PLEA 2017 EDINBURGH

Design to Thrive

Skycourt as a ventilated buffer zone in office buildings: assessing energy performance and thermal comfort

Saba Alnusairat[1], Phil Jones[1] and Shan Shan Hou[1]

[1] Welsh School of Architecture, Cardiff University, UK, alnusairatsf@cardiff.ac.uk

Abstract: Skycourts, recently, have been considered as beneficial spaces in commercial buildings, in particular offices. Skycourts are perceived as spaces that act as transitional and recreational nodes. Research considering the performance in response to conditions in these regions is steadily growing. However, there is a lack of conclusive results in the available literature about the actual energy performance of these spaces. The primary purpose of this paper is to examine the potential of the skycourt to perform as a buffer zone that suits to the ventilation strategy in office buildings in a temperate climate, thus could potentially reduce energy demands for heating and cooling, furthermore ensure thermal comfort in these spaces. Using a hypothetical reference office building in London, coupled Building Energy Simulation (BES) and Computational Fluid Dynamics (CFD) are carried out for two ventilation modes; mode one, the base model represents skycourt with isolated mechanical ventilation and mode two, alternative models that incorporate combined ventilation strategies with the adjacent offices' zones of the skycourt. These are simulated and evaluated regarding energy consumption and thermal comfort. Overall, the simulation results highlight that the incorporation of skycourt as buffer zone can potentially have a significant impact on the annual energy consumption.

Keywords: Skycourt, Buffer zone, Coupling simulation, Office buildings

Introduction

Skycourt is acknowledged nowadays as a beneficial space in buildings. This integrated area offers a modern alternative to the vernacular courtyard or atrium thus could support the social, environmental and economic functions in offices. For example, it can operate as common public space for social interaction, relaxation and leisure in areas, where there is usually lack of engagement between occupants. As well as, it might function as a transitional space to facilitate ease movement and clearness of wayfinding. Skycourt perhaps provides segmentation barriers between spaces. In addition, it can be integrated into the architectural design to benefit from the natural energy sources such as sun and wind to allow views and daylighting, and facilitate ventilation. Thus, it could provide significant outcomes of conserving energy and improving the health and wellbeing of occupants. Moreover, a skycourt could perform as buffer zone between the indoor and the outdoor consequently could mediate the climate conditions, provide thermal and acoustic protection to the interior, reduce heat loss and avoid unwanted solar gain. A growing body of literature has studied the influence of various integrated elements on the performance of buildings, such as skycourts (Ghazali et al, 2014; Pomeroy, 2014; Taib et al, 2010; Etheridge and Ford, 2008; Yeang, 1999). However, the weakness of current studies is the limitations in addressing the impact of such elements by its own on the total performance of the building.

This paper presents an independent study for the office's buildings in temperate regions, represented by London City underlines the function of skycourt as a buffer zone that located between the external façade and indoor controlled office zones, which are subject to mechanical ventilation. Heating and cooling processes consume approximately third of energy use in office buildings (Wood and Salib, 2013). Therefore, minimising energy demand by developing efficient strategies for ventilation, heating and cooling is crucial. This paper focuses on the potentials of skycourt to accomplish energy efficient solution stressing reduction of heating and cooling loads besides ensures thermal comfort in these spaces. It suggests several ventilation strategies relies on the fresh air required for the adjacent office's zones. The air movement causes convective heat transfer inside the skycourt under the buoyancy difference due to variation in temperature and height between the regions of the skycourt. This mechanism could induce thermal comfort significantly cooling without the need for consuming heating neither cooling loads for skycourt.

Methodology

Coupled Building Energy Simulation (BES) and Computational Fluid Dynamic (CFD)

Numerical simulations including Building Energy Simulation (BES) and Computational Fluid Dynamics (CFD) can provide a useful and quick prediction for the thermal conditions and energy performance of buildings. However, there are limitations in using these methods separately. Coupling BES and CFD simulation have generated considerable recent research interest. In this technique, two interrelated models are integrated to produce complementary detailed information by exchanging boundary conditions data. See Figure 1.

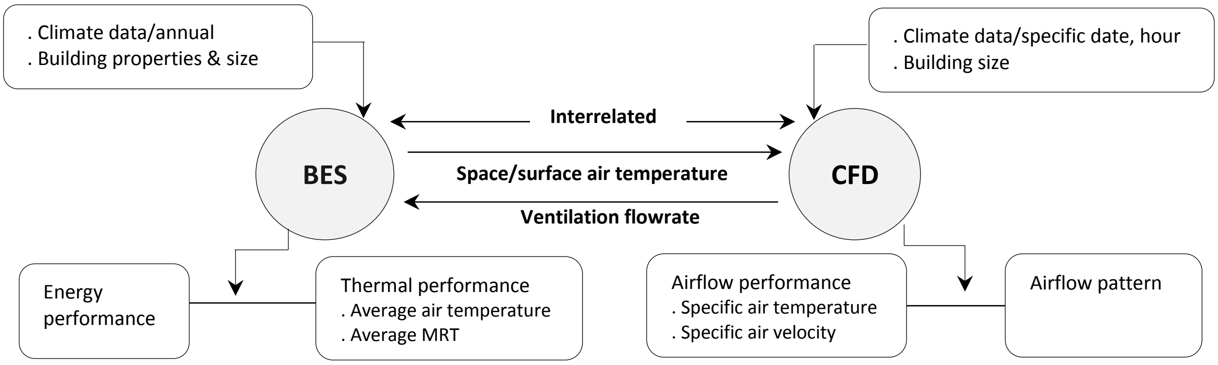


Figure 1. Diagram shows the BES and CFD coupling models

Coupling simulation is highly recommended in ventilation studies due to its accuracy and efficiency. This method could improve prediction of cooling and heating load at least 10% (Zhai et al, 2002). Furthermore, it might eliminate simulation time cost and requirements; it is found that full CFD requires about 12 hours with parallel workstation while coupling CFD requires less than one hour with 1 Gbytes computer to evaluate the same indoor environment (Wang and Wong, 2009). Integration between BES and CFD has been optimised with other numerical methods, theoretical analysis and experimental work. That is exemplified in the works undertaken by Barbason and Reiter (2014); Cropper et al (2010); Wang and Wong (2008); Zhai and Chen (2005); Zhai and Yan (2003); Bartak et al (2002). The validation showed that iteration between BES and CFD could produce correct and converged solutions and inform accurate and efficient prediction for thermal and airflow pattern in short time. Consequently, coupling could be considered as an advanced simulation tool to test the environment of different buildings.

The study aims to investigate the influence of several ventilation strategies in the skycourt space and compare the results regarding thermal comfort at the occupancy level and the energy consumption for heating and cooling. Therefore, coupling model is carried out to predict the performance. The building energy model, HTB2 and the airflow model, WinAir were integrated into the study. The ''Heat Transfer through Building'' (HTB2) was developed by the Welsh School of Architecture (WSA), Cardiff University. This numerical model can predict the indoor thermal performance and estimate the energy demands for buildings (Lewis and Alexander, 1990). HTB2 is recommended due to its high validity since it has been developed over thirty years. Furthermore, it has undergone a series of extensive testing including the IEA BESTEST (Neymark et al, 2011), IEA Task 12 (Lomas et al, 1994) and IEA Annex 1 (Oscar Faber and Partners, 1980) and. Also, it has been validated under ASHRAE standards and used to develop benchmarks for other standards (Alexander and Jenkins, 2015). Coupling HTB2 with WinAir as a CFD can accomplish graduating and accurate information of air temperature, air velocity and air concentration showing the airflow pattern in the skycourt. External coupling is adopted in this study; two models were built separately, a schematic model in the HTB2 and a grid model in the WinAir. The static strategy is carried out to bridge the two models; the thermal conditions for the CFD model are obtained from previously calculated values from the HTB2. These include the surfaces heat transfer, the inlet air supply, the outlet air exhaust and the internal heat gains involved inside the skycourt.

Coupling Simulation

The model is simplified to an eight-storey office building located in temperate climate represented by London. This building combines six-storey skycourt, the hollowed-out pattern. See Figure 2.

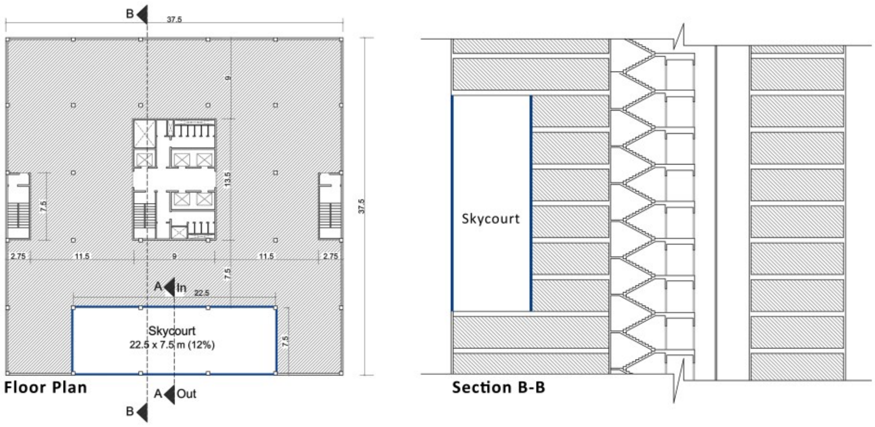


Figure 2. The spatial configurations of skycourt (the white shaded zone) considered in the study

Modelling framework

The simulation is carried out all over the year under different seasons: summer, winter and mid seasons using the HTB2. However, the CFD is measured considering the climate data for the peak summer hour, the coldest winter hour and the mid-temperature hour. These combine the following parameters: the hottest external temperature is 28.3°C on June 28th at 14.00, while the coldest external temperature is -5.0°C on December 7th at 9.00 am. The mid-temperature is 13.2°C on April 19 at 9.00 am. The adapted settings and conditions of the simulation process are defined in Table 1. Similar conditions are conducted for the six models except for the ventilation mode. However, the minimum ventilation rate to maintain an accepted air-quality is defined based on the number of occupants and taking into consideration the building envelope airtightness (infiltration). In the simulation, the heating set point is 18°C, and the cooling set point is 25°C. Single set point controls are used for cooling in the offices, while heating is controlled by air handling unit.

Table 1. Simulation settings for office spaces

Internal heat gain*		Building Fabric		Ventilation setting	
Workplace density	12 m^2 /person	Glazing U-value	1.5 (W/m^2.C)	Infiltration rate	3.5 m^3/(m^2.hr) at 50Pa
		g-value	0.4		
People	12 w/m^2	Window to wall ratio	70%	Air supply rate	10 L/s per person
Equipment	15 w/m^2	External wall U-value	0.18 (W/m^2.C)	Heating set-point	18°C
Lighting	12 w/m^2	Internal wall U-value	0.22 (W/m^2.C)	Cooling set- point	25°C
		Floor/ceiling U-value	0.20 (W/m^2.C)	Operating time	08:00-18:00

*Occupancy profile: the building occupied five days a week, based on the following schedule, for offices 09:00-13:00 occupied 100%, 13:00-14:00 occupied 70%, 14:00-18:00 occupied 100%. For Skycourt 09:00-18:00 occupied 100%

The ventilation strategies

The study was carried out in two ventilation manners,

1. The base case, this represents the current practice, which considers isolated mechanical heating, cooling and ventilation for the skycourt. The base model is used as a benchmark reference to compare the energy and thermal performance when other ventilation strategies are applied. See Figure 3

Skycourt is ventilated isolatable

Base Case (BC)

skycourt and adjacent offices are mechanically ventilated, heated and cooled separately

. Air change rate for offices is 3.1 ac/h at 18° C
. Air change rate for skycourt is 0.167 ac/h at 18°C

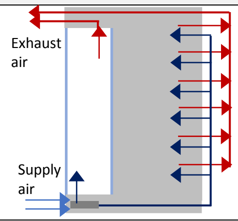


Figure 3. Proposed ventilation strategy for the base case - mode one

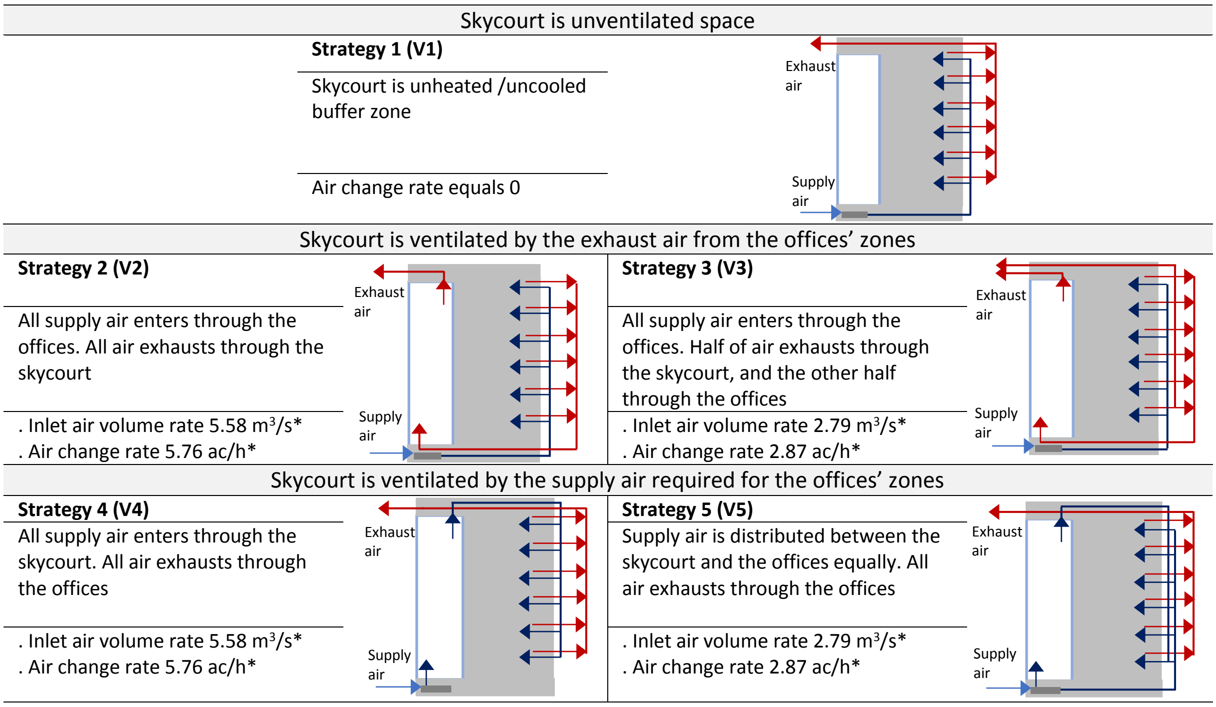
2. Skycourt as a buffer area that does not consume energy for heating either cooling. Five ventilation strategies are suggested to mediate the internal environment of the skycourt depending on the required fresh air for the adjacent offices as air supply or air exhaust. These combined strategies are categorised into three principles. First, skycourt is a sealed space. Second, the exhaust air from the offices mediates the skycourt. Finally, skycourt is ventilated by the supply fresh air required for the offices. Simulation is carried out to nominate the optimum approach. Figure 4 illustrates the principles, air movement and simulation settings for the proposed strategies.

Results and Discussion

The energy demand for heating and cooling of the building and the thermal comfort conditions at the occupancy level of the skycourt are taken as criteria of comparison. Thus to define the optimum ventilation strategy.

Energy performance comparison

The results obtained from the BES of the monthly heating, cooling, solar, fabric, ventilation and power loads for the skycourt are shown in Figure 5 . It is apparent from the charts that the power and solar gain are the same due to similar simulation settings.



Skycourt is unventilated space

Strategy 1 (V1)

Skycourt is unheated /uncooled buffer zone

Air change rate equals 0

Skycourt is ventilated by the exhaust air from the offices' zones

Strategy 2 (V2)

All supply air enters through the offices. All air exhausts through the skycourt

. Inlet air volume rate 5.58 m³/s*
. Air change rate 5.76 ac/h*

Strategy 3 (V3)

All supply air enters through the offices. Half of air exhausts through the skycourt, and the other half through the offices

. Inlet air volume rate 2.79 m³/s*
. Air change rate 2.87 ac/h*

Skycourt is ventilated by the supply air required for the offices' zones

Strategy 4 (V4)

All supply air enters through the skycourt. All air exhausts through the offices

. Inlet air volume rate 5.58 m³/s*
. Air change rate 5.76 ac/h*

Strategy 5 (V5)

Supply air is distributed between the skycourt and the offices equally. All air exhausts through the offices

. Inlet air volume rate 2.79 m³/s*
. Air change rate 2.87 ac/h*

*these settings are defined for the skycourt ventilation process

Figure 4. Proposed ventilation strategies for the skycourt for mode two

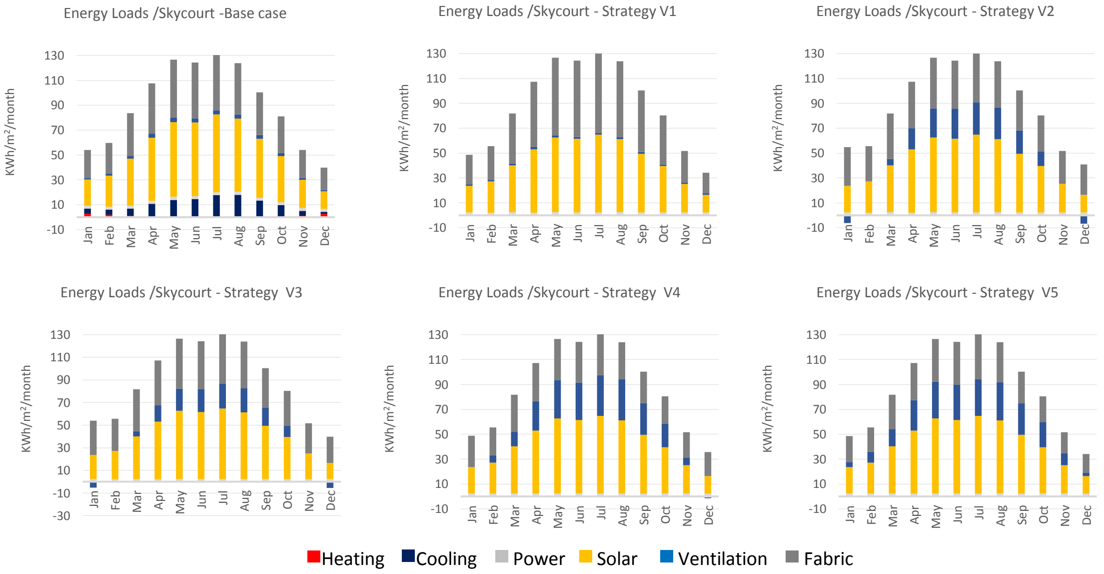


Figure 5. Results of the monthly heating, cooling, solar, fabric, ventilation and power loads for skycourt

In addition, it is seen that strategy two, three, four and five account high ventilation load due to the airflow mechanism. However, as ventilation load increases, fabric load decreases. Strategy one records the least ventilation loss by 17.94KWh/m²/year and the highest fabric loss by 522.63 KWh/m²/year. Strategy two and three account less ventilation load (138.83KWh/m²/year and 117.0 KWh/m²/year) correlated to strategy four and five (216.37 KWh/m²/year and 227.03 KWh/m²/year). That is due to the temperature difference of the inlet air to the skycourt. It is higher in the previous two cases. The results, as shown in Figure 6, indicate that the proposed ventilation strategies account almost 50% reduction in the total annual energy demand for heating and cooling in comparison to the base case. In strategy two, the demand is reduced from 220KWh/m^2/year to 91.9 KWh/m^2/year for each floor. Strategy four and five report higher demand than strategy one, two and three. From this figure, it is clear that less inlet airflow rate requires more heating and cooling demand. The strategies account sequentially the following demand 94.33, 91.9, 93.21, 110.05, 98.30 KWh/m^2/year.

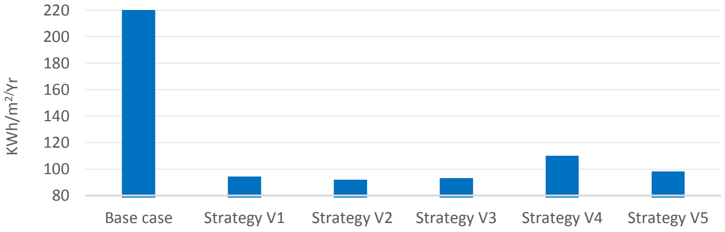


Figure 6. Results of the annual heating and cooling demand

Thermal performance of skycourt comparison

The CFD results predicting the thermal conditions -air temperature gradient (°C) and air speed (m/s) in the skycourt in several seasons are demonstrated in Figure 7. Cross-section location (A-A) is shown in Figure 2. The comfort criteria recommended by the British Council for Offices (BCO) guide (2014) is adapted to verify the thermal conditions at the occupancy level of the skycourt (air temperature ranges in summer 24°C ± 2°C, in winter 20°C ± 2°C and airspeed ranges between 0.1m/s and 0.2m/s). It is evident that the skycourt cannot be considered a thermal comfort space without inlet airflow. The indoor air temperature in summer for strategy one is very high and reaches 50°C at the hottest hour, on the other hand, it is extremely cold in winter with average 8°C at the coldest hour. In additions, the results show that the skycourt is thermally comfortable in transitional seasons. However, the indoor air quality is not satisfied.

The air temperature in the skycourt at summer when adopting strategy two ranges between 25.0°C and 32.0°C in the whole skycourt space, and about 26.0°C of 0.2m/s average air speed at the occupancy level. At the coldest hour, the temperature graduated from 14.2°C to 19.9°C with 0.3m/s. This range might not provide the required comfort degree in winter. However, it is the best temperature recorded between the proposed ventilation strategies in winter. On the other hand, reducing the airflow volume rate inside the skycourt as suggested in strategy three causes raise the air temperature in summer and decline in winter. At peak hour, the temperature increases from 25.0°C to 29.0°C of 0.14m/s, whereas at a cold hour from 12.8°C to 19.7°C of 0.36m/s airspeed. Considering the skycourt as a space for mediating the air temperature before entering the offices' zones as suggested in strategy four, accounts the most comfort conditions in summer peak time. Air temperature ranges between 23.3°C and 26.5°C and air speed records 0.22m/s. Whereas, when the external air temperature is -5.1°C, the temperature inside the skycourt ranges from 13.4°C to 17.9°C with 0.28m/s. Strategy five accounts 27.6°C to 31.5°C with 0.14m/s at summer peak hour and 11.9°C to 17.7°C with 0.32m/s at the coldest hour. The simulation at a normal hour in spring accounts the following results for the skycourt at the occupancy level; 22.7°C, 0.06m/s for strategy one, 22.1°C, 0.17m/s for strategy two, 22.0°C, 0.1m/s for strategy three, 19.0°C, 0.18m/s for strategy four and finally 18.8°C, 0.12m/s for strategy five.

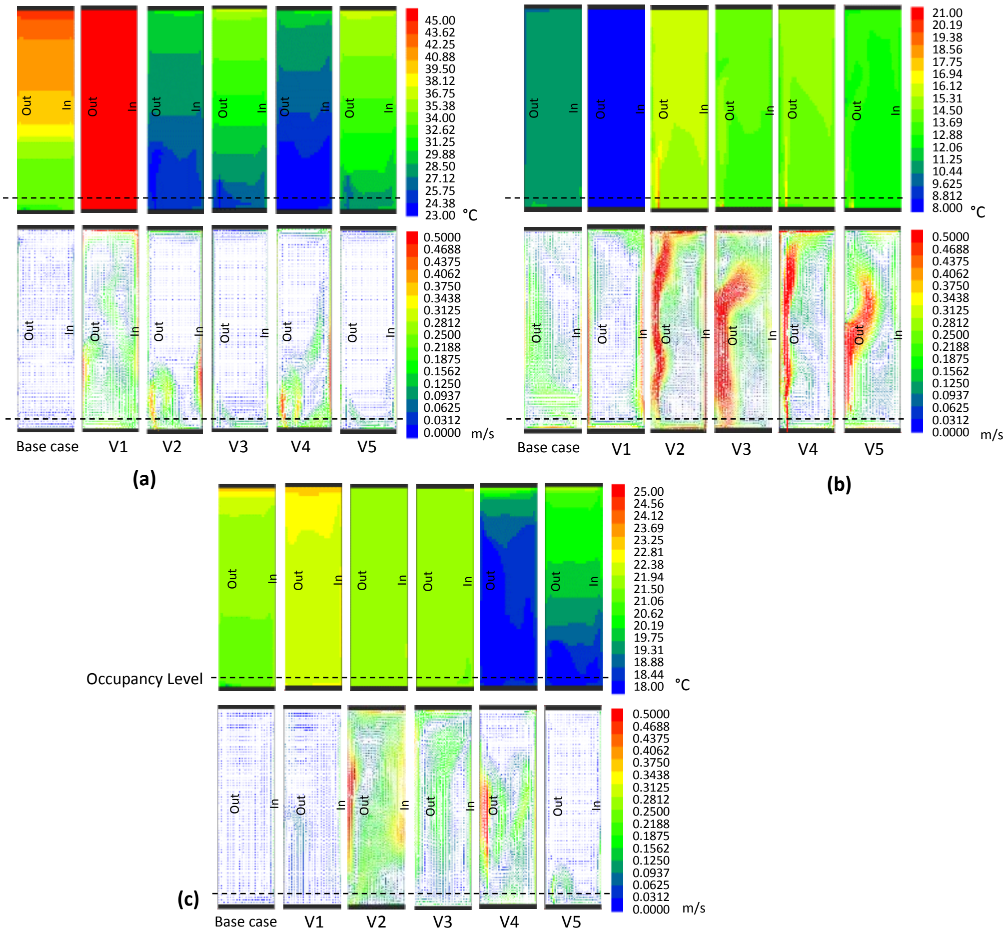


Figure 7. Results of the thermal conditions in skycourt at (a) the hottest hour in summer, (b) the coldest hour in winter and (c) the typical hour in mid-season

Discussion

The simulation results indicate that integration of skycourt in an office building as a space adopts isolated mechanical ventilation increases extremely the total energy demand significantly the cooling loads. In this case, air temperature seems to be comfortable at the occupant level of the skycourt. However, the supply air rate is considered low and might not be efficient due to the height of the skycourt. However, the simulation results highlight that the combined ventilation strategies for the skycourt show potential for energy saving and thermal comfort nevertheless differently. The findings of the study show that the optimum ventilation strategy to minimise the requirements of energy besides ensuring the thermal comfort at the skycourt is strategy two.

Conclusion

The paper has discussed the thermal and energy performance of a skycourt when incorporated as a buffer zone in an office building. Several ventilation strategies based on the concept that skycourt is a non-cooled and unheated space -does not consume energy for cooling either heating- are investigated to mediate the internal thermal conditions of the skycourt. These ventilation systems were developed depending on the required fresh air for the adjacent offices of the skycourt as air supply or air exhaust. The results indicate that a combined ventilation strategy for the skycourt enhances the energy saving for the building and provides advantages on occupants' thermal comfort. A ventilation strategy that depends on the maximum airflow volume rate exhausted from the adjacent offices to the skycourt has a significant effect on cooling the skycourt space. In addition, it can achieve about 58% heating and cooling energy saving compared with mechanical heating and cooling. Furthermore, this strategy could affect the nearby offices positively in terms of reducing heating and cooling demand and providing shading. In addition, the study found that coupling models (HTB2 and CFD-WinAir) provides an efficient prediction of the indoor environment for the skycourt.

Acknowledgement

The authors would like to thank Al-Ahliyya Amman University, Jordan for funding this research.

References

Alexander, D.K., Jenkins, H.G. (2015). The validity and reliability of co-heating tests made on highly insulated dwellings. Energy Procedia, 78, pp. 1732–1737

Barbason, M., Reiter, S. (2014). Coupling building energy simulation and computational fluid dynamics: application to a two-storey house in a temperate climate. Building and Environment, 75, pp. 30–39

Bartak, M., Beausoleil-morrison, I., Clarke, J.A., Denev, J., Drkal, F., Lain, M. (2002). Integrating CFD and building simulation. Building and Environment, 37, pp. 865–871

British Council for Offices (BCO) (2014). Guide to Specification 2014: Best Practices in the Specification for Offices. 6th Edit. London: British Council for Offices

Cropper, P.C., Yang, T., Cook, M., Fiala, D., Yousaf, R. (2010). Coupling a model of human thermoregulation with computational fluid dynamics for predicting human – environment interaction. Journal of Building Performance Simulation, 3 (3), pp. 233-243

Etheridge, D. and Ford, B. 2008. Natural ventilation of tall buildings - options and limitations. In: Council on Tall buildings and Urban Habitat CTBUH 8th World Congress, Dubai, UAE, 3 - 5 March 2008.

Ghazali, M. et al. 2014. The 'Sky Neighborhood' Layout. International Journal on Tall Buildings and Urban Habitat- CTBUH Journal, II, pp.40-47

Lewis, P.T., Alexander, D.K. (1990). HTB2: A flexible model for dynamic building simulation. Building and Environment, 25, pp. 7–16

Lomas, K.J., Eppel, H., Martin, C., Bloomfield, D. (1994). Empirical validation of thermal building simulation programs using test room data, Volume 1: Final report. International Energy Agency, Energy conservation in buildings and community systems programme. *Watford, UK: Building Research Establishment (BRE Ltd)*

Neymark, J., Judkoff, R., Alexander, D., Strachan, P., Wijsman, A. (2011). IEA BESTEST multi-zone non-airflow in-depth diagnostic cases. In: 12th IBPSA, the Building Simulation 2011 Conference. Sydney, Australia, 14-16 November 2011, U.S. Department of Energy: Office of Scientific and Technical Information

Oscar Faber and Partners (1980). IEA Annex 1 computer modelling of building performance: results and analyses of avonban. St Albans, UK: Oscar Faber and Partners

Pomeroy, J. (2014). The Skycourt and Skygarden: Greening the urban habitat. London: Routledge.

Taib, N. et al. 2010. An Assessment of Thermal Comfort and Users' Perceptions of Landscape Gardens in a High-Rise Office Building. Journal of Sustainable Development 3(4), pp. 153–164

Wang, L., Wong, N.H. (2008). Coupled simulations for naturally ventilated residential buildings. Automation in Construction, 17, pp. 386–398

Wang, L., Wong, N.H. (2009). Coupled simulations for naturally ventilated rooms between building simulation (BS) and computational fluid dynamics (CFD) for better prediction of indoor thermal environment. Building and Environment, 44, pp. 95–112

Wood, A., Salib, R. (2013). Natural Ventilation in High-Rise Office Buildings. London: Routledge.

Yeang, K. (1999). The Green Skyscraper: The Basis for Designing Sustainable Intensive Buildings. Munich: Prestel

Zhai, Z., Chen, Q., Haves, P., Klems, J.H. (2002). On approaches to couple energy simulation and computational fluid dynamics programs. Building and Environment, 37, pp. 857–864

Zhai, Z., Yan, Q. (2003). Solution characters of iterative coupling between energy simulation and CFD programs. Energy and Buildings, 35, pp. 493–505

Zhai, Z.J., Chen, Q.Y. (2005). Performance of coupled building energy and CFD simulations. Energy and Building, 37, pp. 333–344