ARCHITECTURAL BUILDING DESIGN PARAMETERS IN AUSTRALIAN EDUCATIONAL BUILDINGS: A REVIEW

[1]SALAH ALGHAMDI, [2]PATRICK TANG, [3]SITTIMONT KANJANABOOTRA, [4]DARIUSZ ALTERMAN

Faculty of Engineering and Built Environment at the University of Newcastle
E-mail: [1]Salah.Alghamdi@uon.edu.au, [2]patrick.tang@newcastle.edu.au, [3]sittimont.kanjanabootra@newcastle.edu.au, [4]dariusz.alterman@newcastle.edu.au

Abstract - A suitable indoor thermal environment in buildings is important to maximize the building occupants' comfort. Additionally, it is imperative for effective building energy consumption, staff productivity, health and well-being. Buildings account for about 40% of the global energy consumption and contribute over 30% of the CO2 emissions. A large proportion of this energy is used for thermal comfort in buildings. In order to obtain optimal energy efficiency two factors need to be taken into consideration: architectural building design, and the occupants (activity and clothing value). Identifying the effect of Architectural Building Design Parameters (ABP) on energy consumption and thermal comfort in the design stage is an important step for enabling the reduction of the heating/cooling energy loads and increasing the level of students' thermal comfort in educational buildings. Building energy consumption and occupants' thermal comfort are usually considered to be conflicting objectives. This paper identifies the ABP that should be optimized in terms of building and envelope design selection in educational buildings to increase the level of students' thermal comfort and decrease the energy consumption during initial design stage. Reviewed studies have assessed the thermal comfort and energy consumption in different building types, climate zone, and ventilation mode separately based on ABP. There are insufficient studies on the effect of ABP parameters on thermal comfort and energy consumption in higher educational buildings in climate zone 5, Australia.

Keywords - Indoor Thermal Environment, Architectural Building Design Parameters, Energy Consumption, Thermal Comfort, Higher education Building.

I. INTRODUCTION

One of the most important negative factors caused by global warming is increase of ambient air temperature [1]. This increase further leads to a rise in indoor thermal air temperature, reduction of thermal comfort and increase of energy consumption [2]. The purpose of the Heating, Ventilation, and Air Conditioning (HVAC) system is to offer a comfortable indoor thermal environment for the occupants [3]. As a result, thermal comfort is one of the main factors in the operational settings of HVAC systems, and this significantly impacts energy consumption in buildings [4]. In Australia, buildings are responsible for approximately 25% of the total energy consumption and 23% of greenhouse gas emissions [5]. The energy consumed by HVAC systems in non-residential buildings comprises approximately 9% of electricity produced in Australia and consumes billions of litres of water per annum in cooling towers [6]. Across Australia, around 9,500 schools and many of tertiary institutions have been built to meet only minimum building code requirements. The result is facilities that are not necessarily designed to provide comfortable, productive or healthy work environments for students and teachers [7]. The New South Wales (NSW) Department of Education currently has in excess of 2,200 schools across the state [8]. Because of their large number around Australia, the second higher energy consumed occurs in educational sectors compared with other sectors such as hotels, retails, offices, and hospitals [5]. In addition, around 50% of the energy consumed by HVAC systems occurs on university campuses in Australia [5]. Students spend around 25% of their time at school [9]. While students have limited options of adaption to the indoor thermal environment as their classroom activities are restricted [10], and educational buildings have specific functional characteristics compared to other buildings [11], attention and focus needs to be more on energy consumption and thermal comfort in educational buildings.

Energy cost is the second highest expense in schools after the payroll [11]. According to estimates of the US Department of Energy, 25% of the expenses on energy in schools could be saved through better building design and using energy-efficient technologies combined with improvements in operations and maintenance [12]. Because of their multitude around the world, educational buildings are a large energy consumer. Saving energy in public buildings might be considered altruistic because often no personal benefits are obtained [13]. Despite the high amount of energy spent on HVAC operations, thermal comfort levels in educational buildings is considerably poor [14].

When architectural design goes beyond form or aesthetic, utilizing the research can achieve an optimal solution within seemingly conflicting parameters [15]. Generally, the design stages include the conceptual, the preliminary and then a detailed design stage. Different stages of building design have

different impact on building performance. As a result, any random selection of ABP in the early design stages is likely to be amplified in the later process [16, 17]. The conceptual design of the building not only makes it conducive to the improvement of the indoor environment, but also helps to reduce building energy consumption [18]. Hence, the important factors that affect the building performance are mainly considered in the conceptual design stage. In this paper, identifying the ABP that should be optimized during initial design stage in Australian educational buildings will be presented through a literature review method.

II. LITERATURE REVIEW

In this paper, the reviewed studies are limited to those focusing on the ABP that affects thermal comfort and energy consumption. These studies have been classified based on two main categories: building and envelope design. However due to the limited number of studies for Australian educational buildings and the variety of ABP, this paper shows different studies in terms of building types, climate zone, and ventilation mode regarding to ABP. ABP identified by investigations the current discourses in research on thermal comfort and energy consumption. A traditional literature review across various databases and repositories was facilitated to identify those parameters. A traditional review was performed using a set of keywords on Google scholar, Scopus, ScienceDirect, and ASCE library which resulted in 160 articles which best suited to the research content. Indeed about most of the addressed studies in the current paper have been conducted over the past 15 years.

A. Architectural building design parameters

ABP separates indoor environment form outside environment as well as provides a comfortable indoor environment [19] including envelope design (e.g walls, roofs, and windows) and building design (e.g orientation, building shape, and floor area). Making early architectural design decisions, including integrating the optimal values of these building parameters depending on the climatic conditions and building types, is an important task during the design process of buildings because the design team has various degrees of freedom for choosing building parameters [20]. In addition, the effects of these parameters should be known in the earlier stages of architectural design, because later attempts to improve the energy performance constitute a lost opportunity for a more cost-effective solution [21]. Table (1) presents number of works done regarding ABP. It is obvious that previous studies usually concentrated on office buildings. Thus, there is a need for research that focuses on the ABP affecting the energy performance and students thermal comfort in educational buildings. From examining previous studies, most of these ABP were not connected to each other and the results in terms of thermal comfort and energy consumption also vary depending on the climate zone as well as building type. Therefore, the relationship between thermal comfort and energy consumption has not been linked based on ABP in educational buildings in New South Wales.

Energy consumption and thermal comfort are two fundamentally conflicting objectives of building design. This creates a challenge to the designer and engineers to study and monitor the impact on performance of built form design determinants. Optimizing the students' thermal comfort in the indoor thermal environment will ultimately lead to the increase in building energy consumption [22]. However, building design is a multi-objective optimization problem [23]. Therefore, both objectives need to be incorporated in the decision-making process in building design.

Output evaluation	Architectural building design parameters: Type of building, Ventilation mode: [Reference], climate (country)
Thermal comfort	Building design
	Room depth: Residential, MV: [24], (Malaysia)
	Orientation: Residential, NV: [25], (Athina)
	Floor height: Residential, MV: [24], (Malaysia)
	Internal partitions configurations: School, NV: [26], Residential, NV: [27], (Denmark), Tropical humid climate
	balcony configuration: Residential, NV: [27], Tropical humid climate
	Floor area: Residential, MV: [24], (Malaysia)
	Envelope design
	Window to wall ratio: Residential, NV: [25], (Athina)
	Type of window: Residential, NV: [27], Tropical humid climate
Energy consumption	Building design
	Building shape: Office, MV:[28], (China)
	Orientation: Office, MV:[28], (China)

	Floor height: Office, MV:[28], (China)
	Floor number: Office, MV:[28], (China)
	Envelope design
	Wall heat transfer coefficient: Residential, MV: [29], (Australia)
	External shading device: Residential, MV: [30], (Hong Kong)
	Various positions/ thickness of thermal insulation: Residential, MV: [30], (Hong Kong)
	Window-to-floor ratio: Residential, MV: [30], (Hong Kong)
Both thermal comfort and energy consumption	Building design
	Building shape: School, MV:[31], cold climates of China
	Room depth: School, MV:[31], cold climates of China
	Orientation: School, MV:[31], Residential, MV: [22], Residential, MV: [24], cold climates of China, (China)
	Floor number: Residential, MV:[22], (China)
	Floor area: Residential, MV: [22], (China)
	Cooling set point: Residential, MV: [23], (Canada)
	Heating set point: Residential, MV: [23], (Canada)
	Envelope design
	Wall heat transfer coefficient: Residential, MV: [22], Residential: [24], (China), (Malaysia)
	Roof heat transfer coefficient: Residential, MV: [22], Residential, MV: [24], (China), (Malaysia)
	Window heat transfer coefficient: Residential, MV: [22], Residential, MV: [24], (China), (Malaysia)
	External shading device: Residential, MV: [24], Residential, MV: [32], (Malaysia), (Taiwan)
	Window to wall ratio: School, MV:[31], Residential, MV: [22], Residential, MV: [32], cold climates of China, (China), (Taiwan)
	Window opening behavior: Office, MV:[33], (UK)
	Type of window: Office, MV:[34], Residential, MV: [32], (Singapore), (Taiwan)

Table (1) the summary of architectural building design parameters in previous studies

B. Indoor thermal environment and energy consumption

Thermal comfort is defined in [35] as: 'that condition of mind which expresses satisfaction with the thermal environment' (p.6). The term 'thermal comfort' describes a person's psychological condition of mind in terms of whether they are feeling too hot or too cold [36]. In general, six factors influence thermal comfort are: A) in the indoor thermal environment including: 1) air temperature; 2) mean radiant temperature; 3) relative air velocity; and 4) air humidity, B) Personal factors include: 5) metabolic activity and 6) clothing insulation [37]. Predicted Mean Vote (PMV) represents the mean thermal comfort vote on a standard scale for a group of building occupants for any given combination of those six factors [37]. While the PMV model can be used to predict the thermal comfort [10, 38, 39], Building Energy Simulation (BES) software, and numerical model can be used to predict the indoor thermal environment [2, 40]. The numerical model based on heat transfer and thermal energy storage equations with implicit or explicit technique methods can be used for approximating non-linear model function [41]. [40] study was confined to the calculation of the ventilated air flow rate by different scenarios in one day only in order to maintain the same interior temperature. They neglected the heat gains of the occupants and equipment through their model was done in Morocco. In the [2] study, the model set out to predict indoor air temperature during heat waves (summer season) only for residential units in Canada.

There have been relatively few studies dealing with predicting indoor air temperature only [42-44], and none of them link the indoor thermal environment with the thermal comfort and energy consumption. Over the last decades a number of studies have proven the success of building assessment especially for energy audits to apply energy efficiency measures [45-47], but there are still insufficient studies on the thermal comfort in educational buildings and their relationship to energy consumption regarding to ABP. BES is the virtual simulation of a building using a computer-based mathematical model created on the basis of fundamental physical principles and energy balance equations [48]. The objective of BES is the quantification of aspects of building performance which are relevant to the design, construction, operation and control of buildings [49]. It allows simultaneous interaction of the building fabric with outdoor conditions, occupancy, and building services to predict several loads arising in the building on an

hourly basis [50]. A building is a complicated object that accommodates constantly changing energy flows between the different thermal zones within the building and the outside. BES software can support designers to take decisions about the optimum choices to apply for any proposed or existing buildings. Most of BES software comes with a graphical user interface (GUI) as well as the actual simulation engine [51]. There can be several GUIs for the same simulation engine [52]. The most popular BES software used comprises DOE-2, eQUEST, EnergyPlus, ESP-r, DeST, and Transys [53]. There are several BES software tools available in the market. The use of EnergyPlus software is very common nowadays for designing any new construction to evaluate the indoor thermal environment through different design options [54]. The indoor thermal environment is affected by different aspects such as outdoor environmental conditions, and ABP [2, 55]. Hence, the evaluation of energy consumption and thermal comfort may change from case to case depending on the indoor thermal environment.

C. Thermal comfort in HVAC buildings

Thermal comfort research and practice is not a static field as it takes into account variables such as climate zone, building type, occupants' activity etc. [25, 56]. One of the highlights in the research was the development of the PMV-model by Fanger in the late 1960's [37], involving over 1000 people exposed to well-controlled environments [57]. PMV model has been adopted in EN ISO 7730 [58] and ASHRAE 55 [35], which provides a method to evaluate indoor thermal comfort. The most widely used index to predict thermal comfort in HVAC buildings is known as PMV [59]. It is range numbers between -3 and +3. The optimal thermal comfort level is when a PMV value is equal to zero. Together with a PMV value and predicted percentage dissatisfaction (PPD) [37], it was proposed to estimate the overall percentage of thermal dissatisfaction inside an air-conditioned space. Mathematically, PMV depends on air temperature, MRT, air velocity, relative humidity, human metabolic rate and clothing insulation level. PPD is only a mathematical function of PMV [60]. While there are large variations from person to person in terms of physiological and psychological satisfaction, it is hard to find an optimal indoor thermal environment for all people in a given room [61, 62].

At present, two approaches exist for the definition of thermal comfort: Rational Thermal comfort (RTC) approach [37] and Adaptive Thermal Comfort (ATC) approach [63]. The RTC approach uses data from climate chamber studies to support its theory, while the ATC approach uses data from field studies of people in buildings [64]. Based on the [65] review of 45 studies, which used 50% RTC,15% ATC, and the remaining 35% used both approaches to evaluate the thermal comfort and compared the results with each other. There has been a growth in the use of the ATC approach in recent years. RTC consists of the Fanger's PMV model, which provides results that are very close to the Actual Mean Votes (AMV) in the mechanical ventilation mode buildings. Thus, to increase the level of thermal comfort and energy consumption, it is necessary to improve provisions for classroom thermal comfort by gaining a better understanding of responses to ABP in the thermal environment. Some such studies related to thermal comfort have looked into age and gender [66], indoor air quality [67], ventilation strategy [68], clothing adjustment effect [69], changes to activity level [70], set-point temperatures and sun shading system [71], envelope design [24], and academic performance [72]. Even studies done in Australia were only focused on children, primary and high school students' thermal comfort [38]. The [62] study indicates that an acceptable summertime range for Australian students is from 19.5 to 26.68 C. Although that is a big gap in set point temperature affect positively in thermal comfort point of view, energy efficiency should take a place in this research field especially when the world seek to achieve the real meaning of sustainable buildings. Although these studies highlight the thermal comfort in buildings, the energy consumption aspect was not taken into consideration in parallel with thermal comfort.

D. Thermal comfort Standards

Educational buildings are required to facilitate student productivity and learning [73]. Standards such as ISO 7730, EN15251 and ASHRAE 55, provide guidelines on indoor thermal comfort. In recent years, many studies mention that high levels of thermal dissatisfaction among students in classrooms and student thermal comfort are not being precisely reflected by the provisions in relevant standards [11, 73]. Some studies suggest that the opportunity to control an environment affects the thermal perceptions of occupants, making them more receptive to the educational environment in terms of thermal comfort [74, 75].

E. Climate change

Australia has a varied climate, resulting in different locations around the country having different heating and cooling requirements. To account for these climate differences the energy efficiency factors vary from location to location [76]. New South Wales is located in climate zone 5 under Australian Building Codes Board (ABCB) classification and has a warm climate. However, there are very few existing studies for educational buildings, especially in climate zone 5 in Australia.

Global warming significantly increases ambient temperature [1]. Higher temperatures have a serious

impact on the electricity consumption of the building sector with increasingly significant peak and total electricity demand [77]. Within Australia, The impacts of global warming are already being felt across all areas of life. In January 2019, which was the hottest month on record, the hottest ever minimum temperature anywhere in Australia was set in New South Wales with average temperatures Australia wide 3 degrees above normal [78]. In 2017, Australia's experienced the third warmest year on record, with the annual national mean temperature 0.95 °C above average [79]. In tandem higher ambient temperatures increase the number of problems such as the deterioration of thermal comfort conditions in buildings [80], exacerbation of health problems, and the increase of energy consumption [81]. In order to manage the energy consumption and predict energy needs induced mainly by urban overheating and global warming, linking this with students' thermal comfort will be a vital process to reach the optimum ABP.

A. Optimization approaches

Table (2) shows different methods of analysis to find effects of ABP on thermal comfort and energy consumption. One form of analysis that performed with building energy models is optimization, which is useful in finding the optimum solution [82]. Previous studies [83] found that optimization process based on a multi-objective optimization approach can be an efficient way to find the optimum ABP based on the energy consumption and students' thermal comfort. Multi-objective optimization approach is the process of simultaneously optimizing two or more conflicting objectives subject to certain constraints. Finding such a solution, and quantifying how much better this solution is compared to other solutions, is the goal when setting up and solving a multi-objective optimization problem [84].

III. DISCUSSION AND FUTURE RESEARCHES

Buildings must be resilient to climate change and be adaptable, flexible and durable in order to increase the level of thermal comfort and decrease the energy consumption [85]. Moreover, students' thermal comfort should be a priority in school alongside the use of energy efficiency [86].

Study	Methodology		Optimization analysis methods, Building type, Country
	Thermal comfort	Energy consumption	
[23]	PMV model	TRNSYS simulations	Genetic algorithm, and Artificial Neural Network (ANN), Residential, Canada
[22]	Percentage of thermal discomfort hours	EnergyPlus simulations	GA–BP network model, and multi-objective genetic algorithm (NSGA-II), Residential, China
[31]	thermal discomfort hour	EnergyPlus simulations	Simple statistical method, School, China
[24]	Reviews the results of the other studies.	Reviews the results of the other studies.	Simple statistical method, high-rise residential buildings, Malaysia
[32]	PMV-PPD model	EnergyPlus simulations	parametric analysis, and (ENVLOAD), Residential, Taiwan
[34]	PMV-PPD model	TAS and CFD	Simple statistical method, Office, Singapore
[33]	PMV-PPD model	The ESP-r dynamic simulation	Regression analysis, Office, UK

Table (2) Different analysis methods in previous studies

Thus, the requirements of energy efficiency in schools should not only be concerned with the reduction of energy consumption but needs to increase the level of students' thermal comfort as an additional priority. In order to obtain better building performance, two factors need to be taken into consideration: ABP and occupants [18].

The occupants' thermal comfort determines the energy consumption by indoor environmental parameters, therefore they play an important role in building sustainability [36]. Although architectural design is an important aspect in building performance, it is not easy to tackle because of the complexity and diversity of the process [22]. Due to the increasing impact of global warming and climate change, which led to high temperatures, attention to the building and envelope design has become very important. The literature on factors that may affect energy consumption and thermal comfort and the relationship between them in terms of ABP was reviewed. One of the main factors determining the indoor thermal environment in buildings is heat gains or losses through ABP such as walls, windows and floors [87].

In turn, this indoor thermal environment determines the amount of energy required for heating and cooling to maintain optimal thermal comfort conditions. Since the negative impact of poor thermal environment may affect students' performance, providing comfortable conditions for educational buildings has always been critical [88]. While the PMV equation can be used to predict comfort indoors, the graphical comfort zone method by using the psychometric chart shows the environmental properties of indoor space. Table (3) shows the proposed variables ranges of ABP can be used for optimization process in educational buildings in NSW.

The category of ABP	Variables, unit	Type of data: Numerical (N), Categorical (C)	Range	Reason of selection/ Sources of Reference (Refs)
Building design	1. Building shape	C	Rectangular, and square	The most common classroom's shape. [89]
	2. Orientation, Degree	N	0≤ OR≤ 270	The main directions/ [22, 90]
	3. Floor height, Meter (m)	C	Base case≤ FH≤ Double height	To figure out the effect of floor heights on classrooms.
	4. Floor number, Story	C	1≤ FN≤ 5	To figure out the effect of floor level on classrooms
	5. Floor area, Square meter (m2)	C	Base case≤ FA ≤ Double area	To figure out the effect of floor areas on classrooms.
	6. Cooling set point, Celsius degree	N	23≤ C ≤ 28	The most common application of cooling/ heating set point. Also, based on recommendation range between 18.4C and 26.4C. (Neutral temp: 22.4C). Another study the range between 20C and 27C./ [23] [38] [62]
	7. Heating set point, Celsius degree	N	18≤ H ≤ 23	
Envelope design	8. Wall heat transfer coefficient, W/(m2 K)	N	0.3≤ WHC≤ 3	The most common practice based on previous study and Arup U values guide/ [22, 90, 91]
	9. Roof heat transfer coefficient, W/(m2 K)	N	0.3≤ RHC≤3	
	10. Window heat transfer coefficient, W/(m2 K)	N	1.5≤ WWHC≤ 6	
	11. External shading device : *vertical and horizontal, with or without, Meter (m)*	C	Base case≤ ESD ≤ Double depth	Based on previous study/ [24]
	12. Window-to-floor ratio (WFR), Percentage (%)	N	20≤ WFR≤ 80	Expand the range of previous study which was between %20 to %35 to cover wider applications./ [22]
	13. Window to wall ratio (WWR), Percentage (%)	N	20≤ WWR≤ 80	
	14. SHGC	N	0≤ SHGC≤ 1	Cover the range between minimum value of 0 and maximum value of 1 based on section J which is part of the building code of Australia./ [76]

Table (3) the summary of variables ranges of Architectural building design parameters will be used for optimization

Despite the efforts of past studies, there are still issues with modelling including: 1) insufficient studies to predict indoor thermal environment in New South Wales for educational buildings, 2) limited time period for prediction, 3) limitations in changing scenarios in terms of ABP to find the optimum result of indoor thermal environment, 4) shortage in validation of prediction model, and 5) linking the level of students thermal comfort with energy consumption concurrently. Based on [37] study it was found that there is a relationship between thermal comfort and environmental variables whether outdoor conditions or indoor and personal factors. Therefore, determining the relationship relationship between students' thermal comfort and energy consumption can help to identify the effect of ABP in the decision-making process during conceptual design stage.

Based on literature review, optimizing a system requires two main layers. Firstly, design parameters which can take on different values, and whose impact on the system is to be investigated (ABP as input layers). Secondly, at least one objective function stating which qualities of the system are to be improved (thermal comfort and energy consumption as output layers). The main findings from the literature review of this paper and recommendations for future study are summarized as follow:

- With the high impact of global warming on buildings, increasing the amount of heat transfer from outside to inside through envelope and building design parameters due to increase the ambient air temperature.
- High energy consumption due to high use of heating, ventilation, and air conditioning (HVAC) systems, as well as increasing the level of students thermal discomfort in classrooms.
- There are insufficient studies on the effect of ABP on students thermal comfort and energy consumption, and the lack of guidelines that could help architects to choose ABP.
- Improving provisions for classroom thermal comfort by gaining a better understanding of responses to ABP in the thermal environment should be helpful in achieving optimal energy usage for thermal comfort.
- Optimizing the ABP to achieve the highest level of students' thermal comfort and energy consumption during the conceptual design stage in educational buildings in climate zone 5 in Australia could be useful for architects and engineers to make effective decisions in the initial stage of building design process.

IV. CONCLUSION

The impact of ABP on the indoor thermal environment is a major new finding for educational buildings' research. The significance of the architectural design study is related to the relationship between the level of students' thermal comfort in the built environment, and the amount of cooling and heating energy consumption. Reviewed studies showed that the optimum selection of ABP is different from location to another due to the difference of building type, climate zone, and ventilation mode. Results from the literature review show the need to understand the relationship between thermal comfort and energy consumption in terms of ABP to reach the

optimum findings in the decision-making process during conceptual design stage. Despite diligence in previous studies, the effect of ABP on both thermal comfort and energy consumption in Australian educational buildings have not yet been clarified.

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