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# Analysing Optimum Building Form in Relation to Lower Cooling Load

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**Abstract**

Energy consumption would be an enormous matter as the number of people is increasing worldwide and resources are limited. The focus of the designer would be designing the building form to ensure less energy consumption. This research investigates the relationship between optimum building form in decreasing the cooling load. The study is conducted using computer simulation analysis program Autodesk Ecotect. The experimentation shows the relationship between building elements and cooling load. The outcome of the research reveals that compactness and lower ratios of surface to volume do give significant impact. Based on the result is assumed that manipulation and selection of building form will help passively in reducing cooling load.
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*Keywords:* Building form; energy efficiency; cooling load

## 1. Introduction

High energy consumption correspondingly starts from inefficient used for energy. In future, usage of energy would be a vital matter, as number people are increasing worldwide, and resources are limited. With the standard of

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living enhanced, people incline to expect a better comfort level, which eventually the usage of the air conditioning system is a must. If the building is designed in such a way that it will enhances energy efficiency and comfort (Zhang & Lei, 2013), in a simple term the building can cool itself. There would be no need for installing air conditioning system that is large and expensive. Small and fewer air conditionings mean significantly less energy consumption and more savings on electricity bills. In Malaysia, most of all commercial offices engaged cooling systems takes up average 70% of the total energy consumption yearly (Ahmad & Abdul-Ghani, 2011; Suziyana *et al.*, 2013).

Markus & Morris (1980) stated that the designer of the buildings can have significant control over the building as merely by changing material and form of construction. Material changing can affect the U-value or insulation value while the building construction method would influence air changes and ventilation loss. The designer has full impact on the parameters considerations. There are numerous ways how the actual dimension of height length and span varies which resulting in the diverse total surface area of a volume. Two different building may have different surface areas and envelope heat loss, but both buildings may have the same size and materials.

This paper aims at exploring optimize building form and its component, that illustrates less heat gain and eventually lower cooling load. Shape, geometry and form of a building is influenced by the solar energy it receives as well giving impact to its energy consumption (Markus & Morris, 1980). The shape of the building has a significant effect on both construction costs, and energy costs of buildings (Mingfang, 2002; Ourghi *et al.*, 2007; Pacheco *et al.*, 2012). However, deviation of energy values of the different shape are comparatively small, and window wall ratio shows a significant value compared to form as the heat gain enters mostly from an opening (Ferdous, 2012). Still, there is a high correlation between the shape of a building and its energy consumption (Ourghi *et al.*, 2007).

The compactness of a form can reduce energy consumption (Granit & Möller, 2008). While AlAnzi *et al.*, (2009) use compactness as an indicator in assessing the impact of shape on energy performance. Building form and building envelope are the most important parameters affecting indoor climate (Hemsath & Alagheband Bandhosseini, 2015; Oral & Yilmaz, 2003). There is a less research on building performance of the form based on cooling load capacity. Most building research based on cooling would relate more towards improving air conditioning system capacity. While in other research context, building forms are explored more towards thermal comfort and solar radiation. Based on these reviews, most studies on building form directly related to building aspect ratios such as surface to volume ratios, width to length, window to wall ratios and compactness. Exploration of various variables can be perceived when building form is being experimented.

The development of building form throughout the architecture design process would undoubtedly provide a better impact of energy efficiency. The building shape development to achieve better energy performance is essential. Effect of heat gain externally and internally towards a building form is crucial. The building shape manipulation and changes will deter the heat calculated for cooling load. Therefore, it is significance to explore the optimum building form that specifically lowered the cooling load and improve energy efficiency.

### *1.1. Building form and energy*

Building form, spatial layout and arrangement configurations that are planned towards energy efficiency and based on climatic data is considered as a passive response. Improvisation of energy used is not only on building orientation but influenced by the form of the building and ratio of the volume to a surface (Yeang, 2006). Size and orientation of the exterior envelope are the ones that exposed directly in an outdoor environment. These elements are determined specifically by the form that in turn affects the thermal performance of a building. Even cost and esthetic are influenced by the building form. Undeniably, selection of an optimum form, orientation, and envelope configuration can reduced energy consumption by 40% (Mohammed Hussein Abed, 2012; Wang *et al.,* 2006). Building form in architecture is an external appearance that can be identified, a reference to the internal structure and internal outline. The form usually includes 3d mass or volume and a defined shape that gives its outlook (Ching, 2007).

### *1.2. Cooling load*

The main purpose of the mechanical and electrical systems in buildings is to provide the space occupants to live and works comfortably and safe. Through decades, building energy evolves to ensure better energy conservation compared to previous structures. The trends resulted from the energy crisis. The energy crisis significantly has altered how the designers designed a building. Due to the energy crisis, numerous studies shows that air conditioning impose near 64% towards energy consumption in a building. Thus in identifying a better system of the air conditioning system is to lower its heat gain by understanding its cooling load. To determine how the air conditioning system and building design relates, the cooling capacity is defined as the quantity of heat energy that needs to be eliminated from space to preserve the temperature by cooling apparatus or air conditioning system. The cooling load calculation will directly influence the building cost along with the operating indoor air quality, occupant comfort, energy efficiency, and building durability. There is a lot of design strategies have been attempted to encourage energy efficiency and reduce the energy consumption. By creating and designing building shape using the optimum form, it is one strategy for supporting the best design practice towards energy efficiency.

Architect as the designer are the one who participate in building design, starting from the initial ideas up to construction. Architects have full control over building orientation, shape compactness of building, wall and insulation material selection, area orientation, colors of wall and roof material. The building system such as air conditioning system, water supply, lighting system, services can be controlled effectively to achieve comfort level of human inside the building when work in a collaborative team. Positive collaboration would enhance building energy efficiency of the building. The interaction will give effect to the usage of daylight plus artificial lighting, zone switching with open areas lighting, and task lighting within the interior colours (Nield, 1984; Van Moeseke, Bruyère, & De Herde, 2007).

### *1.3. Building forms and climate*

Malaysia situated near to the equator and having hot and humid along the year with mean relative humidity more than 75 percent and varies throughout the year. Solar radiation is active with partly reflected and scattered by cloud in addition to high water vapor. Solar radiation is a substantial concern in any building that strives for energy efficiency. As it helps in building massing and orient the building form on the site. The experimentation with building shape is closely related to climate, and different environment would yield the different result of its cooling load. Basic understanding of hot-humid climate and based on other research shows that the long axis of a building form should face north as less heat gain can penetrate through the openings of the long axis. As the highest received, solar insolation level is on the east wall (Ling, Ahmad, & Ossen, 2007)

## 2. Methodology

The computer simulation study is used in investigating the optimum building form in decreasing the cooling load. In the search for the optimum building shape that is having solar reduction that will lead to the lower indoor heated environment and the decrease of cooling capacity towards energy analysis. The first stage experimented with basic building form are rectangular, square, courtyard, L, T, U, ellipse, and circle shape (fig.1 (b)). Second stages explored the extended building forms (fig1(c)). Shapes and forms are pure geometry that is commonly found in architecture and industry. The primary and extended building forms created and simulated as a prototype of a five stories institutional building equipped with full air conditioning system.

Based on the fundamental knowledge, these basic shapes are the basic form that will be used and analysed in the software simulation in order to see the dissimilarities or changes of cooling load in preliminary stage. While the second stage is experimenting with extended building forms. The extended forms are generated from the first phase experimentation and research reviews. The first stage and the second phase studies are conducted in primary and extended building form, which are based on Google Earth observation of major institution building of local context of five stories building. The main building shape is identified based on the literature study and existing building.

### 2.1. Parametric analysis

Various design options with the reference to a climate may produce different energy consumption for each design options. Most data and its comparative analysis have been done using computer software. The energy performance can be investigated during the conceptual design stage with the help of computer software. Making several runs on the same building while varying only a single design parameter is known as a parametric study. Effect of design variables on the building form has been investigated varying one variable at a time for a design day.

The study scope is to explore the building shape potential in decreasing the cooling load that significantly creates a lower indoor heated environment. The primary building forms is being created in Autodesk Revit, simulated and analyze its energy analysis in the Autodesk Ecotect 2011. The detail experimentation process of the manipulated building form is shown on Fig 1(a). The experimentation of building forms will be varies according to it variables. The building forms are manipulated, and the variables such as volume, height, floor areas are set constant. The manipulations of basic forms (fig.1 (b)) and extended forms (fig. 1 (c)) can be viewed from its transformation sizes of its length, width and orientation. Once the simulation of the forms completed, it will produce the surface area, volume and surface ratio of the form that were tested. The compactness of the forms can be calculated using the volume to surface ratio. As the dimension and the properties of the building being shown and calculated, so does energy data. Energy data presented are the cooling load, heat gain, and its temperature.

Most of the building elements such as door, column, structure, space floor size and volume, envelope design, type of material is set constant. Then, the form will be simulated into various types of shapes and dimension. To complete the objectives, the study will analyze all alternative shapes and design ideas within the variables in Autodesk Ecotect Analysis. It assumes various forms will give different cooling load calculation based on the building shape transformation and local climate. Different forms will be heated differently based on the different angle of heat penetration and gain towards the building.

Based on American Society of Heating. Refrigerating and Air-Conditioning Engineers, to calculate a space cooling load, data regarding the building design and weather are required. Primarily, ASHRAE has outlined six points that will influence and used in the cooling load calculation, there are:

- The building characteristic.
- Configurations of building
- Outdoor design conditions.
- Indoor design conditions.
- Operating schedules.
- Date and time.

Hence, this data can be added to the software and being calculated using CIBSE method. CIBSE admittance method is based on a 24-hour cycle of a steady-state process. The software uses the CIBSE Admittance Method to calculate the amount of heating and cooling loads for a number of zones within a model. The benefit of the admittance method is fast and can interact dynamically with the design model. Any changes to the material and design, the analysis result can be calculated quickly.

To analyze, the selection of time and month in a year need to be identified to gather data on peak load time. Individual exposure based on the month and solar condition around a year would be calculated, and usually the warmest temperature must be identified. As the weather data is the critical parameters in identifying the cooling load, the cooling load calculation will be based on selected location. The simulated building form is using Kuala Lumpur (Subang Jaya based) design weather data linked with the Autodesk Ecotect software.

Once, all data in all steps collected, the space cooling load at different design conditions will be calculated. However, only cooling load and heat gain calculation related to building form, shape, and design will be taken. The form typology and its components will correspond to its local climate and site context. From there, the result of cooling load data can be compared and analyzed.

### 2.2. Primary building form layout

The study investigates the manipulation of the basic shape and form of medium five stories building in hot, humid climate and its impact towards the cooling load. The building is considered as unoccupied with internal loads and infiltration. The important observation is how the cooling capacity differs from the architectural parameter being altered and manipulated, especially the transformation of forms. The study focus on the building forms which using entirely air-conditioning system, under the influence of hot and humid climate. The shape of the building to be analyzed would be based basic building forms and extended manipulated forms as shown in figure 1(b), (c).

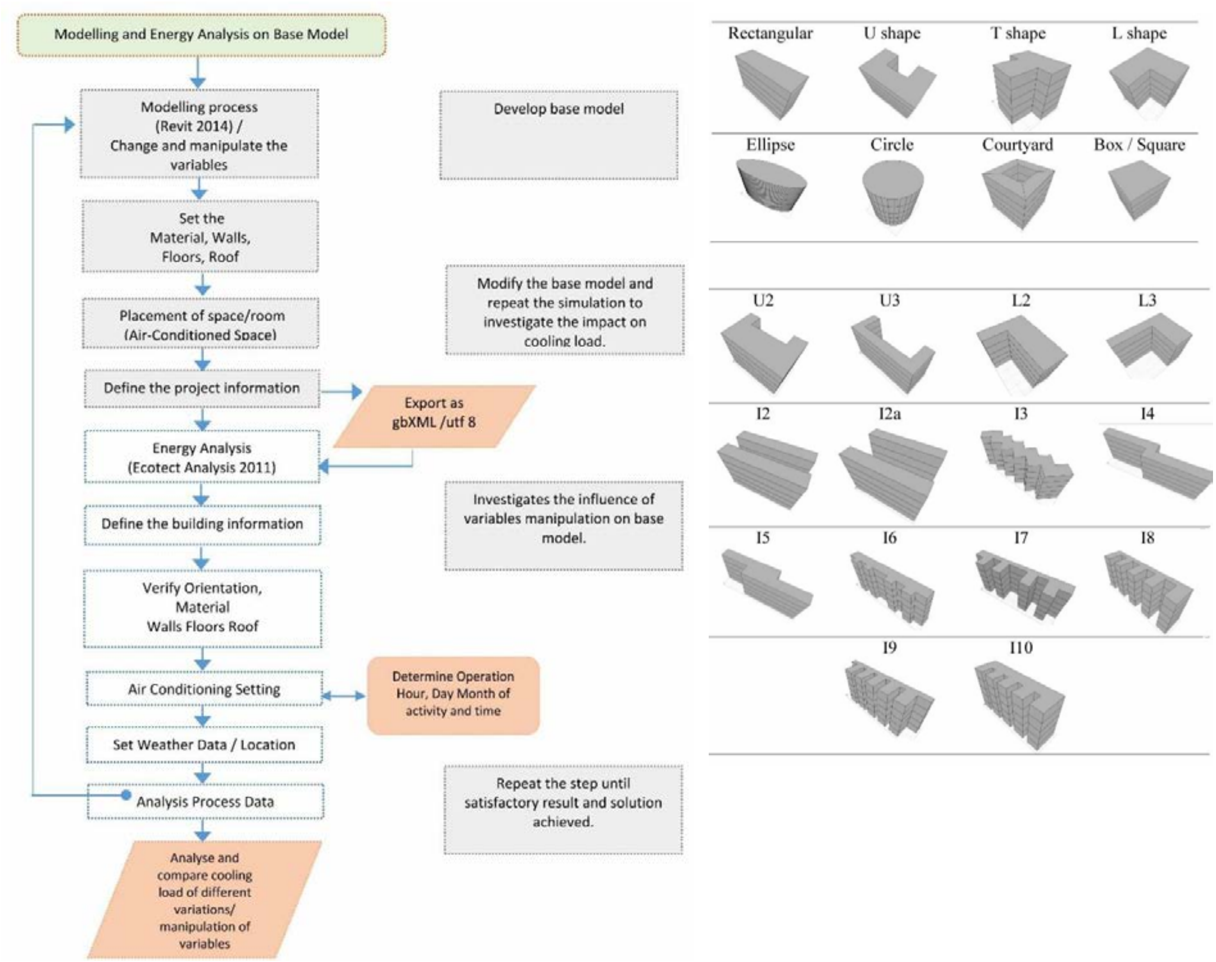



Fig.1. (a) Experimentation process; (b) stage 1 experimentation of basic forms (c) stage 2 experimentation of extended forms

The building forms floor area, volume, and height are being constant to ensure the calculation of its cooling load. While pertaining the building configurations, all forms will have the same information entered in the software shown in Table 1. Such data are operation schedules, regulations, space usage, desirable temperature, occupancy and other operational parameters.

Table 1. Building form design properties

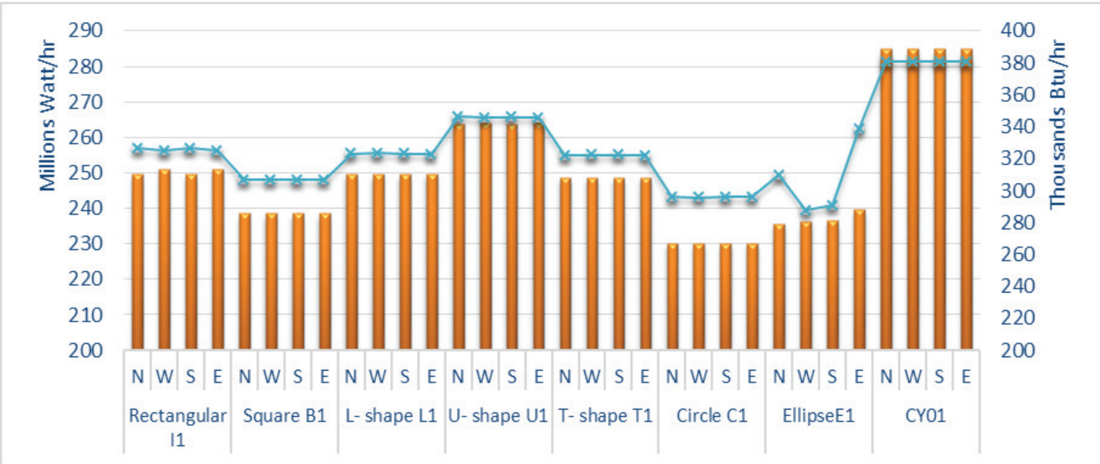
| Properties | Dimension |
|---|---|
| Five stories building | |
| Height of each floor | 4000m² |
| Volume | 6000m³ |
| Area of each floor | ±300m² |
| Overall floor area | 1500m² |

## 3. Results and discussion

Selected results of the parametric analysis are discussed.

### *3.1. Compactness and surface to volume ratio*

Fig. 2 illustrates the impact of different primary building forms on the cooling load. The result of Fig.2 indicates the cooling capacity or the rate of energy needed to remove the heat increased consequently within its loose shape. While the most compacted shape such as a circle (Ling, 2007) and square shows lower cooling load. Compactness of a shape is also identified as shape factor and defined as the surface area to volume ratio (Herde, 2003). Fig.2 graphs show the cooling load result are consistent with the surface to volume ratio relative to various basic forms. The lower its surface to volume ratio, the more compact the form become, the lower its cooling load. On which, the less amount of heat needed to be removed. The loose shape such as courtyard is shown to have higher cooling load when compared with the other fundamental forms. Due to the most surface are prone to heat penetration from all sides. It is assumed as the more surface disposed of the sun radiation, the higher its cooling load. While a study by Muhaisen & Gadi, (2006) in the temperate climate indicate courtyard form that is deeper and shallower and extended longer are better in reducing cooling load. Introducing shading devices in courtyard form also help improve reducing cooling load. This strategy would be one way of designing to ensure lower cooling load.



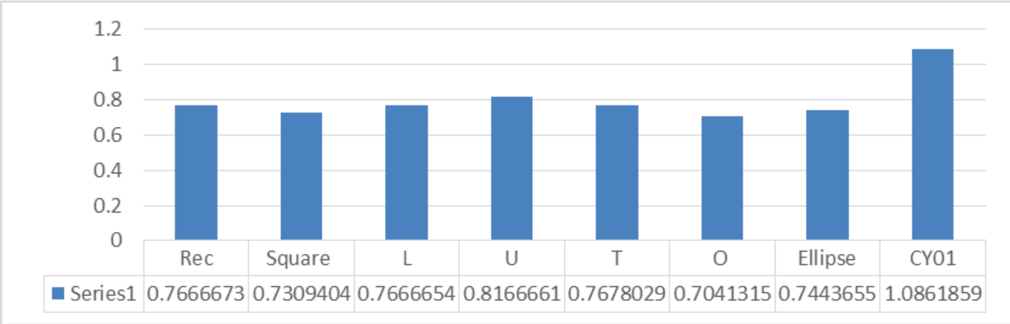



Fig. 2. (a) Basic forms cooling load (Btu/hr) (b) basic forms surface to volume ratios

### *3.2. Orientation*

Orientation plays an important part as it relates to the climate. The direction of long axis wall facing the east shows higher cooling load. The result is aligned with the fundamental knowledge of orientating the long axis facing north as the best orientation of a building form. Based on the fundamental shape analysis the most fluctuated cooling load on orientation are the rectangular form as its width and length differ vastly compared to the other basic forms shape. A study on façade design, shows that orienting the larger façade away from the heated solar radiation will give much more lower heat gain (Tzempelikos, Athienitis, & Karava, 2007). The other primary forms width and length shows not much significant difference based on the orientation. However, looking at the second stage analysis that explores on extended building shapes in fig.3. There is more fluctuated cooling load data of manipulated extended building forms compared to different orientation. The data has been calculated, and the percentage difference between building forms in hot-humid orientations shows only 1% up to 3% difference.

### *3.3. Extended building forms*

Based on the primary building shapes in stage 1, the next phase explores the manipulation of building forms, the manipulation can be seen from the figure 2 (c). The rectangular forms are being split into smaller rectangular forms, then orientated and cut through like a see-saw form, combined with the longer axis and narrow width. The variations of basic form is classified as I2, I2a, I3, I4, I5, I6, I7, I8, I9, I10, L2, L3, U2, U3, and CourtY is representing courtyard form. The manipulation of building shape typology is based on sky overview of institution building typology and also based on building forms fundamental by Francis D.K Ching. Extended building shapes in figure 3 (b) shows more complicated result as the form is being transformed by various manipulation.

The shapes, I2, I3, I4, I5, I6.I7, I8, and I9 has been manipulated to identify how the building forms react in hot-humid climate in reducing the cooling load. Indeed, the manipulation of I forms that represent the manipulation of rectangular primary form shows a difference result between orientations. That conclude small changes of the cooling load based on the orientation. The forms manipulation of the five stories building is designed without having windows, to see the effect on surface heat gains only. The introduction of window and opening towards the building form shows a nearly 62% percentage increase in cooling load.

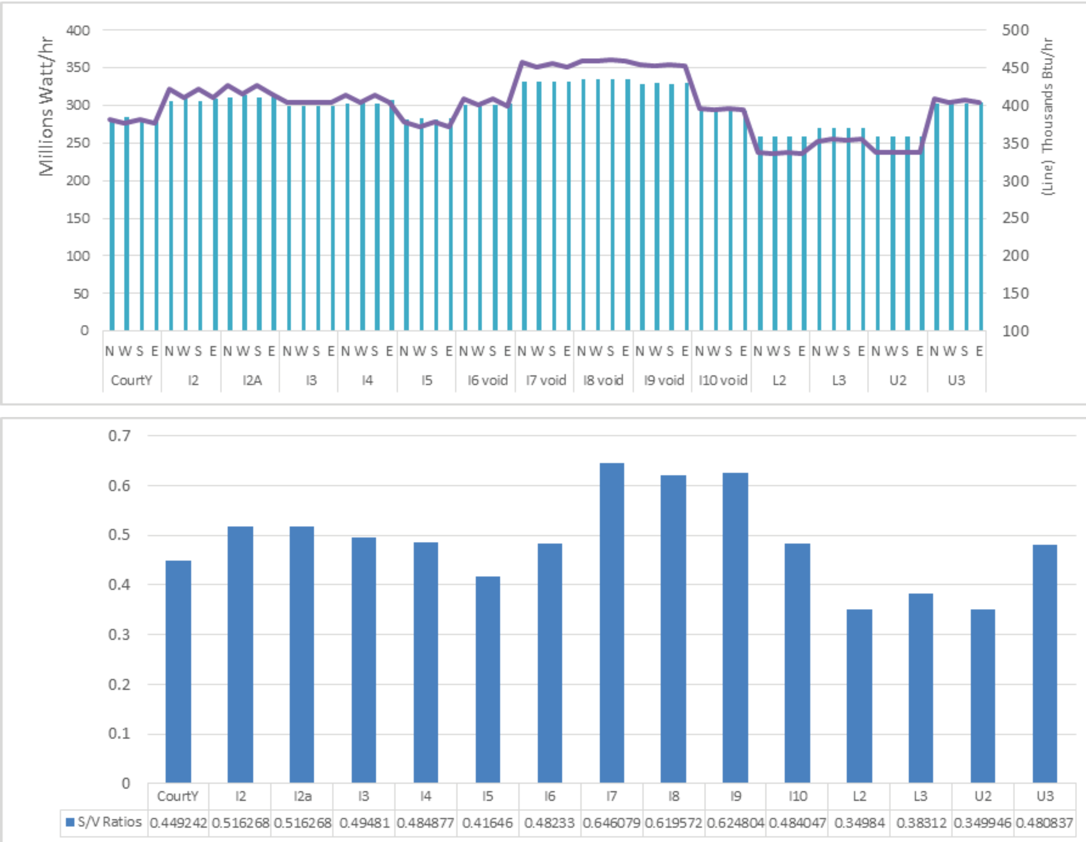


Fig. 3(a) Extended forms cooling load (Btu/hr) (b) extended forms surface to volume ratios

L2, L3, and U3 forms show a decrease in cooling capacity compared to I manipulated forms. The analysis indicates that compactness of L2, L3 and U3 plays important elements in decreasing the cooling load. While I7, I8, and I9 building shapes in graphs show a higher cooling load. Due to the manipulation of solid and void in between the form as can be seen from figure 2 (c). The larger cooling load is due to more surface expose to the sun heat gains. Indeed, this experimentation result indicates a similar result within the previous study and shows that better forms can decrease cooling load passively. The result would initiate a better building forms design for air conditioning building. The result also indicates having longer axis orientating towards the east would have the higher cooling load. Then, having a narrow axis and a small difference between its width and length also indicate lesser cooling load of the building forms. Further studies will be based on a base case model.

## 4. Conclusion

The study revealed the optimized building form and geometric generated based on lower cooling load and better energy performance. A particular type of building shape and its components can lower down cooling load. Still when considering the optimum way the shape is still based on its manipulation, so the result will be highlighted on how manipulation can be done to introduce better building form design. Analyzing building form in relative to the cooling load gives imperative result significantly.

- Building form with a loose form may have higher cooling load compare to the compact form.
- Manipulation of building forms significantly affect the cooling load of the building.
- The more surface of a form prone to sun radiation, the higher its cooling capacity in line with the higher surface to volume ratios.

- Lower surface to volume ratio, the more compact the form, the lower the cooling load.
- A different orientation has the moderate effect on cooling, still orientating the long axis facing north would be the best alternative.

Considering optimize building form would be a guideline for the designer to start designing a building that is having the lower cooling load. The form would have a passive impact towards lowering electricity cost. The designer would opt certain techniques based on the guideline in ensuring the building significantly has reduced cooling load. Eventually, when the engineer calculated the actual cooling load for the building the building would passively have energy efficiency.

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