INFLUENCING FACTORS ON COOLING DEMAND OF HIGH-RISE BUILDINGS IN HOT/HUMID CLIMATES: A REVIEW

BARA ANAYA[1], DANLIN HOU[2], IBRAHIM HASSAN[1], LIANGZHU (LEON) WANG[2] & AZIZ RAHMAN[1]
[1]Texas A&M University at Qatar, Qatar
[2]Concordia University, Canada

ABSTRACT
A significant amount of energy is consumed on cooling buildings in countries that experience hot/humid climates. The increasing demand for high-rise buildings, with their inherent air conditioning systems, adds extra requirements to electricity grids or local district cooling systems. Thus, this work is structured to identify the influencing factors of cooling energy demand in high-rise buildings that are geographically restricted to countries of these climates. The influence of the factor is quantified as its contribution to cooling energy savings when manipulated or optimized. It is found that the average annual cooling reductions are 12%, 24.7%, 18.3%, and 20% with ranges of 3%–27%, 2.6%–60%, 5.6%–30%, and 11%–29% for building typology, envelope, system, and operation factors, respectively. Environmental factors lack quantification in the literature, although they are considered, however their effect is not quantified. In general, most studies considered building typology and building envelope factors which are related to building design, while few studies considered building operation and building system factors. The aforementioned factors and their importance lead to suggestions of conducting more studies on building operational and building system factors as they significantly contribute in cooling energy savings. Since Urban Heat Island (UHI) can cause a change of a city's microclimate which may double the cooling demand, it is listed as one of the essential environmental factors. This review has shown various aspects that are vital in studying building cooling load demand and its related energy performance.
Keywords: cooling load, building energy, high-rise building, humid climate, hot climate, building cooling, high-rise building energy, cooling demand, cooling influencing factors, energy demand.

1 INTRODUCTION

In areas of hot climates, up to 80% of the building electricity is consumed to run cooling systems [1]. For example, in 2016 in Qatar, the electricity consumption reached 85% of the country's capacity [2] and this increase is correlated to the high ambient temperature [3]. In 2015, Kahramaa [4] reported that air-conditioning and residential electrical appliances are the main two sources (representing 60%) of Qatar's high electricity consumption. This is frequently observed in other countries with extremely hot climates, with the highest annual per capita electricity consumption led by Qatar, followed by UAE, Kuwait, Bahrain, the KSA, Oman, and then the middle east, followed by the rest of the world [5]. The high energy consumption on space cooling also includes countries with humid climates, with an estimated 60% of electrical energy used for air-conditioning in Hong Kong, China, during the summer months [6] and up to 48% of the energy used for space cooling in Malaysia [7]. Another energy extensive factor that adds-up to cooling is building altitude. High-rise buildings contribute significantly to energy consumption in buildings which accounts for 40% of the total world energy use [8]. Radhi [9] found that the cooling requirements of a high-rise building is 22% more than a low-rise building at the same occupancy rates. Thus, high-rise buildings that are in hot/humid countries are energy extensive due to their cooling demand. The Council on Tall Buildings and Urban Habitat [10] showed the rapid increase in high-rise building construction through a timeline, considering the Middle East of which up to 98%

WIT Transactions on Ecology and the Environment, Vol 253,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/SC210351

are being constructed in countries classified under hot climates. Also, it reports the rapid urbanization of high-rise building in Shenzhen, China, which has a humid climate. This gives an idea about the severity of the problem when hot climatological areas worldwide acquire high-rise buildings urbanization.

Understanding the factors that influence the cooling energy consumption in high-rise buildings in countries with hot/humid climates is necessary to analyze how to reduce energy consumption. This literature review explores the studies that have addressed the cooling and energy performance of high-rise buildings in the hot/humid climate. It is structured as follows. In Section 2, the selection criterion of articles available in the literature is presented. In Section 3, the categories of influencing factors are presented and analyzed in detail. Then, conclusions are drawn in Section 4.

2 SELECTION CRITERIA OF LITERATURE

In this section, the criteria and basis of selecting the case studies are presented. While in the literature, many studies are assessed for cooling and energy requirements, not all are necessarily relevant due to the variation in the altitude (height) of the building, as well as the climatological conditions of where the building is located. This section describes the selection criteria of the literature used for this review and how they are determined. The first criterion is about climate. In this paper, only the literature focus on a study in a hot/humid climate is analyzed. Owing to the high possession and on-going requirement of high-rise buildings and their unique cooling load/energy performance, the second criterion is about building altitude. This paper will focus on high-rise buildings.

2.1 Hot/humid climates

To determine the areas of hot/humid climates around the world, the Köppen–Geiger climate classification is used [11]. A world map screening is conducted over the different climates according to universal standards, identifying seven climate descriptions according to the Köppen–Geiger world map classification code: Arid/desert Hot climate (BWh), Tropical Rainforest climate (Af), Tropical Monsoon climate (Am), Mediterranean Hot Summer climate (Csa), Humid Subtropical climate (Cfa), Dry-winter Humid Subtropical climate (Cwa), and Hot-summer Continental Climate (Dwa)

2.2 High-rise buildings distribution

The selection of the countries based on climate consideration only is not sufficient since all land is not urbanized. For example, Australia exhibits a wide geographical area that experiences BWh climate. However, this area is a desert that is not subjected to urbanization. Besides the climatic classification, urbanization with high-rise buildings is taken as another criterion. Hereby, a definition of a high-rise building is set according to Knoke [12] which gives a range of 23–30 m of the available fire-fighting equipment altitude as a measure to define a high-rise building. Cities with high-rise buildings in countries that experience BWh climate are identified to be those with up to 970 of 150+ m buildings, along with considering cities that are extremely humid such as Hong Kong (Cfa climate with up to 364 of 150+ m buildings), Shenzhen (Cfa climate with up to 394 of 150+ m buildings) and Kuala Lumpur (Af climate with up to 122 of 150+ m buildings) [13].

3 CASE STUDIES OF HIGH-RISE BUILDINGS AT HOT/HUMID CLIMATE

This section is structured to focus on analyzing and identifying the influencing factors on cooling loads and energy consumption of studies identified to meet the criteria of considering high-rise buildings in hot/humid climates. As shown in Fig. 1, the main categories of factors can be summarized as building typology, building envelopes, building systems, building operation factors, and climatological factors. The significance of each factor influencing the cooling loads in each study is reflected in the factor order. The influence of the factor is quantified as its contribution to cooling energy savings when manipulated.

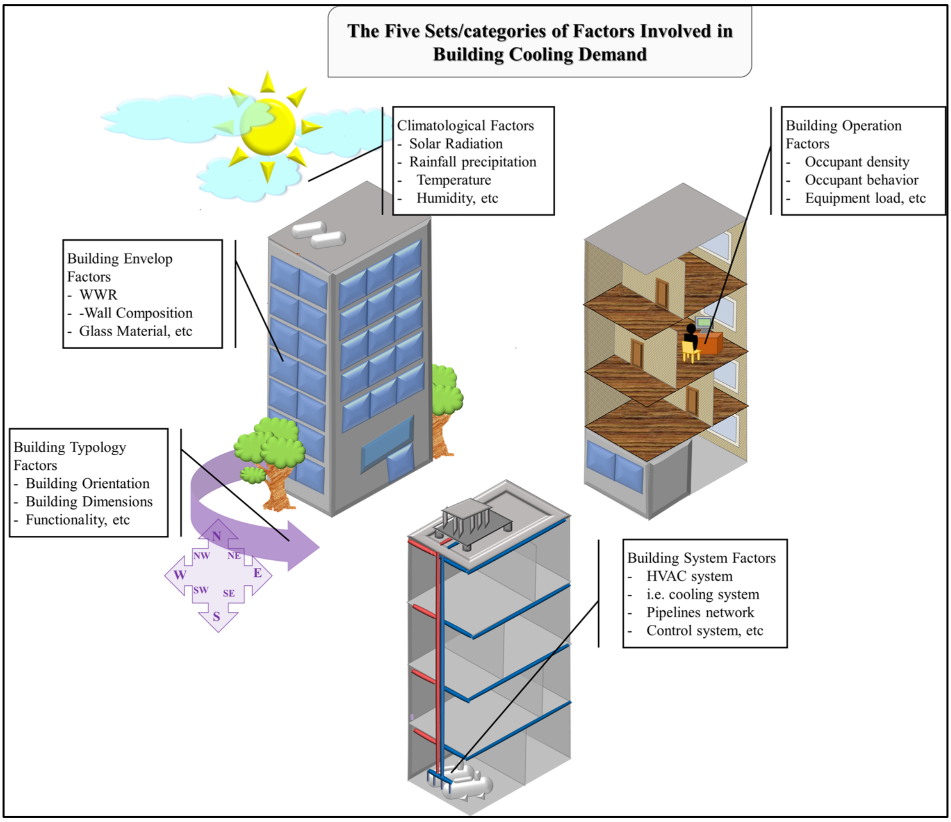

Figure 1: The five categories of factors involved in high-rise buildings cooling demand used in this review.

3.1 Building typology factors

Examples of building typology factors are the total floor area, floor height, shape, orientation, aspect ratio, shading (can be a building envelope factor upon relevance), building function, etc. Building shape is one factor that is analyzed by AlAnzi et al. [13] who found that window to wall ratio (WWR), which is the ratio of the surface areas of the windows to the wall of a given building, is independent of building shape at 0% and 50%. Also, the relative compactness (RC) of the building, which is defined as the ratio of the building volume to its surface area, is found to be inversely proportional to its cooling load for all buildings' shapes where a decrease in RC from 0.99 to 0.17 increases cooling energy to 115% and 90% building energy. Also, Ourghi et al. [14] found that cooling loads and total energy decrease with the increase in building RC, WWR, SHGC. Friess and Rakhshanb [15] concluded that better performances are recorded by the square compact buildings relative to elongated ones. Window to Floor area ratio (WFR) is another shape-related factor that is addressed in several studies which can be defined as the ratio of the surface areas of windows to floor of a given building. Cheung et al. [16] verified the effect of increasing WFR from 10% to 40%, showing 12.8% and 10.4% reductions in annual and peak cooling loads, respectively. Also, both loads showed a linear increase with WFR, i.e., a 1.3% increase in annual cooling load is found for every 10% increment increase in WFR. Raji et al. [17] showed that when using Y plan shape instead of ellipse plan shape, the total energy consumption can increase by 15.7% and 12.8 in Cfa and Af, respectively. For the plan depth, its impact is less significant in Cfa (around 6% increase in total energy consumption), while for Af, its impact can increase to 8.8%, and the suggested depth is from 1:1 to 3:1. It is also concluded that, for the factor of building orientation, its impact on energy consumption has no particular significance among the different climates. Krem et al. [18] found that the position of the vertical structural core/wall, the aspect ratio, and shape of the floor plan (central, edge, half sides, and sides) represent significant impacts. The factors presented in the previous two studies belong to building typology and envelope parameters, showing that these two categories are dependents in influencing the cooling loads.

Shading and orientation are two other factors that affect the cooling loads in building, as they help in controlling the amount of solar irradiation received by the buildings. Cheung et al. [16] found that the wing wall can reduce up to 4.6% and 4.9% of the annual and peak cooling loads, respectively, and the overhang can reduce up to 2.9% and 3.2% of the annual and peak cooling loads, respectively. Friess and Rakhshanb [15] indicated that delicate attention should be given to the length to width ratio, orientation, and shadings of the buildings in verifying energy requirements for buildings. A peak reduction of up to 9% can be accomplished if overhangs are applied at 1 m depth. Sozer et al. [19] showed how the design parameters, orientation, elements might significantly impact the cooling loads. It is shown that a 38% reduction of cooling loads can be achieved by reducing the WWR, with the reduction reaching up to 57% if made in conjunction with caving and backyards and applying shadings by cables.

Lau et al. [20] found the best performance is by applying the egg-crate type with savings up to 3.4%, followed by vertical and then horizontal shadings. Savings up to 10% are achieved when shadings are applied on all orientations. However, they recommended to apply shading specifically at west and east façades. Building orientation is also addressed by Naamandadin et al. [21] who found that the east and west orientations receive the highest sun intensity that cause high cooling energy consumption using office building located in Malaysia as a case study. Also, Aflaki et al. [22] confirmed that indoor air temperature and relative humidity were influenced by orientation and height through a field study. Chan and Chow [23] investigated the effect of balcony addition at several orientations, finding that a balcony can reduce the annual cooling load by 12% when it faces the southwest, while only 3.4% reduction when it faces the north. The significant effect of building orientation on cooling energy is further confirmed by the study of Du and Pan [24] who verified the building orientation impact on cooling loads at same floor (building height/level), finding a difference of 10% of cooling loads among the two flats of different orientations. Other studies reported savings in cooling loads by considering the building orientation as a stand-alone factor, finding that up to 6.7% can be reduced from the annual cost when the building is reoriented [25]–[27]. Also, building orientation is highlighted in building envelope-based studies. Tibi and Mokhtar [28] highlighted the importance of considering the building orientation while selecting the building glass characteristics. Although building orientation is widely addressed in building energy studies, it shows limited contribution to cooling energy reduction which was the conclusion reported by other studies [29], [30]. As for building functionality factor, Tibi and Mokhtar [31] showed that commercial building requires a higher cooling load when compared on equal bases.

As for building altitude, this is also addressed. Radhi [9] found that the high-rise building requires almost 22% more cooling than the low-rise building when compared at the same occupancy levels. Bruelisauer et al. [32] noticed a significant impact of building altitude on the stack effect, which could increase the temperature by up to 13 with increasing building altitude. Weerasuriya et al. [33] found that the apartments that are located near the windward side of higher floors have higher energy saving up to 23% relative to the apartments in the middle and lower floors. This conclusion is also confirmed by Du and Pan [24], who considered a number of flats at floors 3 and 39, finding that at higher floors, cooling loads reduce up to 12% due to climatic factors, i.e., wind speed. Also, Du et al. [34] found that electricity bills of apartments on 20th floor and higher are up to 26% lower than those of lower floors due to the different usage of air-conditioning and natural ventilation, i.e., opening windows.

3.2 Building system factors

The building system involves parameters that directly impact the cooling requirements in the building since they involve the cooling system. Parameters of building systems include Heating, Ventilation, and Air Conditioning (HVAC) system, component efficiency, control settings, lighting fixtures, daylight control, etc.

Radhi [9] found that the HVAC system is the most significant energy consumer in the building. Afshari et al. [40] found that the elements that are responsible for satisfying cooling requirements are chillers, pumps, and fans which acquire 47%, 7%, and 7% of total electricity consumption, respectively, leaving cooling requirements with a total of 61% among energy consumption in the building. Deng et al. [41] showed that chilled water system can achieve up to 35% savings with 29% better energy performance by applying systematic optimization of operational and control factors of cooling system and device design selection factors. Sun et al. [42] found that up to 6.6% can be reduced of chiller energy consumption. By altering operational strategies, a difference in the peak cooling loads can reach up to 21%, showing the significant effect of operational factors on cooling loads in high-rise buildings. Attia et al. [43] concluded that the air-conditioning is the main energy consumer for the cooling demand in buildings. The significant contribution of the HVAC system has motivated some studies to develop solutions. Assem and AI-Mumin [44] noted that the heat recovery of the HVAC system during the hot seasons can reduce the cooling requirements by 15% and 18% for water- and air-cooled systems respectively. Shaikh and Chaudhry [45] conducted a numerical investigation of the cooling system performance of a high-rise building in the UAE. The involved cooling system is based on the vapor-compression cycle with the refrigeration system. By the use of a variable speed drive (VSD) fan, which is a type of fans that is designed to slow down or speed up upon necessary, a reduction of 20% in cooling loads is achieved, and an 8% reduction in the overall building energy requirements. The variable refrigerant flow principle is applied to result in a roughly 30% reduction in cooling requirements. The study recommends that a high-rise building that is present in a BWh climate should use a hybrid cooling system to promote energy savings.

3.3 Building envelope factors

In this section, the studies that considered energy performance measures concerning building envelope parameters and building physical characteristics are reviewed. Cleveland and Morris [51] defined building envelope as the layer that physically separates the indoor and outdoor environmental conditions such as air, moisture, heat, light, etc.

Glass-related characteristics such as type, SHGC, WWR, U-Value, spacing manner, etc., contribute greatly in building energy consumption on cooling due to high solar gains [35], [36]. Hassan and Al-Ashwal [37] showed that the lower the shading coefficient value, the lower the cooling energy consumption and peak load. Double Low-E glass can perform best with the cooling energy reduction of 19% and peak cooling reduction of 30%. While using single tinted glass can decrease the cooling energy and peak cooling by 9.5% and 10.0%. On the other hand, it is worth mentioning that reducing this value also reduces the saving related to lighting energy [38]. As shown in savings, up to 30% can be achieved in peak cooling in a tropical climate (Malaysia, Af climate). Cheung et al. [16] identified several glazing systems of which up to 4.6% and 4.9% of annual and peak cooling loads can be reduced, respectively. For the same climate, Bojic et al. [25], [26], and Bojic and Yik [27] studied several aspects of glazing types under the influence of solar absorptance and orientation, finding that up to 10% and 11% can be reduced from annual and peak cooling loads, respectively. Chan and Chow [23] varied the glazing type in their study, namely, clear glass, absorptance glass, and reflective glass. The results show that the clear glass shows the best performance in terms of reducing annual cooling load with 12% followed by the reflective glass of 8% with a southwest facing balcony. Since the performance of the same glass type would be different when coupled with different orientation balcony, this study further confirms various influencing factors should be considered together to attain the best energy saving performance. Cheung et al. [16] showed that as solar absorptance increase the cooling loads decrease after a value of 0.5. Wall insulation has a direct effect on building temperature as the insulation layer can be used to control the building heat transferee via building envelope [39]. Al-Tamimi [29] and Al-Tamimi and Fadzil [30] presented the effect of using Extruded Polystyrene (EPS) in thermal insulated wall on annual and peak cooling loads. They studied the effect of increasing the thickness of the EPS thermal insulation on annual and peak cooling loads reductions, showing reduction at ranges of 8.4% to 10.0% and 20.2% to 26.3%, respectively. Hassan and Al-Ashwal [37] reported that as the insulation thickness increases, the annual cooling reduces. Up to 18% in annual cooling reduction is achieved by increasing the thickness of the 25 mm thermal insulation of the external wall by the double. Also, a reduction in peak cooling of 22% is encountered at 25 mm that can reach up to 29% when increased to 100 mm. Cheung et al. [16] tested insulation at several thicknesses ranging from 0 mm to 100 mm and found that the maximum reductions achieved are 19.4% and 29.2% for annual and peak cooling loads, respectively, when 100 mm insulation is applied. Bojic et al. [25], [26] and Bojic and Yik [27] studied the effect of the several positions which showed reductions in annual and peak cooling load of 38% and 16% respectively. On the other hand, it showed increase in peak cooling load of 19% of other case, depending on the layers and position of insulation layers on the walls. WWR is another building envelope factor that is widely addressed in literature due to its overwhelming influence on cooling loads. Sozer et al. [19] indicated that reducing WWR resulted in a 38% reduction in cooling loads. Afshari et al. [40] showed a minor difference in peak load percentage reduction of 4.2% and 3.6%, respectively. By comparing these results to the conclusion of the data presented by Tibi and Mokhtar [28], it can be concluded that the lower the SHGC and U-values, the more cooling reduction is obtained.

3.4 Building operation factors

One of the key parts for improving building performance and for reducing energy consumption is building operations [46]. It includes parameters that directly impact building energy consumption. Parameters of building operation involve schedules, plug and process loads, lighting densities, ventilation needs, occupancy details such as number, ages, etc. Among building operation parameters, the occupant's behavior aspect is presented by Friess and Rakhshanb [15] for a high-rise building, reporting a reduction in cooling loads up to 29% when the temperature set point is increased by occupants from 22°C to 26°C. This shows the significant role that the temperature setpoint plays.

Natural ventilation is a factor that is controlled by the occupant behavior which affects the cooling loads and consequently total energy consumption. The use of balcony, opening windows in a high-rise residential building as presented by Weerasuriya et al. [33] in Hong Kong (Cfa climate) reveals that up to 27% energy savings can be achieved when wind-driven natural ventilation is used. The authors also reported higher savings that can reach 45% if the wind and buoyancy-driven natural ventilation are facilitated. Unlike the wind-driven ventilation that is recommended for apartments at higher floors, the wind and buoyancy-driven natural ventilation is recommended to occupants who occupy the middle and lower floors. Du and Pan [24] studied the effect of windows' operation on cooling load and found that ventilation that is controlled by occupant behavior is found to have a large impact on cooling loads, with reductions in energy consumption reaching around 11%. This aspect is addressed in humid climates more than in hot climates which is reasonable since one or two seasons of the year are of acceptable weather that allows natural ventilation such as region of BWh climates.

3.5 Environmental factors

The climatological and weather data are vital in determining the building energy efficiency [40], and the cooling energy requirements [47]. They represent the main inputs for simulation, especially for high-rise buildings in BWh climate [19]. Examples of climatological elements are temperature (including dry- and wet-bulb temperatures), humidity and relative humidity, wind speed, wind direction, pressure, rainfall, etc. Afshari et al. [40] found that temperature and relative humidity together are sufficient to represent the BWh climate.

Urban Heat Island (UHI) is a terminology refers to the urban/metropolitan area that is significantly warmer than its surrounding rural areas that is mainly caused due to human activities such as urbanization, affecting back the building's thermal performance. Radhi [9] reported up to 5°C increase in ambient temperature due to UHI effect when examined at arid/desert hot conditions. Palme et al. [48] found that high-rise buildings, for all urban cases, acquire more than double amount of cooling demand, showing that the effect of the building height is dominant over the rural area or different urban layout. Lima et al. [49] concluded that, in a hot climate region, a decrease of direct solar radiation reduces the energy consumption, while the UHI (increase in temperature) increases it. They found that up to 18% in cooling energy reduction is detected mainly due to shading induced by the geometry of the surrounding buildings. Radhi and Sharples [50] reported an increase in consumption of air-conditioning electricity up to 10%, particularly from April to October (summer season).

Giridharan et al. [6] showed that reduction of UHI intensity during daytime can be achieved by increasing the tree cover from the range of 25% to 40%.

4 CONCLUSION

This literature review identified the factors that influence cooling loads of high-rise buildings in the hot/humid climates around the world. The influence of the factor is quantified as its contribution to cooling energy savings when manipulated or optimized. These identified factors can comprehensively assist researchers and engineers to slow down the increase of extensive energy consumption records on the cooling of this specific type of buildings. A selection criterion for both climate and building altitude were defined according to Köppen–Geiger climate classification and buildings above 23 m. Then, the categories of factors were defined and classified under five categories: environmental related data, building typology, building envelope, building system, and building operation data sets.

In this review up to 90 articles are reviewed. All of them focus on studying parameters that influence cooling demand of high-rise buildings at hot/humid climates. Only 30% of these studies quantified the effect of the studied parameter. It is found that the average annual cooling reductions are 12%, 24.7%, 18.3%, and 20% with ranges of 3–27, 2.6–60, 5.6–30, and 11–29 for building typology, envelope, system, and operation factors. However, most studies considered building typology and building envelope factors which are related to building design. while few studies considered building operation and building system factors.

Based on the literature review, the conclusion is drawn that there is a serious requirement in conducting more studies that investigate the effect of building operation and system factors. The building operation and system building factors are found to contribute greatly to cooling energy savings, however, they are found to be understudied; only a few studies consider them. Building operation factors maybe further investigated by conducting on-site surveys and questionnaires since occupant behavior is found to have a dominating effect. Building system factors can be investigated by developing optimization analysis for the cooling systems used or investigate new systems.

ACKNOWLEDGEMENT

This paper was made possible by an NPRP award (#NPRP11S-1208-170073) from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

REFERENCES

[1] Shanks, K. & Nezamifar, E., Impacts of climate change on building cooling demands in the UAE. Paper presented at *SB13 Dubai: Advancing the Green Agenda Technology, Practices and Policies*, Dubai, United Arab Emirates, 2013.
[2] Saffouri, F., Bayram, I.S. & Koc, M., Quantifying the cost of cooling in Qatar, 2018. DOI: 10.1109/IEEEGCC.2017.8448269.
[3] Gastli, A., Charabi, Y., Alammari, R. & Al-Ali, A., Correlation between climate data and maximum electricity demand in Qatar. *IEEE GCC Conference and Exhibition*, November 12–20, Doha, Qatar, 2013.
[4] Kahramaa, Statistics report 2014, Qatar General Electricity and Water Corporation, Doha, Qatar, Tech. Rep., Aug. 2015
[5] Asif, M., Growth and sustainability trends in the buildings sector in the GCC region with particular reference to the KSA and UAE. *Renewable and Sustainable Energy Reviews*, **55**, pp. 1267–1273, 2016. DOI: 10.1016/j.rser.2015.05.042.

[6] Giridharan, R., Ganesan, S. & Lau, S., Daytime urban heat island effect in high-rise and high-density residential developments in Hong Kong. *Energy and Buildings,* **36**, pp. 525–534, 2004.

[7] Chua, S.C. & Oh, T.H., Green progress and prospect in Malaysia. *Renew. Sustain. Energy Rev.* **15**(6), pp. 2850–2861, 2011.

[8] Linxue, L., Shen, X. & Qian, R., Typological evolution of high-rise buildings in terms of thermodynamics and energy formation. *International Journal of High-Rise Buildings*, **4**(2), pp. 127–133, 2015.

[9] Radhi, H., A comparison of the accuracy of building energy analysis in Bahrain using data from different weather periods. *Renew. Energy,* **34**, pp. 869–875, 2009.

[10] Council on Tall Buildings and Urban Habitat (CTBUH), The Skyscraper Center, 2020. https://www.skyscrapercenter.com/.

[11] Peel, M.C., Finlayson, B.L. & Mcmahon, T.A., Updated world map of the Köppen–Geiger climate classification. *Hydrology and Earth System Sciences Discussions, European Geosciences Union*, **11**(5), pp. 1633–1644, 2007. DOI: hal-00305098.

[12] Knoke, M.E., Managing Editor, CPP. High-rise structures: life safety and security considerations. *Protection of Assets Manual*, ASIS International: Alexandria, VA, 2006.

[13] AlAnzi, A., Seo, D. & Krarti, M., Impact of building shape on thermal performance of office buildings in Kuwait. *Energy Conversion and Management*, **50**, pp. 822–828, 2009. DOI: 10.1016/j.enconman.2008.09.033.

[14] Ourghi, R., AlAnzi, A. & Krarti, M., A simplified analysis method to predict the impact of shape on annual energy use for office buildings. *Energy Conversion and Management*, **48**, pp. 300–305, 2005. DOI: 10.1016/j.enconman.2006.04.011.

[15] Friess, W. & Rakhshanb, K., A review of passive envelope measures for improved building energy efficiency in the UAE. *Renewable and Sustainable Energy Reviews*, **72**, pp. 485–496, 2017. DOI: 10.1016/j.rser.2017.01.026.

[16] Cheung, C.K., Fuller, R.J. & Luther, M.B., Energy-efficient envelope design for high-rise apartments. *Energy Build*, **37**, pp. 37–48. DOI: 10.1016/j.enbuild.2004.05.002.

[17] Raji, B., Tenpierik, M.J. & van den Dobbelsteen, A., Early-stage design considerations for the energy-efficiency of high-rise office buildings. *Sustain*., **9**, 2017. DOI: 10.3390/su9040623.

[18] Krem, M., Hoque, S., Arwade, & Breña, S., Structural configuration and building energy performance. *American Society of Civil Engineers*, 2013. DOI: 10.1061/(ASCE)AE.1943-5568.0000103.

[19] Sozer, H., Clark, R. & Elnimeiri, M., Applying traditional architectural rules for energy efficiency and lateral structural stiffness to an 80 story tower. *Energy*, **36**, 4761e4768, 2011. DOI: 10.1016/j.energy.2011.05.010.

[20] Lau, A.K.K., Salleh, E., Lim, C.H. & Sulaiman, M.Y., Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates: The case of Malaysia. *Int. J. Sustain. Built Environ.*, **5**, pp. 387–399, 2016. DOI: 10.1016/j.ijsbe.2016.04.004.

[21] Naamandadin, N.A., Sapian, A.R. & Noor, S.N.A.M., Site planning and orientation for energy efficiency: A comparative analysis on three office buildings in Kuala Lumpur to determine a location for building shading device. *Key Eng. Mater.*, **700**, 247–255, 2016. DOI: 10.4028/www.scientific.net/KEM.700.247.

[22] Aflaki, A., Mahyuddin, N. & Baharum, M., The influence of single-sided ventilation towards the indoor thermal performance of high-rise residential building: A field study. *Energy and Buildings,* **126**, pp. 146–158, 2016.

[23] Chan, A.L.S. & Chow, T.T., Investigation on energy performance and energy payback period of application of balcony for residential apartment in Hong Kong. *Energy Build.*, **42**, pp. 2400–2405, 2010. DOI: 10.1016/j.enbuild.2010.08.009.

[24] Du, J. & Pan, W., Impact of window opening behaviors on cooling load of high-rise residential buildings in Hong Kong. *Proc. Build. Simul. 2019 16th Conf. IBPSA*, **16**, pp. 2403–2410, 2020. DOI: 10.26868/25222708.2019.211418.

[25] Bojic, M., Yik, F. & Sat, P., Influence of thermal insulation position in building envelope on the space cooling of high-rise residential buildings in Hong Kong. *Energy Build.*, **33**, pp. 569–581, 2001. DOI: 10.1016/S0378-7788(00)00125-0.

[26] Bojic, M., Yik, F. & Sat, P., Energy performance of windows in high-rise residential buildings in Hong Kong. *Energy Build.*, **34**, pp. 71–82. DOI: 10.1016/S0378-7788(01)00079-2.

[27] Bojic, M. & Yik, F., Cooling energy evaluation for high-rise residential buildings in Hong Kong. *Energy Build.*, **37**, pp. 345–351, 2004. DOI: 10.1016/j.enbuild.2004.07.003.

[28] Tibi, G. & Mokhtar, A., Glass selection for high-rise residential buildings in the UAE based on life cycle cost analysis. *Energy Procedia*, **62**, pp. 270–279, 2014. *6th International Conference on Sustainability in Energy and Buildings*, SEB-1. DOI: 10.1016/j.egypro.2014.12.388.

[29] Al-Tamimi, N.A.M., Evaluation on cooling energy load with varied envelope design for high-rise residential buildings in Malaysia. *Building*, 2010.

[30] Al-Tamimi, N. & Fadzil, S.F.S., Energy-efficient envelope design for high-rise residential buildings in Malaysia. *Archit. Sci. Rev.*, **55**, pp. 119–127, 2012. DOI: 10.1080/00038628.2012.667938.

[31] Tibi, G. & Mokhtar, A., Glass selection for high-rise buildings in the UAE considering orientation and window-to-wall ratio. *Energy Procedia*, **83**, pp. 197–206, 2015. *7th International Conference on Sustainability in Energy and Buildings*. DOI: 10.1016/j.egypro.2015.12.210.

[32] Bruelisauer, M., Meggers, F., Saber, E., Li, C. & Leibundgut, H., Stuck in a stack: Temperature measurements of the microclimate around split type condensing units in a high-rise building in Singapore. *Energy and Buildings*, **71**, pp. 28–37, 2014.

[33] Weerasuriya, A.U., Zhang, X., Gan, V.J.L. & Tan, Y., A holistic framework to utilize natural ventilation to optimize energy performance of residential high-rise buildings. *Build Environ.*, **153**, pp. 218–232, 2019. DOI: 10.1016/j.buildenv.2019.02.027.

[34] Du, J., Yu, C. & Pan, W., Multiple influencing factors analysis of household energy consumption in high-rise residential buildings: Evidence from Hong Kong. *Building Simulation*, **13**, pp. 753–769, 2020.

[35] Hien, W.N., Liping, W., Chandra, A.N., Pandey, A.R. & Xiaolin, W., Effects of double glazed façade on energy consumption, thermal comfort and condensation for a typical office building in Singapore. *Energy Building*, **37**(6), pp. 563–572, 2005.

[36] Datta, G., Effect of fixed horizontal louver shading devices on thermal performance of building by TRNSYS simulation. *Renewable Energy,* **23**(3–4), pp. 497–507, 2001.

[37] Hassan, A.S. & Al-Ashwal, N.T., Impact of building envelope modification on energy performance of high-rise apartments in Kuala. *Int. Trans. J. Eng. Manag. Appl. Sci. Technol.*, **6**, p. 91, 2015.

[38] Mirrahimi, S., Mohamed, M., Haw, L., Ibrahim, N., Yuopff, W. & Aflaki, A., The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot-humid climate. *Renewable and Sustainable Energy Reviews,* **53**, pp. 1508–1519, 2016.

[39] Wang, Y. & Fukuda, H., The influence of insulation styles on the building energy consumption and indoor thermal comfort of multi-family residences. *Sustainability*, **11**, p. 266, 2019. DOI: 10.3390/su11010266.

[40] Afshari, A., Nikolopoulou, C. & Martin, M., Life-cycle analysis of building retrofits at the urban scale-a case study in United Arab Emirates. *Sustainability,* 2014.

[41] Deng, J., He, S., Wei, Q., Liang, M., Hao, Z. & Zhang, H., Research on systematic optimization methods for chilled water systems in a high-rise office building. *Energy and Buildings,* **209**, 109695, 2020.

[42] Sun, Y., Wang, S. & Xiao, F., In situ performance comparison and evaluation of three chiller sequencing control strategies in a super high-rise building. *Energy Build.,* **61**, pp. 333–343, 2013. DOI: 10.1016/j.enbuild.2013.02.043.

[43] Attia, S., Evarard, A. & Gratia, E., Development of benchmark models for the Egyptian residential buildings sector. *Applied Energy*, **94**, pp. 270–284, 2012. DOI: 10.1016/j.apenergy.2012.01.065.

[44] Assem, E.O. & Al-Mumin, A.A., Code compliance of fully glazed tall office buildings in hot climate. *Energy and Buildings,* **42**, pp. 1100–1105, 2010. DOI: 10.1016/j.enbuild.2010.02.001.

[45] Shaikh, Z. & Chaudhry, H.N., Energy modelling and indoor air quality analysis of cooling systems for buildings in hot climates. *Fluids*, **2018**(3), p. 77, 2018. DOI: 10.3390/fluids3040077.

[46] Xiaonuan, S. & Siu Yu, S.L., Existing buildings' operation and maintenance: Renovation project of Chow Yei Ching Building at the University of Hong Kong. *International Journal of Low-Carbon Technologies*, **10**(4), pp. 393–404, 2015. DOI: https://doi.org/10.1093/ijlct/ctu008.

[47] Alpuche, M., González, I., Ochoa, J., Marincic, I., Duarte, A. & Valdenebro, E., Influence of absorptance in the building envelope of affordable housing in warm dry climates. *Energy Procedia*, **57**, pp. 1842–1185, 2013.

[48] Palme, M., Inostroza, L., Villacresesd, G., Lobato-Corderod, A. & Carrasco, C., From urban climate to energy consumption: Enhancing building performance simulation by including the urban heat island effect. *Energy and Buildings,* **145**, pp. 107–120, 2017. DOI: 10.1016/j.enbuild.2017.03.069.

[49] Lima, I., Scalco, V. & Lamberts, R., Estimating the impact of urban densification on high-rise office building cooling loads in a hot and humid climate. *Energy Build.*, **182**, pp. 30–44, 2019. DOI: 10.1016/j.enbuild.2018.10.019.

[50] Radhi, H. & Sharples, S., Quantifying the domestic electricity consumption for air-conditioning due to urban heat islands in hot arid regions. *Applied Energy*, **112**, pp. 371–380, 2013. DOI: 10.1016/j.apenergy.2013.06.013.

[51] Cleveland, C.J. & Morris, C., *Dictionary of Energy*, Elsevier: Burlington, 2009.