that the studied DSF shows reduction in energy consumption compared to a traditional façade, which indicates that shading devices have its influence on the performance of DSF.

3. Methodology

A typical office building in Phnom Penh city as shown in Figure 3 was used as base case model for this study. Table 1 presents brief description about the building. To determine the optimum configurations of DSF, three strategies were adopted to analyse the energy performance of the building. EnergyPlus programme version 8.6.0 was used to perform the simulation of total energy use and for cooling purpose, along with OpenStudio, and Google SketchUp 2016 to model the interface of the studied office building as illustrated in Figure 4.

Table 1: Building description.

Building type:	Office	Floor:	100 mm concrete slab
Level:	10 storeys	Internal partition:	Lightweight gypsum plasterboard with 100 mm cavity
Ground floor area:	230 m^2	Glass type:	Laminated glass 6 mm + 1.14 mm + 6 mm
North length:	17 m	Window shading:	Vary from floor to floor
South length:	12 m	Lighting type:	Open fluorescent luminaire/Recessed round downlight
East and west width:	15 m	Cooling type:	Air cooled
Total height:	34.93 m	Air-conditioning:	Variable Air Volume (VAV) system
Front Orientation:	North-west	Operating schedule:	9:00 to 19:00
Wall:	Double brick plaster	Working day:	Monday to Friday
Roof ceiling:	100 mm concrete and 10 mm plasterboard	Weather data:	Phnom Penh city

Figure 3: Base case building, B-Ray tower.

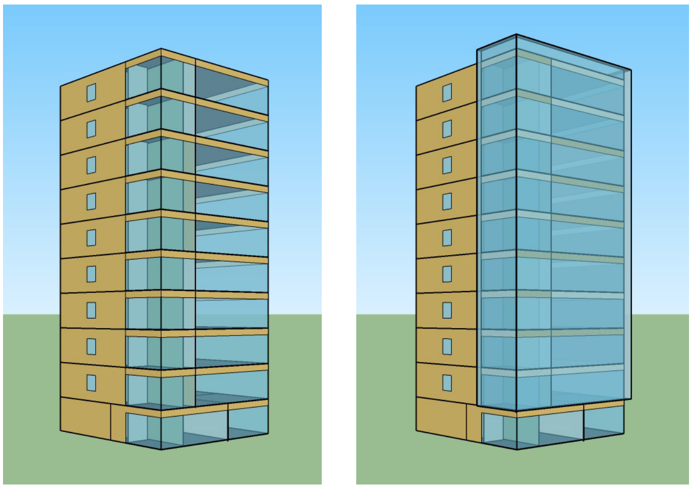

Figure 4: Modelling of single skin, and double skin façade buildings.

The first strategy was to find the optimum cavity depth of DSFs, thus three categories of DSF configurations were proposed for the study. At this point, every aspect of DSF model was based on the base case model as shown in Table 2, except the DSF configurations, and parameters including ventilation type, external materials, and shading devices were based on other previous studies, in which they were conducted in similar context.

Table 2: DSF models with different cavity depth.

Category	C-1	C-2	C-3
DSFs configuration	Multiple-storey DSF	Multiple-storey DSF	Multiple-storey DSF
Ventilation type	Natural ventilation	Natural ventilation	Natural ventilation
Cavity depth	500 mm	1000 mm	1500 mm
Internal glass	Bronze laminated glass	Bronze laminated glass	Bronze laminated glass
External glass	Clear e-glazing	Clear e-glazing	Clear e-glazing
Shading device	No shading device	No shading device	No shading device

The second strategy was to determine the optimum glazing materials used for DSF parameters. In this section, base case glass, and two new proposed glass materials were used. Next, the result of the optimum cavity from strategy one was applied into strategy two for investigation. Four categories of DSF were proposed and tabulated in Table 3.

Table 3: DSF models with different glazing materials.

Category	G-1	G-2	G-3	G-4	G-5
DSF configuration	Multiple-storey DSF	Multiple-storey DSF	Multiple-storey DSF	Multiple-storey DSF	Multiple-storey DSF
Ventilation type	Natural ventilation	Natural ventilation	Natural ventilation	Natural ventilation	Natural ventilation
Cavity depth	500 mm	500 mm	500 mm	500 mm	500 mm
Internal glass	Clear e-glazing	Clear double glazing	Clear e-glazing	Clear double glazing	Bronze laminated glass
External glass	Clear double glazing	Clear e-glazing	Clear e-glazing	Clear double glazing	Bronze laminated glass
Shading device	No shading device	No shading device	No shading device	No shading device	No shading device

The third strategy was determining the optimum shading devices for DSFs. Like strategy one and strategy two, three categories of DSF were proposed for investigation with different shading devices as illustrated in Table 4. Similarly, the optimum results from strategy one and strategy two were also applied into strategy three for investigation.

Table 4: DSF models with different shading devices

Category	S-1	S-2	S-3	S-4
DSF configuration	Multiple-storey DSF	Multiple-storey DSF	Multiple-storey DSF	Multiple-storey DSF
Ventilation type	Natural ventilation	Natural ventilation	Natural ventilation	Natural ventilation
Cavity depth	500 mm	500 mm	500 mm	500 mm
Internal glass	Bronze laminated glass	Bronze laminated glass	Bronze laminated glass	Bronze laminated glass
External glass	Bronze laminated glass	Bronze laminated glass	Bronze laminated glass	Bronze laminated glass
Shading device	No shading device	Internal shade rolling blind	Internal blind louvre	External blind louvre

4. RESULTS AND DISCUSSION

4.1 ANNUAL ENERGY CONSUMPTION OF STRATEGY ONE

The results of simulation from strategy one shows that the buildings with DFS system consume less energy than the single skin façade building as summarized in Figure 5. A gradual reduction of the end-use energy occurs from the model with cavity depth of 1500 mm to 500 mm, i.e. 374406 kWh to 368698 kWh. Table 5 gives the amount of energy savings, showing that the DSF model with 500 mm cavity depth (C-1) consumes the lowest energy, in which the saving of up to 56882 kWh or 13.37% can be achieved annually. The results also show a similar trend of reduction in cooling energy use. Percentage wise, more saving is achieved for the annual cooling energy, i.e. 17.09%.

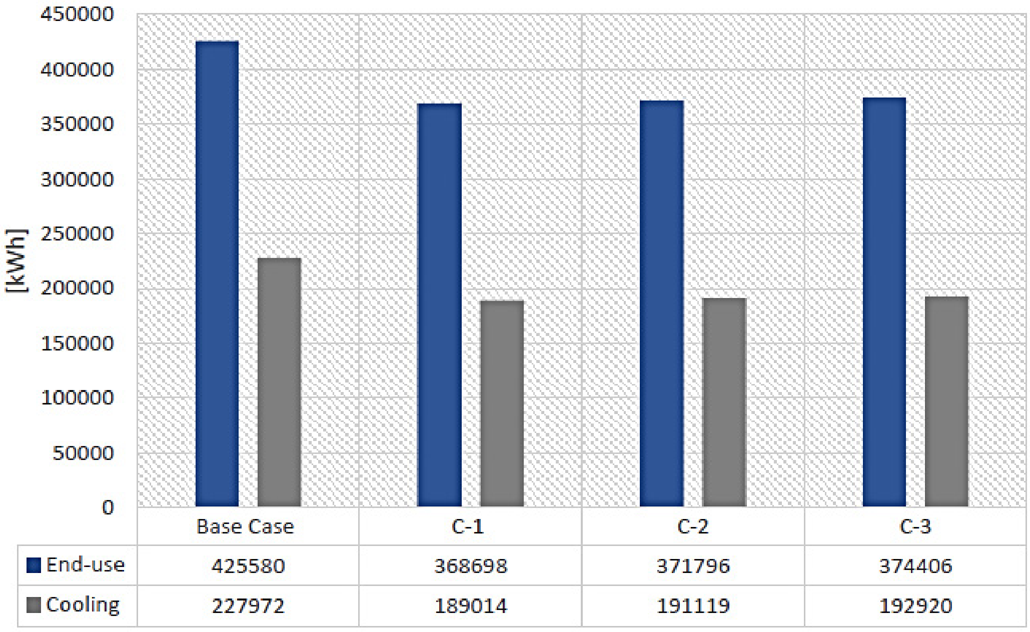

Figure 5: Annual end-use and cooling energy of DSF models with different cavity depth [kWh].

Table 5: Annual end-use energy [kWh], and annual saved energy [kWh], [%].

Category		Base case	C-1	C-2	C-3
Annual end-use energy [kWh]		425580	368698	371796	374406
Annual cooling energy [kWh]		227972	189014	191119	192920
Annual saved energy (End-use)	[kWh]		56882	53784	51174
	[%]		13.37	12.64	12.02
Annual saved energy (Cooling)	[kWh]		38958	36853	35052
	[%]		17.09	16.17	15.38

DSF with 500 mm cavity has the highest capability to reduce the energy consumption in the building as its solar radiation level is found to be lesser than the 1000 mm and 1500 mm cavities. The bigger the cavity depth, the higher solar radiation received. It could also be due the optimum depth of the cavity that provides a better stack effect to remove excessive heat from its space.

Generally, all DSF categories in strategy one can reduce around 12% and 15% of the annual end-use energy, and cooling energy respectively.

4.2 ANNUAL ENERGY CONSUMPTION OF STRATEGY TWO

The optimum cavity depth found in strategy one is applied into this second strategy to determine the optimum glass properties for DSF configurations. Figure 6 presents the annual energy demand of each category. Surprisingly, the new proposed glass materials used in model G-1, G-2, G-3, and G-4 cause the building to consume more energy than the base case model. The range of increase is approximately between 1 to 5 %, combining the end-use and cooling energy. Nevertheless, comparing these four models, G-1 which uses clear low-e glass as the internal skin, and clear double glazed as the external skin, consumes less energy than the others, i.e. 431192 kWh, even though the amount is 1.32% more than the annual end-use energy. Table 6 summarises the annual energy use and saving for strategy 2, in which negative means excess in energy use.

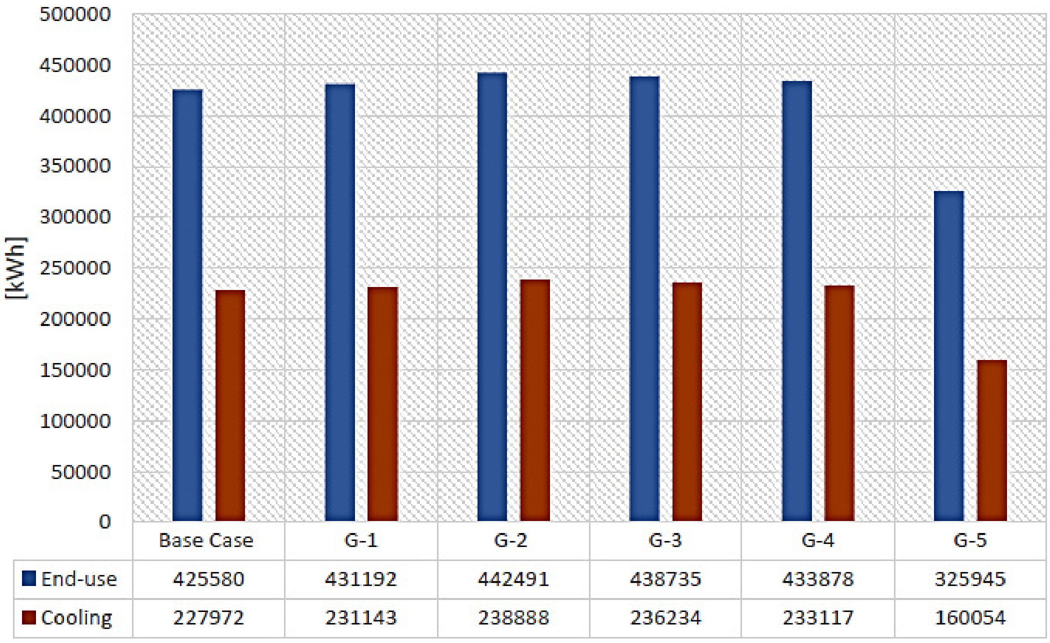

Figure 6: Annual end-use and cooling energy of DSF with different glass materials [kWh].

Table 6: Annual end-use energy [kWh], annual saved energy [kWh], [%], and exceeded energy [%].

Category		Base case	G-1	G-2	G-3	G-4	G-5
Annual end-use energy [kWh]		425580	431192	442491	438735	433878	325945
Annual cooling energy [kWh]		227972	231143	238888	236234	233117	160054
Annual saved energy (End-use)	[kWh]		-5612	-16911	-13155	-8298	99635
	[%]		-1.32	-3.97	-3.09	-1.95	23.41
Annual saved energy (Cooling)	[kWh]		-3171	-10916	-8262	-5145	67918
	[%]		-1.39	-4.79	-3.62	-2.26	29.79

The results show that G-5 is the optimum model, which has the lowest annual energy demand with 325945 kWh or about 23% decrease in annual end-used energy from the base case. This indicates that the laminated glass has a higher capability to block solar radiation through the window into the cavity and building. Besides, based on this finding, the color of glazing materials could also help in reducing the heat transfer, thus heat gain into the cavity.

4.3 ANNUAL ENERGY CONSUMPTION OF STRATEGY THREE

Strategy three utilizes the optimum results from strategy one and strategy two, i.e. 500 mm cavity depth, and bronze laminated glass for internal and external skins, to determine the optimum shading device of DSF. Results in Figure 7 shows that the DSF without shading device (S-1) consumes the highest annual energy compared to others, excluding base case. On the other hand, the DSF with external blind (S-4) contribute to the highest annual end-use energy saving of about 34% (280716 kWh) as shown in Table 7.

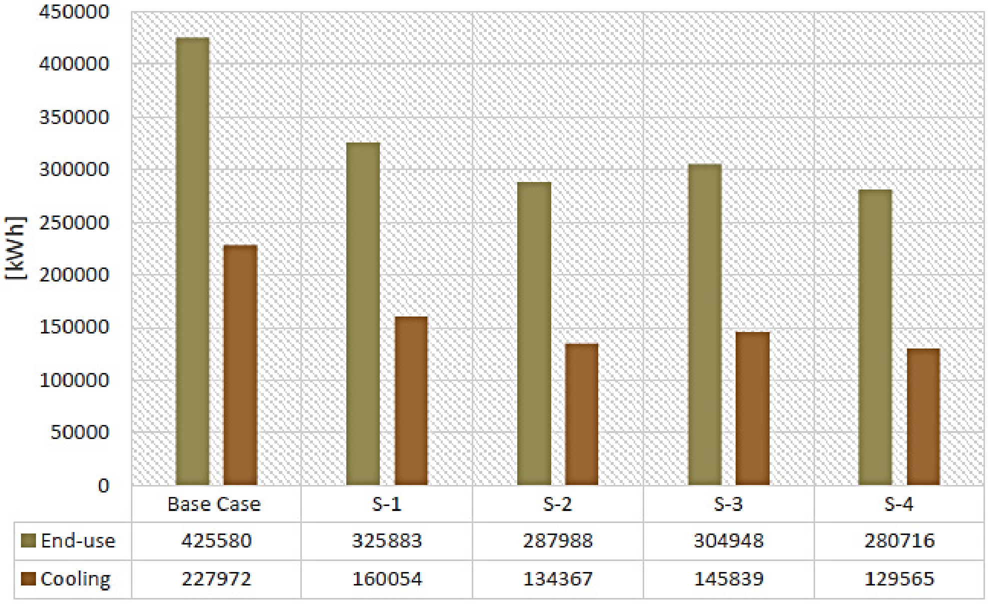

Figure 7: Annual end-use and cooling energy of DSF with different shading devices [kWh].

Table 7: Annual end-use energy [kWh], and annual saved energy [kWh], [%].

Category	Base case	S-1	S-2	S-3	S-4
Annual end-use energy [kWh]	425580	325883	287988	304948	280716
Annual cooling energy [kWh]	227927	160054	134367	145839	129565
Annual saved energy (End-use)	[kWh]	99697	137592	220632	144864
	[%]	23.43	32.33	28.35	34.04
Annual saved energy (Cooling)	[kWh]	67918	93605	82133	98407
	[%]	29.79	41.06	36.03	43.17

Interestingly, DSF with internal rolling blind (S-2) reduces more energy than internal blind louvre (S-3), but consumes more energy than the external blind louvre (S-4). This indicates that the external louvre has more ability to block solar radiation through the window into the building. The internal, and external blinds used have the same properties, and physical characteristics except for

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the locations where there are placed. Despite those similarities, the results show different capabilities in energy savings. Therefore, besides the properties of shading devices, the location of the devices is also relevant to achieve savings in energy use.

5. CONCLUSION

DSF has its potential for energy efficiency in office buildings in Phnom Penh city. The results of the study show that the system contributes to a better energy performance by reducing the annual end-use and cooling energy demand in the studied building. Nevertheless, a proper design of DSF is required to avoid the unexpected issues on building envelopes such as excessive solar radiation and thermal transfer into the space. The recommended configurations of DSF parameters for office buildings in Pnom Penh city are 500 mm cavity depth, bronze laminated glass for the internal, and external layers of DSF, and external blind louvre to achieve as minimum as 34% saving in the annual energy demand.

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7. REFERENCES

Aksamija, A. (2009). Context-Based Design of Double Skin Facades: Climatic Considerations during the Design Process. Perkins+ Will Research Journal, 1(1).

Arons, D. M. (2000). Properties and Applications of Double-Skin Building Facades (Doctoral dissertation, Massachusetts Institute of Technology).

Author, L. & Pollard, B. (2000). Double Skin Façades More Is Less? In Proc. Int. Sol. Energy Soc. Conf (Vol. 21, pp. 1-25).

Azarbayjani, M. (2014). Comparative Performance Evaluation of a Multistory Double Skin Façade Building in Humid Continental Climate. In ARCC Conference Repository.

Baldinelli, G. (2009). Double Skin Façades for Warm Climate Regions: Analysis of a Solution with an Integrated Movable Shading System. Building and Environment, 44(6), 1107-1118.

BBRI (2005). Ventilated Double Facades - Classification and Illustration of Facade Concepts: Department of Building Physics, Indoor Climate and Building Services

Cambodia National Energy Statistics. (2016). Ministry of Mines and Energy, Cambodia and Economic Research Institute for ASEAN and East Asia, 2016. http://www.eria.org/RPR_FY2015_08.pdf

Chan, A. L. S., Chow, T. T., Fong, K. F. & Lin, Z. (2009). Investigation on Energy Performance of Double Skin Facade in Hong Kong. Energy and Buildings, 41(11), 1135-1142.

Gavan, V., Woloszyn, M., Roux, J. J., Muresan, C. & Safer, N. (2007). An Investigation into the Effect of Ventilated Double-Skin Facade with Venetian Blinds: Global Simulation and

Assessment of Energy Performance. In Proc. of X IBPSA Conference BS (pp. 127-133).

Ghaffarianhoseini, A., Berardi, U., Tookey, J., Li, D. H. W. & Kariminia, S. (2016). Exploring the Advantages and Challenges of Double-Skin Façades (DSFs). Renewable and Sustainable Energy Reviews, 60, 1052-1065.

Haase, M. & Amato, A. (2006). Design Considerations for Double-Skin Facades in Hot and Humid Climates. Envelope Technologies for Building Energy Efficiency Vol.II-5-1.

Haase, M. & Amato, A. (2009). A Study of the Effectiveness of Different Control Strategies in Double Skin Facades in Warm and Humid Climates. Journal of Building Performance Simulation, 2(3), 179-187.

Hendriksen, O. J., Sorensen, H., Svenson, A. & Aaqvist, P. (2000). Double Skin Façades—Fashion or a Step towards Sustainable Buildings. Proceedings of ISES, Eurosun, 2000.

Hien, W. N., Liping, W., Chandra, A. N., Pandey, A. R. & Xiaolin, W. (2005). Effects of Double Glazed Facade on Energy Consumption, Thermal Comfort and Condensation for a Typical Office Building in Singapore. Energy and Buildings, 37(6), 563-572.

Hong, T., Kim, J., Lee, J., Koo, C. & Park, H. S. (2013). Assessment of Seasonal Energy Efficiency Strategies of a Double Skin Façade in a Monsoon Climate Region. Energies, 6(9), 4352-4376.

Lee, E., Selkowitz, S., Bazjanac, V., Inkarojrit, V. & Kohler, C. (2002). High-Performance Commercial Building Façades. Building Technologies Program, Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory (LBNL). University of California, Berkeley, USA (LBNL–50502) Web address: http://gaia. lbl. gov/hpbf/documents/LBNL50502. pdf.

Oesterle, E., Leib, R. D., Lutz, G. & Heusler, B. (2001). Double Skin Facades: Integrated Planning: Building Physics. Construction, Aerophysics, Air-Conditioning, Economic Viability, Prestel, Munich.

Poiraziz, H. (2004) Double Skin Facades for Office Buildings. Division of Energy and Building Design Department of Construction and Architecture Lund Institute of Technology Lund University, 2004 Report EBD-R--04/3

Rahmani, B., Kandar, M. Z. & Rahmani, P. (2012). How Double Skin Façade's Air-Gap Sizes Effect on Lowering Solar Heat Gain in Tropical Climate? World Applied Sciences Journal, 18(6), 774-778.

Regazzoli, A. (2013). A Comparative Analysis on the Effect of Double- Skin Façade Typologies on Overall Building Energy Consumption Performance in a Temperate Climate. Supervisor: Rory Greenan.

Safer, N., Woloszyn, M. & Roux, J. J. (2005). Global Modelling of Double Skin Facades Equiped with Venetian Blind Model Based on CFD Approach. In CISBAT 2005.

Sinclair, R., Phillips, D. & Mezhibovski, V. (2009). Ventilating Façades. ASHRAE Journal, 51 (4), pp. 16-27

Streicher, W. (2005). WP 1 Report 'State of The Art', BESTFAÇADE, Best Practice for Double Skin Façades (Vol. 7, p. 38652). EIE/04/135.

Uuttu, S. (2001). Study of Current Structures in Double-Skin Facades. MSc thesis in Structural Engineering and Building Physics. Department of Civil and Environmental Engineering, Helsinki University of Technology (HUT), Finland. Web address:

http://www.hut.fi/Units/Civil/Steel/SINI2.PDF

Wong, P. C., Prasad, D. & Behnia, M. (2008). A New Type of Double-Skin Façade Configuration for the Hot and Humid Climate. Energy and Buildings, 40(10), 1941-1945.

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