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Lisbon – Malacca Port Cities Twin Conferences 2019 / 2020

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9th Asia Pacific International Conference on Environment-Behaviour Studies,
Faculty of Architecture, Ulisboa, Lisbon, Portugal, 03-04 Jul 2019

The Impact of High-Rise Residential Building Design Parameters on the Thermal and Energy Performance: A Literature Review

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Abstract

Nowadays, high-rise buildings are developing very fast to cater to the increase in demand in major urban cities. This phenomenon has contributed to several environmental problems in both construction and operation. High-rise buildings design parameters seem to lack contextual environmental consideration. Evaluating the impact of such design parameters is a practical approach to enhance the overall energy and thermal performance. Existing research gaps are distinguished based on this review. Future research directions are also proposed through a methodological scheme to investigate comparatively, the effects of different geometric factors on both thermal and energy performance, specifically in the high-rise residential buildings with consideration to different climatic regions.

Keywords: Energy Performance; Thermal Performance; High-rise Buildings; High-rise Residential Buildings

DOI: https://doi.org/10.21834/e-bpj.v4i11.1717

1.0 Introduction

Globally, the population in rural areas are lesser than in urban areas. According to World Urbanization Prospects: The 2018 Revision (United Nations, 2018) more people, live in urban areas than in rural areas, with 55 % of the world's population residing in urban areas in 2018. In 1950, 30 % of the world's population was urban, and by 2050, 68 % of the world's population is projected to be urban due to the economic growth and job opportunities in metropolitan cities. Majority of these cities are dominated by a drastic amount of high-rise office and residential buildings to accommodate the increase in population. A research undertaken by Siew, et al., (2011) specified that buildings are consuming 40% of world energy. The massive magnitude of energy consumption in buildings for cooling and heating by heaters and air-conditioning systems portray a considerable problem to the system. In the last decade, international organizations have put significant endeavors towards energy-efficiency in buildings as evinced by the European Union Energy efficiency action plans for 2020 and 2030 (European Commission, 2014). Different countries building sector has also adopted initiatives to the reduction of energy requirement and mitigation of environmental impacts as a critical target energy policy, to address the state-of-art of sustainable technologies. Concerns about sustainable development remain to be a challenging task. To tackle such challenges, attempts are done on different scales to reduce energy consumption globally. Under design and construction zone, bioclimatic design, utilizing renewable energy and passive design strategies like smart design of building envelope has been considered as a primary solution for the reduction of energy loads.

Moreover, studies validate that the potential modification of building envelope variables has a tremendous impact on energy efficiency and thermal performance in high-rise residential buildings. Simply stated, a building envelope is an interface between the interior of the building and the outdoor environment. A building's energy consumption and thermal comfort level to a large extent, depends on certain envelope design elements. The intensity of environmental factors differs according to climate zones and particular

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DOI: https://doi.org/10.21834/e-bpj.v4i11.1717

site conditions as well. Consequently, for achieving high-levels of energy-savings in buildings, design measures with high impact should be firstly defined and then optimized. This is supported by researchers (Al-Tamimi & Fadzil, 2010), (Chen, Yang, & Wang, 2017), (Elgheriani, Parid Wardi Bin , & Almhafdy, 2018), (Bojic, Yik, & Sat, 2002) and, (Aflaki, et al., 2019), who recommend further analysis of design variables such as; building geometry, Relative Compactness (RC), orientation, wall materials, Window to Wall Ratio (WWR), glazing materials, shading devices, and their impact on the energy and thermal performance in high-rise residential buildings. Based on the reviewed literature, the effective elements were examined through several studies in different climate regions. However, there is a gap concluded from the literature on the application of such elements in a specific study investigating a high-rise residential building; site parameters, material properties and façade design variables as a complementary concept. This paper proposes a methodological approach to investigate further the integration of how the mentioned design variables could improve a building's energy and thermal performance comparatively in different climate regions.

2.0 Methodology

The research methodology consists of five main steps:

- Conducting a keyword-based search: A keyword-based search of research articles and abstracts was conducted using Scopus, Science Direct, Google Scholar, Web of Science, Taylor & Francis and others. Examples of the keywords that were used are high-rise residential, thermal performance, energy consumption, thermal comfort and energy performance. These databases were selected because they can rank articles based on some factors such as several citations, authors, and publishers.
- Screening the retrieved articles: The articles were screened for relevance using the following criteria: (1) Impact of various design variables on the thermal or/and energy performance; and (2) The ventilation strategy.
- Identifying and screening additional articles: The articles that cited or were cited by an article that passed the first screening were further classified as additional articles. These articles were also screened using the same two relevance criteria defined above.
- Reviewing all relevant articles: All articles identified in the previous steps were analytically examined to define the implied design parameters, selected climatic region, ventilation strategy, methodological approach, and the impact on thermal and/or energy performance.
- Analyzing the review results to identify gaps and future directions: The review results were analyzed to determine the research gaps in the field of building energy consumption and thermal performance in high-rise residential buildings. Future research directions were highlighted with a proposal of a methodological research scheme for further research.

3.0 Literature Review

High-levels of energy savings usually can be achieved by an optimal combination of several measures. A building's performance can be affected by a few parameters: site parameters such as building orientation and climatic features; building material properties such as thermal mass, insulation and air-tightness; and façade design parameters such as glazing materials, WWR and shading as shown in Figure 1. This section summarizes the current literature focusing on studies with multi-objective optimization approach for envelope components with goals to improve thermal comfort in high-rise residential buildings while reducing the energy consumption. A summary of the analyzed articles is shown in Table 1. All reviewed articles are categorized based on different criteria, including the year of study, continent, country, climate, ventilation strategy, building form and the studied parameters. Then, further sub-categorized based on their impact on thermal performance and/or energy performance.

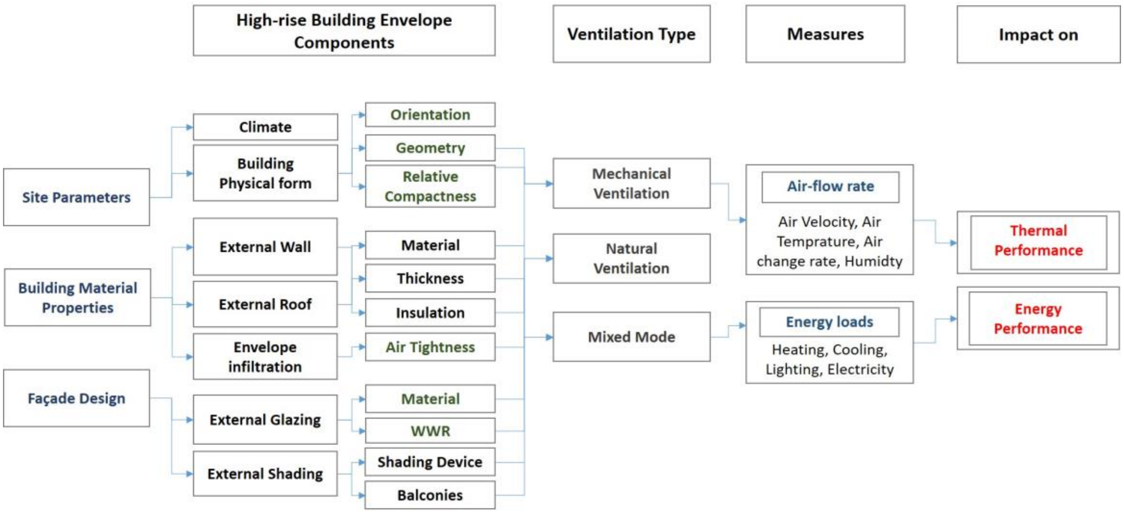


Fig. 1. High-rise building evaluation model
(Source: Author)

3.1 Thermal performance

The American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) defines thermal comfort as the mind condition in which satisfaction with the thermal environment is expressed (ASHRAE, 2004). Thus, the judgment of comfort should be regarded as a cognitive process which involves several inputs affected by physical, psychological, physiological and other factors (Lin & Deng, 2008). Moreover, the impact of building physical form and orientation on thermal performance has been investigated widely since the development of building performance simulation tools. Several studies have shown that a strong correlation exists between a building's compactness, orientation and its thermal behavior (Elgheriani, Parid Wardi Bin , & Almhafdy, 2018), (Liu & Kojima, 2017), (Park, Lee, & Song, 2007), (Kotani, Sato, & Yamanaka, 2000), (Aflaki, Hirbodi, Mahyuddin, Yaghoubi, & Esfandiari, 2019), (O'Brien & Bennet, 2016), (Nebia & Aoul, 2017).

In a parametric study, Elgheriani, et al. (2018) investigated the effect of design variables such as WWR, orientation and courtyard size using Computational Fluid Dynamics (CFD) simulation on the thermal performance in a high-rise residential building in Malaysia. The study concluded significantly that the ratio between the WWR and the courtyard size is relatively related. Hence, the wider the corridor width and the larger the WWR percentage, the higher air velocity patterns and the lower indoor temperature. Chen & Yang (2017) established a baseline building model that both are coupling local construction practice and green standard in Hong Kong, including weather data analysis, different internal loads assumptions and methods of ventilation control. All output results were generated based on specific input parameters using a CFD program; EnergyPlus. The calculated sensitivity indices on different output indices showed that the window Solar Heat Gain Coefficient (SHGC) and WWR ratio are consistently among the most influential design factors. In a study in Malaysia, Aflaki et al. (2016) evaluated the indoor thermal condition for a high-rise residential building for one month. Results reveal that a living room located on a higher floor facing the prevailing wind achieves an average air velocity of 0.52 ms−1 with approximately 90% thermal acceptability. CFD analysis performed on light-well as a source of natural ventilation revealed that it works better when cross-flow is made possible at double level of the light-well walls (Farea, Ossen, Alkaff, & Kotani, 2015). The findings obtained from the CFD simulation of Zhou et al. (2014) adjusting building orientation and ventilation strategies shows that with an optimized design, a reduction of the age of air to less than 6 minutes in 90% of the rooms was achieved, as compared to an age of greater than 30 minutes in 50% of the rooms in a conventional design.

Lastly, Prajongsan & Sharples (2012) analyzed a high-rise residential building in Bangkok to examine enhancing natural ventilation and thermal comfort using ventilation shafts. The study was done considering 12 different wind conditions (six wind speeds and two wind directions). CFD analysis revealed that a ventilation shaft located at the rear of a room could significantly increase the pressure difference across the room, which increases internal air velocity magnitude by 1.5 m/s. Burnett, Bojic, & Yik (2005) in a simulation study used k- turbulence model, and two and a three-dimensional model of a high-rise residential building in Hong Kong. The results reveal that an optimal building orientation relative to the wind can be found; the windward flats possess the best cross-ventilation potential; in the investigated flats, location of windows and rooms is not adequate to maximize cross-ventilation potential. Existing researches for thermal performance of curtain walls mainly dealt with the mullions and transoms with glazing's of the aluminum frame curtain wall. No & Kim's (2005) simulation results concerning moisture condensation lengths showed that high-rise conditions affected the insulation efficiency of curtain walls because the change in the heat transfer coefficient number by height was equal for all types. However, the increase ratio of moisture condensation length varied.

3.2 Energy performance

Previous work in this domain has shown that buildings can be sensitive to changes in specific design parameters based on the local climate. Factors including WWR (Chen, Yang, & Wang, 2017), (Xie, Xue, Mak, & Liu, 2017), (Tibi & Mokhtar, 2014) , (Yu, Tian, Yang, Xu, & Wang, 2013), (Yik, Bojic, & Wan, 2002)], ventilation strategies (Hachem-Vermette, 2018), (Chen & Yang, 2017), (Al-Tamimi & Fadzil, 2012), (Chan & Chow, 2010), (Leigh, Bae, & Ryu, 2014), glazing materials, (Tibi & Mokhtar, 2014), (Zhao, Künzel, & Antretter, 2015), (Yasar & Kalfa, 2012), (Cheung, Fuller, & Luther, 2005), (Bojic, Yik, & Sat, 2002), external shading (Cheong, Kim, & Leigh, 2014), (Al-Tamimi & Fadzil, 2012), (Lin, Jan, & Liao, 2017), (Yik & Bojic, 2006), (Cho, Yoo, & Kim, 2014) and envelope infiltration (Carlsson, Touchie, & Richman, 2017), (Kosonen, Juha, Ilari, & Koikkalaninen, 2017), (McKeen & Fung, 2014), (Yik & Bojic, 2006) were among the most common parameters that influence a building's energy performance.

A study conducted in the UAE by Tibi & Mokhtar (2014) on a typical 30-storey high-rise residential building with a WWR of 50 % and a north-south orientation focused on the decision of selecting a glass type for the building. In order to assess the significant impact on the initial and running cost of the building, glass types were classified in terms of SHGC and U-value from 0.25 to 0.14 and 2.00 to 1.10 W/m 2 K, respectively. According to simulation results, the authors recommend the use of WWR of 50 % with an almost north-south orientation in the UAE and glass type of U-Value = 1.9 W/m^2°K and SHGC = 0.28. Considering the influence of shading strategies on energy demand and visual comfort, Kim et al. (2012) investigated the various type of external shading devices in terms of energy savings for heating and cooling, via the IES_VE software program. Through this study, it was concluded that the external shading device had a better technical performance than the internal shading device. The utilization of the overhang could cut down nearly 18% to 20% of the cooling load in summer in Seoul. Another study carried out on a Nordic high-rise residential building, examined the effects of air-tightness, air leakage distributions, and outdoor environmental conditions on air pressure conditions and energy consumption with the aid of simulation. The results revealed that air-tightness of the envelope together with the internal air-tightness of shafts play a significant role in the stack effect. With the air-tightness of envelope 0.5 $m^3/h,m^2$, it is possible to get 20 % energy saving in the heating energy consumption (Kosonen, Juha, Ilari, & Koikkalaninen, 2017).

Finally, Cheung, Fuller, & Luther (2005) investigated the effect of six passive strategies on cooling energy and peak cooling load for the refurbishment of a high-rise residential building in Hong Kong with the aid of simulation. The variables investigated were: Thermal insulation, thermal mass, glazing type, WWR, the color of the external wall and shading. For a hot-humid climate, it was found that the optimal integration of passive strategies can save up to 31.4% in annual required cooling energy and up to 36.8% in peak cooling loads.

3.3 Thermal and energy performance

Weerasuriyaa, Zhanga, Gan, & Tan (2019) established a novel holistic framework integrating CFD simulation multi-zone-air-flow modelling, and energy simulation model to calculate ventilation rates under the mechanisms of wind-driven and wind-buoyancy-driven ventilation. The results showed that a building could save up to 25% of the electricity consumption if it employs wind-driven natural ventilation instead of mechanical ventilation. The electricity consumption can be further reduced up to 45% by facilitating the buoyancy-driven natural ventilation. Sohail (2017) designed a 25-story high-rise residential building in an arid climate relying primarily on natural ventilation. The author suggests that solar gains are the significant source of heating the tower and could be reduced with the use of glazing ratios of a maximum of 10–20 %. Lastly, Berardi & Manca (2017) evaluated the effectiveness of increasing the thermal capacity of a building enclosure on energy savings in a High-rise apartment building in Canada. With the adoption of Phase Change Material (PCM) in lightweight constructions, the authors' simulation results showed a reduction in the energy consumption for cooling between 5% and 21%, using a higher level of heat capacity.

Table 1. List of the analyzed literature

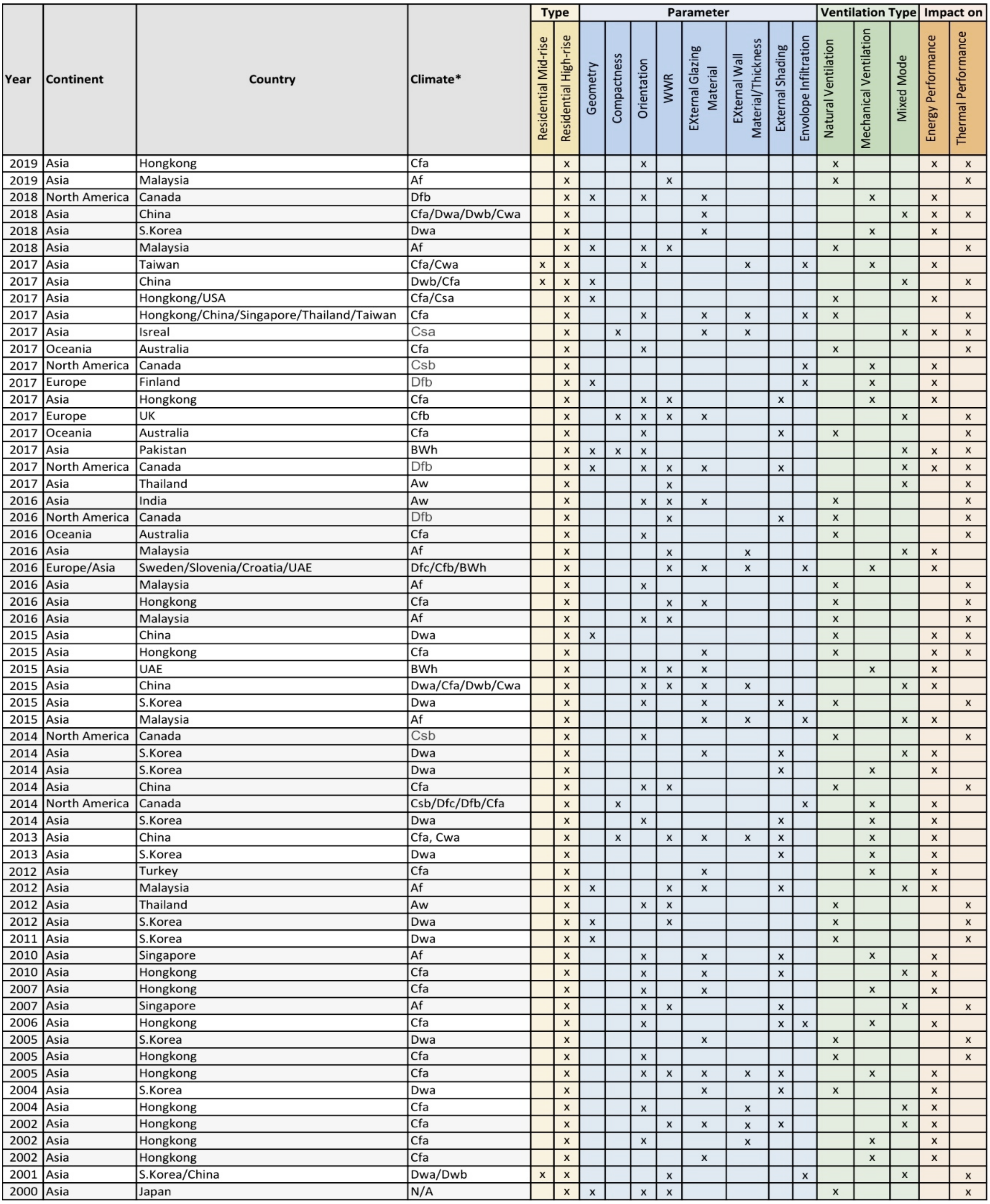
	Ventilation Type	Climate	Design parameter	Impact	Methodology	Reference
Thermal Performance	Natural	Hot-humid	WWR	Air-flow rate, Air-temperature	CFD-simulation, FloEFD, Numerical simulation, Field measurements	(Aflaki, et al., 2019)
	Natural	Hot-humid	Building geometry, Orientation, WWR	Air-flow rate, Air-temperature	CFD-simulation, IES_VE	(Elgheriani, et al., 2018)
	Mixed-mode	Continental, Humid sub-tropical	Building geometry	Air-temperature, Humidity, Predicted-Mean Vote (PMV)	Field measurements	(Liu & Kojima, 2017)
	Natural	Humid sub-tropical, Tropical	Orientation, Glazing-material, Wall-material, Inlet-To-Outlet opening, Air-tightness	Air-change rate, Air-temperature, Humidity, Illuminance	Simulation, EnergyPlus	(Chen, et al., 2017)
	Natural	Humid sub-tropical	Orientation, Inlet-To-Outlet opening	Air-flow rate, Air-temperature, Humidity	Field measurements	(Omrani, et al., 2017)
	Mixed-mode	Oceanic	Orientation, RC, WWR, Glazing-material	Air-temperature, Daylight factor	Simulation, IES_VE	(Nebia & Aoul, 2017)
	Natural	Humid sub-tropical	Orientation, External shading	Air-flow rate, Air-temperature, Solar radiation	Numerical Simulation, ECOTECT, Field measurements	(Cho, Yoo, & Kim, 2014)
	Mixed-mode	Hot-humid	WWR, Inlet-to-outlet opening	Air-temperature, Humidity	Field measurements	(Srisuwan & Shoichi, 2017)
	Natural	Hot-humid	Orientation, WWR, Glazing-material	Air-flow pattern, Daylight factor	CFD-simulation, IES_VE	(Sahoo, Kumar, & Sastry, 2016)
	Natural	Continental	WWR, External shading	PMV	Simulation EnergyPlus, Field measurements	(O'Brien & Bennet, 2016)
	Natural	Humid sub-tropical	Orientation, Inlet-to-outlet opening	PMV	Field measurements	(Omrani, et al., 2016)
	Natural	Hot-humid	Orientation, Inlet-to-outlet opening	Air-temperature, Humidity	Field measurements	(Aflaki, et al., 2016)
	Natural	Humid sub-tropical	WWR, Glazing-material	Air-flow rate, Daylight factor	Sensitivity Analysis, EnergyPlus, jEPlus	(Chen, Yang, & Sun, 2016)
	Mixed-mode	Humid sub-tropical	Glazing-material	PMV	Monte Carlo Simulation	(Chen & Yang, 2016)
	Natural	Hot-humid	Orientation, WWR	Air-flow rate, Air-temperature	CFD-simulation, ANSYS Fluent	(Farea, Ossen, Alkaff, & Kotani, 2015)
	Natural	Continental	Orientation, Glazing-material	Air-flow rate, Air-temperature	CFD-simulation, STAR-CD	(Kim, Cho, Lee, Yeo, & Kim, 2007)
	Mechanical	Hot-humid	Orientation, Inlet-to-outlet opening	Air-flow rate	Field measurements	(Ricketts & Straube, 2014)
	Natural	Sub-tropical Semi-arid	Orientation, WWR	Air flow rate, Air-change rate	CFD-simulation, ANSYS Fluent, Field measurements	(Zhou, Wang, Chen, Jiang, & Pei, 2014)

	Mechanical	Hot-humid	External shading	Air flow rate, Air-temperature	Simulation, IES_VE	(Kim, Lim, Lim, & Schae, 2012)
	Mixed-mode	Continental	Orientation, WWR	Air flow rate, Air-temperature	CFD-simulation, DesignBuilder	(Prajongsan & Sharples, 2012)
	Natural	Continental	Building geometry	Air-pressure	Simulation, CONTAMW	(Park, Lee, & Song, 2007)
	Mixed-mode	Hot-humid	Orientation, WWR, External shading	Air flow rate, PMV	CFD-simulation, FLUENT, ESP-r	(Liping & Hien, 2007)
	Natural	Hot-humid	Building geometry, WWR	Air flow pattern	CFD-simulation, STAR-CCM+	(Cho, Yeo, & Kim, 2013)
	Natural	Continental	Glazing-material	Air-temperature	Simulation, FLUENT	(No & Kim, 2005)
	Natural	Humid sub-tropical	Orientation, Inlet-to-outlet opening	Air flow rate, Air-pressure	CFD-simulation, FLUENT	(Burnett, Bojic, & Yik, 2005)
	Mixed-mode	Continental	WWR, Air-tightness	Air-flow rate, Air-tightness	Numerical simulation, COMIS	(Khoukhi & Al-Maqbali, 2011)
	Natural	N/A	Building geometry, Orientation, WWR	Air-flow rate	Wind-tunnel test	(Kotani, Sato, & Yamanaka, 2000)
Energy Performance	Mechanical	Continental	Building geometry, Orientation, Glazing-material	Cooling/heating loads	Energy Simulation, EnergyPlus	(Hachem-Vermette, 2018)
	Mechanical	Continental	Glazing-material	Cooling/heating loads	Energy Simulation, EnergyPlus	(Oh, Tae, & Hwang, 2018)
	Mechanical	Humid sub-tropical, Dry sub-tropical	Ventilation-outlets, Wall material, Air-tightness	Energy loads	Energy Simulation, ECOTECT	(Lin, Jan, & Liao, 2017)
	Natural	Humid sub-tropical, Mediterranean	Building geometry	Cooling/lighting loads	Energy Simulation, EnergyPlus	(Chen & Yang, 2017)
	Mechanical	Mediterranean	Air-tightness	Heating-load	Energy Simulation, EnergyPlus	(Carlsson, Touchie, & Richman, 2017)
	Mechanical	Continental	Building geometry, Air-tightness	Heating-load	Energy Simulation, IDA-ICE	(Kosonen, Juha, Ilari, & Koikkalaninen, 2017)
	Mechanical	Humid sub-tropical	Orientation, WWR, Shading	Cooling/lighting loads	Energy Simulation, EnergyPlus	(Xie, Xue, Mak, & Liu, 2017)
	Mixed-mode	Hot-humid	WWR, Wall material	Cooling-load	Energy Simulation, ECOTECT	(Al-Tamimi & Fadzil, 2010)
	Mechanical	Continental, Oceanic, Arid	WWR, Glazing-material, Wall material, Air-tightness	Cooling/heating loads	Energy Simulation, IDA ICE	(Soleimani-Mohseni, Nair, & Hasselrot, 2016)
	Mechanical	Arid	Orientation, WWR, Glazing-material	Cooling-load	Energy Simulation, IES_VE	(Tibi & Mokhtar, 2014)
	Mixed-mode	Continental, Humid sub-tropical, Dry sub-tropical	WWR, Glazing-material, Orientation	Cooling/heating loads	Energy Simulation, WUFI	(Zhao, Künzel, & Antretter, 2015)
	Mixed-mode	Hot-humid	Glazing-material, Wall material, Air-tightness	Cooling-load	Energy Simulation, EnergyPlus	(Hassan & Al-Ashwal, 2015)
	Mixed-mode	Continental	Glazing-material, Shading	Cooling-load	Energy Simulation, ECOTECT	(Cheong, Kim, & Leigh, 2014)
	Mechanical	Continental	Shading	Cooling-load	Energy Simulation, ECOTECT	(Cho, Yoo, & Kim, 2014)
	Mechanical	Humid sub-tropical, Continental, Mediterranean	RC, Air-tightness	Cooling/heating loads	Energy Simulation, eQUEST	(McKeen & Fung, 2014)
	Mechanical	Continental	Shading	Cooling-load	Energy simulation, IES_VE	(Kim, Lim, Lim, & Schae, 2012)

	Mechanical	Humid sub-tropical, Dry sub-tropical	Orientation, Shading	Cooling-load	Simulation, eQUEST	(Cho, Yoo, & Kim, 2014)
	Mechanical	Humid sub-tropical	RC, WWR, Glazing-material, Wall material, Shading	Cooling/heating loads	Energy Simulation, eQUEST	(Yu, Tian, Yang, Xu, & Wang, 2013)
	Mechanical	Hot-humid	Glazing-material	Cooling/heating loads	Energy Simulation, DesignBuilder	(Yasar & Kalfa, 2012)
	Mixed-mode	Continental	Building geometry, WWR, Glazing-material, Shading	Cooling-load	Energy Simulation, ECOTECT	(Al-Tamimi & Fadzil, 2012)
	Mechanical	Hot-humid	Orientation, Glazing-material, Shading	Cooling/electricity loads	Energy Simulation, eQUEST	(Chua & Chou, 2010)
	Mixed-mode	Humid sub-tropical	Orientation, Glazing-material, Shading	Electricity load	Energy Simulation, EnergyPlus	(Chan & Chow, 2010)
	Mechanical	Humid sub-tropical	Orientation, Glazing-material	Cooling/electricity loads	Energy Simulation, EnergyPlus	(Bojic & Yik, 2007)
	Mechanical	Humid sub-tropical	Orientation, Shading, Air-tightness	Cooling/electricity loads	Energy Simulation, EnergyPlus	(Yik & Bojic, 2006)
	Mechanical	Humid sub-tropical	Orientation, WWR, Glazing-material, Wall material, Shading	Cooling-load	Energy Simulation, TRNSYS	(Cheung, Fuller, & Luther, 2005)
	Natural	Continental	Glazing-material, Shading	Cooling-load	Energy Simulation, ESP-r	(Leigh, Bae, & Ryu, 2014)
	Mixed-mode	Humid sub-tropical	WWR, Glazing-material, Wall material, Shading	Cooling-load	Energy Simulation, HTB2	(Yik, Bojic, & Wan, 2002)
	Mechanical	Humid sub-tropical	Orientation, Wall material	Cooling-load	Energy Simulation, HTB2	(Bojic M. , Yik, Wan, & Burnett, 2002)
	Mechanical	Humid sub-tropical	Glazing-material	Cooling-load	Energy Simulation, HTB2	(Bojic, Yik, & Sat, 2002)
Thermal and Energy Performance	Natural	Humid sub-tropical	Orientation, Inlet-to-outlet opening	Electricity consumption, Air-flow rates	CFD-simulation, Energy Simulation, eQUEST	(Weerasuriyaa, Zhanga, Gan, & Tan, 2019)
	Mixed-mode	Humid sub-tropical, Continental, Dry sub-tropical	Glazing-material	Energy demand, Air-change rate	Sensitivity Analysis Model, EnergyPlus	(Chen & Yang, 2018)
	Mixed-mode	Mediterranean	RC, Glazing-material, Wall material	Cooling/heating loads, Air-flow rate, Air-temperature	Energy Simulation, EnergyPlus	(Sarogloua, Meir, & Theo, 2017)
	Mixed-mode	Arid	Building geometry, RC, Orientation	Energy loads, Air-temperature, Solar gains	Energy Simulation, DesignBuilder	(Sohail, 2017)
	Mixed-mode	Continental	Building geometry, Orientation, WWR, Glazing-material, Shading	Cooling/heating demand, Air-temperature	Energy Simulation, EnergyPlus	(Berardi & Manca, 2017)
	Mixed-mode	Continental	Building Geometry, Ventilation-Strategy	Cooling-load	CFD-simulation, Energy simulation, DeST	(Li & Li, 2015)

4.0 Discussion

According to the previous session, there are different elements and techniques through the selection of site parameters, building material properties, and façade design, that influence the indoor thermal comfort and energy consumption. The studies mentioned above show the different implication of the applied elements through different climatic conditions and present effective strategies implemented in high-rise residential buildings. Summary of the analyzed articles is shown below in Figure. 2.



Year	Continent	Country	Climate*	Type		Parameter								Ventilation Type			Impact on	
				Residential Mid-rise	Residential High-rise	Geometry	Compactness	Orientation	WWR	EXternal Glazing Material	EXternal Wall Material/Thickness	External Shading	Envolope Infiltration	Natural Ventilation	Mechanical Ventilation	Mixed Mode	Energy Performance	Thermal Performance
2019	Asia	Hongkong	Cfa		x			x						x			x	x
2019	Asia	Malaysia	Af		x				x					x				x
2018	North America	Canada	Dfb		x	x		x		x					x		x	
2018	Asia	China	Cfa/Dwa/Dwb/Cwa		x					x						x	x	x
2018	Asia	S.Korea	Dwa		x					x					x		x	
2018	Asia	Malaysia	Af		x	x		x	x					x				x
2017	Asia	Taiwan	Cfa/Cwa	x	x			x			x		x		x		x	
2017	Asia	China	Dwb/Cfa	x	x	x										x		x
2017	Asia	Hongkong/USA	Cfa/Csa		x	x								x			x	
2017	Asia	Hongkong/China/Singapore/Thailand/Taiwan	Cfa		x			x		x	x		x	x				x
2017	Asia	Isreal	Csa		x		x			x	x					x	x	x
2017	Oceania	Australia	Cfa		x			x						x				x
2017	North America	Canada	Csb		x								x		x		x	
2017	Europe	Finland	Dfb		x	x							x		x		x	
2017	Asia	Hongkong	Cfa		x			x	x			x			x		x	
2017	Europe	UK	Cfb		x		x	x	x	x						x		x
2017	Oceania	Australia	Cfa		x			x				x		x				x
2017	Asia	Pakistan	BWh		x	x	x	x								x	x	x
2017	North America	Canada	Dfb		x	x		x	x	x		x				x	x	x
2017	Asia	Thailand	Aw		x				x							x		x
2016	Asia	India	Aw		x			x	x	x				x				x
2016	North America	Canada	Dfb		x				x			x		x				x
2016	Oceania	Australia	Cfa		x			x						x				x
2016	Asia	Malaysia	Af		x				x		x					x	x	
2016	Europe/Asia	Sweden/Slovenia/Croatia/UAE	Dfc/Cfb/BWh		x				x	x	x		x		x		x	
2016	Asia	Malaysia	Af		x			x						x				x
2016	Asia	Hongkong	Cfa		x				x	x				x				x
2016	Asia	Malaysia	Af		x			x	x					x				x
2015	Asia	China	Dwa		x	x								x			x	x
2015	Asia	Hongkong	Cfa		x					x				x			x	x
2015	Asia	UAE	BWh		x			x	x	x					x		x	
2015	Asia	China	Dwa/Cfa/Dwb/Cwa		x			x	x	x	x					x	x	
2015	Asia	S.Korea	Dwa		x			x		x		x		x				x
2015	Asia	Malaysia	Af		x					x	x		x			x	x	
2014	North America	Canada	Csb		x			x						x				x
2014	Asia	S.Korea	Dwa		x					x		x				x	x	
2014	Asia	S.Korea	Dwa		x							x			x		x	
2014	Asia	China	Cfa		x			x	x					x				x
2014	North America	Canada	Csb/Dfc/Dfb/Cfa		x		x						x		x		x	
2014	Asia	S.Korea	Dwa		x			x				x			x		x	
2013	Asia	China	Cfa, Cwa		x		x		x	x	x	x			x		x	
2013	Asia	S.Korea	Dwa		x							x			x		x	
2012	Asia	Turkey	Cfa		x					x					x		x	
2012	Asia	Malaysia	Af		x	x			x	x		x				x	x	
2012	Asia	Thailand	Aw		x			x	x					x				x
2012	Asia	S.Korea	Dwa		x	x			x					x				x
2011	Asia	S.Korea	Dwa		x	x								x				x
2010	Asia	Singapore	Af		x			x		x		x			x		x	
2010	Asia	Hongkong	Cfa		x			x		x		x				x	x	
2007	Asia	Hongkong	Cfa		x			x		x					x		x	
2007	Asia	Singapore	Af		x			x	x			x				x		x
2006	Asia	Hongkong	Cfa		x			x				x	x		x		x	
2005	Asia	S.Korea	Dwa		x					x				x				x
2005	Asia	Hongkong	Cfa		x			x						x				x
2005	Asia	Hongkong	Cfa		x			x	x	x	x	x			x		x	
2004	Asia	S.Korea	Dwa		x					x		x		x			x	
2004	Asia	Hongkong	Cfa		x			x			x					x	x	
2002	Asia	Hongkong	Cfa		x				x	x	x	x				x	x	
2002	Asia	Hongkong	Cfa		x			x			x				x		x	
2002	Asia	Hongkong	Cfa		x					x					x		x	
2001	Asia	S.Korea/China	Dwa/Dwb	x	x				x				x			x		x
2000	Asia	Japan	N/A		x	x		x	x					x				x

*The climate type is based on the climate classification by Köppen Geiger

Fig. 2. Summary of the analyzed literature

(Source: Author)

From the overview of previous studies, it can be highlighted that not a single, or a few combined variables are the only measure influencing the thermal or/and energy consumption, although some variables might be the most critical parameters in specific climates and have a higher impact on heating or cooling loads. The knowledge about the effects of influential design parameters on both thermal and energy performance as a complementary concept is limited. Many of the relevant studies focus on validating of analytical methods, comparing the correlation of one or couple of design parameters. However, the application of such effective elements in a specific study investigating a high-rise residential building holistically is seldom. Hence, the arrangement and variation of these elements may bring about the novel and promising results for future developments of high-rise residential building. There is a clear gap in the literature concerning the evaluation of those elements concurrently and their performance in terms of both comfort acceptability and energy saving in high-rise residential buildings.

5.0 Conclusion

In conclusion, the increase in the number of high-rise residential buildings, the increase in population and the high living standards have caused an increase in energy demand in recent years. The selection and application of the appropriate site parameters, building material properties, and façade design at the early stage of the design process help improving a building's performance. As seen from the review, environmental studies on high-rise residential buildings have been attracting significant research attention. Multiple design variables serving different purposes have different scopes, were evaluated in different climatic settings.

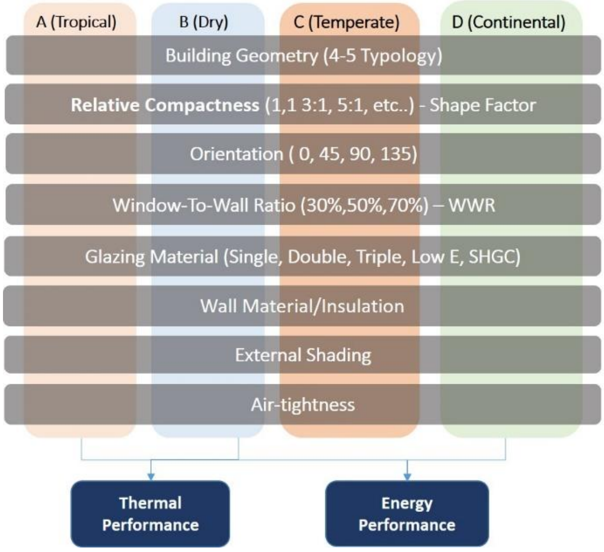


Fig. 3. Proposed methodological scheme of research on high-rise residential buildings
(Source: Author)

The results of this review indicate some research areas that require more attention. As this review paper fills the gap in literature; a methodological scheme of further research is proposed above in Figure 3. The main objective of the proposed methodological scheme is to investigate the impact of the site parameters, building material properties, and façade design on energy-efficiency and thermal performance of high-rise residential buildings comparatively in four different climates. The factors that have been investigated in the literature are building geometry, RC, orientation, WWR, glazing materials, external shading, air-tightness, wall material and insulation. While comparing the climate and population density maps, the selection of potential locations for further research shall be determined based on the most densely populated cities and the potential of extensive high-rise residential buildings development.

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