BORDER Jurnal Arsitektur, Vol. 2 No. 1, Juni 2020
ISSN 2656-5889 (cetak) / ISSN 2685-1598 (online)

A STUDY OF ENVIRONMENTAL APPROACH IN EARLY DESIGN STAGE

Fenty Ratna Indarti[1*]
[1]Department of Architecture, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo Surabaya 60111
* fenty.ratna@arch.its.ac.id

ABSTRACT

Due to the ozone layer depletion, global warming and climate change, there is a significant increase to reduce carbon emission. Practitioners and academia undertake studies to promote environmentally friendly built environments. Developed countries have established specific standards to achieve a carbon neutral as their commitment to contribute for a better earth condition. Design phases are considered as the early stage where the environmental approach needs to be applied to predict the building performance as soon as possible to maximise the energy efficiency of the proposed building. Another significant factor affecting the building energy performance is climate. Climate becomes the first parameter to generate building proposals as it is contextual to the site. This study aims to assess the application of environmental approach in designing educational building in temperate climate in the early design stage. The combination of design and simulation helps to define the best design proposal to adopt passive design that harvest the environment condition as much as possible to deliver comfort into the building.

Keywords: building performance; climate responsive; design decision support; early design; environmental approach

INTRODUCTION

Fossil fuel-based energy consumption has resulted in negative environmental impact such as ozone layer depletion, global warming and climate change (Dincer, 1991). There is a significant increase in effort to develop a low carbon lifestyle in regard to reducing carbon emission. More practitioners and academia develop and investigate more sustainable approaches and to create a user-friendly environment in order to promote well-being and personal enjoyment by not neglecting the environment (Li, 2011). Developed countries have established specific standards to achieve a carbon neutral as their commitment to contribute for a better earth condition.

The International Energy Agency (IEA) in 2004 reported that buildings account for up to 40% of their total energy in the developed countries (Jain et al, 2014). One of the most notable factors to control energy use in building is how the building is designed during the design phases. Wang, Zmeureanu and Rivard (2005) and Granadeiro et al (2013) confirmed that decisions made during design stages significantly affect the energy used for building operations. Those decisions help to design a more energy efficient design proposal for the development. Furthermore, MacLeamy (2004) illustrates how decisions made during early design stages consequently contribute to the environmental imprint of the building in the future. McLeamy curve represents the increase of cost of design change getting higher when approaching the building construction and operation. As opposed, the possibility to influence impacts is getting lower when approaching the building construction and operation. It indicates that changing design later leads to difficulties and high cost (Fenga, Lua & Wang, 2019). It becomes highly complex to fix for very bad early design decisions during the design phase (Chong, Chen and Leong, 2009). Therefore, improving decision support during the design phase for building energy can help reduce building energy consumption and increase building energy performance efficiency (Hoes et al, 2009).

Another significant factor contributing the building energy performance is climate. The decision made during the design phases should take into account climate-specific consideration (Gercek & Arsan, 2019). A literature study conducted by Gercek & Arsan (2019) depicts that the systematic knowledge accumulation is significant to provide environmental and energy performance improvement schemes. Thus, during the design phase it is essential to involve climate-responsive design to make a robust decision to propose a more environmentally friendly and energy efficient building.

This study aims to investigate the application of environmental approach in designing educational building in temperate climate during the early design stage. The objectives to achieve the aim of the study are presented as follows:

- Investigating common practice of environmental approach
- Analysing the climatic conditions
- Formulating design strategies based on climate condition
- Applying design strategies in form making process
- Investigating the performance of the proposed design
- Optimising the proposed design through simulation

METHODOLOGY

This paper focuses on the application of environmental approach in the design process. The investigation describes how the environmental approach is applied to deliver the preliminary design. The study of environmental approach in the early design stage incorporates literature review to formulate the stages as a guideline during the design process. The scope of the literature is narrowed down into climate-responsive design. Along with the literature review, the study collects meteorological data as a primary data on the first stage of the study to generate design strategies. The collected meteorological data consists of annual average temperature, sun path diagram, wind rose and geographical location.

In order to gain a deeper analysis of the design effectiveness, software simulations are required to analyse the performance of the design proposal. The software generated data such as Daylight Factor (DF), illumination level and room performance based on ASHRAE 55-2013. The daylight performance is calculated under overcast sky at 750 mm above the floor. It represents the frequent sky condition of the site (Nottingham) and at the surface of the working table. The room performance explains the predicted condition of the proposed design in regards to availability of fresh air and cooling.

Climate-responsive Design

Environmental approach revolves around how the surrounding environment will potentially affect the proposed building. One of the direct factors of the building energy use is the climate condition of the site. Every decision made during the design phase to deal with climate lead to specific consequences for the building. Several studies have been conducted to investigate how to utilise a climate-responsive approach during the design phase.

The School of architecture in Argentina had adopted an environmental approach in 1991 to train their students to be more aware of climate consideration. The various climatic conditions in Argentina required them to understand how to deal with it. The study reported that microclimatic modification in their studio was delivered through three stages; introduction, development and synthesis (Evans & Schillers, 1991). Introduction is the initial stage where the climate, comfort level and the preferred as well as not preferred climatic variables are investigated. The main topic in this stage are bioclimatic design concept, basic world climates introduction, meteorological data interpretation, desirable comfort conditions observation, design recommendations and initial design proposals assemblies. The second stage is development where students integrate theoretical conception and utilise practical approach of bioclimatic design. This stage analyses the initial proposals and formulate design guidelines as well as making modification and improvement of the project outline. Technical exercises in this stage consist of design of winter outdoor spaces for direct sun, summer direct sun protection, direct sun radiation intensities assessment and utilisation, direct sunlight penetration in building interiors, winds protection through building form and organisation, outdoor space wind and comfort conditions, employment of various vegetation, utilisation natural ventilation, thermal requirement based for material selection from regional resources and passive solar systems application. Lastly, students build and provide design proposals that incorporate results from the previous stage.

There are three phases to incorporate climate-responsive approach in studio design activities (Lenzholzer & Brown, 2013). The first phase is literature review. All reviewing and summarising information is based on literature related to climate issues. It is followed by the assessment of the site and region to understand how the climate affects it. The analysis covers wind patterns, sun, shade and urban heat distribution during different points of time and seasons. Afterwards, climate responsive design proposals are proposed. It comes along with its simulation. The simulation quantifies the qualitative parameter in the design proposals.

From the practice, Brown (2010) explains that climate consideration in the design stage should be introduced as early as possible. He starts accumulating and analysing climate data to investigate the climatic conditions in different seasons and different times of the day. As addition, regional precedents review helps to provide additional knowledge and it is specific enough to respond to the selected site. Assessing the site helps to find characteristics that are useful for prevailing climate modification in order to provide microclimates. At last, to sustain the performance of the building quality, the design proposal is monitored and evaluated after construction.

Quantification of Environmental Uncertainty

This paper incorporates the three stages environmental approach during the early design of an educational building. The selected site for this study is in the University of

Nottingham, United Kingdom, with the latitude of 52.95° N and the longitude of 1.13° W. It is situated on the north side of the site is Derby Road which brings noise to the site.

The first stage concerns the analysis of the environmental conditions. It involves the study of meteorological data, design guideline formulation, identification of desirable comfort conditions and analysis of the needs of the building to achieve it. This stage produces design recommendations and initial design proposals such as schematic design. Afterwards, design ideas and concepts are developed. The main drive for this design stage is how to achieve comfort during all seasons in terms of daylight, thermal and condition. Furthermore, all design proposals will be evaluated to predict its performance in the optimising design stage. The analysis was derived from Ecotect for illumination level while Optivent provided data for natural ventilation.

RESULTS AND DISCUSSION

Formulating Design Guideline

Microclimate analysis provides early design guidelines to develop design concepts for the proposed building. Microclimate analysis is based on meteorological data that is available for public use. It involves annual temperature profile, sun and wind profile. It directly affects the process of form making and form finding. Sun movement analysis is generated by investigating the sun path diagram (azimuth and altitude) and shadow analysis. This paper looks at Nottingham's climate conditions as the object of the study. The findings and design guidelines based on the climate analysis of Nottingham is illustrated in Table 1.

Making the form

The building form utilises the design guidelines in Table 1 to shape the proposed building as depicted in Figure 1. It indicates how the proposed building adapts to the environment in the surrounding site. The proposed building requires 4 main features that are gallery, lecture room, library and studio. The design strategies also regulate the space arrangement inside the building as depicted in Figure 2 and Figure 3. Furthermore, it helps to formulate the environmental strategy for the building to respond to the climate condition as illustrated in Figure 4.

In the summer, the building proposal blocks the sun by using shading devices to avoid overheating during the day and maximise the use of natural ventilation during at all time. The proposed building uses stack-effect to increase the airflow inside the building. By opening the windows during the day, the fresh air infiltrates the room and the difference temperature of the chimney and the room creates buoyancy to ventilate the room and let the hot air comes out from the chimney. Meanwhile, during the night the heat which is stored during the daytime is released and goes up to the chimney where the wind will erase the hot air.

Table 1. Climate-responsive design strategies for the selected site based on Nottingham, UK meteorological data

Period / season	Findings	Design strategy	Code
Temperature analysis			
October - April	Temperature is below the comfort zone (below 20°C)	Building is in the need of heating	TA1
May - September	– Temperature is in the range of comfort zone (around 20-25°C). – Highest temperature and direct solar radiation of the year (up to 0.4k W/m^2).	– Building is able to free run (no heating or cooling) – Possibility of overheating	TA2
Sun path analysis			
Winter solstice	– Sun rises at 8.30 am and sets at 3.30 pm. – The lowest altitude is 5° at 9 am 20° SE and at 3 pm 20° SW. – The highest altitude is 13° at 12 pm from the south.	The east, south and west facade will receive sunlight that is beneficial for passive heating.	SP1
Summer solstice	– Sun rises at 3.30 am and sets at 8.30 pm. – The temperature starts to rise at 12 pm. – The altitude is 60° from south.	Minimising the solar gain can be implied by providing horizontal sunshade to south façade.	SP2
Shadow analysis			
Winter solstice and equinox	The site is fully overshadowed, little solar radiation	The most inhabited area should be elevated to increase direct solar gain	S1
Summer solstice	The site is not overshadowed, high solar radiation	Provide sun shading device to prevent overheating	S2
Wind analysis			
Summer	The prevailing wind mostly comes from the west	Provide more opening in the west	W1
Winter	Cold wind comes from the north	The wind should be avoided to reduce the heat loss	W2

(Source: Indarti, 2015)

As illustrated in Figure 4, the proposed building captures the direct sun as much as possible to warm up the space in the winter without using additional heating during the day and closes the building tightly during the night to keep it warm and reduce the heat loss for the following day. Letting the solar gain comes through the room helped heating the inhabited space. The room introduces the fresh air into the room through the parapet wall. It is used to bring the preheated fresh air into the room. Ventilation is provided by creating buoyancy using the high temperature different in the chimney and the room then let the hot air comes out from the chimney. In the night there is no windows opened to avoid the heat loss. The thermal mass of the building absorbs the heat in the room while the envelope of the building is exposed by the outdoor temperature.

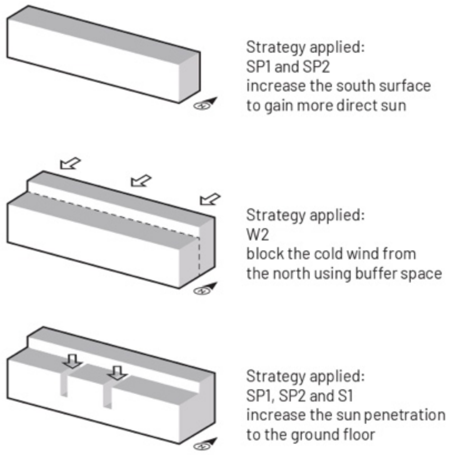

Figure 1. Early design building form making
(Source: Indarti, 2015).

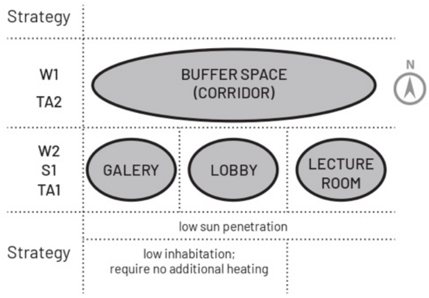

Figure 2. Ground floor space arrangement process
(Source: Indarti, 2015).

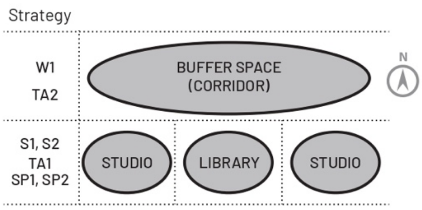

Figure 3. First floor space arrangement process
(Source: Indarti, 2015).

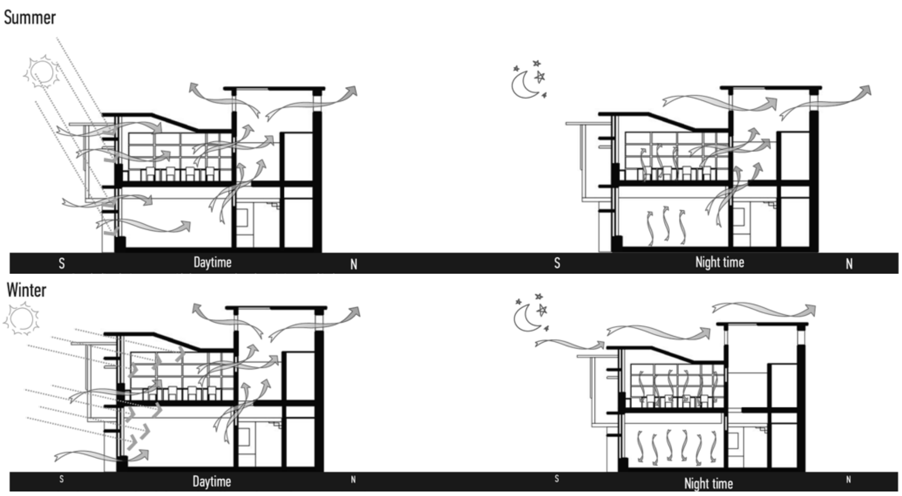

Figure 4. Environmental strategy for summer and winter (the most extreme condition)
(Source: Indarti, 2015).

Predicting performance and optimising design proposal

A 1:50 scale model (Figure 5) is tested in the heliodon to investigate the shading implication in the room condition. The room represents the proposed building due to its poor performance regarding visual and thermal comfort. The testing results show that in the summer the sun has been cut down by the shading device. On the other hand in the equinox and winter the sun comes through the room. This implies that there is glare opportunity in the room. As mentioned before, on the south side of the proposed building stands the Marmont Center (existing building) which creates overshadowing to the site during winter and equinox. Taking advantage of this condition the room will not be having high glare.

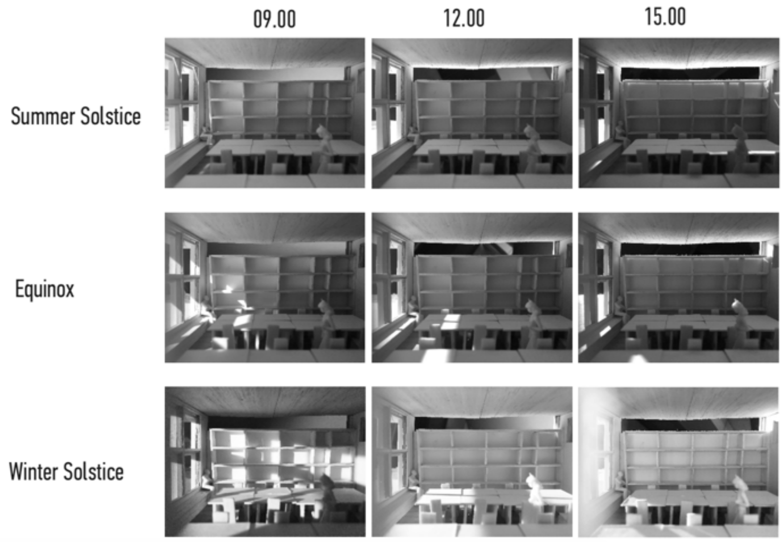

Figure 5. Heliodon testing results
(Source: Indarti, 2015).

Steady state building simulation is conducted to optimise illumination level and natural ventilation of the most vulnerable part in the design proposal which is the lecture room. The results of the simulation directly affect the building expression. It determines the opaque and solid composition of the building as well as the aperture of the building. Table 2 illustrates the development of transparent area in the selected room.

Table 2. Daylight factor and illuminance level optimisation

Case	**Transparent Area**		**Daylight Factor (%)**	**Illuminance level (lux)**
	South (m^2)	**North (m^2)**		
Case 1	9.7	2.8	5.81	118-368
Case 2	19.7	2.8	8.10	101-794
Case 3	19.7	5.9	8.68	103-801
Case 4	19.7	5.9 + 10.7 (additional window at the buffer space)	8.67	400-766

(Source : Indarti, 2015)

Daylighting recommendation from the British Standard Code of practice is 5% of an average daylight factor assuming that the room does not use additional lighting and to be daylit (Rennie & Parand, 1998). Average daylight factor in Case 1 (early design) is 5.81%. But the illuminance on the surface of the table ranges from 118-368 lux which does not fulfil the minimum requirement of a studio (based on CIBSE Guide A) 300 lux. After expanding the south elevation windows, the average daylight factor in this case is 8.10%. It indicates that the room is daylit and does not need the artificial lighting. But the illuminance on the surface of the table ranges from 101-794 lux. The north part is the vulnerable part since it has the lowest illuminance. By expanding the north windows in order to maximise the daylight penetration, the average daylight factor increases to 8.68%. But the illuminance on the surface of the table ranges from 103-801 lux. The illuminance in the north part of the room still needs to be increased. Providing a window on the north side of the corridor increases the light from the north side through the corridor. It increases the daylight factor to 8.67%. The illuminance on the surface of the table ranges from 400-766 lux which fulfils the minimum requirement of a studio (assumed as teaching spaces) 300 lux. In conclusion, the selected space needs to have windows on both the south and north side. As a studio, single side openings cannot provide enough illuminance to the table surface in the north side (the furthest part from the window) even though the average daylight factor is more than 5%.

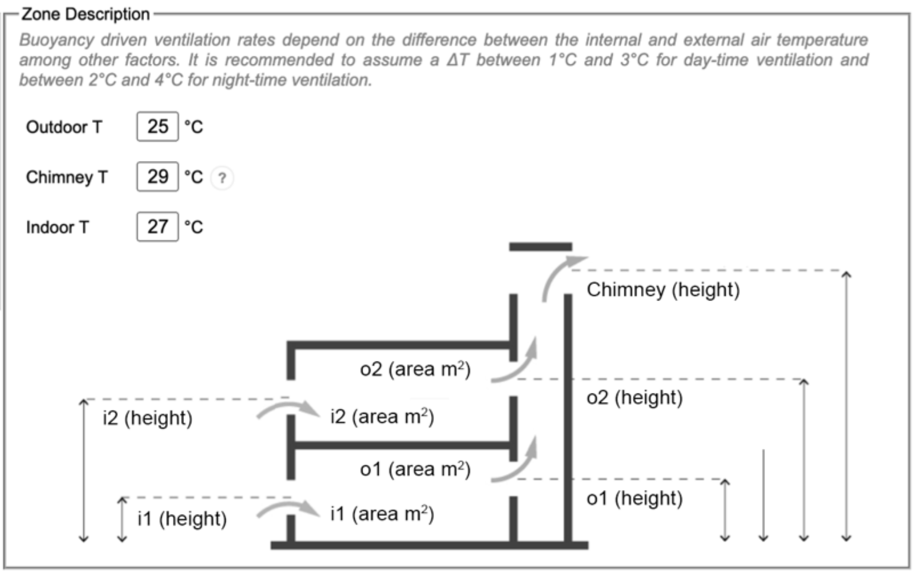

Figure 6. Optivent workflow diagram and case study illustration (Source: Indarti, 2015).

Here Optivent is used to determine the natural ventilation system and the implications to the proposed building design in the early design stage. Studies have been carried out based on 4 cases to investigate the most effecient design for the natural ventilation in the selected space (refer to Table 3). Optivent calculates the airflow of the buoyancy and wind driven of the selected space based on different temperature and aperture height as illustrated in Figure 6. The results of the simulation are depicted in Figure 7.

Table 2. Apertures profiles of the 4 cases

Case	Effective area (m^2)				Height (m)				
	i1	**o1**	**i1**	**o2**	**i1**	**o1**	**i1**	**o2**	**Chimney**
Case 1	9	2	9	2	2.8	3.6	5.3	5.8	8.3
Case 2	9	6	9	6	2.8	3.6	5.3	5.8	8.3
Case 3	9	6	9	6	2.8	3.6	5.3	5.8	9.3
Case 4	9	6	9	8	2.8	3.6	5.3	5.8	9.3

(Source : Indarti, 2015)

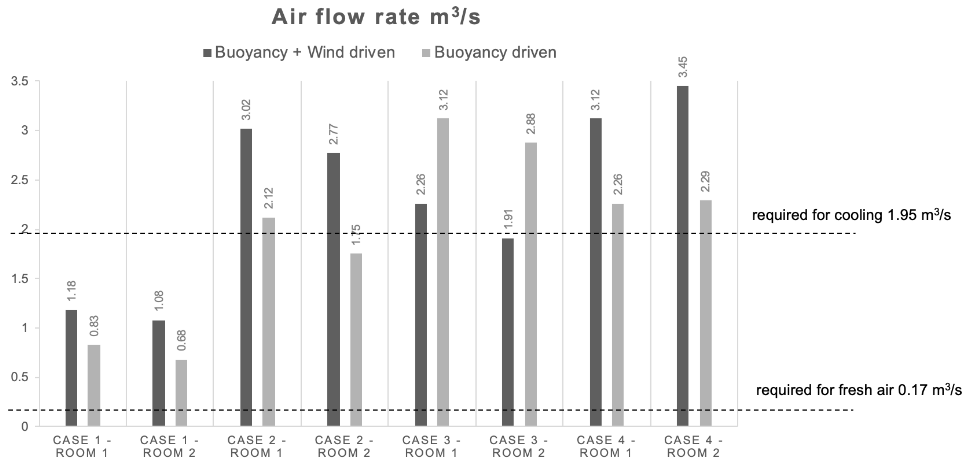

Figure 7. Optivent simulation results
(Source: Indarti, 2015).

Based on the simulation result (Figure 7), Case 1 (the original design) needs to increase the airflow in order to cool the space. Considering heat loss during winter, the proposed building must keep the south part, which has direct connection with the environment, to have minimum openings. It regulates the optimisation of natural ventilation to use the corridor space (buffer space) in the north part. The north aperture is increased in Case 2 but the airflow is not enough for cooling in Room 2 if the room only uses buoyancy driven. The chimney height is increased in Case 3 but the buoyancy driven is still not able to cool down the room. After increasing the north aperture once more in Case 4, the airflow of Room 1 and Room 2 are increased and able for cooling both on wind+buoyancy and buoyancy driven only.

CONCLUSION

Environmental approach involved the surrounding climate condition to set parameters for building design. It acknowledges the climate conditions not only as a threat but also takes the most advantage of it to help building deliver a comfortable space for the inhabitant. Analysis of microclimate condition helps to set basic guidelines and prioritise consideration of the design. It also accelerates design decisions in regards to developing early stage environmental strategies. Design strategies act as environmental parameters in the process of form making. It reduces the subjectivity to achieve environmental satisfaction. Microclimate climate helps to form the architecture to cope with the environmental condition. The design strategies (as illustrated in Table 1) orientate the building to face the south and avoid the north due to sun orientation and prevailing wind. Additional openings are provided to deliver more daylight for the building where it is shadowed during the winter.

Simulation helps to optimise early design proposals. By keeping on record for several cases, proposed building's performance can be predicted in the early stage. Learning from previous design and prioritise several decisions to keep balance environmental satisfaction and architectural quality. Several cases have been investigated in regards to the luminous environment. The early design needs to be enhanced by enlarging the window ratio. Meanwhile natural ventilation simulation optimises the building air quality by using a stack effect system. Early design is optimised by increasing the aperture of the outlet and the height of the chimney. By combining design and simulation during the early design stage, more robust design proposals can be developed. Environmental approach helps to determine passive strategies used in the building to harvest the environment in order to maintain comfort for the inhabitant. It maximises the use of solar gain to warm up the space to minimise the heating energy demand and natural ventilation to diminish the cooling energy demand. It accelerates the compliance of energy efficient building to tackle the energy demand crisis.

REFERENCES

Brown, D., 2010. Design with microclimate. Berkeley and Avant Garde. Washington.

Chartered Institution of Building Services Engineers, 2006. CIBSE Guide A: Environmental Design. CIBSE, London.

Chong, Y, Chen, C and Leong, K., 2009. A heuristic-based approach to conceptual design, Research in Engineering Design, vol. 20, pp. 97-116.

Dincer, I., 1999. Environmental impacts of energy. Energy Policy, vol. 27, 8pp. 45-854.

Fenga, K, Lua, W and Wang, Y, 2019. Assessing environmental performance in early building design stage: An integrated parametric design and machine learning method. Sustainable Cities and Society, vol. 50, pp. 2210-6707.

Gercek, M and Arsan, Z., 2019. Energy and environmental performance based decision support process for early design stages of residential buildings under climate change. Sustainable Cities and Society, vol. 48, pp. 2210-6707.

Granadeiro, V, Duarte, J, Correia, J and Leal, V., 2013. Building envelope shape design in early stages of the design process: Integrating architectural design systems and energy simulation. Automation in Construction, vol. 32, pp. 196-209.

Hoes, P, Hensen, J, Loomans, M, Vries, B and Bourgeois, D., 2009. User behavior in whole building simulation. Energy and Buildings, vol. 41, pp. 295-302.

Jain, R, Smith, K, Culligan, P and Taylor, J., 2014. Forecasting energy consumption of multi-family residential buildings using support vector regression: Investigating the impact of temporal and spatial monitoring granularity on performance accuracy. Applied Energy, vol. 123, pp. 168-178.

Lenzholzer, S and Brown, R., 2013. Climate-responsive landscape architecture design education. Journal of Cleaner Production, vol. 61, pp. 89-99.

Li, W., 2011. Sustainable design for low carbon architecture. Procedia Environmental Sciences, vol. 5, pp. 173-177.

MacLeamy, P., 2004. Collaboration, integrated information and the project lifecycle in building design, construction and operation. WP-1202. The Construction Users Roundtable, Cincinnati.

Rennie, D and Parand, F., 1998. Environmental design guide for naturally ventilated and daylit offices. Construction Research Communications, London.

Wang, W, Zmeureanu, R and Rivard, H., 2005. Applying multi-objective genetic algorithms in green building design optimization. Building and Environment, vol. 40, pp. 1512-1525.