LOW ENERGY BUILDING IN INDONESIA

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Dissertation

Erstellt am Institut für Wärmetechnik,
eingereicht an der Fakultät für
Maschinenbau und Wirtschaftsingenieurwesen
der Technischen Universität Graz

zum Zwecke der Erlangung des akademischen Grades
eines Doktors der technischen Wissenschaften

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Graz, 2010

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I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Graz, …………………………… *………………………………………..*
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For my husband, Leko Dwi Harjono,

my pearls Miko & Indri,

&

my parents

thanks for your never ending love

ABSTRACT

It is undeniable that energy crisis affecting the economic development in Indonesia. As the price of energy is rising, the Government subsidizes the domestic energy usage. For that reason, the Government has to set energy saving as a national priority. The building sector is found contribute to the major part of energy consumption. Moreover, in line with the rapid development of the cities, there will be massive building construction activities in Indonesia. Consequently, energy efficient building is of crucial importance in a context where cities are booming.

The cooling energy apparently dominates the total energy consumption in a building in Indonesia. Hence, obtaining the strategies on how to minimise the cooling energy demand in the building is essential towards energy efficient building. This research aims to formulize the main parameters that give significant impact to the reduction of building's cooling energy demand by applying thermal building simulation.

The simulation and visualization tool used is DesignBuilder, an EnergyPlus based dynamic thermal simulation engine. Four different buildings are simulated in this work using the weather data of Jakarta and Surabaya, Indonesia. The first simulation is undertaken using a three-storey office building proposed as the reference office building of IEA SHC Task 25. All parameters were set as defined in IEA SHC TASK 25 except the weather data. The second building is a shophouse, a typical mixed-use two storey building, which lower floor is used as a shop or other small business purpose and the upper floor as a dwelling. The third simulation is done for a single-family row house which is located in an estate complex with the shophouse, in south-western part of Jakarta. The latest building simulated is a high-rise nine-storey office building which is situated in Sidoarjo, residence close to Surabaya. Both the buildings of IEA SHC Task 25 and the high-rise office buildings are simulated using the weather data of Surabaya.

A sensitivity analysis is done in order to obtain the parameters that play an important role in reducing the cooling energy demand. The results show that increasing indoor air set point temperature gives the most valuable effect of the cooling energy demand. The buildings orientation is preferable to the south or north, and if possible the east and west orientation is to be avoided. Alternatively, the window on the east and west surfaces should be minimised. To reduce the solar energy radiation on window glazing, window shading or overhangs, as well as window blinds can be installed. They will be more effective for the east and west windows. Additionally, choosing a window glass material with low SHGC and high light transmission will minimise the solar heat transmitted into the building but maximises the use of natural lighting. Roof insulation in building with unoccupied roof spaces has no significant effect to the room beneath. As in Indonesia the roof space is unoccupied, therefore, it still need more consideration to install a roof insulation. However, a sloping roof with a roof space is more recommended compared to the flat roof because it will prevent the solar radiation directly penetrate the building. Instead of applying the optimum design of the building, the power limitation of the cooling equipment is beneficial in decreasing the energy consumption of the building without reduces the thermal comfort too much. As these thermal building simulations were done for buildings that are still in their design stage, the results can not be compared to those of existing buildings. However, these are valuable for the designers as they are still able to alter the building designs in order to obtain the most optimum design concerning low energy building.

Keywords: thermal building simulation, sensitivity analysis, tropical climate, low energy building

KURZFASSUNG

Die Energiekrise beeinflusst die wirtschaftliche Entwicklung in Indonesien. Als der Preis der Energie gestiegen ist, musste die Regierung die Energie subventionieren. Aus diesem Grund hat die Regierung die Energieeinsparung zu einer nationalen Priorität gemacht. Der Gebäudesektor macht den Hauptteil des Energieverbrauchs aus. Hiervon hat die Gebäudekühlung wiederum den höchsten Anteil. Einhergehend mit der schnellen Entwicklung der Städte, wird es riesige Gebäudekonstruktionstätigkeiten in Indonesien geben. Deshalb sind energieeffiziente Gebäude von entscheidender Wichtigkeit in einem Kontext, wo Städte boomen.

Da die Kühlenergie im Gebäudeenergiebedarf dominant ist sind Strategien zu entwickeln, wie dieser zu minimieren ist. Die vorliegende Arbeit zielt darauf ab, die wichtigsten Parameter zur Reduzierung des Kühlenergiebedarfs in Gebäuden zu ermitteln und quantitativ darzustellen. Als Hilfsmittel wird die thermische Gebäudesimulation verwendet. Hierbei kam als Simulations-und Visualisierungs-Tool ist DesignBuilder zur Anwendung, welches auf der dynamischen thermische Simulations-Plattform EnergyPlus basiert.

Vier Gebäude wurden die in dieser Arbeit unter Verwendung der Wetterdaten von Jakarta und von Surabaya, Indonesien simuliert. Als erstes wurde ein dreistöckiges Bürogebäudes analysiert, welches als Referenz-Bürogebäude im IEA SHC Task 25 verwendet wurde, allerdings mit den Klimadaten aus Surabaya, Indonesien. Das zweite Gebäude ist ein sogenanntes „Shophouse“ eine für den südostasiatischen Raum typische gemischt genutztes zweistöckiges Gebäude. Im Untergeschoss befindet sich ein Geschäft oder ein anderer Kleinbetriebzweck und das Obergeschoss dient als Wohnung. Die dritte Simulation wurde für ein Einfamilien-Reihenhaus in einem Besitzkomplex südwestlichen von Jakarta durchgeführt. Das letzte simulierte Gebäude war ein neun-stöckiges Bürogebäude, das in Sidoarjo in der Nähe von Surabaya errichtet wird. Das Gebäude des IEA SHC Task 25 und das hohe Bürogebäude wurde mit Wetterdaten von Surabaya, die anderen beiden Gebäude mit Wetterdaten von Jakarta simuliert.

Die Sensitivitätsanalysen wurden durchgeführt, um die Parameter, die eine wichtige Rolle bei der Reduzierung des Kühlenergiebedarfs spielen, zu erhalten. Die Ergebnisse zeigen, dass eine Erhöhung der Raumlufttemperatur von zumeist 24°C Ausgangswert die größte Wirkung auf den Energieverbrauch hat. Die Gebäudeorientierung sollte möglichst nach Süden oder Norden sein, da hier wenig Solarstrahlung auf die Fassade fällt. Ost- und West-Ausrichtungen der Fenster sollten vermieden werden oder die Fensterflächen zumindest klein gehalten werden. Um eine weitere Reduktion der Solarstrahlung zu erreichen sollten Verschattungen oder Überhänge, sowie Fensterläden eingesetzt werden. Dies wirkt besonders für Ost- und Westfenster. Zusätzlich können Fensterglasmaterialien mit niedrigem Energiedurchlassgrad SHGC (bzw. g-Wert) für Nicht sichtbares Licht verwendet werden, um möglichst viel Solarwärme nicht in das Gebäude kommen zu lassen aber gleichzeitig eine hohe natürliche Belichtung zu ermöglichen. Bei den in Indonesien häufig eingesetzten unbenutzten belüfteten Dachräumen bewirkt eine zusätzlich Wärmedämmung des Daches oder der Geschossdecke wenig in Bezug auf den darunterliegenden nutzbaren Raum. Bei Gebäuden ohne hinterlüftetes Dach bewirkt eine Dachdämmung hingegen eine signifikante Veränderung des Kühlenergiebedarfs, da die vom Dach absorbierte Solarstrahlung nur geringfügig als Wärme in das Gebäude eindringen kann. Eine weitere Möglichkeit der Reduktion des Kühlenergiebedarfs besteht in der Reduktion der angebotenen Kühlleistung gegenüber der theoretisch notwendigen. Dies bewirkt beim Einschalten und Herunterkühlen der Räume kurzzeitig höhere Temperaturen (26°C statt 24°C).

Da die thermischen Simulationen für noch nicht ausgeführte Gebäude durchgeführt wurden, gibt es keine Validierungen mit Messergebnissen. Die Simulationen zeigen jedoch ähnliche Ergebnisse wie z.T. in anderen Literaturen dargestellt. Außerdem stellen sie wertvolle Inputs für die Planer der drei letzten Gebäude dar, die Gebäudeentwürfe noch zu ändern, um eine optimale Gestaltung für Niedrigenergiegebäude zu erhalten.

Stichwörter: thermische Gebäudesimulation, Sensitivitätsanalyse, tropisches Klima, Niedrigenergiegebäude

ACKNOWLEDGEMENTS

بِسْمِ اللهِ الرَّحْمٰنِ الرَّحِيْمِ

Alhamdulillah, thanks Allah for all the miracle in my life.

This work would not be realized without the excellent supervisions, thinking, ideas, advices and assistances from my supervisor, Ao.Univ.-Prof. Dipl.-Ing. Dr.techn. Wolfgang Streicher. I am indebted for all of his uncountable contributions.

I would like to acknowledge the Austrian Agency for International Cooperation in Education and Research (ÖAD) for providing me the opportunity to accomplish my study in Austria.

I would also like to appreciate the very useful comments from Univ.-Prof. Arch. Dipl.-Ing. Dr.techn. Martin Treberspurg that makes me realize about the important collaboration of different disciplines working on energy efficient building, as well as Ao.Univ.Prof. Dipl.-Ing. Dr.techn. Erich Lehner and Univ.-Ass. DI Petra Gruber for providing the data dealing with traditional buildings in Indonesia.

I would also like to grateful for the inputs and contributions from my colleagues at the Institute for Thermal Engineering especially at the working group Energy Efficient Building. From them I have learned a lot new things, knowledge, skills, experiences, co-operation, as well as motivation. I am indebted for your time and energy.

I also appreciate:

- Ir. Anna Kunti Pratiwi, M.Eng.Sc, (Head of Planning and Development Division at PT Jaya Real Property, Tbk, currently as a fellow of Nanyang Fellows Programme, Nanyang Business School, NTU)
- E.Yogha Haksono, ST, MM (building designer at PT. Jaya Real Property),
- Heksa Kamawardhana, ST and Ir. Edwin Nafarin, ST (dPavillion Architects),
- Ir. Totok Sulistyanto, MEngSc (PT. Narama Mandiri)

for the assistances during my field studies and providing the data for my building thermal simulations.

I am very grateful to Mr. & Mrs. David Robert, Angeline Wuysang Robert, and Debbie Burt in Melbourne, my friend Rosebud Lambert (NSW, Australia), for their contributions as the proofreaders.

Special thanks to Mrs. Ulrike Gerhard, Mrs. Dr.iur. Heide Streicher and Mrs. Mag. Dr. Rosemarie Kurz for their 'non-technical' unfaltering supports during my stay in Austria. Last but not least, the Indonesian community in Graz, Austria deserve a special mention for being wonderful friends.

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GLOSSARY

GHG	Greenhouse Gasses
OECD	The Organisation for Economic Co-operation and Development
LPG	Liquefied Petroleum Gas
PLN	Indonesian State Electricity Company
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CFC	Chlorofluorocarbon
HCFC	Hydrochlorofluorocarbons
Uv	U value, overall heat transfer coefficient
SHGC	Solar Heat Gain Coefficient, or G Value
IEA	International Energy Agency
SHC	Solar Heating and Cooling
ASEAN	Association of Southeast Asian Nations

CHAPTER 1: INTRODUCTION AND SCOPE OF THE WORK

The energy crisis is, without a doubt, one of the world's major current issues. The scarcity of oil supplies causes unstable oil prices and a shortage of electricity and, further, creates difficulties in supplying other natural resources by creating increased difficulties in transportation, distribution and processing. In Indonesia, the energy crisis creates a significant impact on economic development. Therefore, the Government has to set the saving energy as a major priority. Further, such energy saving must be in line with the efficient use of energy to have a positive influence to the environment, such as reducing GHG emission. Using energy efficiently means reducing the fossil fuel being burned and therefore decreases greenhouse gas emission. The main activities associated with emissions from the energy sector include transportation, electricity generation, manufacturing industries and construction, energy in residential and commercial sectors, as well as agriculture, forestry and fishing activities.

1.1 World Energy Situation

The increase of the world's energy consumption by 2.4% in 2007 was mainly caused by the economic growth that was above average during the preceding five years. China still contributes half f the growth of the global energy consumption with its growth of 7.7%, whilst the energy consumption for the European Union nations declined by 2.2%. In 2008, the world primary energy consumption such as oil, natural gas, coal, nuclear and hydropower grew by 1.4%, noted as the slowest such growth since 2001. The primary energy consumption of non-OECD countries for the first time exceeded the consumption of OECD countries. The Asia-Pacific region dominated the growth of the world's energy consumption, and China accounted for nearly three-quarters of global growth even though its consumption growth was slower than for each of the five preceding years. The US consumption decreased by 2.8%, the largest reduction since 1982 (Hayward 2008). Generally, the growth of the energy consumption is now forecast to be slower to 2030 than was anticipated in 2007 (IEA 2009). However, the general upward tendency is mainly strong, and fossil fuels, such as oil, gas and coal, will still play an important role, caused by the consuming countries' dependence on imports of oil and gas. As a consequence, the greenhouse-gas emission as well as the global temperatures will also increase, which will exacerbate the global climate change.

In addition, the current global trends in energy supply and consumption are patently unsustainable – environmentally, economically, and socially. Therefore, those conditions must be changed. Oil is the world's vital source of energy and will remain so for many years to come, even under the most optimistic of assumptions about the rapidity of development and deployment of alternative technology (OECD/IEA 2008).

1.2 Experiences of OECD

The OECD is an international organisation, which is mainly made up of high-income economies countries or regarded as developed countries. In 2007, OECD countries showed the most significant reaction to the high level of energy prices (Rühl 2008). The energy consumption increased by 0.9% annually between 1980 and 2006, and is projected to decrease to 0.6% on average per year in the projection years of 2010 until 2030 (Hayward 2008).Therefore, to maintain this projection, it is essential to consider some solutions in utilizing the energy efficiently. This part will explain the OECD experiences dealing with the energy efficiency program, specifically for building.

According to the summary report of the OECD Environment Program, the building sector has the most important impact not only on economic and social activities, but also on the natural and built environment. This sector is responsible for about 30% of primary energy use in OECD countries (OECD 2002). The objective of the OECD's Sustainable Building Project is to examine how government should design policies to address this environmental impact and provide suggestions for policymakers, with a focus on three environmental objectives that are closely related to the sector: reduction of CO_2 emissions, minimisation of construction and demolition waste, and prevention of indoor air pollution.

The specific discussion of OECD nations concerning sustainable building policies reveals that the construction sector accounts for between one-third and one-half of commodity flows, hence there has been a considerable amount of construction and demolition waste produced (OECD 2002). As a consequence, improving the design of environmental policies will reduce the impact of the building sector on the environment.

As it is reported, the major OECD nations have substantially reduced the demand of energy to fuel economic development over the last thirty years (Geller et al. 2006) . It is also claimed that without the enhancement of energy efficiency, the OECD countries would have consumed about 49% more energy than was actually consumed as of 1998. These achievements can be drawn from the various experiences dealing with the policies and programs designed to foster energy efficiency. Well-designed policies can result in significant energy reduction, as shown in the United States where nine specific policies and programs successfully reduced the use of primary energy by 11% in 2002. Reducing subsidies for fossil fuels can also result in enhancing significant energy efficiency. The other lesson learned is to apply the scheme of labelling, information dissemination and training that effectively increase the awareness of energy efficiency measures and improves knowledge with respect to energy management.

The policy concerning energy efficiency in OECD countries has mainly focused on the improvement of the energy efficiency of buildings, appliances, transportation, and industrial sectors. On the other hand, consumer behaviours received less attention, whereas it is presumable that shifting behaviour, such as encouraging people to value nature and improving knowledge with respect to the environmental impact as the consequences of people's lifestyle, and others, would possibly contribute to the reduction of energy demand. Furthermore, still under discussion is the opportunity of giving incentives for the building's owner additional cost for upgrading energy efficiency, such as using environmentally friendly materials, energy efficient equipments, as well as applying renewable energy in their building.

1.3 Energy Situation in Indonesia

Climate change, which is indicated mainly by the increase of global air and sea surface temperature and green house gasses concentration, becomes a common global issue and is turning into one of the key development issues that requires long-term sustainable solution. As a matter of fact, the increase of energy consumption such as for transportation purposes, industrial and commercial use and for household purposes is then asserted as the key contributor to climate change.

Energy consumption will increase in line with the growth of the population as well as the economic development. The energy consumption of Indonesia has grown rapidly in recent years after the recovery from the Asian financial crisis in 1998. Primary energy consumption increased from 137.4 Mtoe in 2000 to 168.9 Mtoe in 2004, growing at 5.2% per year between 1995 and 2000 (Asia Pacific Energy Research Centre 2006). The most significant variables affecting Indonesia's residential energy consumption are growth in income, the number of households and improvement of living standards. The electricity demand is projected to grow 4.3% annually through 2030 (Asia Pacific Energy Research Centre 2006). IEA statistics show that the total final consumption of energy in Indonesia in 2004 and 2005 is mainly dominated by the household sector, which is always above 40% (OECD/IEA 2008).

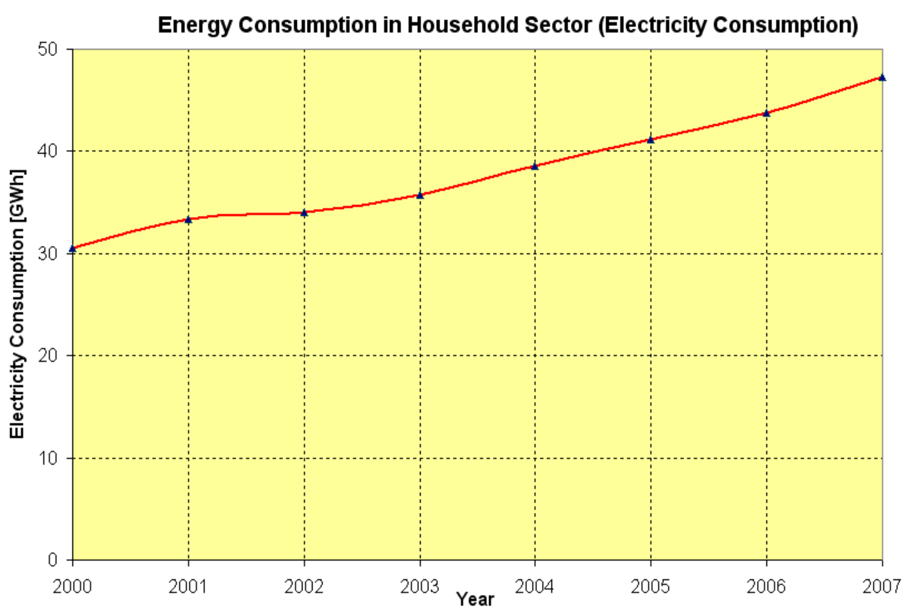

Figure 1. Energy Consumption in Household Sector (Electricity Consumption) of Indonesia (Zed & Mujiyanto 2008)

Figure 1 shows the energy consumption in the household sector, for electricity consumption from 2000 until 2007. The household sector here is defined by the group of energy consumers who use energy for cooking, lighting, and household appliances but not including energy consumption for private cars. The electricity means the electricity power produced in electric power plants such as Hydro Power Plant, Geothermal Power Plant, Gas Power Plant, Gas Steam Power Plant, Coal Steam Power Plant, Diesel Power Plant and others (Zed & Mujiyanto 2008). Figure 1 reveals that the electricity consumption for the household sector increases substantially about 6% each year between 2000 and 2007 and remarkably increases by 55% during these seven years.

This trend is estimated as the influence of high rates utilization of electrical equipments in households. Consequently, people education is crucial in order to improve the public awareness concerning the efficient use of the energy.

Figure 2 shows the share of energy consumption in the household sector, which shows that the usage of gas is not too significant as its value on average is below 1% of the total share, and the energy consumption is mainly dominated by oil (kerosene).

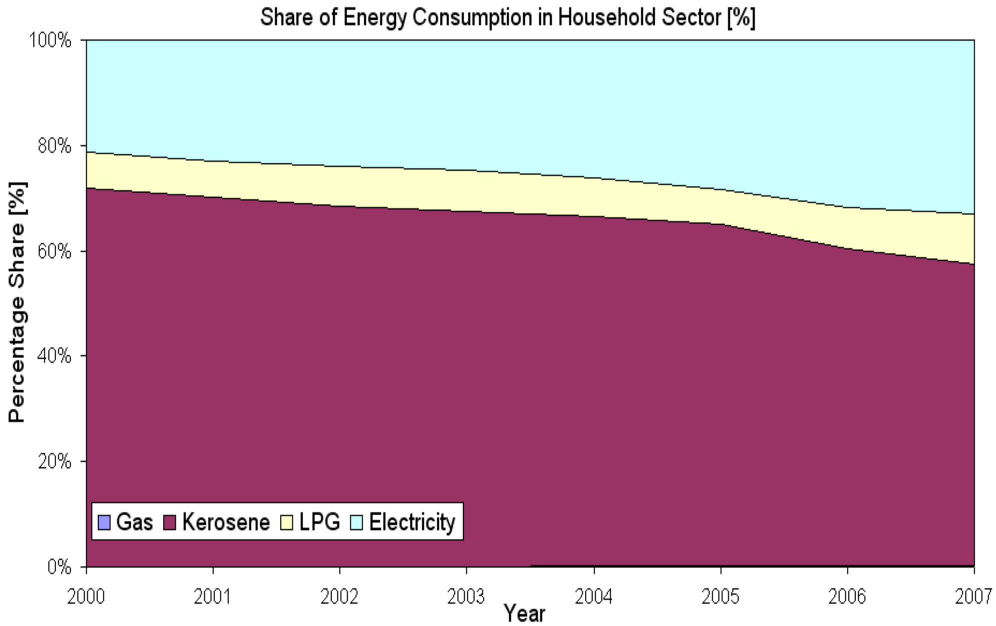

Figure 2. Share of Energy Consumption on Household Sector of Indonesia (Zed & Mujiyanto 2008)

The share of electricity consumption increases gradually aligned with the consumption shown in Figure 1 while the share of kerosene is gradually decreased. This decrease is possibly due to the new regulation of the Indonesian Government in 2007 that dealing with the energy conversion usage of energy resource, from kerosene into LPG with the purpose of reducing the subsidy for oil. This usage of LPG is mainly for kitchen stove and lighting equipment. The Government has slowly reduced the availability of traditional stoves, which use kerosene as the fuel and freely provide the gas stove as well as its cylinder for low income family and small enterprises.

In addition to the household sector, the other sector that contributes a significant increase in its consumption is the commercial sector. In the commercial sector, which is classified as the group of energy consumers who use energy for lighting, air conditioning, mechanical equipment, cooking appliances, and water heating but not including consumption for vehicles/transportation, the trend of energy consumption is shown in Figure 3. The energy consumers included in this group are commercial and general business such as commerce, hotel, restaurant, financial institution, government agency, school, hospital, and others (Zed & Mujiyanto 2008) .

The rise of the electricity consumption between 2000 and 2007 is depicted in Figure 3. It is on average 8,5% annually between 2000 and 2007, and during these seven years, the electricity consumption substantially increased by 93%. In comparison with the other energy sources, the commercial sector is mainly dominated by the utilization of electricity. On the other hand, the Indonesian Government has reduced the subsidies for the electricity sector.

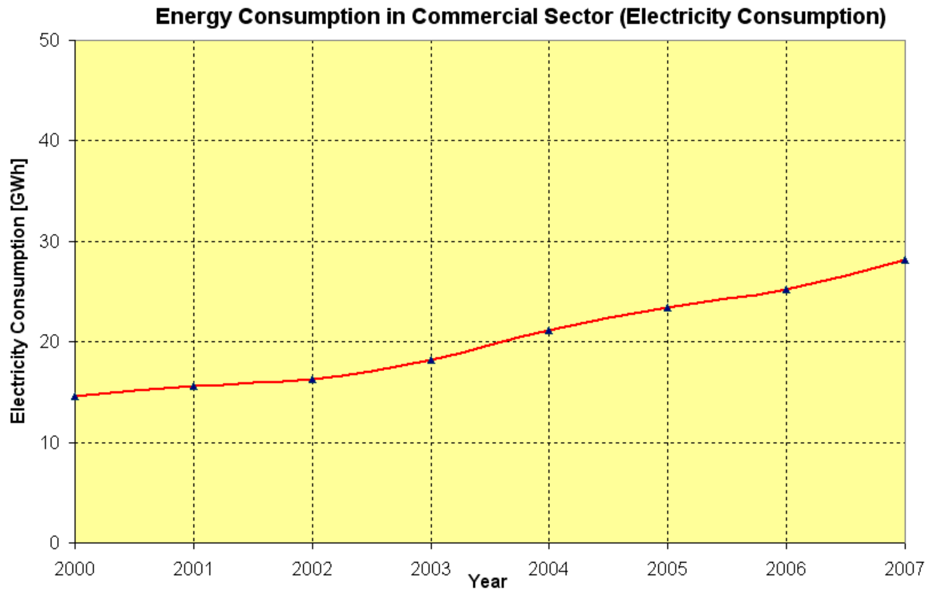

Figure 3. Energy Consumption in Commercial Sector (Electricity Consumption) of Indonesia (Zed & Mujiyanto 2008)

The electricity price was increased in 2003, there were four phases of gradual tariff increase, and each phase allows an increase of electricity sales price in Rp/kWh approximately 6% (www.pln.go.id). Undoubtedly, the increase of electricity price will also increase the price of other daily needs. This obviously will make people more concerned in consuming energy. However, the trend of electricity consumption still increased in the period from 2000 to 2007 as shown in Figure 3.

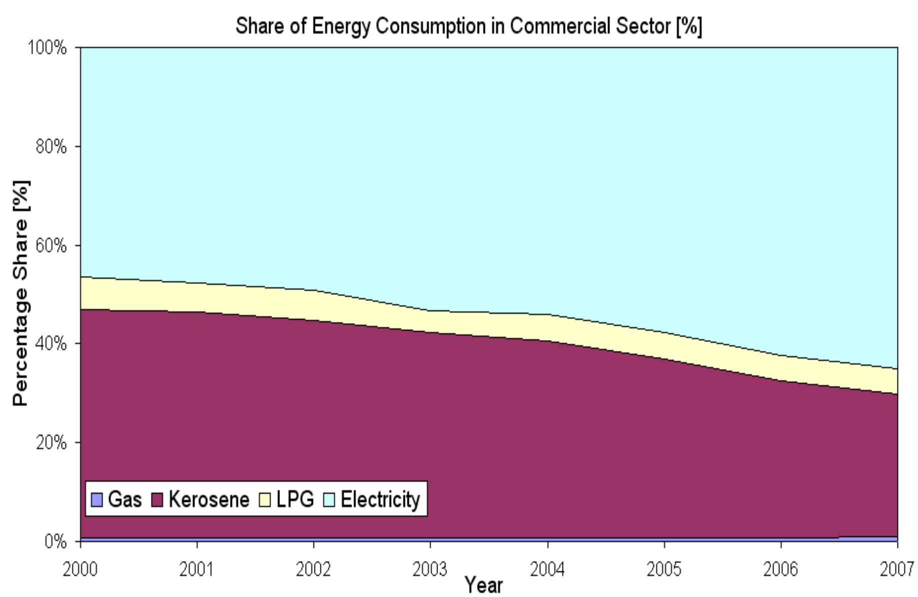

Figure 4. Share of Energy Consumption in Commercial Sector

Figure 4 shows the share of energy consumption in the commercial sector, regarding the energy sources, such as gas, kerosene, LPG, and electricity. In 2000, the share of energy consumption between electricity and kerosene is almost equal, however, the trend reveals that during seven years, the electricity consumption dominated the energy utilization in this sector, and the use of kerosene gradually decreased. This tendency is estimated as the impact of the reduction in the subsidy of oil for commercial sector by the government. Similar to the share for the household sector, the gas consumption is not significant.

The distribution of the electricity consumption of Indonesia in 2008 is depicted in Figure 5. It can be seen that the household sector and commercial sector in total consumed more than half of the electricity consumption in 2008. Therefore, it is important to obtain the strategies on how to reduce the electricity consumption in these two sectors as well as encouraging people to use energy efficiently. Furthermore, the Government has to increase further the use of renewable energy in electricity generation as Indonesia has a very huge potential of these sources.

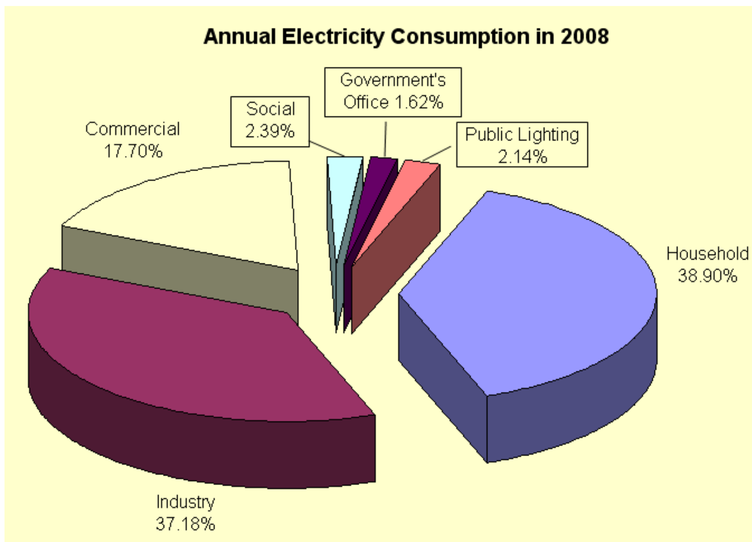

Figure 5. Distribution of Annual Electricity consumption of Indonesia in 2008 (www.pln.go.id)

The energy crisis had a significant impact on economic development in Indonesia (Gray & Schuster 1998). Therefore; the Government had to develop policies, which supported the improvement in economic growth. It has been known that the economic growth cause the growth of cities, such as Jakarta as the capital city of Indonesia and Surabaya as the biggest city in the eastern part of Indonesia. According to APEC (Asia Pacific Energy Research Centre 2006), the population in Jakarta is expected to exceed 15 million in 2015, making the city one of the world's mega cities. Further urban migration will also increase the population of Surabaya city to more than 5 million. As an indicator, since the last decade, both Jakarta and Surabaya have grown very rapidly, and it can be seen that many high rise buildings have been built, and it can also be predicted that in the next five or ten years there will be many more buildings constructed (www.property.net). The development of these cities obviously contributes to the energy problems, such as the increase of temperature of the environment, as well as the increase of energy consumption. In Surabaya itself, the urban design team has no research experience in assessing the impact of temperature increase caused by commercial buildings, especially in the Central Business District (CBD).

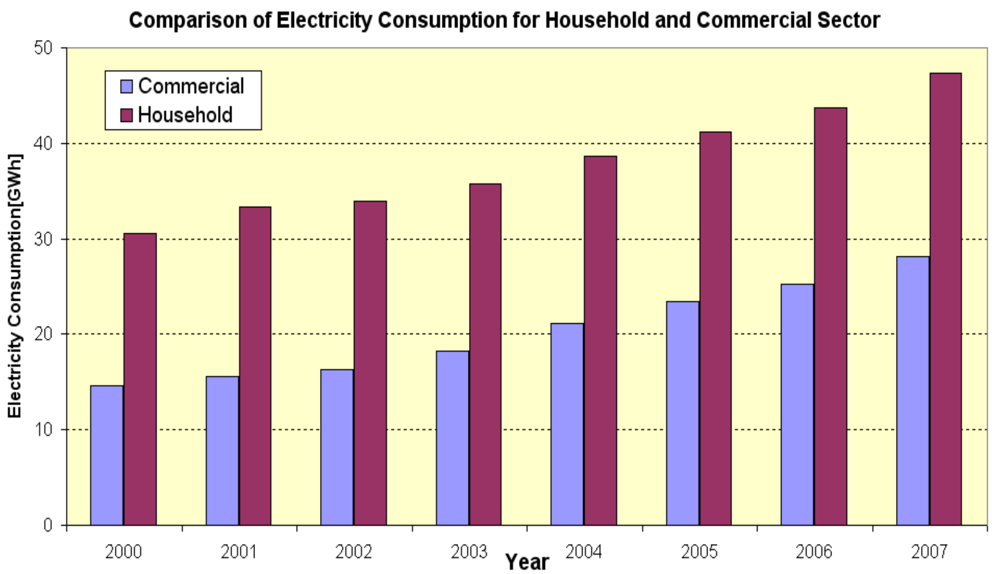

Figure 6. Comparison of Electricity Consumption for Household and Commercial Sector

Growth of urban population obviously will lead to a higher demand for oil in transport, and electricity in the residential and commercial sector. The substantial increase of electricity utilization in the residential and commercial sector is described in Figure 6, based on the data of the Ministry of Energy and Mineral Resources, Indonesia (Zed & Mujiyanto 2008). The graph shows the comparison of electricity consumption for the household and commercial sector between 2000 and 2007. The trends illustrate that the electricity consumption for the household sector are about twice as high as that of the commercial sector, yet commercial sector increases more rapidly compared to the consumption in the household sector. It is presumed that the commercial sector has a tendency of higher usage of the electricity.

The presumed rapid increase of electricity consumption for the commercial sector is supported by the survey results in 60 buildings with 11 different types of buildings in Jakarta by PT. KONEBA (KONEBA 2006) as shown in Table 1. The table shows the distribution of energy consumption of the buildings, such as air conditioning, elevator and escalator, lighting and office appliances, which is categorised in other utilisation. It is clearly reported that the energy consumption in buildings is mainly dominated by the use of air conditioning, which on average is above 50% of the total energy consumption. The next dominating contributor is electricity use for other purposes such as office, laundry, and cooking appliances, except for the three star hotels, where the second dominating factor is the use of electricity for the elevator purpose.

From the previous explanation and data presented, it is understandable that in the situation where the cities in Indonesia are booming there will be much more commercial buildings because apartments, malls, hotels, and office buildings will be constructed. Obviously, electricity demands will go up while the energy price rises and the Government, as the electricity producer, will face difficulty in covering these demands. For that reason, the low energy buildings are of crucial importance. It is also urgent that Indonesia learns from other countries' experiences in applying the strategies of dealing with energy efficient building.

Table 1. Energy Consumptions in Buildings (KONEBA 2006)

TYPE	DISTRIBUTION OF ENERGY CONSUMPTION			
	AC (%)	ELEV/ESC (%)	LIGHTING (%)	OTHERS (%)
1. Office				
a. Government	46.80	1.80	21.10	30.30
b. Private	45.74	3.20	21.00	30.05
2. Shopping Center	51.55	4.78	18.57	25.10
3. Office & Shopping Center	47.56	3.82	14.82	33.80
4. Hospital				
a. Public	60.25	4.43	10.82	24.50
b. Private	62.04	4.27	11.77	21.92
5. Hotel				
a. Five Stars	60.18	6.44	14.54	18.84
b. Four Stars	60.15	7.68	9.57	22.40
c. Three Stars	65.40	16.10	10.40	8.10
6. Mall	51.90	0.92	11.95	35.20
7. Apartment	53.45	6.75	12.25	27.55

1.4 Objectives and Scope of Work

1.4.1 Objectives

The objectives of this research mainly focus on discovering the most appropriate strategy to reduce the energy consumption for buildings in Indonesia. In order to formulate the general strategy, it is important to apply the building thermal simulation as simulation nowadays is a very powerful tool for assessing the energy performance during the design phase. Moreover, thermal building simulation is highly recommended during this phase because there are many possible scenarios on how to arrange the building envelopes, and to observe the effect of these arrangements on the energy consumption of the building. It is also obvious that thermal simulation gives an economic benefit as well as being time saving. By this research, it is intended to broadly introduce the importance of thermal building simulation.

It is hoped that the examples of some thermal building simulations which are presented in this research will be useful for the building designers, architects, engineers, building's owners and others as inputs while planning to construct a building. Moreover, the outcomes of this research are expected to become one of the references for the building management in controlling the energy consumption of the building, as well as appropriate for the Government in composing the guidelines for low energy building in Indonesia or in the process of composing standards for building certification.

1.4.2 Scope of Work

This work focuses on the strategies important to be implemented in Indonesia, regarding the energy efficiency of buildings, as well as the general summary on what steps need to be put into practice to enhance the measure of energy efficiency. However, it is not possible for this research to cover all the aspects, hence; there are some limitations in the discussion, which are not included in this dissertation such as the detailed system of cooling equipment and the calculation of CO_2 emission.

1.5 Organization of Dissertation

The dissertation is presented in six chapters covering background information regarding the world energy situation and the energy situation in Indonesia as well as the objectives, the scope of this research and analysis of the energy performance in buildings specifically concerning the cooling energy demand and thermal building simulation. Also covered are the available tools together with the validation method, literature review on the application of thermal building simulation in hot and humid regions, and some examples of case studies of thermal building simulation in Indonesia, and finally, the conclusions and recommendations.

Chapter one gives background information and presents the world energy situation and Indonesia's situation. The overview on the topic of lessons learned from OECD work on sustainable buildings is also described. In this chapter the problem statement and the objectives are presented, as well as the scope and limitations of the research.

Chapter two reviews the general idea of energy efficiency for buildings, the available standards of building energy as well as lessons learned in Austria, and also building regulations in Indonesia. The overview of some building certification will also be presented.

Chapter three presents the basic principles of thermal building simulation and the available research on the integration of thermal simulation in building design. This chapter also addresses the available simulation tools, and its applications, scope, and limitations for thermal simulation in buildings. The validation of the tools applied in this research is also presented by performing the simulation of the reference test case and comparison to other simulation results

Chapter four discusses the importance of this research to the improvement of the buildings development in Indonesia. In addition, this chapter also presents the lessons learned regarding low energy buildings in hot and humid climates regions. In this chapter, the results from previous researches on building certification and the strategies on how to reduce the energy consumption are also summarized.

Chapter five discusses some examples of thermal building simulations of typical buildings in Indonesia. It also addresses the boundary conditions considered in the simulations, such as climate data and user behavior. Afterwards, the results of the thermal building simulations are analyzed in order to obtain the parameters that give the most significant impact in reducing the cooling energy demand of the building.

Chapter six summarizes the research results, and formulizes the general guidelines concerning the integration of thermal building simulation during the design phase of a building in Indonesia. It also presents the strategies on how to design a low energy building and what variables have to be taken into account to reduce the cooling energy demand. It also gives the recommendation for future research.

CHAPTER 2: ENERGY IN BUILDINGS

The major energy consumption for most countries is accounted for buildings (World Business Council for Sustainable Development 2007). One-third or more of the energy consumption of the industrialised countries is expended on creating acceptable conditions of thermal comfort and lightings in their buildings and it is about 10% for air conditioning (Davies 2004). According to the experience in the European countries (Chwieduk 2003), the final energy demand of the residential sector splits in about 57% for space heating, 25% for domestic hot water and 11% for electricity. Moreover, it is evidenced that in the developing countries almost one-third of the primary energy supply is utilised for building purposes (Asia Pacific Energy Research Centre 2006) (Zed & Mujiyanto 2008). In Indonesia, the survey results confirmed the condition in the developed countries concerning the electricity consumption for the commercial buildings (KONEBA 2006).

2.1 Energy Efficiency for Buildings

Based on the facts that buildings consume a major part of energy in most countries, therefore, energy efficiency in buildings is urgent to be realized. This is because energy efficient buildings not only influence the overall energy consumption, but also potentially reduce the GHG emission. Additionally stakeholders such as local authorities or government, investors, developers, as well as the users will take positive influence caused by energy efficient buildings. Moreover, with the current development of the technologies, the essential enhancement of energy efficiency building is relatively more realistic to be implemented (World Business Council for Sustainable Development 2007).

Although it is not easy to determine the key figures that characterize energy efficient buildings, yet there are some criteria to be fulfilled in order to achieve energy efficient buildings. The energy performance of a building depends not only on its physical structure and design components, but also on the uncertainties factors such as user behaviour, appliances performances, and climate. An energy efficient building should involves the reduction of energy consumption in order to achieve acceptable level of comfort, air quality and other requirements for the users, including embedded energy during manufacturing process of building materials and construction (World Business Council for Sustainable Development 2007). Furthermore, the utilisation of energy efficient appliances as well as constructional materials that are appropriate to the location and conditions is also an important aspect of energy efficient buildings. The other criteria is that the building should be operated appropriately concerning to the intended function of the building while it was designed; and is used in such a manner as to have a low energy consumption (Meier et al. 2002). Therefore, one applicable method in order to evaluate the efficiency level of a building is to compare the energy performance of a building to the recommended available value.

2.2 Building Certification

Based on the standard available, it is important to give an energy performance rating for a building. Building certification is an instrument useful to express the level of energy performance of a building. The following part will describes the available certification for building in Europe and the United States.

The Energy Performance of Buildings Directive (EPBD) of the European Union

EPBD is a program that aims to promote energy efficiency in building, approved by The European Parliament and Council in December 2002. The main goal of this directive, which set into force by January 4th 2006, is to reduce the energy demand and the CO_2 emission of buildings (Streicher 2007) (Olesen 2007). The primarily motivation in developing this directive is due to the fact that the improvements in the European Union in associating with energy efficiency since early 1990s have been less than expected. Its target is to reduce energy consumptions for space heating and cooling, hot water, air conditioning and lighting, by 22% in 2010 (Janssen 2004).

In order to achieve the stated target, the directive forecs the member countries to develop methodology for calculation the integrated energy performance of buildings and HVAC systems including heating, cooling, ventilation and lighting. Moreover, the directive states that the member countries have to set minimum and maximum requirements of energy of new buildings and existing buildings. Developing an energy certification system for buildings, increasing the use of renewable energy sources as well as regular inspection of heating and air-conditioning systems by independent specialists are pointed out in the directive as well (Streicher & Eiper 2006) (Streicher 2007). The standard also specifies the designed values of indoor environment in order to calculate the energy demand as well as the methods on how to evaluate the specified indoor environment in the buildings. It also includes methods for long-term evaluation of the indoor environment (Olesen 2007).

Two emphasizes of the EPBD are on the ‘‘energy performance of a building’’ and “energy performance certificate”. The energy performance of building is defined as the quantity of actual or estimated energy consumption to satisfy the different requirements associated with a standardized use of the building. In calculating the amount of energy consumption, the parameters that must be taken into account consist of insulation, technical and installation characteristics, design and positioning associates with the climatic condition, solar exposure and influence of neighboring structures, own-energy generation, as well as indoor climate. The document that assigns the energy performance of a building which is calculated based on the general framework set out by the EPBD is called the ‘‘energy performance certificate’’ (Poel et al. 2007).

The methodology in calculating energy performance shall be applied at national and regional level, and involves some factors such as thermal characteristics of the building (envelope and internal partitions, etc.); these characteristics may also include air-tightness; heating installation and hot water supply, including their insulation characteristics; air conditioning installation; ventilation; built-in lighting installation (mainly the non-residential sector); position and orientation of buildings, taking into account outdoor climate; passive solar systems and solar protection; natural ventilation; indoor climatic conditions, including the designed indoor climate.

There are three main steps in the calculation procedure; the calculation of the net energy of the building, the calculation of delivered energy based on the characteristic evaluation of the heating, cooling, domestic hot water, and lighting systems as well as the control and building automation. The results from the previous calculations are then combined in order to obtain the overall energy use and associated performance indicators (Poel et al. 2007).

However, it is found that EPBD encompasses operational energy only, while other phases of the life cycle of buildings are almost completely neglected. Therefore, it is recommended taking into account the energy needed for manufacturing of building materials, the so-called embodied energy, as well, to check the rationality of operational energy saving measures. In addition, by considering life cycle analysis, it will be more effective leading the building sector towards sustainability (Szalay 2007) (Casals 2006).

LEED Certification Information

LEED is an internationally recognized green building certification system developed by the US Green Building Council (USGBC). It was primarily intended for commercial buildings but has become a model for other building sectors and regulatory programs (Gowri 2004). LEED is a third-party certification program and widely adopted as benchmark for the design, construction and operation of high performance green buildings (www.usgbc.org). The measure of LEED rating elaborates the aspects of sustainable sites, water efficiency, energy and atmosphere, material and resources, and the indoor environmental quality as well as the innovation and design process (Gowri 2004). The energy ratings approved from the lowest rating to the highest one consist of certified, silver, gold, and platinum rating. This rating is based on the credits obtained from the measured factors mentioned.

From the post occupancy evaluation, it is found that measured energy saving for the LEED buildings are close to the predicted value presented in the LEED submittals (Turner & Frankel 2008). The recent findings reveal that on average the LEED buildings consumed energy for each floor area is 18-39% lower than non-LEED buildings. However, it is found that 28-35% LEED buildings consumed more energy than that of the conventional counterparts. In addition, there is no essential correlation between the level of LEED certification and the amount of energy consumed by the building. The main factors that caused these occurrences include the difference of occupancy hours between the assumption in the design and the actual condition. The final as-built building often differs from the initial design as well as the building does not behave as the prediction resulted from the simulation tools (Newsham et al. 2009). In comparison with occupants of non-LEED building, the occupants of green building were more satisfied with the thermal comfort and air quality in their workspace, however, they felt dissatisfied with lighting and acoustic quality (Abbaszadeh et al. 2006).

In Indonesia, the LEED rating system of green building is adopted, initiated with the establishment of The Green Building Council of Indonesia in 2008. The main objective is to promote the implementation of ‘Green Building’ in the property sector in Indonesia, associating with the design, constructional, operational and maintenance of a building. It also aims to provide certification of LEED Indonesia by implementing the rating system, as well as deliver information regarding the knowledge of green building via seminars, trainings, and workshops. In addition, this organization assists industries in order to apply environmentally friendly standards (www.gbcindonesia.org 2008).

In general, the LEED rating system adopted in Indonesia consists of the guideline for the new building construction in order to register the building design for the LEED evaluation (Yusuf Nasir 2007). The steps that must be fulfilled involve:

- The building owner set up the LEED certification goals and the Energy Efficiency Index (EEI) before the design stage
- Integrate an inter-disciplinary discussion between Architecture, Structure, Mechanical and Electrical Engineers during the design stage
- In the designing phase, the measures that has to be considered are :
  - OTTV setup for roof structure and material, wall structure, material and colour, windows design and window to wall ratio, thermal mass stores, building orientation.
  - The design of landscape which is benefit to the micro climate, involving such as grass area, trees, water ponds and fountain
  - Using non-CFC and reduce more ozone depletion substance (HCFC)
  - Maximised the use of natural lighting

However, as this is quite expensive, it is not interesting to the buildings owner. Moreover, there is still no incentive for a building when it has a good certification. In addition, apparently the standard to determine a green building is not yet available, as this is still developed and discussed (quoted from Indonesian online newspaper, www.kompas.com, 25th November 2009, *Belum ada standar “Green Building”*).

2.3 Building Energy Standards

With the dramatically booming of buildings’ construction and buildings claimed as the major factor of energy consumption, a regulation that control the growth of buildings as well as its energy consumption is very crucial. The important factors that enhance the implementation of energy efficiency for buildings consist of building energy regulations and standards, information, incentive-based scheme and subsidy, eco-labelling scheme or building certification (Lee & Yik 2004) (Janssen 2004).

Unlike the standards for constructional material and electrical appliances, building energy standards require more involvement of uncertain parameters. Most of the existing standards are based on the judgement of professionals and experts, and the powerful simulation tools seldom to be involved, whereas computer simulation is beneficial as it requires less time and cost in providing a building model as well as its optimization compared to the construction of a physical prototype.

In order to establish the criteria whether a building is categorized as an energy efficient building, it is important to introduce guidance on how a building should be constructed. The guidance must also define the target value for energy efficient building, so that the constructed building behaves according to the standards, such as the standard for air conditioning and indoor air quality. The energy efficient building should perform appropriately refers to those standards and has at least similar or even lower energy consumption. Therefore, the most important thing to achieve energy efficient buildings is to implement a mechanism in the construction community and appropriate educational program in line with the application of the standards. Obviously, building energy standards that are appropriate for one country may be ineffective in another country, depending on climate conditions, occupant behaviour, existing building stock, and construction (Janda & Busch 1994). In the following, the lesson learned from Austria, which has already well established building standards, will be overviewed, and compared with the situation in Indonesia.

2.3.1 Lesson learned from Austria

The energy policy associating with energy efficient building in Austria is primarily intended to decrease the heating energy demand. Consequently, the fuel demand for space heating in building and the CO_2 emission will also be reduced (Faninger 2003). According to the experience from Austria, before 2007, there were building codes which were different for each federal state, whereas there are nine federal states. Hence, Austria had nine different building codes, and nine different regulation concerning new or refurbishing old buildings, as well as nine different conditions in the subsidy scheme for new and existing buildings (Streicher & Eiper 2006). In 2007, Austria started to apply a national standard developed by the Austrian Institute of Building Technology (ÖIB). ÖIB consists of representatives from all federal states. Each province has ratified the standard, which has set into force for all federal provinces since then. There are six harmonized directives mandated to be applied in Austria (Mach & Heinz 2007):

(a). Directive 1 : mechanical strength and stability
(b). Directive 2 : fire control
(c). Directive 3 : environment, healthiness and hygiene
(d). Directive 4 : safety and accessibility for disabled person
(e). Directive 5 : noise protection
(f). Directive 6 : energy saving and thermal insulation

The Directive 6 includes the calculation procedure of useful and end use energy demand for different types of building for space heating and cooling. In general, there are two main types of buildings, residential and non-residential, either for new and renovated buildings. For non-residential buildings, there are twelve different types of building such as office building, school, hospital, hotel, and others. The calculations scheme of useful space heating and cooling demand as well as the assessments criteria basically are the same except the boundary conditions are different for each building's type. The allowed heat demand is related to the characteristic of length, l_c, which is defined as a ratio of volume to the area of building.

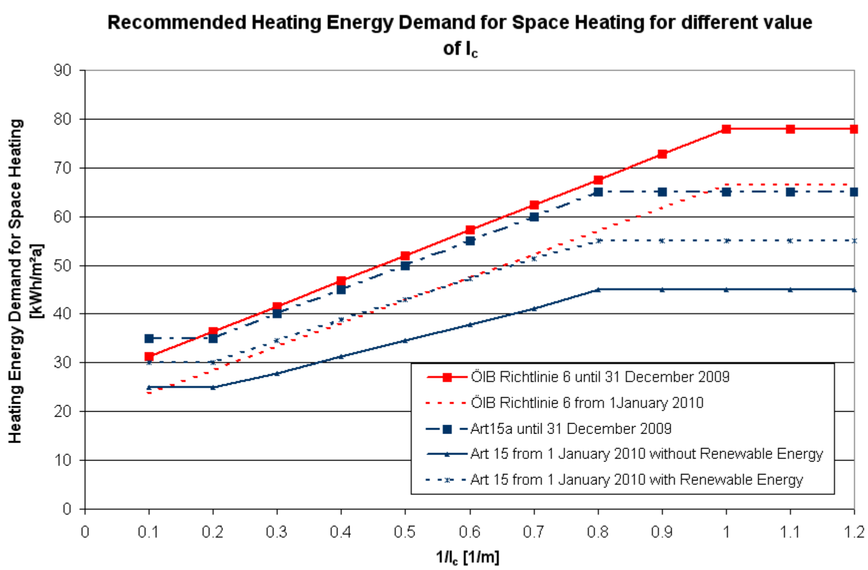

Figure 7. Recommended heating energy demand for space heating for different value of l_c (Streicher & Eiper 2007)

Figure 7 shows the recommended value of heating energy demand for residential building for different value of I_c. According to the Directive 6, the maximum allowable amount of annual heating energy demand for new residential building is 78.0 kWh/m², and start from the 1st January 2010, it will be reduced to 66.5 kWh/m² for residential building, and 102.0 kWh/m² and 87.5 kWh/m² for refurbished buildings, respectively. For the non–residential buildings, the current maximum allowable value is 27.0 kWh/m³a for new building and 33.0 kWh/m³a for renovated building, and will be decreased to 22.75 kWh/m³a and 30.0 kWh/m³a started from the 1st January 2010. For the cooling energy demand, the acceptable value is only 1.0 kWh/m³a for new and 2.0 kWh/m³a for refurbished non-residential buildings for some overheated days during summer. For the residential building, it is mentioned that for both new and renovated residential buildings, the annual cooling energy demand has to refer to the ÖNORM B 8110-3, which assumes that there is no overheating in summer without cooling machine.

The following pattern shows the energy flows in building which is used in order to calculate the heating energy demand of the building. In case of cooling demand, the similar diagram as shown in Figure 8 is applied, except the absence of boundary heating plant and boundary of the heated zone is changed into a boundary of the cooling zone.

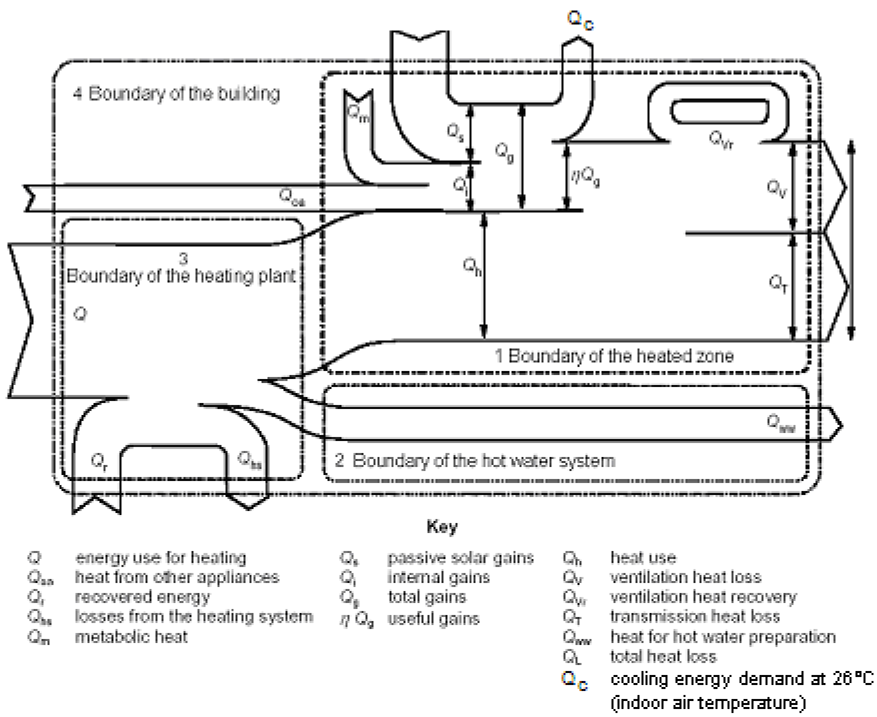

Figure 8. Energy flows in Building (ÖNORM EN ISO 13790 2004)

The Directive also presents the energy certification and the rating systems for buildings in Austria (Österreichisches Institut für Bautechnik 2007). The building certification was implemented in Austria in January 2008, as an implementation of EPBD. Certificates have to be made for buildings which will be constructed, or which are sold or rented and for public buildings with more than 1000 m² of area. The certification criteria for residential building are also different from those of non-residential building. The main difference is in the boundary conditions and the reference used in the calculation procedure (Mach & Heinz 2007). Figure 9 shows an example for an energy certificate for a residential building. The certification is valid for 10 years.

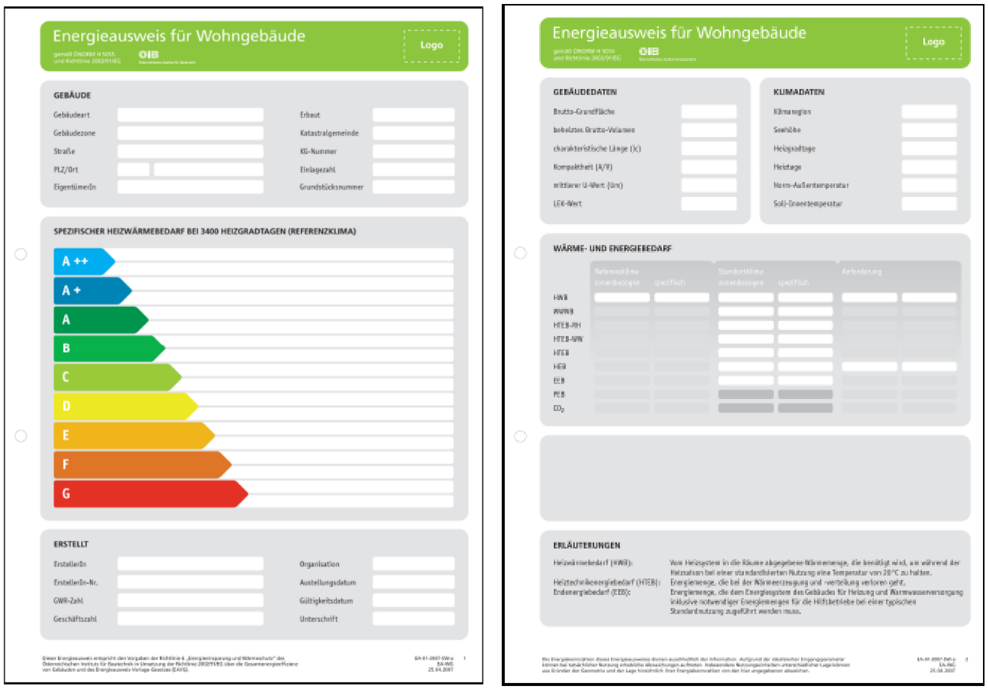

Figure 9. Example of Energy Certificate of a Residential Building (Österreichisches Institut für Bautechnik 2007)

In order to fostering the implementation of low energy buildings, there is a subsidies scheme provided by the Austrian provinces dealing with energy efficient buildings, which are granted for new building constructions and renovated existing buildings. The criteria of this subsidy is shown in Figure 7. For instance, in order to receive the subsidy, the building's annual heating energy demand for space heating of a residential building has to be lower than the recommended value in that graph. In the future, therefore the value of the building depends not only on its strategic location, but also on its energy performance that determines its operational cost (Streicher 2007).

The Austrian "Building of Tomorrow" research fund program is initiated by the Austrian Government, which aims to achieve higher energy efficiency throughout the whole life cycle of the building. It also intends to implement a greater use of renewable energy sources, especially solar energy as well as the greater use of sustainable raw materials, and efficient use of materials with considering the comparable cost compared to conventional building (www.hausderzukunft.at 1999).

The other efforts planned by the Austrian government in the period of 2007 -2010 concerning the energy efficient building (Mach & Heinz 2007) consist of:

- National programme for energy efficiency
- Enhancement of the energy intensity by at least 5 % until 2010 (at least 20% until 2020)
- Energy assessment for all Austrian households until 2010
- Increase the renovation rate in the building sector, focused on the thermal renovation of all buildings of the postwar period (1950-1980) until 2020
- For the new building sector, the government enforces the low energy and passive house standard together with the federal states
- A "Klima:aktiv standard" is aimed for 50 % of all new buildings

Klima: aktiv is a program aimed as a climate protection initiative launched by the Austrian Ministry of the Environment and embedded in the Austrian federal climate strategy. The Austrian Energy Agency has been responsible for the implementation since it is launched in 2004 and coordinates all programmes in the four thematic clusters Building, Energy Efficiency, Mobility and Renewable Energy. The criteria aim primarily at a reduction of the total energy consumption and the CO_2 emissions as well as healthy living. For a klima:aktiv house standard, the recommended criteria for space heating energy demand is 45 kWh/m²a, and for klima:aktiv passive house standard, the value is 15 kWh/m²a (Liebel 2007).

- From 2015 only low energy and passive houses meeting the “klima: aktiv-standard” will be subsidized
- Development and use of energy efficient devices and solutions (stand-by)
- Extension of combined heat and power plants as an efficient method for producing electricity and heat

2.3.2 Indonesian National Standard (www.bsn.go.id)

The Indonesian National Standard (SNI) is the official standard which is nationally applied in Indonesia. SNI was formulated by a Technical Committee and defined by National Standardization Agency (BSN). The BSN is the agency that is responsible in developing and providing the guidance, as well as to coordinate national scope activities focusing on standardization. It is also in charge in the assessment and preparation of national policy, specifically the national standardization (www.bsn.go.id). In correlation of energy policy for building in Indonesia, there are some standards providing by BSN. These following standards mainly deal with the energy conservation for building in Indonesia.

SNI 03-6389-2000 Konservasi Energi Selubung Bangunan pada Bangunan Gedung (Energy Conservation for Building) (National Standardization Agency of Indonesia 2000c)

This standard provides the criteria and procedures of designing a building with the consideration of energy conservation and recommendation of the optimum building envelope, therefore, the energy efficient use of the building is achieved without reducing or altering the function of the building, maintaining the comfortable condition and productivity of the occupants as well as considering the financial aspect. The references used in developing this standard consist of ASHRAE Standard, ASEAN-USAID project, Building Officials and Code Administrators International, Inc.(BOCA) International energy conservation code 20, and the Handbook of Energy Conservation in Building and Building Services (PWD) Singapore. In the planning stage of a building, the building envelope should satisfy the following conditions: wall and roof are appropriate for conditioned building, the total solar heat gain of the wall and roof must not be exceed the recommended overall thermal transfer value (OTTV), of which maximum is 45 Watt/m².

SNI 03-6390-2000 Konservasi Energi Sistem Tata Udara pada Bangunan Gedung (Energy conservation of air conditioning system in buildings) (National Standardization Agency of Indonesia 2000d)

This standard specifically intended to assist the designers, building owners, and building management concerning the air conditioning and refrigeration system of the building. The standard includes the technical calculations, the selection, measurement and testing method of the air conditioning system. It also provides the recommendation on the optimum operation of air conditioning design, in order to accomplish the energy consumption efficiently and considering the comfortable environment for the occupants. In developing the standard, the committee referred to the ASHRAE Standard 90.1: on the subject of energy efficiency and BOCA, International energy conservation code 20.

SNI 03-6196-2000 Prosedur Audit Energi pada Bangunan Gedung (Procedure for energy auditing of buildings) (National Standardization Agency of Indonesia 2000a)

The energy audit is the most common activity done for an existing building in Indonesia, in order to asses the energy performance of that building. The main goal of energy audit is to evaluate the whole picture of energy consumption and obtaining the efforts in order to improve the efficient utilisation of energy. The components involved in the ‘whole picture of energy consumption’ are the type and amount of energy consumption, the available equipment and electronics appliances as well as its performance, the energy intensity, the profile of energy load, and the energy saving opportunities for all and partly area of the building in the certain period. The stakeholders involved in the energy audit are including planner, operation and monitoring components, as well as building management. This standard provides the technical guidance and the procedures on how to perform energy audits. The procedures consist of preliminary energy audit, detailed energy audit, identification of energy saving opportunities, analysis of energy saving opportunities, reporting, and recommendation. Figure 10 shows the flowchart of the energy audit procedure.

The preliminary energy audit involves the activities of data collection and determination of energy consumption intensity (IKE). The data required to be audited consist of drawings of the building, such as floor plan, side view, and others, installation of lighting system, and electricity diagram network. In addition, the data of monthly electricity, other energy sources such as oil, gas, etc, and water expenses during the previous year are important. Furthermore, the data of occupancy rate and profile is required. From these data, subsequently the IKE is calculated. IKE is defined as the total annual energy consumption per area, presented in kWh/m^2.year. In order to evaluate the efficiency level of the energy consumption, the IKE is compared to the available recommended values (Ayuni 2004). When the IKE is higher than the targeted value, then the measurement procedure is done in order to obtain the detailed energy consumption.

The detailed energy audit is performed only when the IKE is found higher than the recommended value for specific type of building. Again, when the IKE after the measurement is found higher than the target, then the auditor will identify the energy saving opportunities (PHE). The analysis of PHE involves the comparison between the potential energy saving and the level of costs required, the potential of limiting the installed electricity power and operating hour without disregarding the occupant’s comfort. Furthermore, the improvement of the energy performance of the equipments and appliances are also analysed as well as the possibility to use cheaper price of energy sources. The recommendations will be given based on the results of PHE's analysis, with the following consideration: improvement of energy efficiency with no cost investment, such as only changing the operational procedure in the building, improvement with low cost investment, and improvement with high cost investment, such as changing the design of the building, additional equipments, and others.

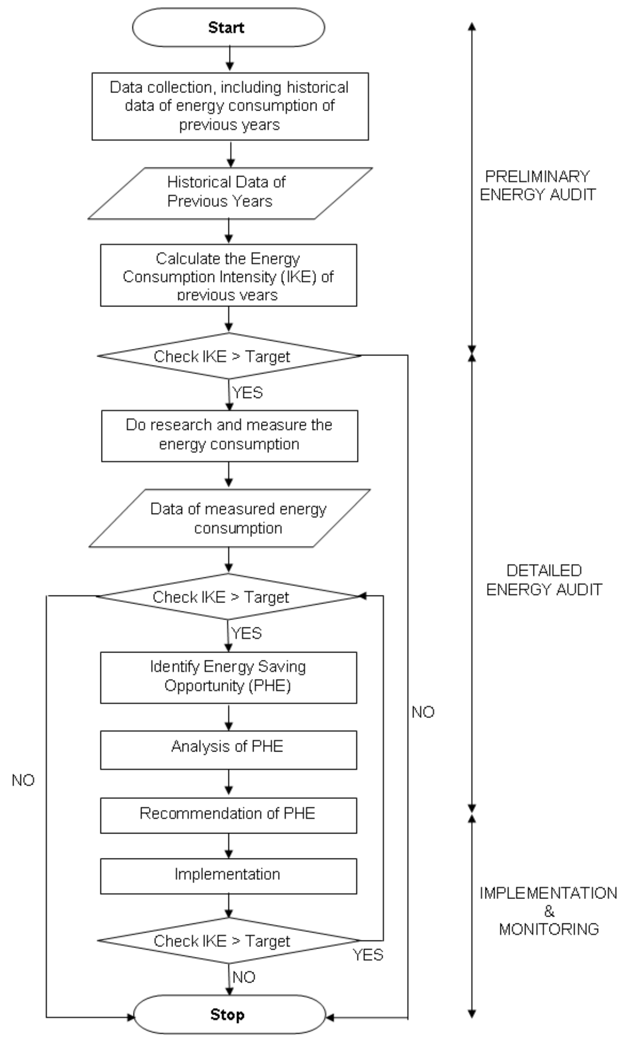

Figure 10. Flowchart of Energy Audit (National Standardization Agency of Indonesia 2000a)

This standard however has not yet integrated the energy audit as a part of energy management for building. Moreover, it must also be integrated with other management scheme, such as quality management (ISO 9000), environmental management (ISO 14000) and safety management (OHSAS 18000), which has been implemented by other standard, i.e AS/NZS 3598-2000 (Sujatmiko 2008). The common difficulty in implementing the energy audit of a building is the limited data available, such as the monthly electricity bill, the drawing of the building, and so on, which leads to the unpreparedness of the building management in providing data to be audited.

SNI 03-6197-2000 Konservasi Energi Sistem Pencahayaan pada Bangunan Gedung (Energy conservation of lighting system in buildings) (National Standardization Agency of Indonesia 2000b)

This standard provides the guidance in designing lighting system for building in order to achieve an optimal operation as well as an efficient use of energy without reducing and / or changing the function of the building, sacrificing the occupants' comfort. The lighting system of the building consists of artificial and natural lighting. The standard includes the recommended values of light intensity as well as energy consumption suggested for the various types of buildings.

SNI 03-6759-2002 Tata Cara Perancangan Konservasi Energi Pada bangunan Gedung (Codes for energy conservation designation of buildings) (National Standardization Agency of Indonesia 2002)

This standard presents the requirements and the technical regulations concerning the electricity source for building, lighting system including artificial and natural lighting, air conditioning for building, building's envelope, thermal comfort for unconditioned building and energy management. This standard defines the energy conservation as the effort to utilise energy efficiently in order to avoid the lavishly consumption of energy.

SNI 04-6958-2003 Label Tingkat Hemat Energi Pemanfaatan Tenaga Listrik untuk keperluan Rumah Tangga dan sejenisnya (Energy Conservation Labelling for Electrical Household Appliances) (National Standardization Agency of Indonesia 2003)

This standard provides the regulation of the labelling for electrical household appliances concerning its level of energy saving. The background in developing this standard is because the dramatically increase of annual sales of electrical households appliances in Indonesia in the last decade (Hilmawan & Said 2009), followed by the substantial increase of electricity consumption in the residential sector (Zed & Mujiyanto 2008). Therefore, it is important for the government to develop a regulation, which includes the energy rating for the electrical household appliances. The implementation of this standard currently still covers the energy labelling for lamps, refrigerator, television, air conditioning, and air circulation fan. The proposed labelling will be intended for other appliances such as rice cooker, water pump, washing machine, and others. In developing the standard, the committee referred to the Australian Standard AS 2575.1-1989 and New Zealand Standard NZS 6205.1-1989 concerning energy labelling for appliances (Hilmawan & Said 2009).

In addition, currently the opportunity to develop a new standard concerning the adaptive thermal comfort is still discussed. The realisation of this standard is very important in order to support the efforts in energy saving of buildings. Moreover, the available international standards are apparently not appropriate to be applied in Indonesia (Sujatmiko et al. 2008).

2.4 Regulations in Indonesia and the Problems

Ministerial Decree No. 0002/2004 on green energy policy, states about implementing of the maximum utilization of renewable energy. This regulation also consists of the efficient utilization of energy and public awareness in energy efficiency. Practically, the implementation mechanism of this regulation is supported by the available national standards. However, the provided standards apparently refer to foreign standards, which are obviously not proper to the situation in Indonesia. Especially for the standards concerning the energy conservation for buildings, the international standards are developed based on the local climatic behaviour, user manners and habits, available resources, and so on.

In terms of climatic condition, Indonesia lies in a hot and humid climate, where it is not easy to design a passive building and too ambitious to set the indoor temperature as low as in the cold climate region. A passive building is defined as a building that does not require mechanical cooling in order to achieve thermal comfort for the occupants, and mainly takes the advantage of the natural climate to maintain the thermal comfort (Reardon 2008). Normally, during the day, the outdoor air temperature is very high, and the temperature difference between day and night is also not too big, therefore, the use of night cooling does not give a significant effect to the reduction of cooling energy demand.

In addition, the building energy simulation is not quite popular in Indonesia. It is rare to simulate the energy performance of the building prior to the construction. Mainly people are doing energy audit for the building after several years of the occupancy period of the building. Obviously, this is ineffective as normally the recommendation given from this auditing is costly. It would be better if the energy performance were predicted in the design stage of building. The skill of the people who are capable to operate the simulation program are also not very good, moreover, the technique, facility, and human resources are not sufficiently available.

The improvement of the economic condition leads to the development of large-scale housing areas, imbalanced between the constructional activities of skyscrapers and the availability of land, energy supplies and environmental conservation (Firman 2002). The lack communication between interrelated multi-disciplinary elements, such as engineers, architects, owners in the design process also counteracts the realization of energy efficient buildings. Concerning the utilisation of energy appliances, there is still limited information on equipment performance, and the users are more aware to the technical performance, comfort, and design than to the energy performance. Moreover, it is often the case that more energy efficient appliance cost more than the conventional ones. In summary, there are still many programs to be planned and implemented in order to realize energy efficient buildings. The supporting program could be possible adopted from the Austrian experiences with the adjustments appropriate for Indonesian conditions.

CHAPTER 3: BUILDING SIMULATION

One of the important steps in planning a building is to asses its energy consumption during the design phase of the building, as changes can be easily adopted. Simulation of the thermal behaviour of a building gives deeper insight during the designing phase of a building. Figure 11 shows the correlation between the level of ability to influence the design of a building and the cost required, for some different phases during the building's lifetime. During the planning or design phase, there are still nearly unlimited possibilities to change the design while this requires almost no cost. Conversely, when the building is commenced to be constructed, the design has less chance to be changed as well as more costly. Furthermore, in the occupancy phase and beyond i.e renovation phase, it will requires higher cost even just for a slight alteration in the building's design. For that reason, the modification of the building's design in order to satisfy the energy efficiency building undoubtedly is essential to be performed during the planning phase.

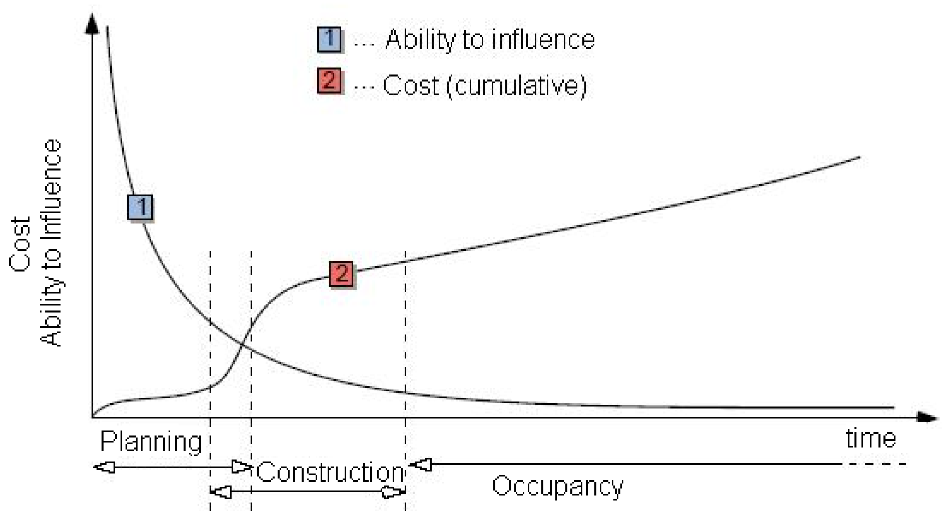

Figure 11. The influence on cost effectiveness during the lifetime of a building (C. Müller 1999)

This chapter presents the importance of thermal building simulation during the design phase of buildings and the tools that are employed in this research. The overview of the heat transfer mechanism as well available energy simulation tools for building will also be presented. Prior to perform the simulation, it is essential to present the validation of the simulation tools as well as asses the competency of the author in applying these tools by comparing author's results with the reference results. Additionally, as in the thermal building simulation involves a complex as well as large number of parameters, therefore it is important that the user has sufficient knowledge, experience and clearly understanding in utilizing the simulation tool.

3.1 What is Thermal Building Simulation

In fact, there are some definitions concerning the thermal building simulation. According to the lecture of EnergyPlus (GARD Analytics, Inc & University of Illinois at Urbana-Champaign 2000), simulation is defined as the imitative representation of the functioning of one system or process by means of the functioning of another (a computer simulation of an industrial process). Simulation, from a Latin word 'simulare' also means 'to pretend'. In this case, simulation can also represent the employ of mathematical model of a system to predict its output for a given input (Jan Hensen 2007). The building thermal simulation has an approximate definition as *a computer model of the energy processes within a building that are intended to provide a thermally comfortable environment for the occupants (or contents) of a building* (GARD Analytics, Inc & University of Illinois at Urbana-Champaign 2000).

In the context of achieving energy efficiency for a building, the building simulation is a vital effort as by performing simulation, it can be understood the energy performance of a building. However, prior to the introduction of computer-aided building simulation, architects and building services engineers depended primarily on manual calculations using pre-selected design conditions or even often using the traditional 'rule of thumb' method and extrapolations in extending beyond conventional design concepts. It is obvious that the accuracy is still questioned as this approach frequently causes to oversized plant and poor energy performance. The development of building thermal simulation began in the 1960s and turn into an energy research focus amongst the energy research community in the 1970s. During this period building simulation was regarded as the key to turning building great consuming energy into energy-efficient thermally conducive built environment. In the late 1970s and beginning 1980s, there are more simulation tools are developed such as DOE-2, ESP, and TRNSYS. However, they still remained mostly in the research laboratories and rarely applied in the building design practice because of the level of difficulty and high cost involve in their use. The building thermal simulation has changed its role from the research community to be implemented in the professional practice in the beginning of 1990s as the demand of energy efficient building become a must rather than a need (Hong et al. 2000). Optimistically speaking, as the technology is applied wider, therefore the demands on simulation programs will grow (J.A Clarke 2001).

The thermal building simulations indeed require a complex interaction of energy flow. There are many parameters involved, of which one often depends on some others parameters. The energy requirements of a building depend not only on the individual performance of the envelope components such as roofs, walls and windows, HVAC system and lightings, but also on their overall performance as an integrated system within the unique building as well as the unavoidable influence from its environment.

Figure 12 shows the flow path of energy in a building. It can be seen that the parameters involved in the energy performance of a building cause the complexity and uncertainty in the building simulation. The uncertainties in the simulation involve internal factors as well as external ones. Therefore a careful planning and determining the assumptions in a thermal building simulation is a crucial part in order to achieve realistic simulation results. In fact, there are many sources of uncertainty which exist almost in the entire aspect of simulations, such as building's dimensional, constructional and operational specification, climate and microclimate, and occupant interactions (J.A Clarke 2001). It has been analyzed that the main sources of uncertainties consist of four categories, those are **abstraction**, i.e boundary conditions, simplified geometry;

databases, i.e climate, thermophysical properties; **modeled phenomena**, i.e heat flow model, solar model, moisture flow; and **solution methods**, which is generally beyond the control of the user (Macdonald et al. 1999).

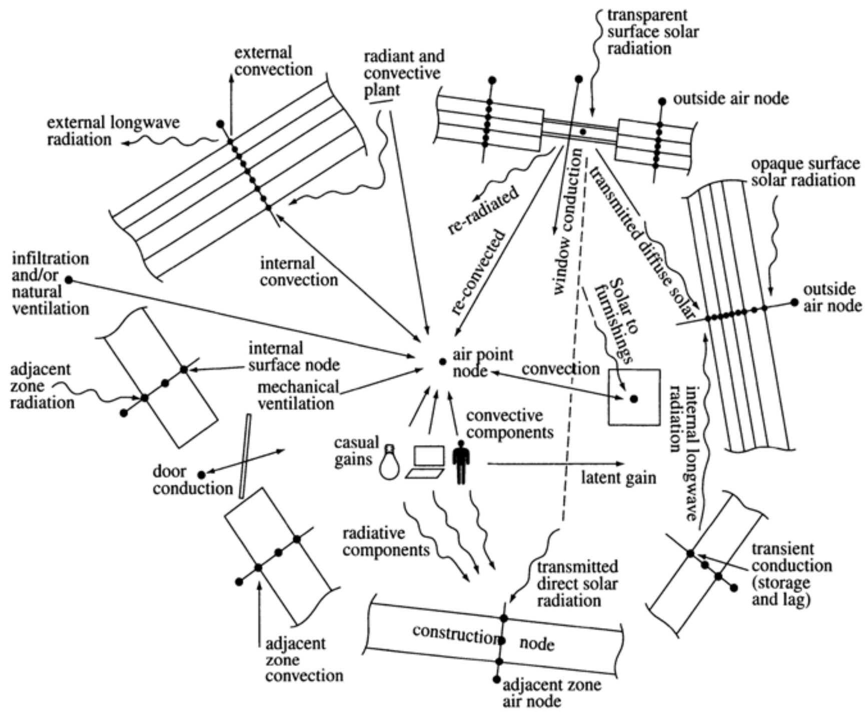

Figure 12. Building Energy Flowpaths (J.A Clarke 2001)

Undoubtedly understanding the performance of a simulation tool before using it is important for the users. The aspects that should be considered in applying a building thermal simulation tool including computing capability, usability, the capability of data exchange and the database support. The computing capability involves the core algorithm, application scope, computing speed and accuracy, as well as the user extensibility. The other aspect that is also important is the usability of the tools, which comprises user-centered, flexible, reliable, responsible, and believable. The simulation software should be easy to learn and user-friendly, which let the user understand what is behind the running process and allow the user to control the process. Moreover, the aspects of data exchange capability and database support are also essential in evaluating the performance of simulation software (Hong et al. 2000).

The implementation of thermal building simulation involves the design, construction, operation, and maintenance as well as the management. It is also possible to apply the simulation for the life cycle analysis. By applying thermal simulation of a building, the profile of the annual building energy demand can be analyzed. Moreover, there is the possibility to evaluate the part-load performance of major energy-consuming equipment as well as determining which component contributes to which extend to the energy consumption of a building. Consequently, innovative strategies in reducing energy consumption are feasible to be observed before implemented and the energy budget of the building for investment and operation can be estimated. This leads to a higher chance to realize energy efficient buildings.

Applying thermal building simulation is essential as it has a wide field of applications such as building heating/cooling load calculation (peak energy demand and its profile), building energy performance analysis, building energy management and control system design, building regulations/codes/standards compliance checking, as well as life cycle cost analysis and quality assurance (Commissioning) (Shah et al. 2002). The main concern of performing thermal building simulation is to determine the energy, thermal, as well as environmental performance of a building (C.M Hui 1996).

3.1.1 Heat transfer in the thermal building simulation

Heat transfer is defined as the thermal energy transported due to a spatial temperature difference (Incropera et al. 2002). In the thermal simulation of the building, the core calculations are the heat transfer in the building and the user behaviour and its interaction with the environment, which is obtained from the given weather data. The heat transfer in the building occurred in the middle range of temperature, means that it does not involve low or high temperature as well as high pressure (Davies 2004). The equations in the building thermal simulation are based on the laws of thermodynamics in determining the heat gain and heat loss of the building. The basic equations in the building thermal simulation consist of conduction, convection and radiation heat transfer modes. These include the phenomenon of shading, insulation, airflow, internal gains due to occupant behaviour and equipments, as well as ventilation, infiltration and air conditioning (J.A Clarke 2001) (Davies 2004) (Incropera et al. 2002). These factors cannot be ignored and always give influences to the thermal building performance: Those all parameters' interactions are time and temperature dependent.

Conduction

The transient conduction is an essential equation in the building modelling as it involves the variation of heat flux achieving at one boundary of a solid material and transferred to another boundary as the result of temperature difference, which is time-dependent. It is also important that the heat is considered to flow in more than one single directions.

The thermophysical properties of interest in the transient conduction heat transfer include conductivity, λ (W m^{-1} $°C^{-1}$), density, ρ (kg m^{-3}), and specific heat capacity, c_p (J kg^{-l} $°C^{-1}$). These properties are time-dependent because of material temperature and/or moisture fluctuations, and may be position or direction dependent if the material is non-homogeneous or anisotropic respectively. In some applications, such dependencies may be neglected and the thermophysical properties assumed to be constant. Usually in modelling the building, it is often to assume these constant properties in order to approach simple steady state model to assess the heat gain and loss characteristics of the building fabric.

It is no doubt that in modelling the building envelopes, there are some layers of building material in the construction. Hence, it is important to introduce the overall thermal transmittance, or U-value (W m^{-2} $°C^{-1}$), which is given by the following equation.

$$U = \frac{1}{\sum_{i=1}^{N} \frac{x_i}{\lambda_i} + R_{si} + R_{so} + R_c}$$

where

N = number of layers in the construction,

xi = thickness of layer i (m),

R = combined radiative and convective thermal resistance (m^2 K W^{-1})

si, so, and c refer to the innermost surface, outermost surface and cavity respectively.

It is also important to introduce thermal diffusivity, $\alpha = \lambda/\rho c_p$ ($m^2 s^{-1}$), and effusivity, $\varepsilon = (\lambda\rho C)^{½}$ (J m^{-2} K^{-1} $s^{-½}$) since these values are useful as dynamic performance indicators. Materials with high α values transmit boundary heat flux fluctuations more rapidly than materials with correspondingly low values, while materials with high ε values will more readily absorb a surface heat flux (J.A Clarke 2001).

Surface convection

The convection heat transfer involves the heat flux that is exchanged between a surface, either opaque or transparent, and the fluid moving over the surface or in the building usually in the form of the adjacent air layer. The mode of convection heat transfer can be divided into two mechanism, those are forced convection and natural or free convection. The thermophysical property in the convection heat transfer includes the convection coefficient U_c (W m^{-2} K^{-1}).

The forced convection occurs when there is ‘external forcing condition’ such as fluid motion that might be induced by fan or pump. In the building modelling, the location of the building and its environmental condition will influence the wind speed reaching the external building surfaces.

In the situation where there is no forced velocity, the body force acts on a fluid when there are density gradients and this mechanism is referred to as natural convection. The natural convection occurred as an effect of buoyancy force, which involves the density gradients due to a temperature gradient, as well as body force due to the gravity. Many formulations have emerged which give convection coefficients as a function of the surface-to-air temperature difference, surface roughness, direction of heat flow and characteristic dimensions. As the flow velocity for the natural convection is much smaller than the forced convection, hence the corresponding convection transfer rates are also smaller.

Longwave radiation exchange

This mechanism often involves a combination of radiation and convection heat transfers on a surface. As a result, the surface heat transfer coefficient is also not easy to define since the two processes are related, and influence the surface temperature. The longwave radiation from a surface is a function of the existing surface temperature, the emmisivities of the surface, the view factor or the orientation of the surface regarding the visual contact to the incident radiation counterpart, and the character of the surface reflection such as diffuse, specular or mixed.

During the night, the clear sky conditions could possibly reduce the surface temperature as the effect of the radiation exchange between the external surface and the sky vault. This can be used in hot climate regions, with substantial diurnal temperature difference. This effective sky temperature is dependent on the existence of clouds and its type.

Shortwave radiation

The shortwave radiation contributes the most heat gain of the building. The heat transferred by means of direct solar radiation incident on the surface, diffuse solar radiation as the influence of atmospheric scatter, clouds, and topography reflection. The thermophysical properties of interest include shortwave absorptivity for opaque elements and absorptivity, transmissivity and reflectivity for transparent elements. The values of these constants are dependent on the angle of incidence of the shortwave flux and on its spectral composition. In the simplified form of spectral composition, it is often to use the average value for the entire solar power spectrum.

The shortwave energy imposing on the transparent material will partially be reflected, partially absorbed, and partially transmitted. The absorption process will take place internally and increase its temperature. As a result, the transient conduction increases hence raise the inside and outside surface temperature. This leads to the surface convection as well as longwave radiation flowpaths. Thus, in effect, absorbed shortwave radiation penetrates the building via convection and longwave radiation.

In the building case, roof is the most common component of which its material absorbs more solar radiation than reflect it. In the tropical region, the roof's colour has significant influence on the absorption of incident energy. Dark roofs leads to high absorption, which cause the external surface temperature of the roof far higher than the ambient temperature, hence the transient conduction will augment. Consequently, it should be considered that for the roof's material, the high solar reflectance is beneficial.

Shading and insulation

As mentioned before the main heat gain of the building is due to the shortwave solar radiation. The window glazing are the main media that transfer the shortwave radiation into the building, and possibly the internal façade will release the heat internally as longwave radiation and via convection, which results to the heat, trapped inside the building. For a region with cold climate, this phenomena is obviously beneficial as it will raise the temperature inside the building. However, in the hot and humid area where the diurnal temperature difference is not significant, undoubtedly that trapped heat must be avoided. Therefore, the consideration of shading and insulation are capable to reduce the incident solar energy. The shading effect normally caused by façade obstruction such as neighbouring buildings and trees, however, it is also possible to provide constructional shading such as overhang, awning, and others.

The insulation will be essential for cold climate region in order to prevent heat loss to the environment, conversely, for the regions which have hot and humid climate condition, the insulation should be installed on the surface of which the solar energy mostly enters the building, such as roof. The glazing material will also contribute to the effective insulation of the building, since in this region glazing which prevents heat penetrate to the building but transmitting high value of light is preferable. Moreover, it is not recommended that building have a very large part of glazing area.

Airflow

The airflows in the building are mainly caused by infiltration and window ventilation, zone-coupled flows and mechanical ventilation. Infiltration is the occurrence of outside air entering the building, which unintentionally exist and mostly as the effect of leakage paths such as cracks of the building envelope. The pressure variation in the building as well as buoyancy force often influences the airflow exchange between different zones of the building, named as zone-coupled airflow. Whereas the first two airflow paths are always present (could be avoided by improving the construction details of the building), the mechanical ventilation is designed in order to fulfil the fresh air requirement or may be to heat or cool a space.

During the occupational time of the building, the magnitude of the infiltration as well as the inter-zone air flow are varied due to the random occurrences such as opening the windows or doors by the occupants. To handle these stochastic occurrences, airflow models of varying complexity should be developed.

In the building energy modelling, air movement is often represented by a nodal network. Nodes represent fluid volumes and inter-nodal connections represent the distributed leakage paths connecting these volumes and through which flow can occur. Numerical techniques are then applied to this network to establish the mass balance corresponding to any given nodal temperature field and boundary pressure condition. Such a method is well suited for the determination of the contribution of air movement to energy requirements. A more comprehensive approach involves the solution of the energy, continuity (mass) and momentum (Navier-Stokes) equations when applied to a finely discretised flow domain. In addition to supporting energy analysis, such a method will also provide information on the spatial variation of indoor air quality and thermal comfort levels. This method is known as computational fluid dynamics, and nowadays this simulation is sometimes used coupled with thermal building simulation.

Casual gains

The common heat gain in the building consists of gains from occupants, lighting, and appliances. Therefore, it is essential to develop the most realistic groups of input data, such as the specification of heat, either radiant or convective, moisture emissions, and the nature of the mechanism to allow each casual source to change its value by the designed input or via control action. It is usual to assume that the convective heat emission is experienced instantaneously as an air load whereas the radiant part, acts similar to shortwave radiation penetrating the building envelope, which is distributed between the internal opaque and transparent surfaces according to some distribution strategy. Because of the inherent relationship with the construction capacity, the radiant component will experience a time lag before it can contribute to the cooling and heating load or influencing the increase of the internal air temperature.

Some casual gain sources, such as lighting and appliances, will require the elaboration of a model of their electrical behaviour in order to modulate heat emission as a function of the electrical power usage, for example, the effect of the natural lighting to the magnitude of the luminary from electrical lighting.

Heating, ventilating and air conditioning (HVAC) systems

In the simulation process, the energy consumption of the building is mainly divided into two different groups of stage. The first stage is dealing with the energy demand of the building, which is influence by the design of the building and the inside activities. In this stage, the cooling or heating energy demand is calculated. Consequently, in this stage the designers are allowed to modify the assumption in order to reduce the energy requirements. The second stage is correlating with the plant design, which is based on the operating characteristic of the system plant and its operational. Hence, the best system plant should be considered in order to satisfy the requirements and therefore minimise the consumption as well as the (gaseous) emissions of the plant. In order to obtain the most acceptable results, the simultaneous simulation is recommended as the building and system plant are strongly coupled.

3.2 Available Tools

There are many simulation tools available and each has its own characteristic and advantage, as well as has its strength and weaknesses. (D. B Crawley et al. 2008) analyzed the differences of characteristic of twenty simulation programs. These twenty simulation programs including BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, Energy Plus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, TAS, TRACE and TRNSYS. The comparison comprises some categories such as general modeling features; zone loads; building envelope and daylighting and solar; infiltration, ventilation, room and multizone airflow; renewable energy systems; electrical systems and equipment; HVAC systems; HVAC equipment; environmental emissions; climate data availability; economic evaluation; results reporting; validation; and user interface, links to other programs, and availability. Here, the main objective is not to judge whether one simulation tool is better than the other, but presented the capabilities of those tools in order to give overviews to the users. Furthermore, the users should be able to consider selecting a tool which would support the range of simulation needs that they usually see in the practical application (Drury B. Crawley et al. 2005).

3.2.1 Overview of some Building Simulation Tools

The following overview of some building simulation tools are based on the previous comparative surveys (Drury B. Crawley et al. 2005) (D. B Crawley et al. 2008) (Shah et al. 2002) and the overview of the tools designer and users (Roberts & Marsh 2001) (www.esru.strath.ac.uk 2005) (www.trnsys.com).

BLAST

The Building Load Analysis and System Thermodynamics (BLAST) is a comprehensive set of program for predicting energy consumption and energy system performance and cost in buildings. BLAST consists of three subprograms called Space Load Prediction, Air System Simulation, and Central Plant. The first subprogram calculates the hourly space load of building with the input parameters of weather data and the building construction and operation. The Air System Simulation then uses this hourly space load, weather data, and the detailed construction of the building and operation to calculate hot water, steam, gas, chilled water, and electric demands of the building and air handling system. The sequence process is the calculation of monthly and annual fuel and electrical power consumption by the Central Plant Simulation. This calculation is based on the results of previous subprogram together with the weather data and the building and operational input data. Since 1998, BLAST is no longer under development and no new versions have been released.

DOE-2

DOE-2.1E predicts the hourly energy use and energy cost of a building given hourly weather information, a building geometric and HVAC description, and utility rate structure. DOE-2.1E is a public domain program sponsored by DOE which employs FORTRAN as the programming language. This simulation tool has one subprogram for translation input called Building Description Language (BDL Processor), and four simulation subprograms called LOADS, SYSTEMS, PLANT, and ECONOMICS. These simulation subprograms are executed in sequence, such as the output of LOADS then becomes the input of the SYSTEMS, and so on, and it uses weighting factor method in predicting the energy use. The default libraries for building construction are provided. The main use of this tool is for studying the energy conservation as well as the building design studies.

ECOTECT

ECOTECT is a simulation tool with a unique approach to conceptual building design, which is entirely designed and written by architects and proposed basically for use by architects as well. It links 3D modeler with a various range of performance analysis functions including thermal, energy, lighting, shading, acoustics, resource use and cost aspects. The main advantage of this tool is its focus on feedback at the conceptual building design phases. Moreover, ECOTECT aims to provide designers with useful performance feedback both interactively and visually. ECOTECT also capable to communicate with other simulation engine such as Radiance, EnergyPlus, ESP-r, NIST FDS and others, and it includes a group of format suitable for use together with the most leading CAD programs. ECOTECT provides real-time animation features with interactive acoustic and solar raytracking that updates in real times.

ESP-r

ESP-r, developed by the Energy System Research Unit, University of Strathclyde, is an integrated modelling tool for the simulation of the thermal, visual and acoustic performance of buildings and the assessment of the energy use and gaseous emissions associated with the environmental control systems and constructional materials. In undertaking its assessments, the system is equipped to model heat, air, moisture and electrical power flows at user determined resolution. The system is designed for the UNIX operating system, with supported implementations for Solaris and Linux, and is made available under an Open Source licence. It can also be run on Windows in the Cygwin environment, or it can be run in Windows.

In assessing the thermal and energy as well as environmental performance of a building, ESP-r supports an explicit energy balance in each zone and at each surface and uses message passing between the solvers to support inter-domain interactions. Like the other tools, ESP-r also consists of some modules. The main module called the project manager that controls the development of the models and request computational services from other modules. The other supporting modules include climate analysis, an integrated simulation engine, environmental impact assessment, and others.

TAS

TAS is a simulation tool, which simulate the dynamic thermal performance of buildings and their systems. There are three main modules of TAS, those are TAS Building Designer, TAS System, and TAS Ambiens. TAS Building Designer performs dynamic building simulation and integrating natural as well as forced airflow, based on the 3D geometry input that link to CAD. TAS System simulates HVAC systems and controls which are directly coupled with the building simulator. TAS Ambiens produces a cross section of micro climate variation in a space which uses 2D CFD package.

The factors taken into account in the simulation process involve climate, geometry of the building and its orientation, thermal insulation, thermal capacity, glazing properties, shading from nearby buildings and self-shading. It also considers the effect of infiltration, natural ventilation, mechanical ventilation, solar gain, gains from lights, occupants and equipment (both sensible and latent), control set points & bands, optimum start, frost protection, available plant capacities for heating and cooling, plant schedules, plant radiant/convective characteristics, performance of boilers and heat pumps. TAS allows the user to investigate the influence of these factors and provide output in graphical and tabular form showing the effects of the above mentioned factors on air temperature, mean radiant temperature, resultant temperature, surface temperatures, humidity, condensation risk, sensible and latent loads, energy consumption, required plant size.

TRNSYS

TRNSYS (Transient Systems Simulation Program) is simulation tool with a modular structure with the purpose of solving the problems of complex energy system. TRNSYS splits the problem into a series of smaller component called TYPES, which consists of not only simple components such as pipe or pumps, but also complicated ones such as multi-zone building model. These components basically are FORTRAN subroutines. TRNSYS Simulation studio is the interface which integrated, configured, and assembled the components, and the data input for the buildings is configured by the interface called TRNBuild.

The simulation of the HVAC system components are solved simultaneously along with the building envelope thermal balance and the air network each time step, which are typically 1-hour or 15-min time steps (but can be chosen freely). TRNSYS Library provides common components of thermal simulation of building, such as solar thermal, photovoltaic system, low energy buildings and HVAC systems, renewable energy systems, cogeneration, and fuel cell. The DLL (Dynamic Link Library) allows TRNSYS to communicate with various programming language such as FORTRAN, C++, PASCAL, and others. TRNSYS is also capable to directly embed components implemented using other software such as Matlab/Simulink, Excel/Visual Basic, and Engineering Equation Solver (EES).

CONSIDERATION

There are three important considerations concerning the selection of simulation programs from the user's side (Hong et al. 2000). Firstly is the need or purpose of using the simulation tool. The user should be able to choose the appropriate software to solve the problem. Choosing an 'overpowered' tool is not only unnecessary and expensive, but can be costly when mistakes are made due to the complexity of the software. The second is the budget, including the price of the software, maintenance, if necessary, training for the user, and the cost of computer platform to run the software. The third is the availability of the facilities, such as whether the existing computer facilities capable in running the tool and the anticipation of investment in new computer resource are affordable. Based on those considerations, in this research, the tools applied for the building thermal simulation are EnergyPlus and DesignBuilder.

3.2.2 Energy Plus

Energy Plus is a simulation tool, with fully integrated building and HVAC simulation program, which is base on the best features of BLAST and DOE-2 plus new capabilities (Drury B. Crawley et al. 1999). The program is a collection of modules that work together to calculate the energy required for heating and cooling a building using a variety of systems and energy sources. The core of the simulation is a model of the building that is based on fundamental heat balance principles with FORTRAN 90 as the programming language.

The development of EnergyPlus begun in 1996, by the U.S Department of Energy (DOE), with the consideration of improving the performance of BLAST and DOE-2 and expects a more flexible and robust tool with additional capabilities compared to the previous programs. Both BLAST and DOE-2 have a weakness in their simulation methodologies which are often difficult to trace due to decades of development (and multiple authors). The main difference between the programs is the load calculation method. BLAST uses the heat balance approach while DOE-2 uses a room weighting factor approach in determining the load of the building (Drury B. Crawley et al. 1999).

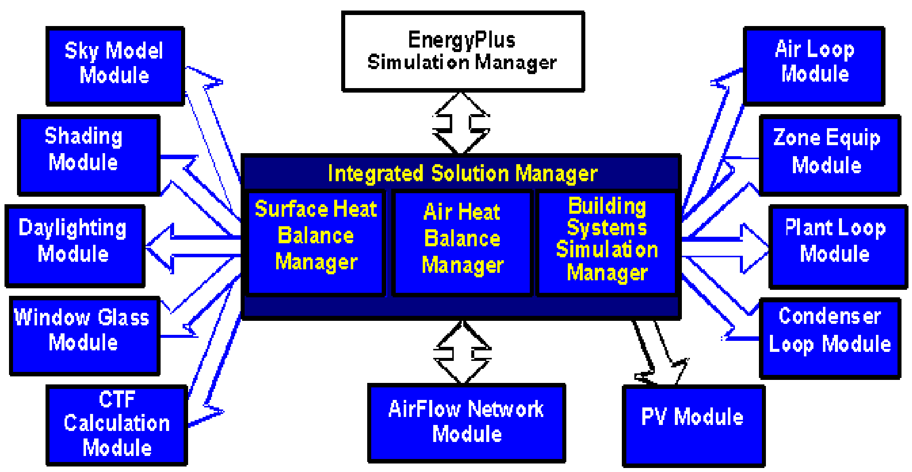

Figure 13. Energy Plus Structure (EnergyPlus 2008)

Figure 13 shows the modules that available in the EnergyPlus. EnergyPlus is an integrated simulation, which means that all three of the major parts, building, system, and plant, must be solved simultaneously. The load calculation is possibly in 1-hour or 15-min time steps, which is then passed to the building simulation module at the same time step. The Building Simulation Module calculates the heating and cooling system and plant as well as electrical system. Surface Heat Balance module simulates the inside and outside surface heat balances, interconnections between heat balances and boundary conditions, and conduction, convection, and radiation as well as mass transfer effects such as water vapor. The Air Heat mass Balance module calculates the various mass flowpaths, such as ventilation, exhaust air, infiltration, which is accounting for zone air thermal mass and direct convective heat gains.

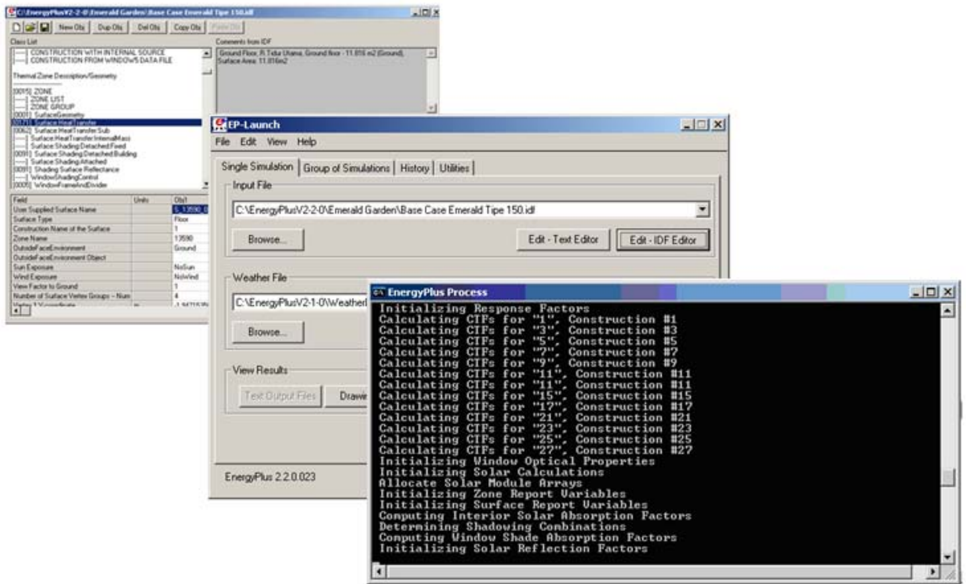

Figure 14. Screen Images of EnergyPlus (EnergyPlus 2008)

Figure 14 shows the screen images of EnergyPlus utilities and example computational process. As EnergyPlus is a simulation engine, therefore it has no interface.

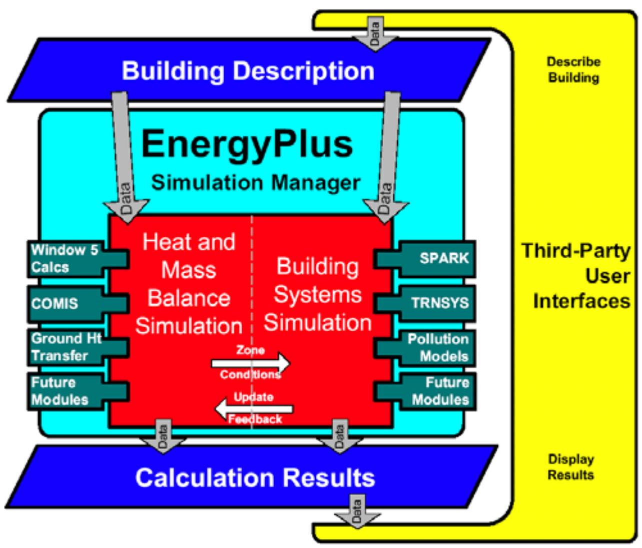

Figure 15. EnergyPlus Program Schematic (EnergyPlus 2008)

Figure 15 shows the overall program structure of EnergyPlus. The basic components of EnergyPlus consist of a simulation manager, a heat and mass balance simulation module, and a building system simulation module.The simulation manager controls the entire simulation process. It also handles the communication between the heat balance engine and various HVAC modules and loops, as well as manages the data communication between the HVAC modules, input data, and output data structures (Drury B. Crawley et al. 1999).

The other capabilities of EnergyPlus include the simple form of input and output file structures, designed for easy maintenance and expansion, as well as accept simulation input data from other sources such as CADD programs (AutoCAD, ArchiCAD, Visio), and preprocessors similar to those written for BLAST and DOE-2. Furthermore, there is no surface, zone or system limits, moreover, it is possible to add the amount of surfaces, zones, as well as the systems. EnergyPlus also links to other software such as COMIS for wind-induced airflow and TRNSYS for e.g. photovoltaic simulation.

EnergyPlus uses the heat balance method in evaluating the building's performance. One of the most important components in the heat balance approach is transient heat conduction of which The EnergyPlus program uses a time series solution commonly referred to as conduction transfer functions (CTFs) to solve for transient heat conduction through building elements. The basic equation for calculating transient conduction with CTFs is

$$q_{i,t} = \sum_{m=1}^{M} X_{k,m} T_{i,t-m+1} - \sum_{m=1}^{M} Y_{k,m} T_{0,t-m+1} + \sum_{m=1}^{k} F_m q_{i,t-m}$$

where $q_{i,t}$ represents the heat flux at the interior surface of a building element at the simulation time step t; $T_{i,t-m+1}$ represents the temperature at the inside surface at time step t and a fixed number of previous time steps; $T_{o,t-m+1}$ represents the temperature at the outside surface at time step t and a fixed number of previous time steps; $q_{i,t-m}$ represents the heat flux at the interior surface of a building element at a fixed number of previous time steps. $X_{k,m}$, $Y_{k,m}$ and F_m are the conduction transfer functions which are constant for a particular building element over the entire simulation (Strand et al. 1999).

In performing the simulation, EnergyPlus simultaneously integrate the zone and the system plant with a short simulation time step. The shorter the time step, the smaller the error will occur, obviously, it requires longer time of computation. In this case, the zone condition experiences retardation of one time step. EnergyPlus uses the information from preceding time step in order to predict the response from the system as well as updating the zone temperature at the current time step. In order to maintain the stability and to minimize the error, the zone air capacity is incorporated in the heat balance. Introduce the equation of the time constant τ for a zone (EnergyPlus 2008):

$$\tau \approx \frac{\rho V c_p}{\left| \dot{Q}_{load} + \dot{Q}_{sys} \right|}$$

where the numerator is the zone air heat capacitance, C_z, and the denominator is the net rate of heat energy input. The value of τ is changed inline with the fluctuation of zone load and system output throughout the simulation. As a result, it is essential to use a variable adaptive time step shorter than one hour in order to update the system condition. The heat balance of the zone is represented in the equation of:

$$C_z \frac{dT_z}{dt} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} U_{c\,i} A_i (T_{si} - T_z) + \sum_{i=1}^{N_{zones}} \dot{m}_i c_p (T_{si} - T_z) + \dot{m}_{\inf} c_p (T_\infty - T_z) + \dot{Q}_{sys}$$

where

$\sum_{i=1}^{N_{sl}} \dot{Q}_i$	= sum of the convective internal loads
$\sum_{i=1}^{N_{surfaces}} U_{c\,i} A_i (T_{si} - T_z)$	= convective heat transfer from the zone surfaces
$\dot{m}_{\inf} c_p (T_\infty - T_z)$	= heat transfer due to infiltration of outside air
$\sum_{i=1}^{N_{zones}} \dot{m}_i c_p (T_{zi} - T_z)$	= heat transfer due to interzone air mixing
$\dot{Q}_{sys}$	= system output
$C_z \dfrac{dT_z}{dt}$	= energy stored in zone air (*C_z is defined as $\rho V c_p$*)

If the air capacitance is neglected, the steady state system output becomes:

$$-\dot{Q}_{sys} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} U_{c\,i} A_i (T_{si} - T_z) + \sum_{i=1}^{N_{zones}} \dot{m}_i c_p (T_{zi} - T_z) + \dot{m}_{\inf} c_p (T_\infty - T_z)$$

The $\dot{Q}_{sys}$ can be formulated as the difference between the supply air enthalpy and the enthalpy of the air leaving the zone, as the air system must provide hot or cold air to the zones to satisfy the heating or cooling loads. Hence, when no air losses from the plenum are assumed, $\dot{Q}_{sys}$ can be presented in the equation:

$$\dot{Q}_{sys} = \dot{m}_{sys} c_p (T_{\sup} - T_z),$$

which results to the heat balance equation for the zone :

$$C_z \frac{dT_z}{dt} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} U_{c\,i} A_i (T_{si} - T_z) + \sum_{i=1}^{N_{zones}} \dot{m}_i c_p (T_{zi} - T_z) + \dot{m}_{\inf} c_p (T_\infty - T_z) + \dot{m}_{sys} c_p (T_{\sup} - T_z)$$

The net zone load is given by the equation :

$$\dot{Q}_{load} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} U_{c\,i} A_i (T_{si} - T_z) + \sum_{i=1}^{N_{zones}} \dot{m}_i c_p (T_{zi} - T_z) + \dot{m}_{\inf} c_p (T_\infty - T_z)$$

which gives the final equation of

$$C_z \frac{dT_z}{dt} = \dot{Q}_{load} + \dot{Q}_{sys}$$

The following procedures are used in order to obtain the surface heat balance in the EnergyPlus.

Outside Heat Balance

The basic of outside heat balance involves the heat transferred from the surrounding to the zone via the outside faces of the zone. The heat transfer mechanism of outside wall can be described in Figure 16.

The heat transfer involved on the outside surface consist of shortwave and longwave radiations, convection on the outside face, and the conduction through the construction material into the zone. The equation for the heat balance on the outside face is:

$$q''_{\alpha sol} + q''_{LWR} + q''_{conv} + q''_{ko} = 0$$

where:

$q''_{\alpha sol}$ = Absorbed direct and diffuse solar (shortwave) radiation heat flux.

q''_{LWR} = Net longwave (thermal) radiation flux exchange with the air and surroundings.

q''_{conv} = Convective flux exchange with outside air.

q''_{ko} = Conduction heat flux (q/A) into the wall.

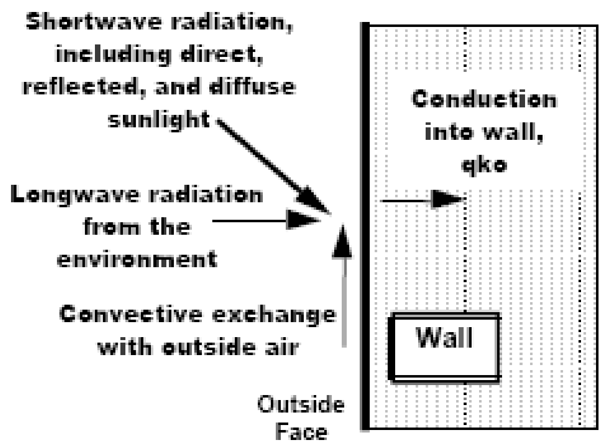

Figure 16. Outside Heat Balance Control Volume Diagram (EnergyPlus 2008)

All terms are positive for net flux to the face except the conduction term, which is traditionally taken to be positive in the direction from outside to inside of the wall. The simplified procedures generally combine the first three terms by using the concept of a *sol-air temperature*. The sol-air temperature is the condition, at which no direct solar radiation and no air motion, therefore their both influences are neglected.

Inside Heat Balance

The basic of inside heat balance include conduction through the building element, convection to the air, short wave radiation absorption and reflectance and long wave radiant interchange. The incident short wave radiation results from the solar radiation penetration to the zone through windows and emitted from internal sources such as lights. The long wave radiation interchange includes the absorption and emittance of low temperature radiation sources, such as all other zone surfaces, equipment, and occupants.

The heat balance on the inside surface can be written as follows:

$$q''_{LWX} + q''_{SW} + q''_{LWS} + q''_{ki} + q''_{sol} + q''_{conv} = 0$$

where:

q''_{LWX} = Net long wave radiant exchange flux between zone surfaces.

q''_{SW} = Net short wave radiation flux to surface from lights.

q''_{LWS} = Long wave radiation flux from equipment in zone.

q''_{ki} = Conduction flux through the wall.

q''_{sol} = Transmitted solar radiation flux absorbed at surface.

q''_{conv} = Convective heat flux to zone air.

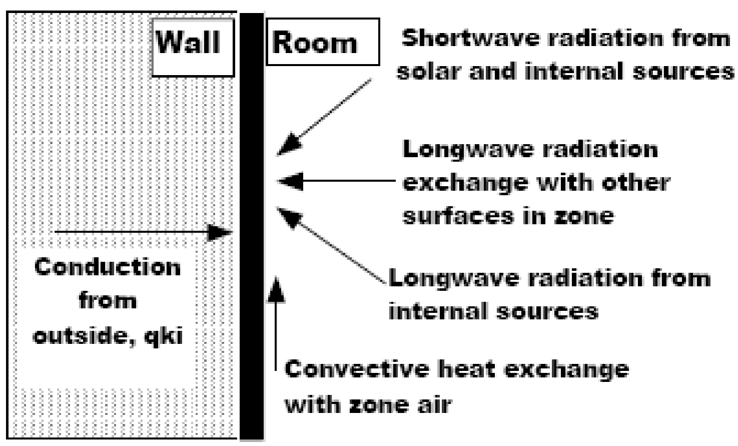

Figure 17. Inside Heat Balance Control Volume Diagram (EnergyPlus 2008)

Figure 17 shows the heat transfer mechanism of the insider surface.

3.2.3 DesignBuilder

DesignBuilder is coupled with the software tool EnergyPlus, which is powerful for modelling three-dimensionally building geometry as well as a tool for building energy performance assessment. There are also CAD links into the 3D modeller as well as report generation facilities. Therefore, the building may be visualised in 3D to aid assessment of design. DesignBuilder combines rapid building modelling with state of the art dynamic energy simulation. DesignBuilder provides a wide range of templates, such as locations as well as their weather data, buildings model, construction materials, schedules, HVAC systems and lighting systems. (DesignBuilder 2006b).

The other capabilities of the DesignBuilder include (DesignBuilder 2006) :

- Environmental performance data, which is displayed without needing to run external modules and import data and any simulations required to generate the data are started automatically.
- EnergyPlus 'Compact HVAC' descriptions provide an easy way into detailed analysis of commonly used heating and cooling systems.
- Natural ventilation can be modelled with the option for windows to open based on a ventilation set point temperature.
- Heating and cooling plant sizes can be calculated using design weather data.
- Daylighting - models lighting control systems and calculates savings in electric lighting.
- Shading by louvres, overhangs and sidefins as well as internal and mid pane blinds.
- A comprehensive range of simulation data can be shown in annual, monthly, daily, hourly or subhourly intervals:
- Energy consumption is possible to be broken down by fuel and end-use.
- Considering the heat transmission through building fabric including walls, roofs, infiltration, ventilation and others
- Computing heating and cooling loads, as well as CO_2 generation
- Parametric analysis screens allow the user to investigate the effect of variations in design parameters on a range of performance criteria.
- Generate EnergyPlus IDF files and work with these outside DesignBuilder to access EnergyPlus system functionality that is not provided by DesignBuilder.

In the recent release, the DesignBuilder is capable to use CFD integrated with the simulation model.

In the parameter setting, DesignBuilder employs the hierarchy model. Figure 18 shows the hierarchy of DesignBuilder's model. All input data of a lower level is taken by default from the upper level. For example, when the parameter setting is done in the 'building' level, the lower level such as blocks, zones, and so on, will inherited the setting of the building. This can be changed by altering explicitly the values of the lower level. The lower level again defines the values of the even lower levels. With this method, the settings for the whole building can be set very fast (just set it once in the highest level). On the other hand, the risk exist, it is often when the lower level has different setting, the user forgets to put in explicitly the different settings of the lower level.

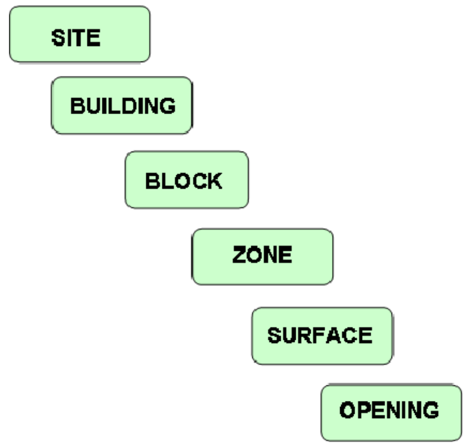

Figure 18. Hierarchy of DesignBuilder's Model (DesignBuilder 2006b)

The visual appearance of DesignBuilder is depicted in Figure 18 which shows the structure of hierarchy model.

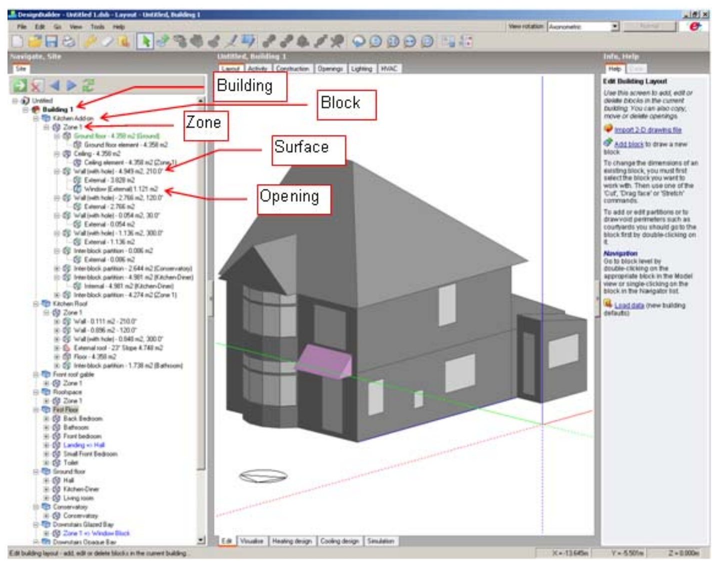

Figure 19. Example of Hierarchy in DesignBuilder (DesignBuilder Software, Ltd.)

Looking at Figure 19, the DesignBuilders allows the designers to adjust the input parameters in the opening level, or using the global data inherited from the building.

The procedures in the building thermal simulation

The first step in the simulation process is the modeling the building. In fact, there is no compulsory step in adjusting the model. The users are able to determine either the form or the geometry of the building, or defining the construction material, or applying the site weather data. Mostly preferable, the step is begun with creating a new site as well as set the weather condition, followed by creating the building geometry. Afterward, the construction material should be defined followed by the setting of internal gains such as occupancy profile, equipment, and lightings, the assumption of HVAC system and temperature setting as well as the schedules. The calculation then can be done by selecting the most appropriate time step and the time period, such as weekly, winter or summer period, or for the entire year.

Post-processing

DesignBuilder provides a wide range of results preference, and the users can select any variables available for output. These results are also possible to be exported to other spreadsheet and data processing programs, as well as presented graphically.

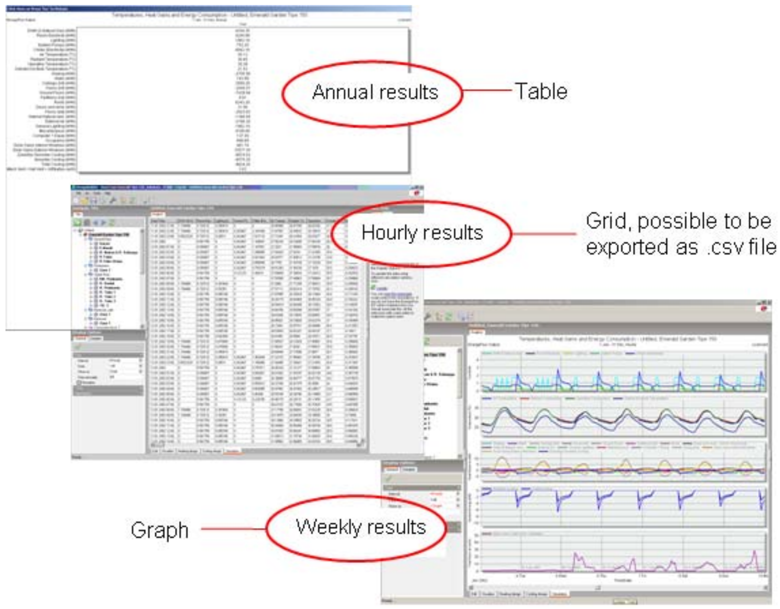

Figure 20. Outputs from the Simulation (DesignBuilder Software, Ltd.)

Figure 20 shows the appearance of some type of simulation results.

DesignBuilder has built-in features to facilitate performance comparisons, for instance, mark multiple points in the design flow, allowing to return to previous designs and also to compare performance data among all bookmarked designs. The parametric analysis facility allows the user to investigate the effect of variations in design parameters on a range of performance criteria, simply by selecting the parameters to vary from drop-down lists

3.3 Validation Case File of DesignBuilder

Validation is an important part in the development of a simulation tool, and necessary to demonstrate the accuracy of the simulation tool as well as the capability of the user in utilizing the tool. There are three basic methods of validating, analytical test, empirical validation, and inter-model comparisons (Olsen 2002). The analytical tests compare the results to the analytical solution for identical solution. Therefore, this test is suitable for very simple cases or subroutines of energy simulation programs, where the analytical solution is available. The empirical validation compares the simulation result to measured data for actual building. This procedure requires a big effort to be performed, such as experiment or skill and is very time consuming.

Inter-model comparisons contrasting the simulation results between some tools. Comparative testing is also useful for field-by-field input debugging. Energy simulation programs have so many inputs and outputs that the results are often difficult to interpret. To determine if a given test passes or fails, engineering judgment or hand calculations are often needed. The main benefit of this assessment is the ability to compare any cases that two or more programs can model. This is much more flexible than analytical tests when only specific solutions exist for simple models, and much more flexible than empirical tests when only specific data sets have been collected for usually a very narrow band of operation (DesignBuilder 2006a). Indeed, there is no alternative for judging whether the program is the most accurate as in the test the results are compared to a various range of results. The validation for both EnergyPlus and DesignBuilder were done by comparing some results from other simulation tools (DesignBuilder 2006a)(D. B Crawley et al. 2008).

In order to validate the accuracy results of the DesignBuilder simulation tool, it is first essential to make a comparison with other simulation results from other software. ANSI/ASHRAE Standard 140 – 2004 is a standard method and defines a procedure on how to test the accuracy of a program result (ASHRAE, Inc 2004). This standard specifies the test procedures for evaluating the technical capabilities and ranges of applicability of computer programs that calculate the thermal performance of buildings and their HVAC systems. Additionally, one of the objectives of this test is to indicate the relative performance of DesignBuilder compared with various other state-of-the-art software tools for thermal building simulation. It is found that from the several validation tests, DesignBuilder gives reasonable results compared to other thermal building simulation programs (DesignBuilder 2006a).

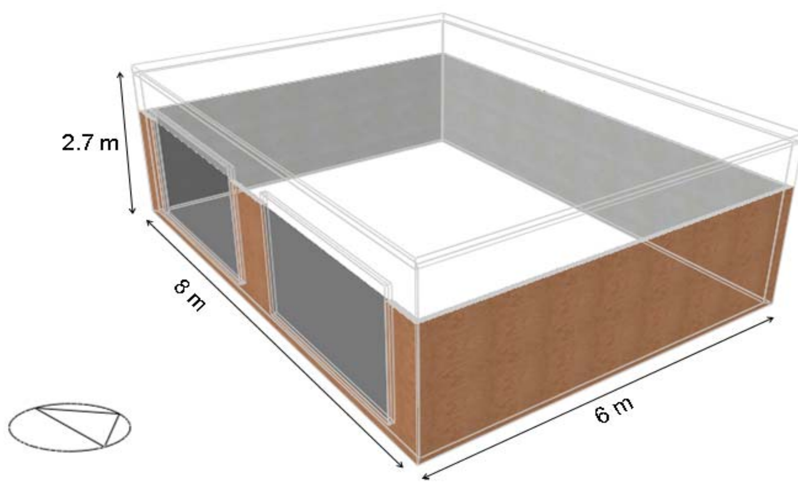

Figure 21. Base Building Case 600 (generated by DesignBuilder)

Concerning the assessment of the user capability in applying DesignBuilder, it is essential to demonstrate a comparative test. The tests were performed based on the benchmark results provided using ANSI/ASHRAE Standard (DesignBuilder 2006a). In this procedure, there are three main groups of the thermal envelope and fabric load test cases, which are designed to evaluate the software using low mass configuration, high mass, and free float condition, respectively. Case 600 is the base case for the low mass building which also the simplest case file as it is used as the reference base case for other case files.

The geometry of the reference building is depicted in Figure 21, the building consists of one zone with the dimension is 8 m x 6 m x 2.7 m which results to the zone area of 48 m², and the zone volume of 129.6 m³. The building has two similar windows on its south wall, with the window area of 6 m² respectively.

The weather data used in this simulation is named DRYCOLD.TMY (ASHRAE, Inc 2004). While comparing the weather data profile given by ASHRAE with the weather data converted into the one that is compatible with the DesignBuilder so called .EPW, it is found that there are some differences in the setting of 'temperature based – day' for heating and cooling, which results to a different number of days that required cooling or heating as shown in Table 2. The heating and cooling degree days is defined as the measure of how many degree (how high/low the temperature) and for how many days the outside air temperature was below the certain level in order to calculate the heating demand and/or above the certain level in order to calculate the cooling energy demand for the building.

Table 2. Comparison of Heating and Cooling degree-days (ASHRAE, Inc 2004)(DesignBuilder Software, Ltd. n.d.)

ANSI ASHRAE STANDARD 140-2004	DESIGN BUILDER
Heating degree-days (base 18.3°C) → 3636.2°C -days	Heating degree-days (base 18°C) → 3379°C -days
Cooling degree-days (base 18.3°C) → 487.1°C -days	Cooling degree-days (base 10°C) → 1446°C -days

Apparently, these differences will not influence to the simulation results as there are already determined the setpoint temperatures of which the cooling equipment will work when the indoor air temperature is above 27°C and the heating equipment will work when the indoor air temperature is below 20°C.

The constructional property, schedule and internal gains of this reference test case follows the data given (DesignBuilder 2006a), and the simulation gives the results in term of the heat balance as depicted in Figure 22.

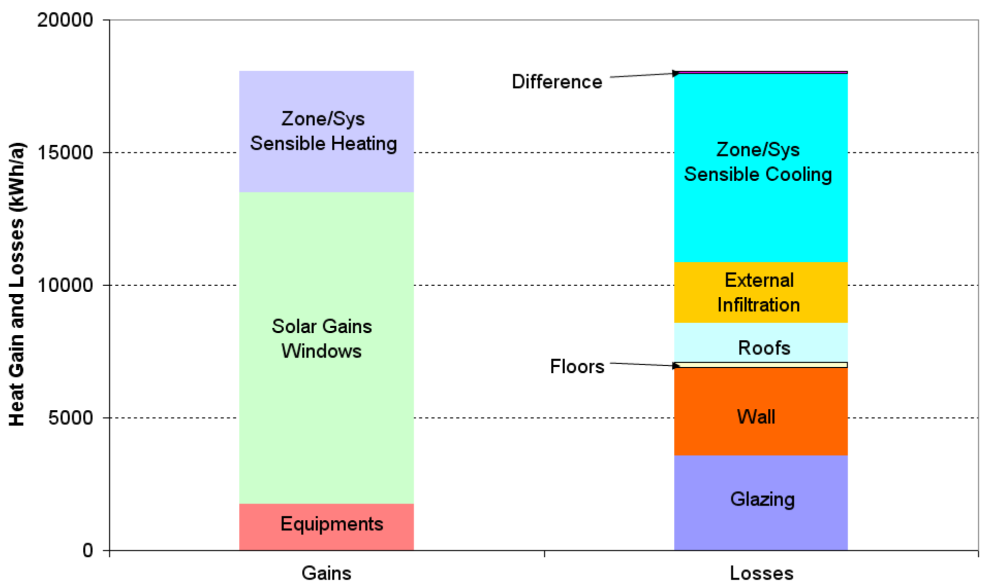

Figure 22. Energy Balance of Case 600

Confirming the energy balance in a thermal simulation is vital as according to the First Law of Thermodynamics energy cannot be created or destroyed. The heat balance approach has the potential to be the most accurate method of solving for heating and cooling loads in a building as it accounts for all energy flows in their fundamental form and avoids simplification (Strand et al. 1999). Based on the graph of the heat balance, it is found that the set of input parameters give a reasonable simulation result. It means that this calculation of the heat transfer for this simple building is valid due to the energy conservation.

Figure 23 shows the comparison results of case 600 between the reference and the author's results.

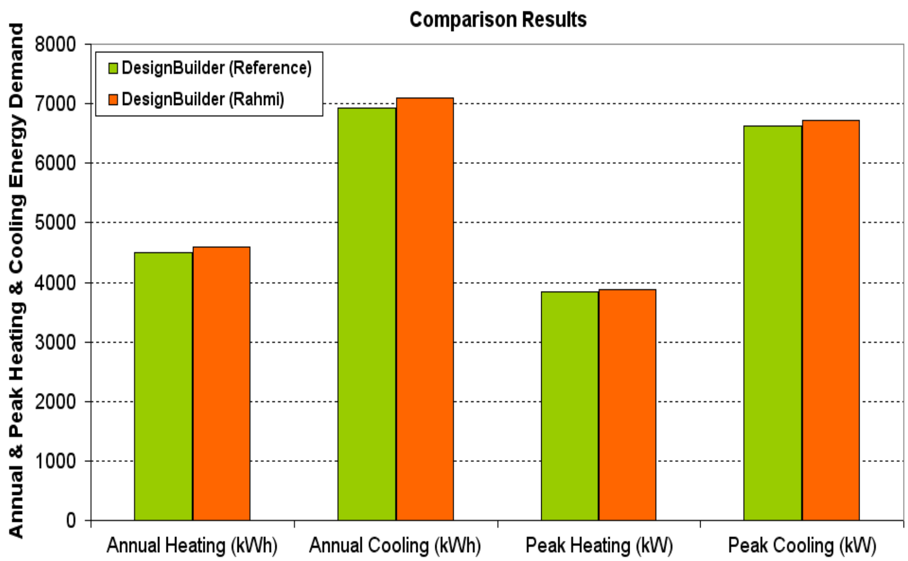

Figure 23. Comparison Results of Case 600, Reference: (DesignBuilder 2006a)

In comparison with the reference model that has been done by the simulation program's developer, the author provide accurate results regarding the annual heating and cooling as well as the peak heating demand and peak sensible cooling demand. The slight difference of results were about 2% for both annual heating demand and annual sensible cooling, and 1.25% for each peak heating demand and peak sensible cooling. This difference occurs as the software version of the reference DesignBuider and the author's were difference. Moreover, it is also found that primarily, performing identical simulation in the two different processing units may result different results.

Figure 24 shows the comparison result of author's with other results of various simulation programs such as ESP-DMU, DOE-2, SRES/SUN, SRES/BRE, S3PAS, TSYS-BEL/BRE, and TASE which are already given (ASHRAE, Inc 2004). It is found that the author gives realistic result, as it is in the middle range of the others, and has 1.3% difference from the average results. The wide range of result from the other simulations tools are suspected as the other tools employed different methods of solar radiation.

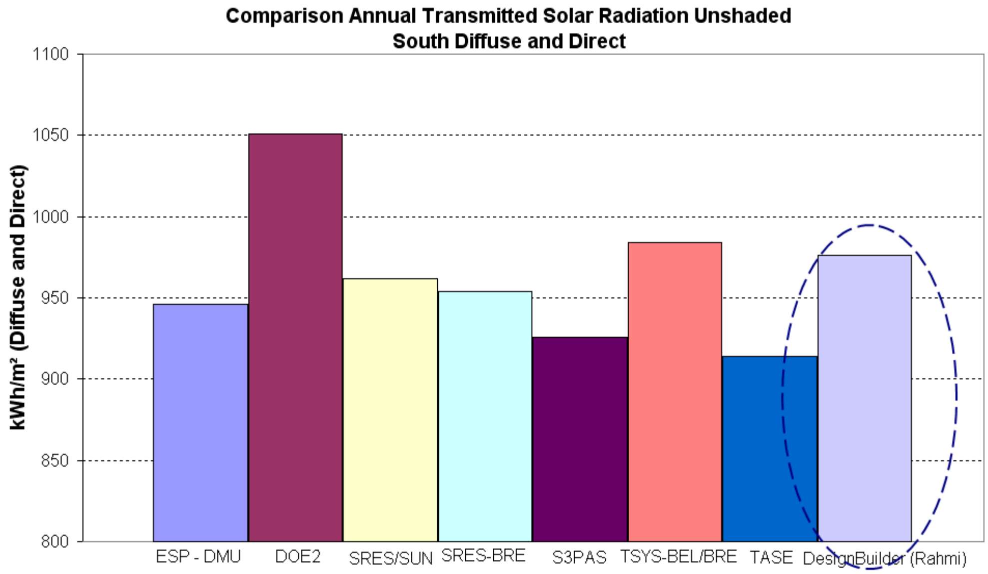

Figure 24. Comparison Annual Transmitted Direct and Diffuse Solar Radiation Case 600 (south side) (DesignBuilder 2006a)

In addition, the following other simulation results are compared, such as annual heating and cooling load, annual peak heating, and peak sensible cooling. These results are depicted from Figure 25 to Figure 28.

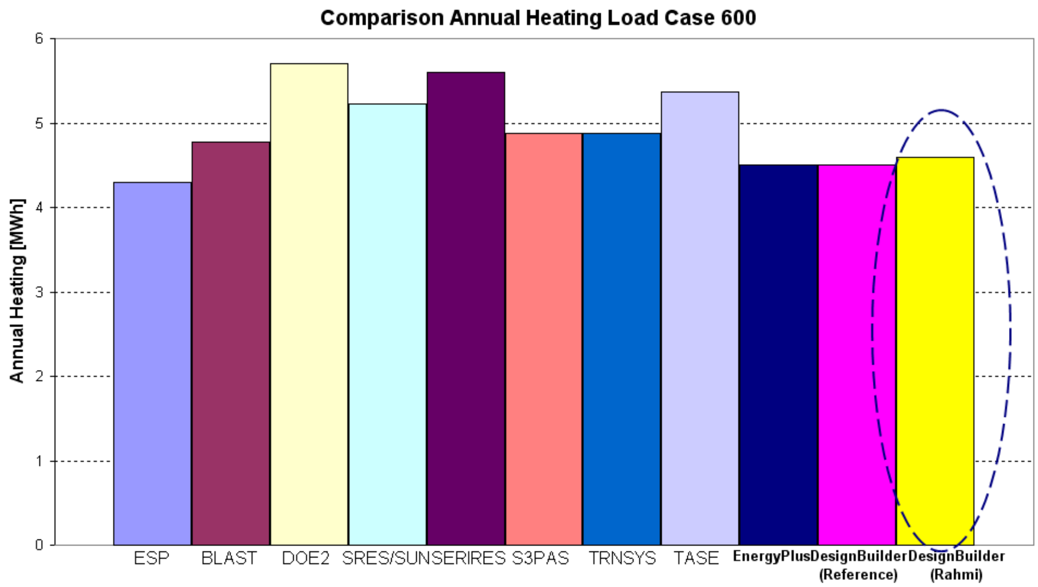

Figure 25. Comparison of Annual Heating Load Case 600 (DesignBuilder 2006a)

Figure 25 is the comparison result of annual heating load of Case 600. It shows that the author's result is in the range among the other results, and is about 6.9% difference from the average result, and of 2.2% difference from the reference result of DesignBuilder.

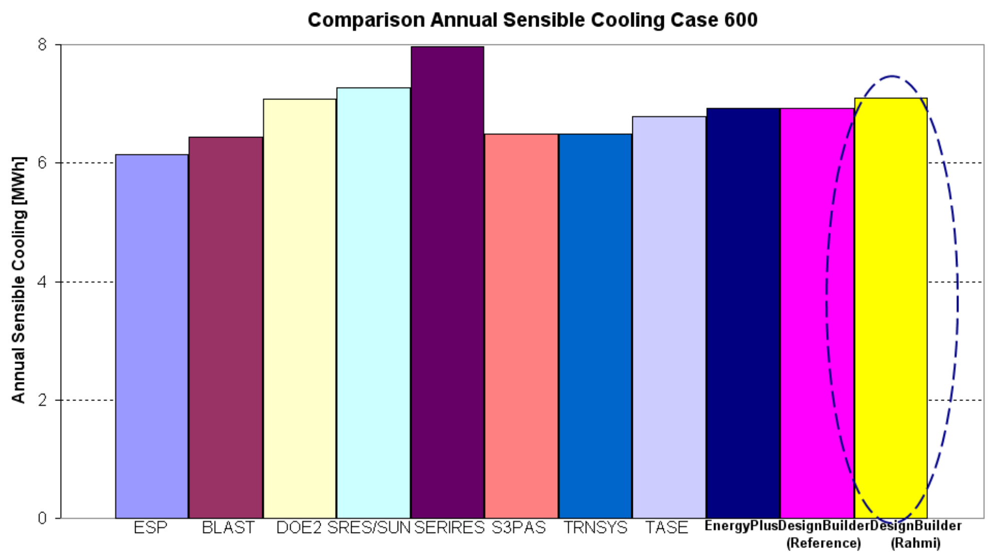

Figure 26. Comparison Annual Sensible Cooling Case 600 (DesignBuilder 2006a)

The simulation results of annual sensible cooling of Case 600 as described in Figure 26 presents that the author result satisfy the other simulation results with 3.2% difference from the average result, and of 2.5% difference from the reference result of DesignBuilder.

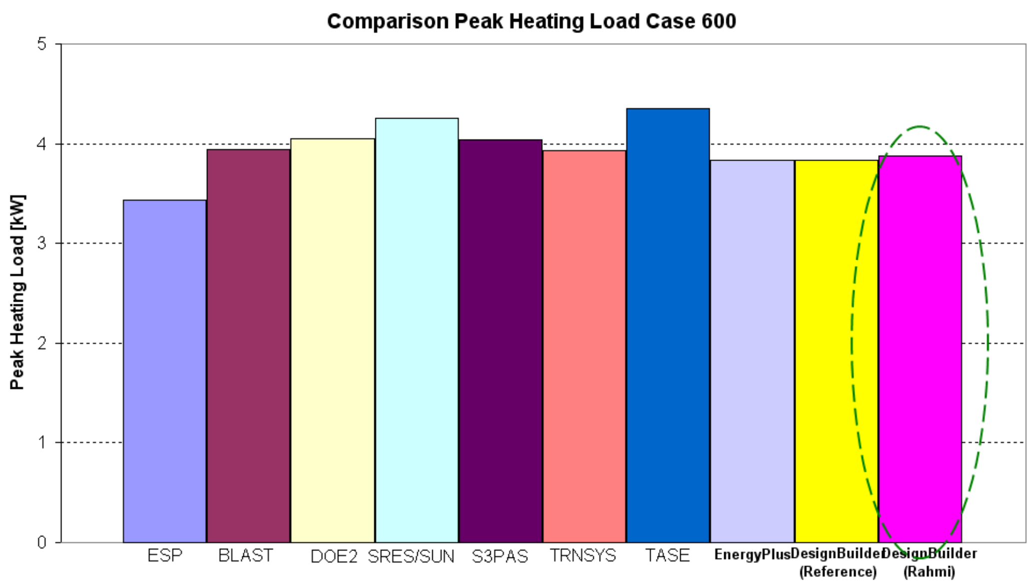

Figure 27. Comparison Peak Heating Load Case 600(DesignBuilder 2006a)

The simulation result for peak heating load and peak sensible cooling load as depicted in the Figure 27 and Figure 28 respectively, show that the author results are acceptable. The difference for the peak heating load is 1.9% from the average result, and 1.3% from the reference result of DesignBuilder. For the peak sensible cooling it gives 3% difference from the average result, and 1.3% difference from the reference result of DesignBuilder.

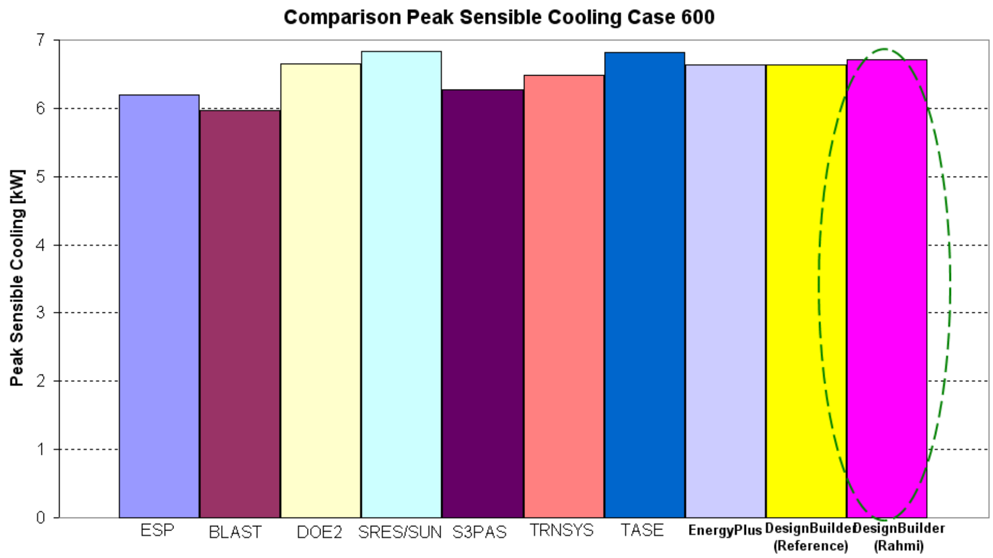

Figure 28. Comparison Peak Sensible Cooling Case 600 (DesignBuilder 2006a)

In summary, it can be concluded that the DesignBuilder gives reasonable results compare to other results from other simulations tools. Moreover, it is also proven that the author's ability in utilising the tool is acceptable.

3.4 Sensitivity Analysis

Sensitivity analysis is a conventional method and most widely used to asses the uncertainty (Macdonald et al. 1999). This method is used to test the correlation between variations of input parameters to the variation of output or predicted parameters. The parameters that give the most significant influence termed as the sensitive parameters. Mainly there are two types of sensitivity that can be evaluated such as individual sensitivities and total sensitivities (Lomas & Eppel 1992). The individual sensitivities address the influence of predictions of variations of each individual input. The total sensitivities involve the uncertainties of all the input data. The basic purpose of applying sensitivity analysis is to identify the inputs to which the outputs are particularly sensitive and those to which they are less sensitive or insensitive.

Indeed, there is no formal rule and well-defined procedures for performing sensitivity analysis for building design because the objective of each study may be different and building description are quite complicated (Lam & S. C. M. Hui 1996). The standard procedure in performing sensitivity analysis mainly commence with formulating a base case reference and its description. Afterward, the parameterisation study is performed followed by defining the parameters of interest as well as determining their base case values. It is also essential to determine which output parameter or which function out of several output preferences (target function) is, to be investigated.

In this research, the sensitivity analysis was carried out for various buildings with the purpose of obtaining the values that give the most influence to the reduction of cooling energy demand of buildings, as there is no heating demand in most part of Indonesia.

CHAPTER 4: LITERATURE REVIEW ON LOW ENERGY BUILDINGS IN HOT HUMID CLIMATES

This chapter presents the examples of low energy buildings in hot humid climates, based on the practical example in Indonesia as well as successfully experiences from the neighbourhood countries. The results from the previous research, mainly focusing on the strategies on how to minimize the energy consumption the energy consumption for the buildings in hot and humid climates will described.

4.1 Traditional Residential Buildings in Indonesia

The architectural history begun spontaneously and developed without architects, which is then called as vernacular architecture (Rudofsky 1965). Traditional houses in Indonesia were designed followed the tropical climatic condition. The people built their houses using the available materials to be appropriate with the local climatic condition. As an archipelago country it has more than 13.000 islands with more than 200 different tribes, there are also numerous different architecture in Indonesia. The traditional houses, or in Indonesian is called *rumah adat*, encompass a wide variety of style and characteristic. However, it still can be seen the common themes and principles, such as the construction of pitched roofs, timber construction, and pile and beam construction.

Figure 29. Map of Indonesia (www.earth.google.com.)

In this part, three different examples of traditional houses in Indonesia will be presented. Figure 29 shows the original location of those traditional houses.

Rumah adat Nias

Nias is a small island located on the west offshore of Sumatra, at approximately 120 km from the Sumatra main island. There are three regions in Nias, north, central, and south Nias, which made the differences on the social and cultural living, as well as the architecture. However, the traditional houses of Nias, *omo sebua*, commonly have a construction of stilts houses, massive ironwood pillars with higher pitched roofs, and nail-less construction, which is beneficial for earthquake durability. In the northern region of Nias, a traditional village usually consists of 6 to 12 of oval houses. In the central and southern part, the constructions of the houses are rectangular and the towering pitched roof's eaves are oriented towards the street. The roof space usually is unoccupied and is used as storage.

Figure 30 shows the constructions of the Nias houses and presents the air movement inside and below the house as well as the lighting source. With the elevated construction, it will provide air movement below the house and allows therefore temperature reduction by natural ventilation. Hence, the living space will experience lower temperature.

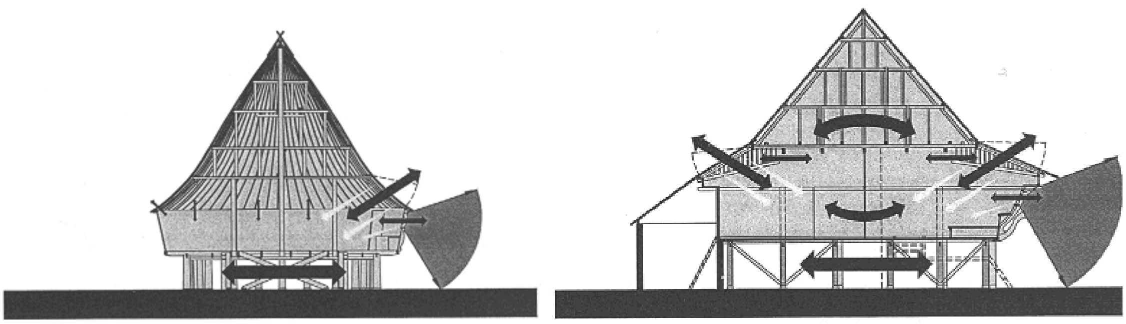

Figure 30. Lighting, ventilation and view to the surrounding for Rumah Adat Nias (left: north Nias ; right: south Nias) (Christoph Müller & Lehner 2005)

The main typical construction for Nias houses is the skylight window, which is specifically only available in Nias. This window is apparently capable to provide natural ventilation as well as lighting for the house.

Figure 31. The skylight window on the roof to provide natural lighting and ventilation (Gruber et al. 2008)

It can be seen in Figure 31 that the interior of the house is light as the effect of the skylight window as well as large openings at the sidewall. In term of thermal comfort, it is found that the internal temperature is considerable lower than the outside air (Gruber et al. 2008). However, there is no measurement regarding this finding.

Figure 32. Three-dimensional model of a north Nias (left) and south Nias (right) house (Gruber et al. 2008)

A three dimensional model of Nias houses is shown in Figure 32.

Rumah adat Betawi (Schefold et al. 2008)

Betawi is the colonial name of Jakarta, Batavia. The Betawi tribe has its own traditional house, and its form is shown in Figure 33. As mostly of the betawi people are living on the land area, therefore their house is not in the form of stilt house.

Figure 33. Traditional house of Betawi (Schefold et al. 2008)

As Jakarta is located in nearly the same high with sea level and often experiences flood, the Betawi houses were commonly constructed on a flat-topped mound, about 20 to 80 cm higher than the surrounding area, depending on the level of local flood. Stone steps were placed at the front and back of the house in order to enter the house. The common arrangement of Betawi houses are divided into 3 main parts (see Figure 34). The front part of the house is an open terrace, at which four to six pillars are constructed in order to support the roof structure and the overhanging eaves that provide shading for the house. Additionally, there is wooden fence at the terrace.

Usually, people put a pair of wooden benches at the terrace. The main door of the house is located in the middle part of wall that separate the terrace from the rest parts. The door is normally constructed from two wooden panels. There are also unglazed wooden window at the right and left side of the main door.

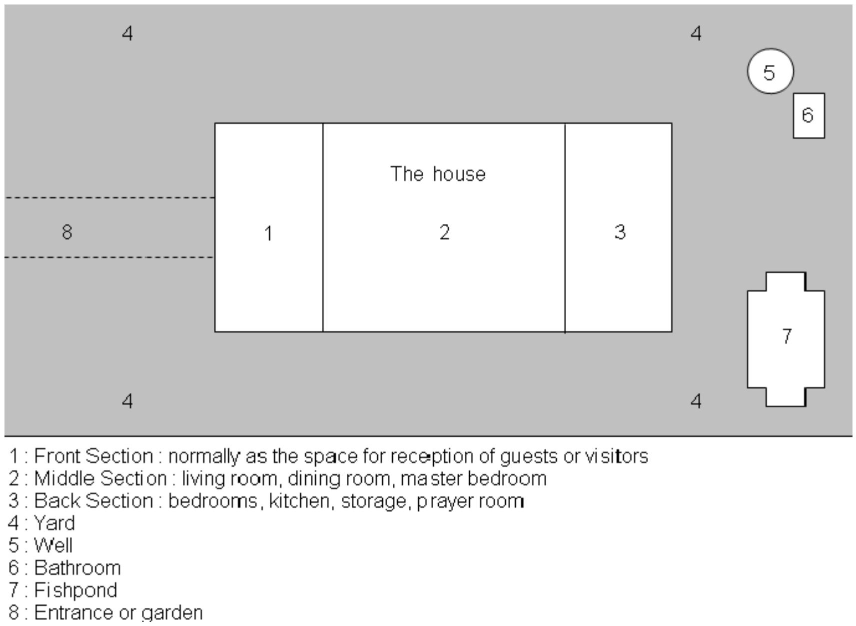

Figure 34. The main components of Betawi house (Schefold et al. 2008)

The middle part of the house is normally divided into two parts, right and left side, which are used as bedrooms and in the middle between these parts is used as a common living or dining room. There is no internal wall between the middle part of the house and the backside that is normally used as kitchen and storage.

The roof construction of Betawi house which is mainly influenced by Javanese architecture, is apparently proven giving a thermal comfort condition for the occupants which is showed with the temperature distribution inside the house. With the high roof construction which were made of clay tile, the outdoor air enters the houses through the lower gaps at the roof will flow upward and carry the hot air outside the house through the upper gaps on the roof. As a result, the hot air caused by solar heat transmission through the roof will not approaching the lower zone (Satwiko 1999).

Rumah adat Toraja (Tjahjono 2001)

Tana Toraja is a regency in the rural area of South Sulawesi Province, approximately 340 km north of Makasar, with its capital city of Makale. The rumah adat of Tana Toraja is called Tongkonan, which means a place for gathering. The design of a tongkonan must oriented along north and south axis, with the main entrance on the north side. This design refers to the belief that north side is the place where the Gods make their entry into the house. The Torajan also believe that earth consists of four different meanings, such as north is the noblest, the eastern side is the place where the sun rises, associates with life-enhancing activities. On the other side, west side is the place of sunset, is analogized as the place for the dead, and the south side is identified as the place to throw away the bad things.

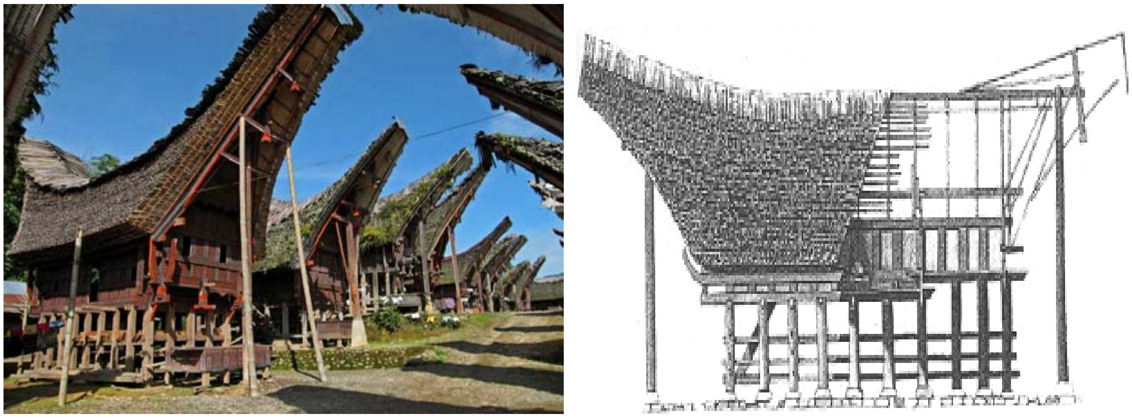

Figure 35. Rumah Adat Tana Toraja (Tjahjono 2001)

Similar to the design of Nias house, the Toraja house is also constructed on piles and has ‘boat-shaped’ roof with its backside is saddle-liked. The roof space is larger compared to the living space. Tongkonan also has small size windows, therefore its interior is a bit dark. This is because the house is mainly intended for sleeping and storage and the daily activities of the people are usually done outside the house. Additionally, at opposite of each house there is the family’s rice storage which is also indicated the family wealth. There are three vertical parts of Tongkonan, the upper part or the roof space is used as the place to keep the regalia and family heirlooms, the living space, and the space under the floor is used to keep the animals.

Instead of the traditional houses which are currently less available, currently, in the rural area, there are still many houses constructed form timber, bamboo, and thatches Figure 36 shows some examples of traditional houses in the rural area of Indonesia

Figure 36. Traditional House in Rural Area in Indonesia (www.panoramio.com 2009)

There are also old buildings in Indonesia, which were constructed by the Dutch administration (The inter-secretariat working party on housing and building materials in Asia and the Far East 1956). Figure 37 shows some example of old houses as heritage of Dutch in Indonesia. It can be seen that the similarity design between traditional houses and Dutch houses are the construction of a high tilted roof and shadings around the house. This Dutch design is apparently still influenced by the Javanese design, which is intended to reduce the solar heat gain through the roof as well as the facades.

Figure 37. Old 'Dutch' house in Indonesia (www.arch.nus.edu.sg)

Moreover, with the height dimension of the house will provide natural ventilation effect as well as better air circulation. It has been proved that those traditional as well as old 'Dutch' buildings are capable to provide comfort conditions for their occupants. These buildings do not require an air conditioning in order to overcome the hot and humid climate of Indonesia. A survey result shows that Indonesian people who live in naturally ventilated housings have higher thermal comfort level as compared to the prediction (Feriadi & Wong 2004)(Soebarto & Handjarinto 1998).

4.2 Examples of Modern Buildings in Hot Humid Climates

The current main problem for buildings in a hot and humid condition is the reliance on the cooling equipment in order to satisfy the thermal comfort condition for the occupants. Conversely, it is already known that the air conditioning consumes the biggest electricity consumption in a building. In this part, the examples of traditional houses in Indonesia will be presented as well as the architectural characteristic applied in order to provide thermal comfort condition for the occupants. Some examples of office buildings that received ASEAN Energy Awards award as low energy buildings will also be overviewed. The ASEAN Energy Awards is a yearly activity that is initiated by ASEAN Centre for Energy since 2001 (www.aseanenergy.org). This program aims to encourage the building designer, engineer as well as the Government dealing with energy efficient use for building. These buildings are located in the ASEAN countries, such as in Malaysia, Singapore, and in Indonesia. The purpose of these overviews is mainly to learn the strategy of managing low energy building in the neighbourhood countries, which have similar weather condition.

The modern design of housing which are developed in the recent years apparently failed to maintain the thermal comfort for their occupants, which is noticed by the increase use of air conditioning for the house (Ekasiwi & Hokoi 2006). Additionally, the attitude of viewing foreign technologies as a symbol of a higher status resulted to the inappropriate implementation of new foreign technologies to local conditions and causing comfort problems in the modern designed buildings. Failure to understand the local climate and architecture coupled with over-eagerness in applying modern technologies have introduced not only environmental problems in buildings but also an architectural identity crisis (Satwiko 1999).

Figure 38. Examples of modern residential building in Indonesia (www.rumah123.com)

In line with the economic growth in Indonesia, it is noticed that there were fast growing of large-scale housing areas during the mid of 1990. The prices of the lands become higher as its availability is limited, moreover, there are found largely uncontrolled conversion of prime farmland to urban use (Firman 2002). As a result, the developers tend to build mass residential constructions, called row houses. The development of row houses in one side will benefit to the developer, as usually mass construction requires low budget, but regardless the thermal comfort for the occupants. Moreover, the forms of the houses are more likely the modern “western” climate design, which is obviously not suitable for the tropical condition. Hence, to meet the thermal comfort condition, the people tend to install air conditioning in their houses, whereas air conditioning consumes the highest of the electricity in a house. As the price of electricity increases, the people must be aware on utilising the energy of the house efficiently. Therefore, it is a crucial important to find the strategy on how to design a modern house that provides thermal comfort condition for the occupants, thus requires low electricity consumption especially for the cooling purpose.

The Low Energy Building in Malaysia (Dato’ Sri DR. Lim Keng Yaik 2005)

In Malaysia, the building sector is among the major energy consumers after the industrial and transport sectors, accounting for some 13% of the total energy consumption and 48% of the electricity consumption. Therefore the Malaysian Government has emphasis programs to promote energy efficiency (EE), with the purpose of minimizing the nation’s energy and electricity intensities, which are presently noticed high even among some of the ASEAN countries.

The Low Energy Office (LEO) Building in Putrajaya, is the first Government building in Malaysia which has integrated a wide range of energy efficiency features and technologies. The building belongs to the Ministry of Energy, Water, and Communications. Its design concepts begun in 2001 and it was completed and occupied in September 2004. The building consists of 6 storey in one part, and 4 stories in the rest. The gross floor area is 38.606 m², and about 19.237 m² is air conditioned area.

Figure 39. Low Energy Office Building, Malaysia (Dato' Sri DR. Lim Keng Yaik 2005)

The Malaysian Standard MS 1525:2001 "Code of Practice on Energy Efficiency and the Use of Renewable Energy for Non-Residential Buildings" has been adopted as guiding principles. The main objective to apply this guide is to minimize energy consumption and therefore reducing the operational cost, but without sacrificing aesthetics and occupants' comfort. Through applying this concept, this building acquired a prestigious achievement as the winner of Best Practice Competition in Buildings, ASEAN Energy Awards 2006, in the category of new and existing buildings. In order to achieve this performance, the LEO building employs some passive and active design strategies. Some passive strategies applied in this building involve:

- The orientation of windows are mostly to the north or south in order minimize solar heat,
- Using light concrete blocks with insulation value 2.5 times better than traditional one, and also finishing for exterior surfaces with light colors painting which help to reduce the radiation absorption;
- Applying roof insulation and the installation of a second roof to protect the roof and also provide shade to the building
- Installing shading for windows with light shelves to provide better shading effect and allow light deeper into the building;
- Glazing material which allows 65% of the light transferred to building and only 51% of the heat;
- Design of non-air conditioned atrium which is cooled by natural ventilation assisted by a solar chimney to provide daylight deep into the building;
- The work areas are designated near the façade to maximize the use of natural daylighting;
- Plantation of tropical vegetation outside the building in order to cool the building as well as provide shading effect

Furthermore, there are some active design strategies such as

- *Air Conditioning System* – the building takes its chilled water supply from Putrajaya central district cooling system via the main underground piping system. As a result, the energy demand from the electricity usage and for air conditioning system is further reduced, as there is no need for the operation of any chillers and cooling tower. In the air-side, the system uses a variable air volume system, which is controlled according to the occupancy, schedule, and temperature setting. Therefore it provides a better thermal comfort as well as air quality, and also prevents excessive cooling in the building. The indoor air temperature is maintained at 24°C, with the possibility fluctuation of 2°C. In fact this values are too low for the building in the tropical region, therefore, there is still opportunity to reduce more the cooling energy demand by increasing the indoor set point temperature by 2°C. The relative humidity is maintained at 55% with the acceptable variation of 5%.
- *Lighting System* – the building uses high efficiency lighting luminaries and energy efficient lamps. It also uses low loss conventional ballast to maintain the power factor to 0.85. The daylight photocell sensors are installed at the perimeter of the rooms with windows to control the switching of the light and it uses zoning of lighting circuits. Lighting management system by combination of photocell sensors, occupancy sensors and programmable/automatic schedule control from building control system.
- Utilizing energy efficient office appliances in order to maintain low demand of electricity
- Applying a comprehensive monitoring program on the building's energy performance since the building was occupied in September 2004, with fine-tuning being carried out to achieve optimal operation.

By applying these strategies, it is found that the annual cooling energy demand of the building is 78.1 kWh/m², based on the occupancy hours of 2930 hours per year. This value is 61% lower than the recommended value for office buildings, that is 200 kWh/m²/year.

The Low Energy Building in Singapore (Yew Choy 2004)

Nanyang Polytechnic Singapore is one example of low energy building in Singapore. The most prestigious achievement of this building is to win the Energy Efficient Building Award (for the New & Existing Building category) in 2004. The building construction is started in December 1994 and it has been ready to occupation in June 1998. The purpose of the building is mainly for educational institution.The building consists of 17 blocks with different numbers of building level, between 2 to 8 storeys and some 10 storeys apartment blocks. The total gross floor area is 226,000 m², with the air-conditioned area of 148,738 m².

Figure 40. Nanyang Polytechnic Singapore (Yew Choy 2004)

This building was initially designed as a low energy building. In order to achieve its goal dealing with the energy consumption, there are some strategies applied, which consist of:

- The design of its landscape with trees, shrubs, plants and grasses provides green area, which causes cooling of the environment and shading of the buildings, and is benefit as a 'green lung' for the campus.
- North and south orientation is useful for low solar energy gain, natural cross ventilation and open design with gardens and courtyards to provide natural daylighting into the building.
- The finishing outside façade with light gray colour will cause low absorption of solar radiation
- The tiling, plaster, paint and all glass windows are covered with special low-emissive heat films on the inside
- The lighting system uses electronic ballast and energy saving lamps throughout the campus, with the lighting load of about 10 W/m².
- The indoor temperature is maintained at 23°C to 25°C, and the relative humidity is maintained between 55% and 65%.
- The building applies a system called Intelligent Building Management System (IBMS), which provides integration for a wide spectrum of services such as HVAC; electrical, plumbing and sanitation, lighting automation, fire alarm, security, structured cabling network and office automation system. This system aims to provide optimal control to minimize the energy utilisation.

By applying these strategies, it is found that the annual cooling energy demand of the building is 116 kWh/m², or 42% lower than the recommended value.

Low Energy Buildings in Indonesia

The BII Plaza is a building complex located in the heart of Jakarta's Golden Triangle Business District in downtown area. It was constructed in 1993 and first operated in 1997. The building consists of three major buildings called Tower 1, 2, and 3, an open plaza, with its water features. In 2005, the Tower 2 of Plaza BII won the ASEAN energy award for retrofitted category The Tower 2 building is mainly used as private commercial office on a leasehold basis. The building consists of 39 storeys and 3 storeys of basement floor. The total gross floor area is 80,000 m² with 70,000 m² of air conditioned area. This building was renovated 2003 with the specific purpose of applying the concept of low energy building (Purwoutomo 2005).

Figure 41. Tower 2 Plaza BII, Jakarta, Indonesia (Purwoutomo 2005)

Figure 41 shows the appearance of the Tower 2 of Plaza BII, Jakarta. The left picture shows that there is no shading effect from other buildings. In the right picture, the lobby is designed as a five-storey column free. Hence, this provides a better air circulation for the occupants. In addition, the lobby also uses brown solar reflective glass walls in order to maximize the use of sun light for lighting during daytime, but less solar radiation transmitted into the building.

Some other features applied by this building that support the concept of low energy building consists of:

- The design of rectangular concrete structure, wide side of the building is facing north south. The façade is made of plaster on solid wall, granite tiles on exterior and interior solid wall with light colour. These designs aim to minimize the solar heat gain of the building
- The design of 45 nozzle flag water fountains at the entrance and plants as a passive strategy in order to maintain the surrounding air temperature lower. This obviously benefit for the micro climatic conditions such as reducing the outdoor temperature. However, as Jakarta has the relative humidity between 40% and 100%, thus water fountains increase the surrounding relative humidity and causes inefficient use of air conditioning.
- The use of radiation repelling glass curtain wall to minimize the solar heat absorption, moreover tenant are obliged to install blind curtain with aims to reduce solar radiation entering the room. These result to an energy saving of 50,000 kWh/year or 8% of energy reduction. However, it is still arguable as in the later simulation results in Chapter 5, window blinds apparently has no significant

effect to the reduction of cooling energy demand. Hence, the installation of blind curtain in this building probably aims to reduce glare.

- The use of natural daylight for indoor lighting, bright colour materials for walls, floors and acoustic ceilings.

Upon the application of passive design, this building also considers active design, such as:

- Upgrading Building Automation System (BAS) by installation of outside temperature sensor, which is programmed to automatically adjust and control the chilled water supply of Air Handling Units (AHU) according to the normal temperature set point and a conducive room temperature. The indoor air temperature is maintained at 23°C ~ 25°C and the relative humidity is about 55%. This strategy is capable to reduce the annual normal operation consumption by 35%.
- Energy Conservation Program and Monitoring Management by cutting off and limiting the use of power supply of floors power outlets in the tenanted area during non-office hour. This strategy apparently contributes to an energy saving of 4% per year.
- The walls of parking area were opened in such a way that will induce a natural ventilation and illumination to the area, contributes to a reduction of 36% of annual energy consumption.

By applying those strategies, it is obtained that there is a significant reduction of energy consumption rate. Before 2004, the energy consumption rate was noticed about 196 kWh/m²/year and it became 154 kWh/m²/year in 2004, or decreased by 20%, whereas before 2004, the occupancy rate were about 90% and in 2004, the occupancy rate increased to 93%.

Another example of a low energy office building in Indonesia is Jakarta Stock Exchange (JSX) building, a high-rise rental office building, which consists of twin 31-floors building located in Jakarta. Figure 42 shows the picture of JSX building. The strategy to reduce the energy consumption of the building was to modify the chilled water temperatures at the building air conditioning system. The air conditioning system in the JSX building is using a water-cooled chiller. The chilled water return carries heat absorbed from the conditioned room at the temperature of 13.5°C. The refrigeration plant is in charge to reduce this temperature to 5.5°C, and delivers it as chilled water supply to the cooling coil of the air handling unit (AHU). The modification of the air conditioning system was done by means of raising the temperature of chilled water supply. The reference temperature of the chilled water supply was increased from 5.5°C to 6.5°C. Increasing the chilled water supply means to reduce the heat absorbed by the refrigeration plant. The plant requires less energy to decrease the chilled water return from 13.5°C to 5.6°C compared to that of 5.5°C.

The small increase is due to the regulation that the indoor air temperature is not allowed being more than 24°C. This is because many occupants of this building are expatriates who come originally from cold climate countries, hence their thermal comforts must be maintained. It is found that by slightly increase of chilled water supply of 1°C could possible reducing the energy consumed by the air conditioning equipment as the , and resulting the reduction of total energy consumption of this building about 7.5% per month (T.H Karyono & Bahri 2005).

Figure 42. Jakarta Stock Exchange Building (www.idx.co.id)

In fact, there are still some possibilities to further reducing the cooling energy demand, as the indoor air temperature is still low. A thermal comfort study (T. H Karyono 2000) found that in some selected multi-story office buildings in Jakarta showed that 90% subjects who worked in those buildings were still felt comfortable at the indoor temperature of 28.4°C. Therefore, shifting up indoors temperatures higher might be still tolerable, and it would save more energy in this building.

The planned Austrian Embassy building in Jakarta, Indonesia, is an example of a planning with integrated building thermal simulation during its design phase (POS Architecture 2007). The design concept of this building is aimed to have a building that has low energy consumption in term of its cooling energy, and adapted the local construction material in the building. Additionally, the use of renewable energy sources is also applied.

The energy concept taking into account in designing this building includes:

- Minimising solar heat gain by designing the window with north and south orientation, three-sided wall's eaves, and using bamboo screed as shading element as well as considering the dimension of the window area
- Minimising solar transmission by designing as compact as possible the uppermost outside surface and installing insulation with thickness of 15 cm, 2 layers of thermal/solar shading glazing with a neutral colour (U value = 1.6 W/m²K and SHGC value = 0.3), continuous shading of all horizontal surfaces (roofs) with bamboo screen
- Minimizing the losses of cool air and drought by reducing the hygienic ventilation rate to 700 m³/h for the whole building
- Reducing the humidity/heat infiltration through the high air tightness

Figure 43 shows the exterior design of the building and the entrance, which shows a modern design of office building with utilising local material construction of bamboo screen in order to provide shading.

Figure 43. The view of Austrian Embassy, Jakarta, Indonesia (POS Architecture 2007)

The interior of this building is shown in Figure 44. It can be seen that the large glass façade area will provide high level of natural lighting, however the combination with the bamboo screen will prevent the heat transmitted into the building.

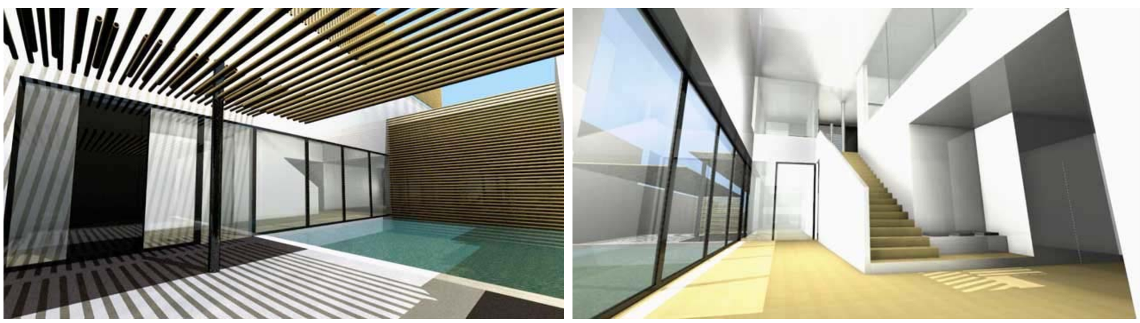

Figure 44. The interior view of Austrian Embassy, Jakarta, Indonesia (POS Architecture 2007)

The structure of external wall is made of concrete and brick with 18 cm of thickness with additional 15 cm mineral wool as insulation. Interior walls are constructed from concrete or brick, plastered and partially glazed. The roof is made of 18 cm reinforced concrete, 18 cm mineral wool, and two layers of waterproofing, screed with roughened surface layer. The internal floor material uses natural stone and ceramic tiles, and the exterior floor is made of a large concrete slab with grass joined.

By applying the strategies of low energy building, it is found from the building thermal simulation, that the cooling energy demand and the dehumidification is accounted for 74.8 kWh/m², which is 75% lower than that of conventional building. The end use energy for overall building for cooling, dehumidifying, ventilation, hot water, lighting and auxiliary power could possibly reduced to 31.25 kWh/m² per year or approximately 17% compared to the conventional building.

This design of the Austrian embassy in Indonesia presents an example of the importance considering energy concepts during the design phase. The tendency of designing a building by contemplating the energy concept can also be seen in some designs of buildings in Austria, which are important to be applied in Indonesian practices (Treberspurg 1999).

4.3 Previous Research

In this part, the strategies dealing with low energy buildings that are applicable for designing buildings in the hot and humid climatic region are presented. The strategies are expected to accomplish two goals, those are providing physiological cooling effect for the occupants and removing the heat from the building (Queensland Government 2005).

The research concerning the influence of building orientation to the level of cooling energy demand have found that buildings in the tropical climate with the shape along north and south orientation will receive lower solar radiation on its façade (Haase & Amato 2009) (Ling et al. 2007). Furthermore, it has been found that circular and square shapes with the ratio of width and length 1:1 are the optimum shape of the high-rise buildings (Ling et al. 2007) (Behsh 2002). For a circular shape, the normal exposed surface is quite small, therefore it receives less solar radiation. With the ratio of width and length of 1:1, the square building will have fewer surfaces exposed to the solar incident. However, there are still more to be considered concerning this type of square building, such as the effect of natural lighting and the natural ventilation.

The constructional factor that also influences the indoor air temperature for the building in the tropical climate is thermal mass. Thermal mass can reduce the maximum indoor air temperature during summer (Shaviv et al. 2001) (Balaras 1996) (Ogoli 2003). Furthermore, it would be better combining thermal mass with night ventilation for the region that has large diurnal temperature difference. Heavy thermal mass retard the increase of the indoor air temperature during the hot day, and becomes warm during the late of the day, moreover as the temperature during the night is far lower, it will cool the heavy thermal mass if a high ventilation rate can be accomplished. As a result, the indoor air temperature will be lower than the ambient temperature during the early morning (Shaviv et al. 2001). For the building at the equator, light thermal mass construction on the other hand closely followed the outdoor condition (Ogoli 2003). Hence, it is suggested that air-conditioned buildings can also be pre-cooled during off-peak hours (Balaras 1996). For the building in the tropical region, it has been found that using light wall materials would result in cooler indoor air temperature at night but warmer during the day. With the heavier constructional building components, the heavy structure delayed the heat transmission in the building, causes the indoor air temperature lower than the outside temperature. However, in the early morning, the thermal mass releases the heat to its surrounding, causes the indoor air temperature warmer than that of using light constructions (Soebarto & Handjarinto 1998).

If a roof space is constructed, the installation of roof and ceiling insulation apparently has considerable influence on the reduction of air temperature inside the roof space, but not in the beneath living space (Zakaria et al. 2008). Reinforced concrete roof slabs without roof space tend to act as heated bodies for the occupants in the free-running building, however, insulated roof slabs could provide acceptable indoor conditions (Halwatura & Jayasinghe 2008). Inclined timber roof construction on reinforced concrete can prevent the solar heat transmitted to the building during summer in the warm climates region. However, to avoid the moisture accumulated, the roof space should be well ventilated. The outside surface material also should have high value of light reflectance in order to reduce heat gain (Özdeniz & Hançer 2005). For buildings in the tropical region, thicker roof slab insulation causes low investment as well as operational cost of for the top floor of air conditioned building. Furthermore, for unconditioned buildings, a 25 mm insulation thickness for the roof slab provide significant improvement compared to the uninsulated building, however, there is no further improvement when the insulation is added to 50 mm. It is also suggested that roof vegetation benefit in some aspects (Halwatura & Jayasinghe 2009). The use of light colour of the building envelope causes the decrease of the outside surface temperature of the building that leads to the reduction of cooling energy consumption for air-conditioned buildings as well as increased thermal comfort for unconditioned buildings (Synnefa et al. 2006) (Cheng et al. 2005).

Instead of arranging the building envelope, the environmental conditioning also plays an important role in reducing the energy consumption of the building. The shading effect of trees apparently results in cooling energy saving during summer (Akbari et al. 1997). The vegetation surrounding the buildings causes the air temperature decrease by 3 – 5°C (Queensland Government 2005). Furthermore, the neighbouring buildings and structures also benefit in providing shading as long as it has an appropriate orientation. The window shading and overhangs are essential in reducing the solar heat transmitted to the building (Sam C.M Hui 2001).

Natural ventilation is also important in reducing the cooling energy demand as well as provides occupants comfort. By maximizing the effect of natural ventilation, it means reducing the indoor air temperature, which is possible to reduce the period of using air conditioning (Bastide et al. 2006), but causes moisture accumulation on radiant cooling surface. Radiant cooling is also benefit in order to achieve thermal comfort in hot and humid climate as it reduces the radiant temperature (Vangtook & Chirarattananon 2006). The mixed mode ventilation strategy has saved considerable amount of cooling energy for the fully air-conditioned office building in the hot climate region (Ezzeldin et al. 2009).

A survey result reveals that the people in the tropical region are more adapted to the warm condition than the prediction (De Dear et al. 1991) (T. H Karyono 2000) (J. F. Nicol 2004). For the residential buildings, it has been found that the people adapt more by changing activity, adapting clothing, opening window, etc, as they have to pay for the energy consumed. Consequently, for the residential building it is obtained that the acceptable temperature range is wider than that for office buildings (Peeters et al. 2009) (Feriadi & Wong 2004) (Soebarto & Handjarinto 1998) (Sujatmiko et al. 2008). For that reason, the indoor air setting temperature should not be adjusted as low the value as mentioned in the international standards as well as provided in the previous examples of low energy buildings that received award. It is because the international standards available are appropriate for other climatic conditions.

The bioclimatic design principle which is identified by a design with climate in mind (Hyde 2008) is essential to be implemented for modern design of buildings. This principle applies the consideration of the form and fabric of the building that can be matched to human and climate factors in order to optimize climate response.

4.4 The Importance of This Research

As cooling energy consumption takes the biggest part of electricity utilisation for the buildings in hot and humid climate, therefore it is important to improve the building energy performance by means reducing the cooling energy demand. The previous examples already have shown the strategies on how to minimize the energy consumption for the building, however, those examples mainly describe the strategies that are applied for the existing building during the renovation phase. Obviously, this is more costly compared to modifying the design during the design phase. Moreover, building thermal simulation has found capable to predict the energy consumption for the building (C.M Hui 1996) (J.A Clarke 1993) (J.A Clarke 2001).

Based on the previous overviews, this research has some importance for the building designers, engineers, as well as Government in Indonesia. Those importances involve some aspects such as:

- Obtaining the strategies to reduce cooling energy demand for the buildings
- Presenting the advantages of integrating building thermal simulation during the design phase
- Facilitating the analysis of energy performance of buildings
- Giving inputs regarding the aspects that should be taken into account in the energy certification for buildings
- Recommend the importance of the Indonesian standard, which refers to the climatic condition as well as the cultural behaviour of the people in Indonesia. This is because the majority of Indonesian standards are based on international standards, which are not suitable for the situation in Indonesia.

CHAPTER 5: SIMULATION OF TYPICAL INDONESIAN BUILDINGS

This chapter discusses the examples of thermal building simulations for different typical buildings in Indonesia. Firstly, the inputs required for the simulations such as the climatic data of Indonesia and user behaviour in tropical climates will be introduced. Afterwards, the thermal simulations for the buildings will be presented and the results of energy simulation and cooling energy sensitivity analysis will be evaluated. The data for the buildings was collected during the field studies in Indonesia in the form of drawing files as well as the construction materials used, except for the first simulation on the reference office building adopted from the IEA SHC Task 25.

5.1 Boundary Conditions

5.1.1 Climatic Data Used in This Research

Meteonorm (Meteonorm 2007)

In the thermal building simulation, there is a great number of input data required, such as weather data, occupants' behaviour, and auxiliary systems which may perform heating, cooling, and/or ventilating duties (J. L. M. Hensen 1999). The weather data used in these thermal building simulations was produced using the weather data generator Meteonorm 6.0, which provides hourly weather data variables.

"Meteonorm is a comprehensive meteorological reference, integrating a record of meteorological data and calculation procedures for solar applications and system design at any desired location in the world. It is based on over 23 years of experience in the development of meteorological databases for energy applications. In generating the databases, Meteonorm uses the data from the satellite for areas with low density of weather stations as well as interpolating models in order to calculate the mean values for any site in the world. Meteonorm also extrapolates hourly data from statistical data for a location, and in the case that the statistical data is not available, it interpolates from other nearby sites (Crawley, D., Energyplus Support). "

In addition, there is already a validation procedure available to examine the accuracy of the interpolation results (Meteonorm 2009). In calculating the meteorological data for any desired location in the world, Meteonorm applies an interpolation procedure. Meteonorm also claims that dealing with the quality of basis data, the radiation data was subjected to extensive tests. The error in interpolating the monthly radiation values was 9%, and for the temperature was 1.5°C. The models used in METEONORM are designed to calculate radiation on inclined surfaces and additional parameters.

Weather Data of Jakarta and Surabaya, Indonesia

Indonesia is an archipelago country, lying on the equator in the tropical region from 6.08° North latitude to 11.15° South latitude, and from 94.45° to 141.05° East longitude. The climate is tropical in almost the entire region. The temperature varies little from season to season and Indonesia experiences relatively little change in the length of daylight hours from one season to the next; the difference between the longest day and the shortest day of the year is only forty-eight minutes (en.wikipedia.org/wiki/).

Figure 45. Map of Indonesia (www.earth.google.com.)

Weather data is an essential variable required in thermal building simulation that is unique and depending on the location of the building. Because of the buildings that are simulated in this research, the climate data used in this research is for both Jakarta and Surabaya. As explained before, the weather data used in this simulation are generated by Metenorm 6.0 (Meteonorm 2007).

Figure 46. Jakarta CBD (www.megacityjakarta.net)

Jakarta is the capital city of Indonesia, a mega city with approximately 750 km² area and the population is about 8.5 million (Dinas Kependudukan dan Pencatatan Sipil 2009). It is located at the north western part of Java Island, at 6.09° South latitude and

106.49° East longitude. The elevation is only 4 m above sea level and Jakarta is situated on the north coast of Java. Jakarta experiences a the tropical climate. It has a rainfall peak season in January and a dry season low point in August with the precipitation level of 70mm/month. The total precipitation is about 2196 mm/year.

Figure 46 shows the situation of the central business districts in Jakarta which is fully made up of skyscrapers and high-rise buildings. The weather profile of Jakarta is graphed in Figure 47. It shows the profile of hourly temperature, direct normal solar and diffuse horizontal solar radiation.

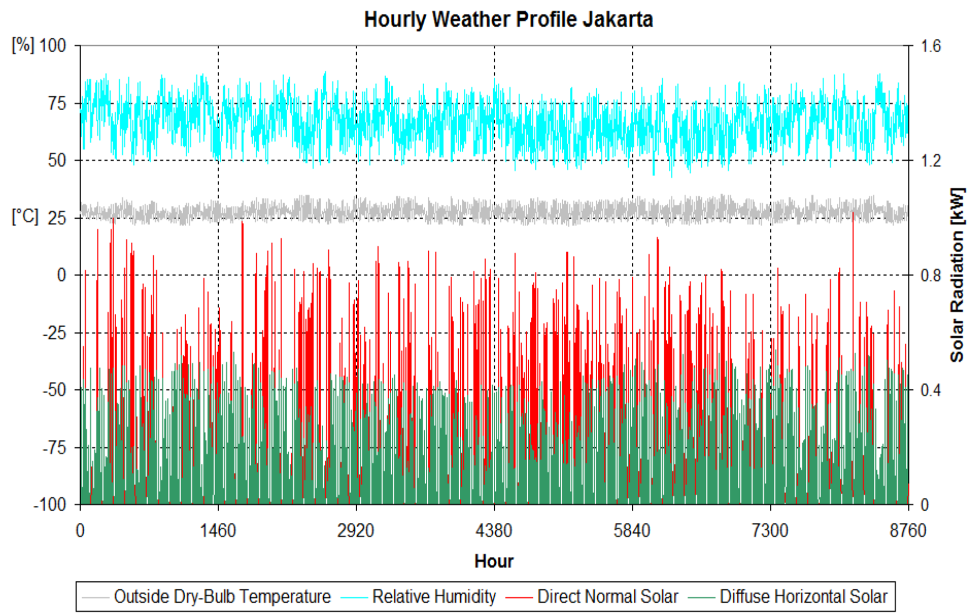

Figure 47. Weather Data of Jakarta, Indonesia (generated by Meteonorm)

The hourly air temperature during a year fluctuates between 22°C and 35°C.The weather data informs that Jakarta is a very humid city with the average relative humidity during the year ranging from 40% to 100%. There is no daylight saving period as the average sunshine hour is similar throughout the year, that is about twelve hours a day. It can be seen that the direct as well as the diffuse solar radiation is remaining high, and with the maximum solar radiation intensity of about 980 W/m².

Figure 48 shows the monthly weather data of Jakarta, with minimum, maximum and the average temperatures and relative humidity, as well as direct and diffuse solar radiation. It informs that there is no heating degree-day for this climate condition as the temperature is oscillated always above 20°C. Hence in further thermal building simulation, the discussion focuses only on the cooling energy demand.

Jakarta (Meteonorm 6)

	JAN	FEB	MAR	APR	MAI	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Year
DIRECT SOLAR RADIATION													
Maximum, [W/m²]	970	829	974	887	870	883	875	876	922	818	778	980	**980**
Middle value, [W/m²	107	82	117	137	127	137	142	141	144	113	92	80	**118**
Energy, [kWh/m²]	80	55	87	99	94	99	106	105	103	84	66	59	**1038**
DIFFUSE SOLAR RADIATION													
Maximum, [W/m²]	481	513	525	466	457	425	426	482	518	519	518	522	**525**
Middle value, [W/m²	98	111	109	94	101	89	94	104	109	116	110	117	**104**
Energy, [kWh/m²]	73	74	81	68	75	64	70	78	78	86	79	87	**914**
AIR TEMPERATURE													
Minimum, [°C]	21.7	21.7	22.7	22.2	23.1	21.8	21.9	21.6	21.4	22.0	21.9	22.2	**21.4**
Maximum, [°C]	33.4	32.5	33.6	34.7	34.1	34.0	33.6	33.4	34.5	35.2	34.8	34.8	**35.2**
Middle Value, [°C]	27.1	26.7	27.6	27.6	28.2	27.3	27.4	27.6	27.7	28.0	27.5	27.5	**27.5**
RELATIVE HUMIDITY													
Minimum, [%]	53.8	55.6	54.0	50.4	50.0	46.0	49.4	47.6	42.4	45.1	49.0	46.0	**42.4**
Maximum, [%]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	100.0	99.6	**100.0**
Middle Value, [%]	82.6	84.6	81.4	81.9	80.2	80.9	78.1	75.6	75.7	77.0	80.5	79.3	**79.8**

Heating Degree Day		Elevation above sea level	4 m
HGT $_{20/12}$, [Kh/a]	0	Latitude:	-6.09
HT $_{12}$, [d/a]	0	Longitude:	106.49

Figure 48. Monthly Weather Data of Jakarta (citation data from Meteonorm)

Surabaya, the second biggest city in Indonesia, has now becoming a new metropolis. Surabaya, the capital of East Java province and is located at 7.4° South latitude and 112.8° East longitude. The elevation is only 3 m above sea level. It is situated along the north coast as is Jakarta, but it is on the eastern part. Hence Surabaya has similar seasons as Jakarta, that is the rainfall peak season in January and its dry season low point is August with the average precipitation level of 182.5 mm/month and the possibility of above 200mm/month between December and May (www.surabaya.go.id).

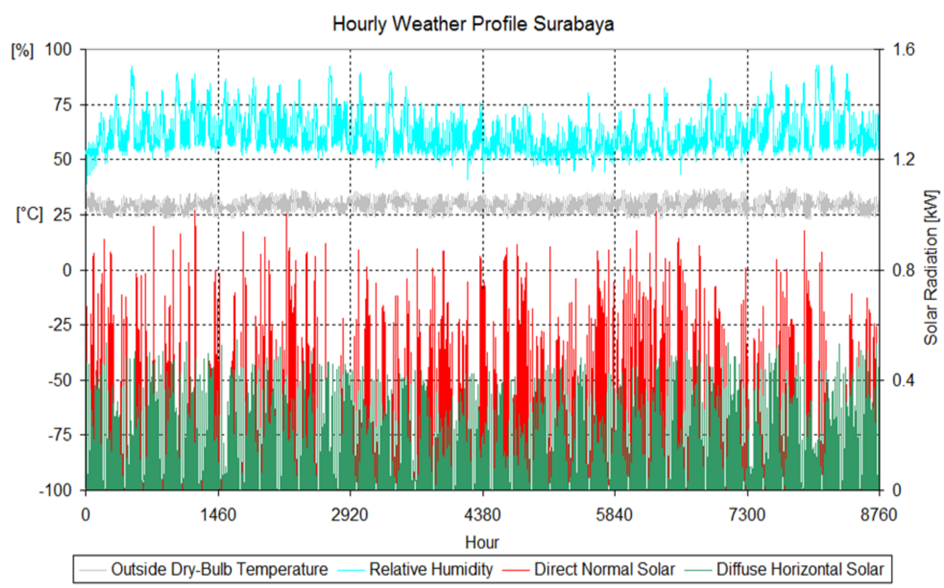

Figure 49. Weather Data of Surabaya, Indonesia (generated from Meteonorm)

The hourly weather profile of Surabaya is depicted in Figure 49, which is generated by Meteonorm (Meteonorm 2007). It describes the outside dry-bulb temperature, relative humidity, the direct normal solar and the diffuse horizontal solar.

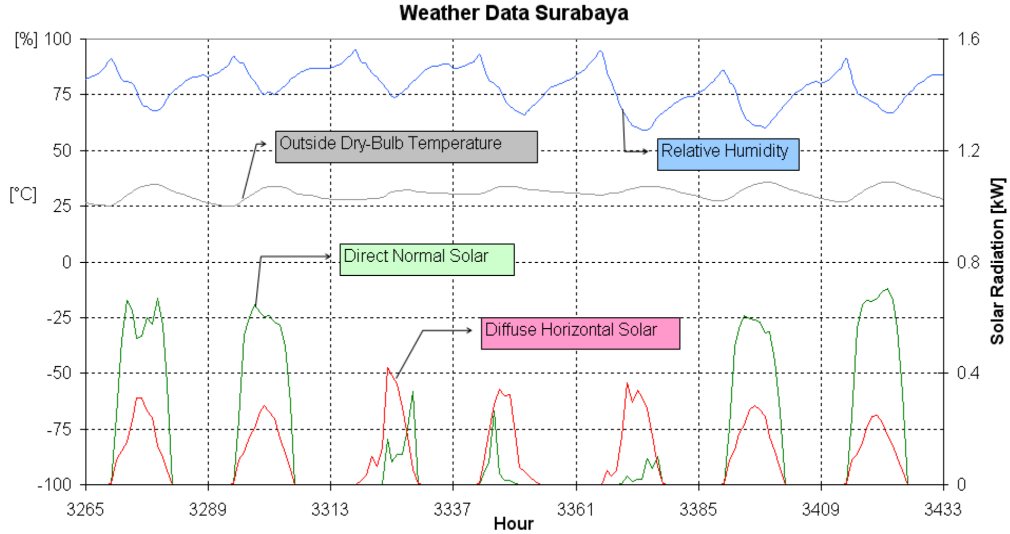

Figure 50. The typical hourly weather profile of Surabaya in a week

The weekly weather profile of Surabaya as shown in Figure 50 is an example that illustrates the detail fluctuation of the weather variables. It clearly indicates that the relative humidity is very high during the day and night and is always above 50%. This means it is difficult in using the effect of natural ventilation as the main cooling strategy, because the outside air will carry high level of moisture into the building and consequently the humidity level inside the building becomes higher.

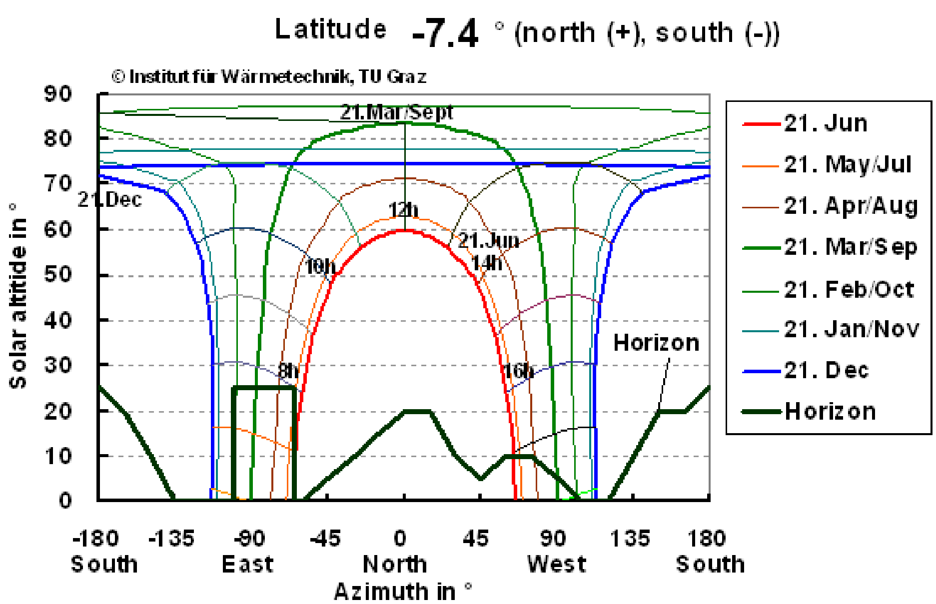

Figure 51. Diagram of Solar Position of Surabaya (Streicher 2009)

The diagram of the solar position of Surabaya is depicted in Figure 51. The graph shows that throughout the whole year the solar angle is always high, ranging between

60° and almost 90°. The solar angle is the representation of the sun's position, which is generally given as an azimuth and altitude angle: Azimuth represents the horizontal angle of the sun relative to true north. This angle is always positive in a clockwise direction from north (0°) when viewed from above. Solar altitude represents the vertical angle of the sun with the horizontal ground plane. It is given as an angle in the range of 0° < alt < 90° (Duffie & Beckman 1980).

Because of the high intensity of the solar radiation and the incident solar angle, the uppermost, east and west side of a building receive the highest solar radiation. Hence, a possible strategy to decrease the cooling energy demand of the building is by reducing solar radiation entering the building through the roof, as well as through east and west sides. As a result, installing roof insulation and reducing window area in east and west is presumed effective in lowering the indoor air temperature, thus, reducing the cooling energy demand of the building.

The hourly outside dry bulb temperature as depicted in Figure 52 shows that there is no significant diurnal temperature variation during the day. Hence, despite the moisture problem, the night cooling also does not give too important effect for the natural cooling strategy of the building. Moreover, the temperature is always above 25°C, which means that there is no heating demand of the building and it is obvious that cooling energy is required during the whole year. Consequently, natural ventilation is not enough to handle the cooling problem, and the possibility of using mixed-mode cooling strategy is assumed more valuable.

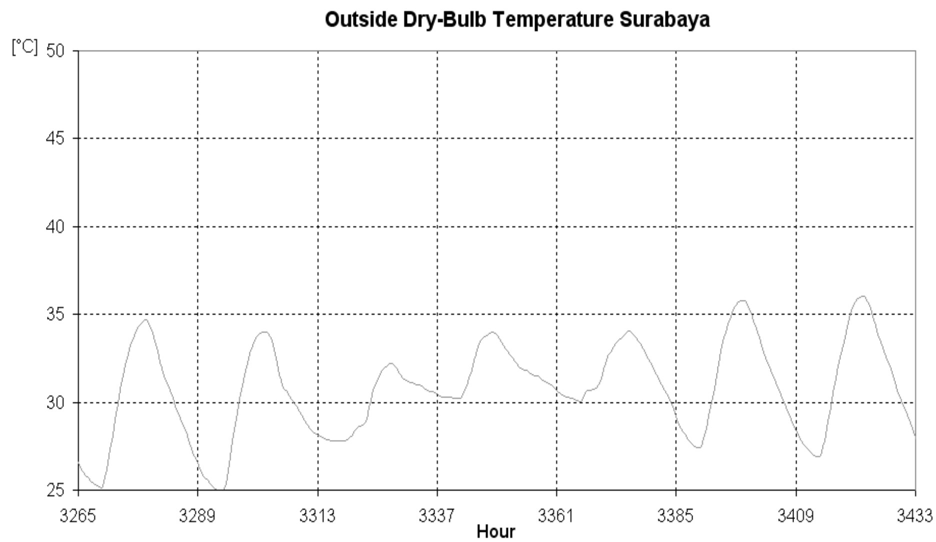

Figure 52. The typical hourly outside dry-bulb temperature of Surabaya in a week

In summary, the hourly weather profiles of Jakarta and Surabaya show that during the year the weather profile is approximately uniform and there is no substantial fluctuation of the weather parameters. The relative humidity is remaining above 50% during the year, and the outside dry-bulb temperature is almost never been below 25°C. As Indonesia lies on the equator the solar incident angle is always high during the year and results in high solar radiation on the horizontal surface during the whole year. This also causes the absence of extreme hot and extreme cold weather during the year and results in a tropical hot and humid type of climate. For those reasons, it is appropriate to do thermal simulations for a shorter periods, such as for a period of six months in order to represent yearly behaviour.

Ground Temperature

As a tropical country, Indonesia always receives solar radiation during the year. Therefore, there is no significant fluctuation of air temperature as well as ground temperature. Figure 53 shows annual disturbed ground temperature below the building used in this simulation, taken from the weather data of Jakarta. The term 'disturbed' refers to the existence of a building above the ground. This ground temperature's profile was obtained by a ground temperature simulation utility using the simulation tool EnergyPlus. It can be seen that the average monthly ground temperature difference between slab depth of 0.1 m and 0.5 m is less than 1°C, and the average annual ground temperature ranged between 26.5°C and 27.8°C, which means the annual variation is insignificant. Therefore, applying insulation for the ground floor slab will not give significant effect in reducing the cooling energy of the building.

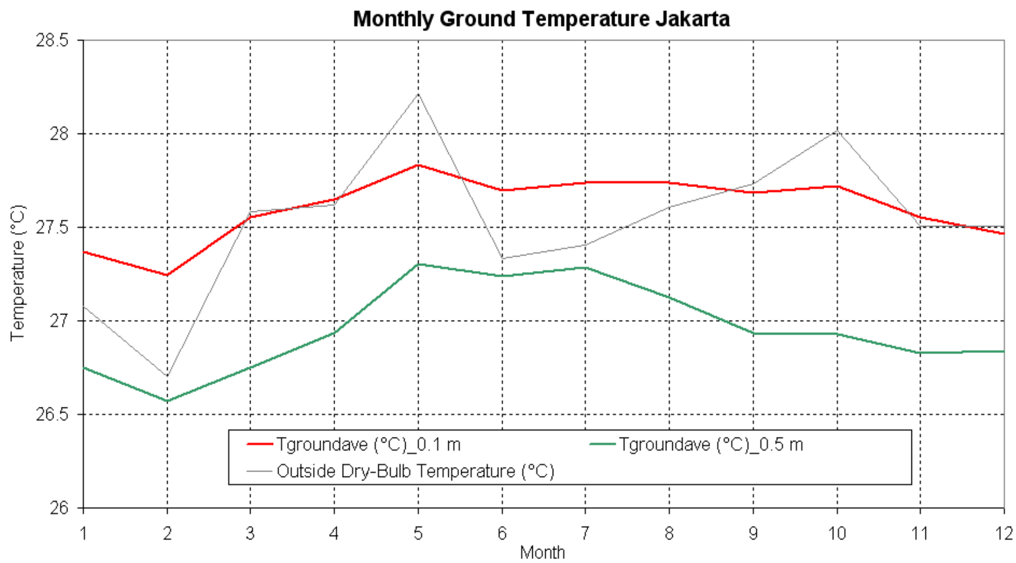

Figure 53. Ground Temperature Profile (Energy Plus)

In addition, as is usual in the Indonesian buildings, the indoor air temperature set point is between 25°C and 26°C, it means that there is no big difference with the ground temperature, therefore, the heat transfer between the ground and ground floor is not important nor is there any improvement in using the ground as the heat sink.

5.1.2 User Behaviour

The energy consumption in building is closely linked with occupant behaviour. Statistically, it is not easy to obtain an accurate model of user behaviour, as it is unpredictable and not routine. Most of the research focused only on the presence of the people but did not analyse in detail the actions of the occupants that influence the indoor conditions, such as opening the window and the door, turning on the light, and so on (J Fergus Nicol 2001)(Mahdavi & Pröglhöf 2009). Energy efficiency of the building is only one relevant point in thermal building performance analysis. Additional or even more important, is to keep the thermal comfort for the occupants. Of course, the occupant actions also influence their comfort.

In the thermal building simulation, the internal heat gain mainly depends on user behaviour. Consequently, user behaviour may be assumed as one of the important input parameters influencing the results of the simulation (Hoes et al. 2009). However, it is still difficult to determine the interaction between the occupant and the environment at the level of an individual person. The possibility available is to extract the general control-related behavioural trends and patterns for groups of occupants of the building from long period of observational data (Mahdavi & Pröglhöf 2009).

In Indonesia, the research dealing with user behaviour discusses the thermal comfort of the occupants in the office buildings (T. H Karyono 2000)(T. H Karyono 1995) and housing (Feriadi & Wong 2004). There were field studies carried out in order to obtain the thermal comfort for 596 workers in seven different multi-storey office buildings in Jakarta. From those studies, it is reported that for the workers in Jakarta the neutral indoor air temperature was found at approximately 26.4°C (T. H Karyono 2000), which means that the occupants are satisfied with the indoor set point temperature of 26.4°C. The neutral temperature is defined as a temperature in which the highest percentage of a group of people being satisfied with their thermal environment would be reached. The comfort air temperature is ranged between 23.3°C and 29.5°C (T. H Karyono 1995), whereas refers to the previous chapter 2, the suggestion for the comfort operational temperature is ranged about 23°C – 25.5°C (Olesen & Brager 2004). In the reality, office buildings Jakarta have adopted the ASHRAE standard (ASHRAE 55-1992) in order to provide thermal comfort for the occupants by setting the indoor air temperature between 22°C and 25°C. Basically, this standard intended for the American people to meet their comfort during summer season (T.H Karyono & Bahri 2005). Obviously, this improper application of the standard causes not only inconvenience condition for the occupants, but also the high energy consumption.

There are some activities of the occupants that cannot be predicted which influence the energy consumption in the building, such as people sometimes do not care that the building is conditioned, and they open the window while the cooling equipment is working. Moreover, people prefer to use curtains in order to avoid glare, but then turn on the light on which causes an increase of not only the electricity consumption, but also the internal heat gain. The clothing behaviour is also influence the thermal comfort. It would be better if Indonesian people prefer to wear light clothes in the office rather than thick suites that causes the requirement of low indoor air temperature.

In another cases, the indoor set point air temperature is too low; sometimes reaching 21°C, whereas the outdoor temperature is 33°C. As a result, the cooling equipment will need more energy to cope with this set point temperature, whereas some people feel uncomfortable with this set point temperature. There are still some more examples of individual occupants that affected the energy consumptions of the buildings (J Fergus Nicol 2001). In this research in order to simplify the profile of user behaviour, it is assumed that the people act equally and regularly.

The characteristics of occupants in Indonesian housing also have unique manners (Feriadi & Wong 2004). As an archipelago country, the different characteristics of people's acceptance of the comfort condition much depend on the different social background and climatic conditions. It reveals that people who live in tropical regions have adapted physiologically and psychologically to the hot and humid conditions. The average indoor air temperature that can be accepted by the people usually ranged between 26°C and 29°C. Many people live in naturally ventilated houses as they cannot afford luxurious living with air conditioning. Moreover, people prefer to overcome this problem by alternative activities such as opening windows, changing clothes, taking a shower more often, other than just using air conditioning. This is because of not only the relatively high price of an air conditioner, but also the high price of electricity consumed by this device. Consequently, people naturally have a tendency to be more tolerant to any uncomfortable thermal conditions.

In line with the economic growth and the urbanisation problems, nowadays developers tend to provide houses in a mass construction namely row houses, which gives more benefit to the developer by way of land use, constructional time and material expenses. Unfortunately, this vastly growing housing construction disregards the negative impact influences. Many developers are not aware on the importance of the housing form that plays an important role dealing with energy consumption and the thermal comfort for its occupants. They believe the buyers of these houses are normally from the middle and upper economic classes and therefore, they do not mind installing air conditioning in their house in order to achieve comfortable conditions. A survey of energy consumption of households in the urban development in Indonesia, found that in a complex of shophouses 91% of the owners use air conditioning to achieve thermal comfort and all respondent's houses are equipped with the air conditioning as well as 53% of this community have installed water heater facilities (Permana et al. 2008).

5.2 Examples of Thermal Building Simulation

In this part, four different types of buildings in Indonesia chosen for thermal building simulations analysis, are presented. Three of them represent typical Indonesian buildings and consist of a mixed-used shophouse and a single-family house in Jakarta which is located in the same region in a so called controlled residential cum commercial areas (Permana et al. 2008) and a high-rise office building in Sidoarjo, regency close to Surabaya. Additionally a more European Office building was used to analyse how European building design behaves in the hot and humid climate of Indonesia.

5.2.1 European Office Building (IEA Task 25 Solar Heating and Cooling)

Initially, the main objective of IEA SHC Task 25 was to improve conditions for the market entry of solar assisted cooling systems in order to promote a reduction of primary energy consumption and electricity peak loads due to cooling (www.iea-shc-task25.org 2004). It also aims to create design tools and design concepts for architects, planners and civil engineers regarding the integration of solar assisted cooling systems into buildings. In this part, the model of the reference office building introduced by IEA SHC Task 25 is used in the simulation with the weather data of Surabaya, Indonesia. The main objective of this simulation is to obtain the most suitable strategy in order to reduce the cooling energy demand of the building and to obtain the most sensitive variable concerning cooling energy reduction. First, a highly insulated reference office building is simulated, in order to obtain its cooling energy demand. This model afterwards named as the reference base case. Subsequently a sensitivity analysis was done with the aim of obtaining the parameters that contribute significantly to the decrease of cooling energy demand of the building. In addition, the simulation of the same model using constructional material provided by Indonesian standard will be performed and compared the result with the reference base case.

This simulation mainly will become the basic reference for the next simulations for different types of buildings, as in this simulation the building reference is an arbitrary building which has a good energy performance in European climatic condition. Therefore, while simulating this building using Indonesian climatic conditions it is hoped to establis which parameters play an important role in providing the energy efficient buildings in hot and humid climates.

5.2.1.1 The Reference Building

Figure 54 shows the view of the reference small three-storey office building studied, generated by DesignBuilder, based on the geometrical data provided by IEA SHC Task 25 (Kouba & Streicher 2002). The building is oriented along the east-west axis and is designed to be internally accessed. The floor space on one level including the areas covered by internal walls and access facilities amounts to 309.9 m². The glazed area on the east façade amounts to 10% of the walls surface area. The window to wall ratio on the south as well as on the north façade is 37.39%. On the west façade there are no windows assumed. The building has a characteristic length (=volume of building/area of building envelope) of 2.63 m.

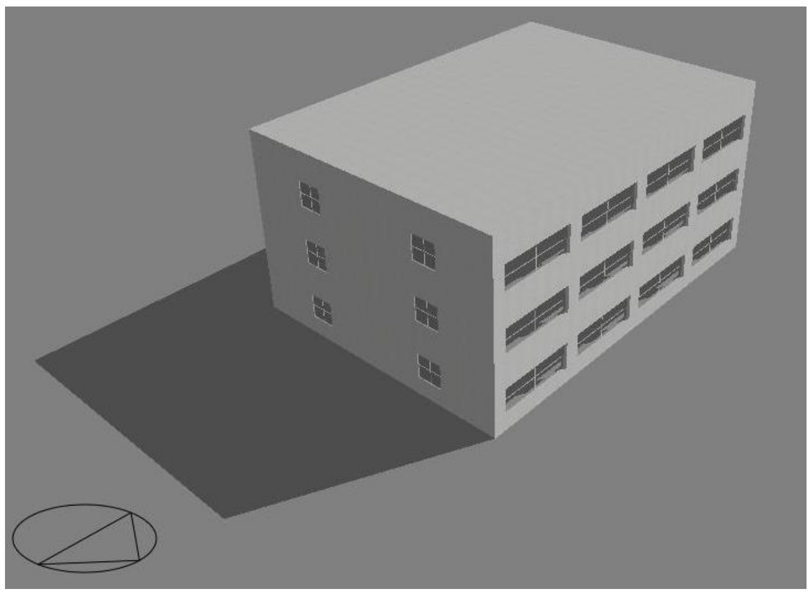

Figure 54. Axionometry of the Reference Office Building

Figure 55 describes the geometry and the dimension of the reference office building simulated. The overall dimension of the floor area is 21.30 m x 15.64 m, and even though there are different sections in every floor, in this simulation each floor is assumed as a single zone. It can be seen that each floor has a different height 3.77 m, 3.98 m, and 4.34 m for the ground floor, first floor, and second floor respectively. However, this will give the same result in that its net height is 3.18 m, as there is thickness of floor slab and ceiling for each floor. The dimensions of the internal walls of the reference building are chosen in accordance with IEA SHC TASK 25. Each floor is estimated to have a length of 80 m and a height of 3.8 m of internal wall, which results in the net area on one side of 254.4 m² (Kouba & Streicher 2002).

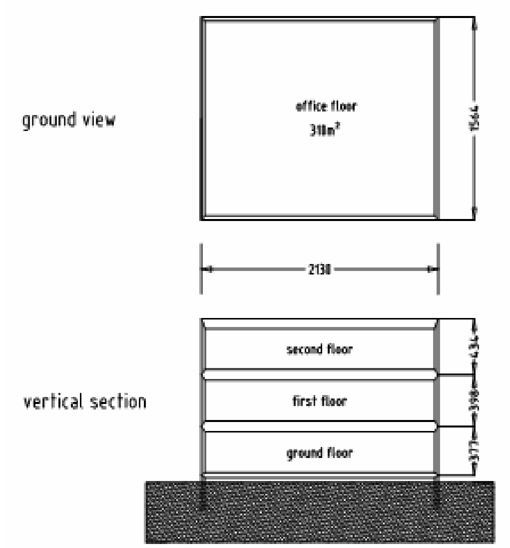

Figure 55. Geometry and Dimension of the simulated building (Kouba & Streicher 2002)

The reference office building has a flat roof construction, which means that there is no roof space. All floors have a total area of 930 m² resulting from the different rooms in Table 3. As explained before, one floor represents one thermal zone, which leads to the assumption that the whole floor is conditioned. Table 3 shows the function of the reference building, as well as its area.

Table 3. Floor Space Areas of Different Sections of the Building (Kouba & Streicher 2002)

Type of building area	Floor area (m²)	Per floor (m²)
Offices	330	110
Meeting rooms	60	20
Access areas (corridors, staircases, etc)	180	60
Social rooms	40	13.3
Lavatory	45	15
Room for customer reception	150	50
Storage rooms (archives, depot)	125	41.6
TOTAL	930	330

5.2.1.2 Constructional Properties

Table 4 shows the thermal characteristics of the building's envelope. These values are taken from the data provided by IEA SHC Task 25 (Kouba & Streicher 2002) which refers to the U value according to middle European practice. Thereafter, the U-value provided by Standard Nasional Indonesia (Badan Standarisasi Nasional 2002) is used and the simulation results between these two cases will be compared.

Table 4. U Value of Reference Office Building's Envelope (Kouba & Streicher 2002)

Component	U-Value (W/m^2K)
External Wall	0.35
Roof	0.17
Floor Slab (ground floor-basement)	0.35
Floor Slab	0.36
Window glazing	1.1
Window frame	2.0

The low U value of the constructional material in the European practice represents the embedded insulation. This aims to prevent heat losses from the building to the environment and hence will be of benefit to the low level of heating demand.

The following Table 5 gives the data of U value given by Indonesian National Standard. For the U values which are not provided by Indonesian Standard, such as floor slabs, then the values are assumed.

Table 5. U Value of Reference Office Building's Envelope provided by Indonesian Standard (Badan Standarisasi Nasional 2002)

Component	U-Value SNI (W/m^2K)
External Wall	1.5
Roof	0.71
Floor Slab (ground floor-basement)	3.1 (assumed)
Floor Slab	3.9 (assumed)
Window glazing	6.2
Window frame	5.9

Table 4 and Table 5 show the significant difference of the U values of the building components. These differences occur because of the different situation, climate condition and the requisite.

Internal Gains

As an input parameter in this simulation, the internal gains of the reference office building consist of occupancy, computers, and lighting. In the area of offices and rooms for customer reception (see also Table 3), the occupant density is assumed to be 0.07 person/m² or one person per 15 m² floor area. In the case of full occupancy, this assumption results in a total of 32 people being simultaneously present in this three story office building. Based on ISO – 7730 standard (ISO 1994), one person will dissipate heat to the surroundings at a rate of 100 W. This value also refers to activity "seated at rest". One person dissipates sensible heat of 60 watts and 40 watts for latent heat. The occupancy profile of people presence in the office building during weekdays and Saturdays is depicted in Figure 56.

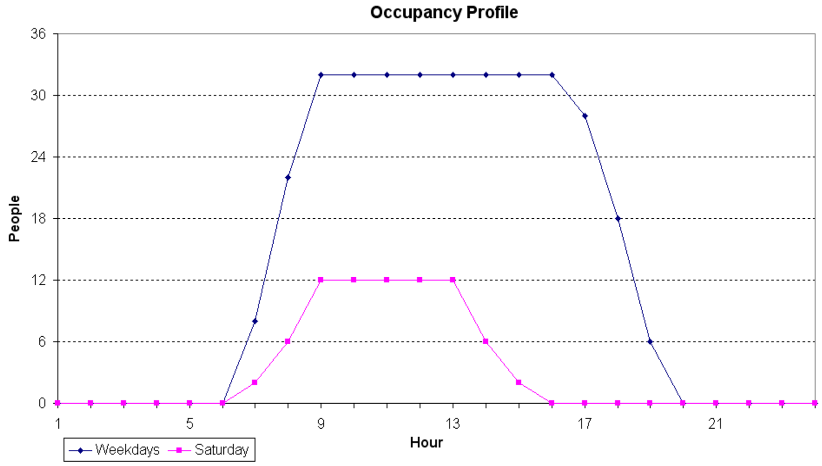

Figure 56. Occupancy Profile of the Reference Building

The graph shows that during the weekdays of Monday to Friday, the building is occupied from 06.00 to 20.00 with the full occupancy period between 09.00 and 16.00. On Saturday, the people start to occupy the building at 06.00 with full occupancy from 09.00 to 13.00, and after 16.00 it is assumed that there are no people present. There are no people in the office during Sunday. As explained before, the people act regularly and consistently. The internal gains due to the computers assumed 230 W for each computer, and 70% of the work places are equipped with a PC including a monitor. Lighting will contribute to the heat dissipation of 2 W/m². All internal gains follow an operational schedule of working hours.

It is assumed that there is an infiltration rate of 0.1 air change per hour due to leakages in the building. In addition, the ventilation rate for hygienic purposes depends on the occupancy, which is 30 m³/h/person. The cooling device is assumed to be operated during only during weekdays, from 07.00 until 19.00.

5.2.1.3 Simulation Results and Analysis

The simulation result of the reference building for Surabaya climate and the U value of constructional material provided by IEA SHC Task 25 shows that the annual cooling energy demand for the building is 110.88 MWh. This result is then called as the base case result.

The energy balance of the reference office building is depicted in Figure 57, which shows that the annual cooling energy demand has almost the same value as the solar heat transmitted to the building through building envelopes. The transmitted heat gain through the building's envelopes is about 70% of the total gain. Computers and equipments contribute 13% of heat gains and occupancy and lighting gains are 12% and 5%, respectively. The heat gain through the building envelope is dominated by the transmitted solar gain through the windows and glazing, which contributes 72.8% and 11.9%, respectively. Here 'windows' heat gain refers to the transmitted shortwave solar radiation through all external windows and 'glazing' refers to the total heat flow to the zone from that glazing, window frame and divider, excluding the shortwave solar radiation (DesignBuilder 2006). Walls contribute 9% of heat gain, and roof, ceiling, and partition transmit the heat of 3.4%, 2.8% and 0.1%, respectively.

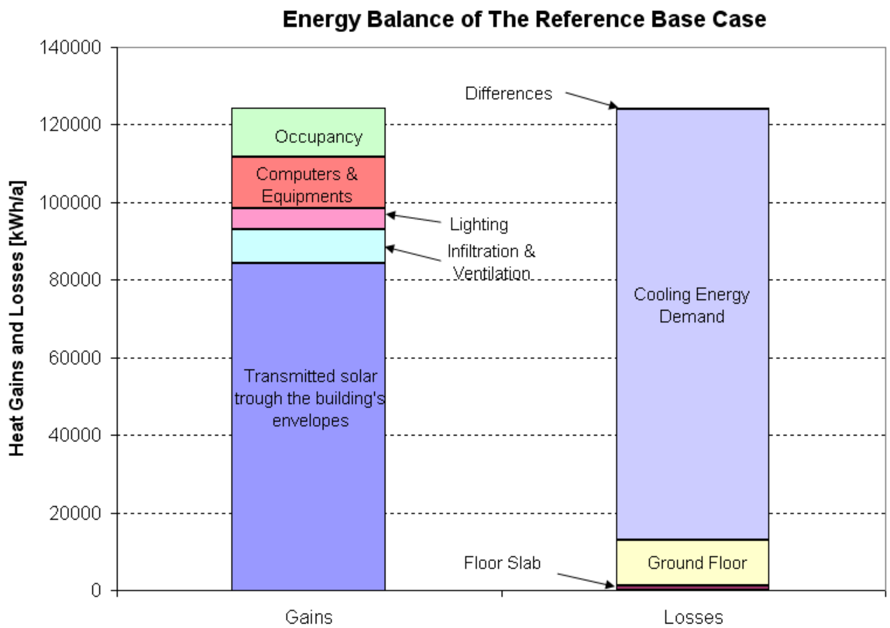

Figure 57. Energy Balance of the Reference Office Building (Surabaya climate)

The simulation using the U value given by the Indonesian National Standard gives a 20.5% higher annual cooling energy demand than the base case. Figure 58 provides the energy balance of the simulation result of using the U value of Indonesian Standard, which shows that the transmitted solar heat gains through the building envelope is approximately 45% higher than the base case.

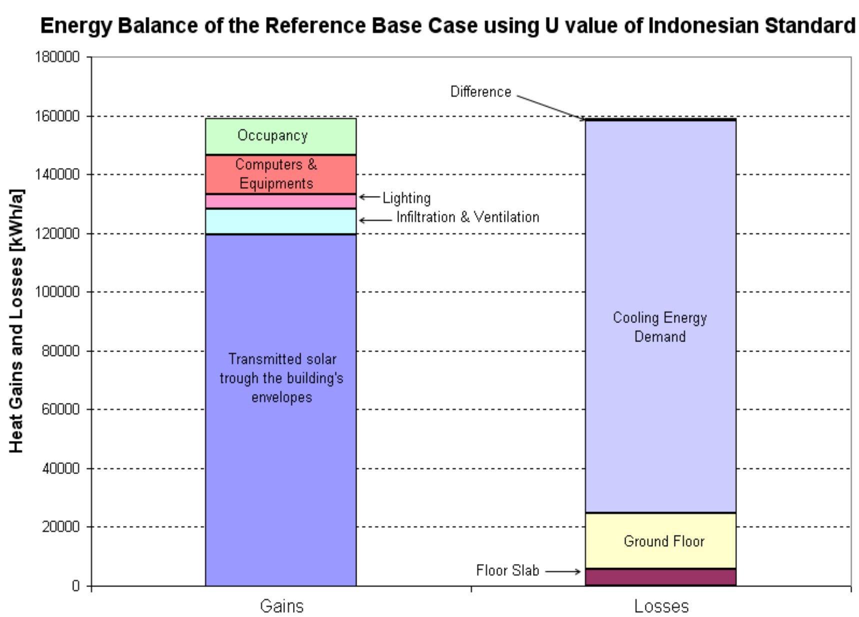

Figure 58. Energy Balance of the Office Building using the U value of Indonesian Standard

The detailed difference on the heat gains and heat losses is depicted in Figure 59. From the comparison chart, it can be seen that the main difference of heat gain and heat losses is mainly caused by the heat transmission from the building envelope (U value) which results in the substantial difference of cooling energy demand. There is no difference of heat gain due to infiltration and ventilation, lighting, computers and equipment, as well as occupancy.

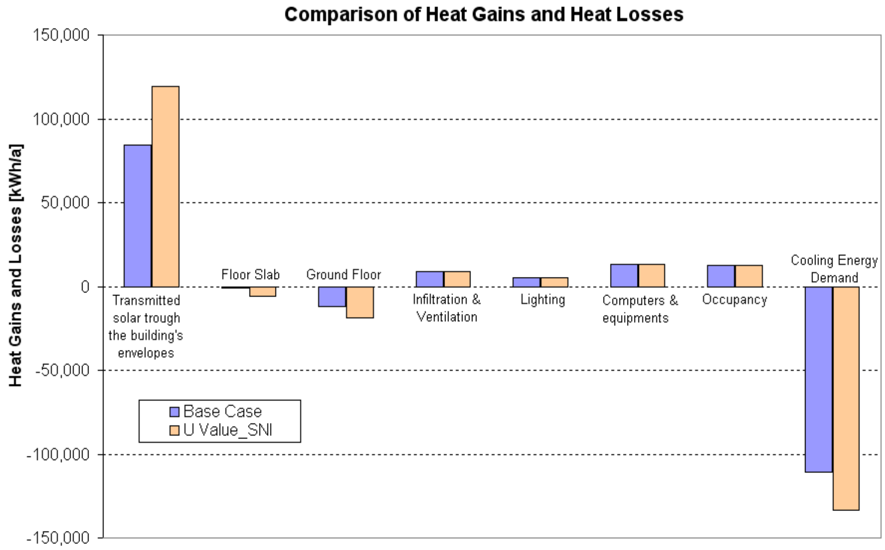

Figure 59. Heat Gains and Heat Losses between the Reference Base Case and the Case of Using U Value of Indonesian Standard

A sensitivity analysis has been carried out in order to find the parameters that cause the most significant impact on reducing cooling energy demand of the reference office building. Nine parameters were chosen for the simulation, such as thermal mass, ratio window to wall with the wall orientation to the north, south and east, U value and SHGC value of the glass, effect of overhangs and shading for both north and south windows and indoor air set point temperature. The summary of the simulation results is depicted in Figure 60.

The graph shows the magnitude of parameter change on the X-axis and the change of cooling energy demand of the building for the Y-axis. The '0' point refers to the base case. The parameter variations were done by increasing and decreasing the magnitude by 0.3 with 0.1 each step. Later, the increase and the decrease of cooling energy demand will be compared to that of the base case, in terms of percentage increase and decrease. In this graph, there are only seven parameters analysed. The magnitudes of these parameters are varied in terms of percentage.

The graph shows that indoor air set point temperature gives the most substantial impact on the change of cooling energy demand, followed by SHGC value of the glazing material and the ratio of north window to the wall as well as south window to wall ratio. Apparently, the U-value of the glazing and thermal mass do not give a valuable effect to the change of annual cooling energy demand.

The effect of constructing overhangs and installing shading equipment for the windows will be discussed separately. There are some scenarios, which are not possible to be compared in term of percentage change of parameters, such as the position of the overhangs and shading as well as the variable of the solar set point that represent the level of the solar transmitted into the building through the windows. Solar set point is one of the control types of window shading. In this case, the shading is 'on' if beam plus diffuse solar radiation incident on the window exceeds the preferred setpoint, in W/m^2 (DesignBuilder 2006).

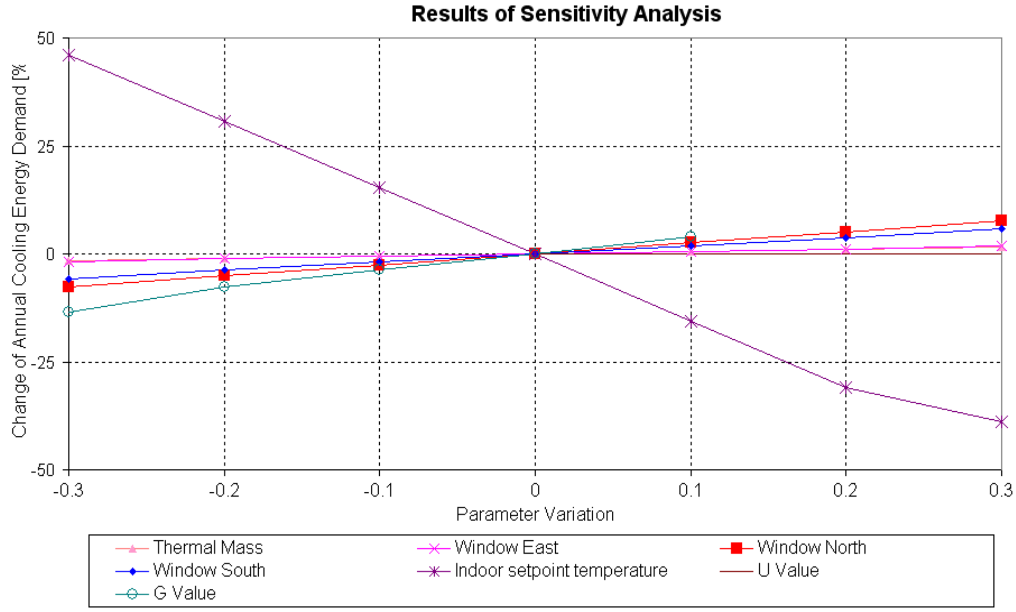

Figure 60. Simulation Results of Reference Small Office Building

Effect of Thermal Mass

Thermal mass is the ability of a material to absorb heat energy. It is particularly beneficial where there is a big difference between day and night outdoor temperatures, and night temperature is well below the maximum comfort temperature (www.greenhouse.gov.au/yourhome/technical/fs17.html). The simulation results show that there is small impact in changing the area of thermal mass inside the building. In hot humid climates area, use of high mass construction is generally not recommended due to the high night temperature and limited diurnal range. It will absorb the heat during the hot day, and during the night, there is not substantial amount of heat releases with this small difference of temperature. Figure 60 shows that reducing thermal mass by 30% will decrease the annual cooling energy demand by 1.70% compared to the base case. Increasing the thermal mass by 30% increases the cooling energy by 1.55%. In general, the impact of the thermal mass variation on cooling energy is not significant.

Figure 61 shows the comparison of hourly indoor air temperature as an effect of thermal mass. It can be seen that during the day for the weekdays when the building is conditioned, thermal mass causes no effect on the indoor air temperature. However, during the night when there is no cooling equipment operated, higher thermal mass maintains the room air temperature lower than the base case. This is because during the day when the air conditioning is operated, the building components exposed to the cold air and become colder during the day and keep this cold until the night time, while the cooling equipments are no longer operated. As a result, the indoor air temperature is significantly lower than the outside dry bulb temperature. During weekends while the cooling device is not operated, the indoor air temperature is the same or even higher than the outside dry bulb temperature for the whole day.

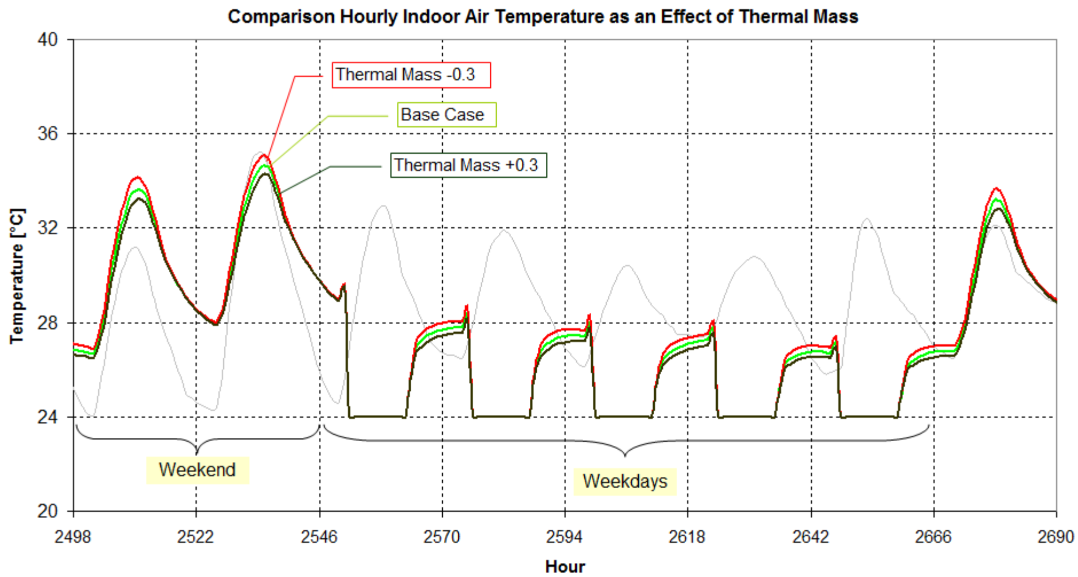

Figure 61. Hourly Indoor Air Temperature as an Effect of Thermal Mass

Figure 62 presents the difference of the maximum indoor air temperature as an effect of thermal mass. These values occur in the period of no cooling, specifically during the weekends. It can be seen that the range of the temperature difference is not significant. For 60% difference of thermal mass, will only results to less than 1°C of temperature difference. In general, higher thermal mass can cause the maximum indoor air temperature to be slightly lower.

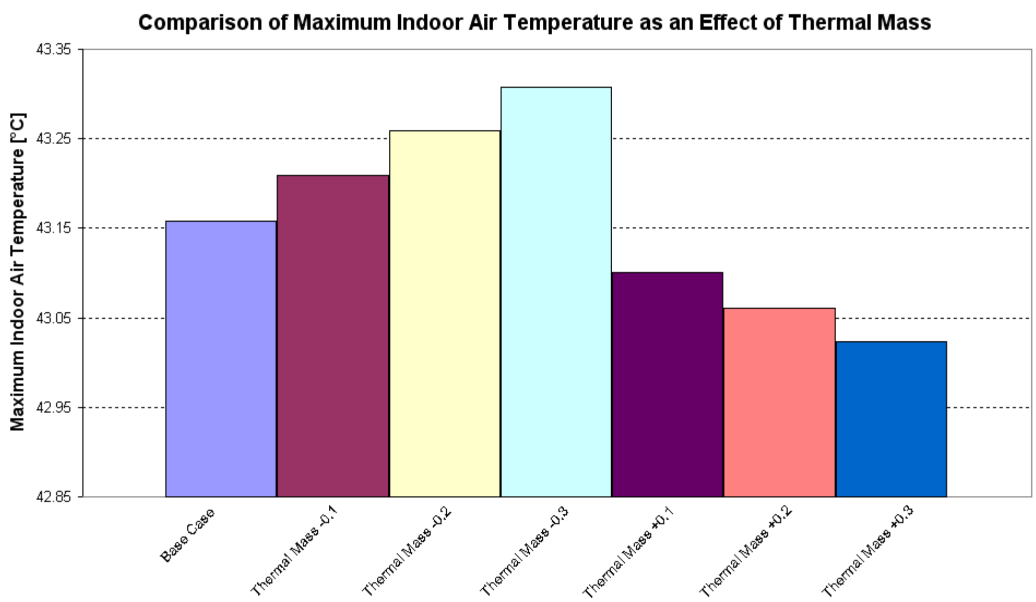

Figure 62. Maximum Indoor Air Temperature as an Effect of Thermal Mass

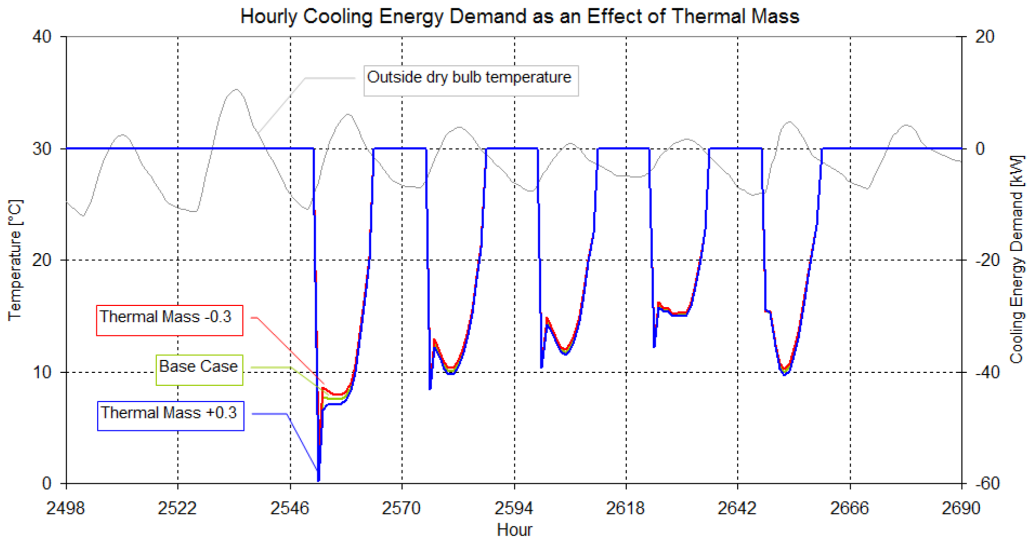

Figure 63. Hourly Cooling Energy Demand as an Effect of Thermal Mass

In comparing hourly cooling energy demand, Figure 63 clearly describes that with lower thermal mass the hourly cooling energy demand is slightly smaller than the base case. In the morning, the indoor air temperature increases as the effect of increasing temperature of the environment as well as no cooling in the building. With higher thermal mass, the building components, which are exposed to the hot air, will absorb more heat, therefore, it requires more energy to achieve the indoor set point temperature. This is proved by the high peak cooling load of higher thermal mass even though this occurrence only exists for a small period.

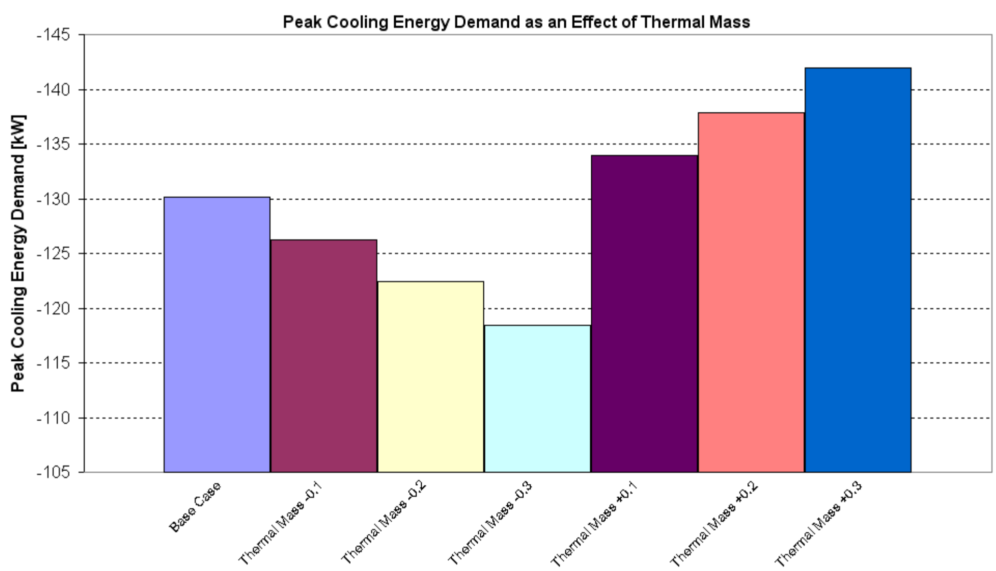

Figure 64. Peak Cooling Energy Demand as an Effect of Thermal Mass

Figure 64 shows the peak cooling load of the building as an effect of the thermal mass. This graph supports the previous explanation that the higher thermal mass will cause the higher peak cooling load. For that reason, it may be possibler to cut the high peak load by operating the cooling device earlier in the morning to make the building components a bit colder.

Effect of Windows to wall ratio and orientation

The window to wall ratio of the base case was increased by 30% in 10% steps. The variations were done for window orientation to the north, south and east. The simulation results show that for all window orientation, the cooling energy will gradually increase with the increase of windows to wall ratio. The larger the window area the more solar radiation is transmitted into the room and, as a result, the higher the heat gain of the room will increase the cooling energy needed.

The results confirm that the most significant effect of parameter change on the cooling energy is caused by north window. North window gives 7.69% of cooling energy increase and 7.64% reduction when the window to wall ratio is added and reduced by 30%, respectively. With the same value of addition and reduction of window to wall ratio (due to the small window area of the base case), window east contributes only 1.77% increase and 1.77% decrease on the cooling energy, and 5.78% increase and 5.74% decrease for window south. This result is reasonable as the building is located in the southern latitude and therefore, north windows will give more substantial effect to the change of the cooling energy demand than south windows.

Effect of U-Value and SHGC Value of Glazing

The change of the U-Value was done only by increasing it three times to 30%, with 10% for each addition. This increase was applied to the glazing material; therefore, it will result in the change of window glazing in all direction. Figure 60 shows that by increasing the U Value of the base case this will also increase the cooling energy, but this change is not very significant. For instance, when the U Value is increased to 10% of the base case, then the cooling energy will slightly increase by 0.11% of base case cooling energy. This is because there is only small difference in inside and outside air temperatures, therefore, the heat transferred is also not significant.

The result of changing the SHGC value by adding 10% as well as subtracting 10%, 20% and 30% respectively is depicted in Figure 60. The low SHGC value means that the glazing material has low solar radiation transmission and this will cause low external heat gain. The simulation results show that increasing the SHGC value of 10%, the cooling energy will increase by 3.95% and by reducing the SHGC value into 10%, 20%, and 30%, the cooling energy decreases by 3.75%, 7.55%, and 13.46% correspondingly. In general, SHGC value causes more significant impact to the change of cooling energy demand than the U value.

Indoor air temperature set point

The simulations on the variation of the comfort temperature have been done by changing the indoor air set point temperature. The set point temperature means the temperature at which the cooling device will operate when the indoor air temperature is above this value. The initial value of the temperature set point was 24°C. The simulation results show that increasing the indoor air set point temperature by 2°C (or 10%) causes a decrease of cooling energy demand of 12.90%, and decreases the set point temperature 2°C to 22°C will increase the cooling energy by 12.83%. It can be concluded that indoor air temperature set point has the highest impact amongst all the parameters investigated.

Effect of Overhangs and Shadings

The variations of overhangs have been done by applying overhangs for window north and south for all storeys and for one floor only (ground floor only, first floor, and second floor). It also has been done with the combination of two floors, such as ground floor and first floor, ground floor and second floor and first floor and second floor. The overhang construction has a dimension of 0.3 m vertical offset from the top of windows and a projection of 0.8 m.

Figure 65 shows the simulation results on the effect of applying overhangs for the north and south windows. In general, overhangs applied for north windows give more significant impact on the decrease of the cooling energy demand than south overhangs. This is due to the location of Surabaya at the 7.4° south latitude, as well as in accordance with the effect of north window being more important than south window. For example overhangs for all windows in the north give a reduction of 10.82% whereas for south only 4.90% can be achieved. Applying overhangs for all north windows leads to the decrease on cooling energy of 10.82%. This value is about 2.5 times higher than the average value of applying overhangs on one floor only, and about 1.5 times higher compared to the average value of applying overhangs with the combination of two floors.

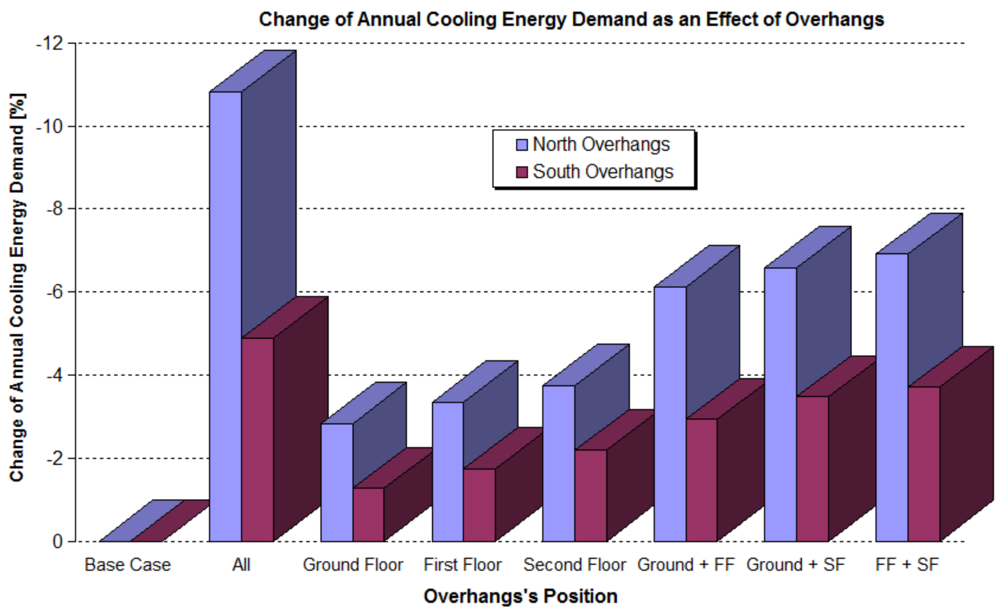

Figure 65. Effect of Overhangs

There is also an effect of the overhangs position. Applying overhangs at the ground floor is slightly different to those of first floor and second floor. Overhangs at second floor have a higher decrease of cooling energy demand compared to first floor and ground floor. This is due to the location of the building close to the equator and, thus, the solar angle will always be high. Therefore, by using overhangs on higher floor levels will reduce the solar radiation not only at this level, but also at the lower floor levels. In contrast, overhangs at lower floor levels will not be able to cover the incoming solar radiation at higher floor levels.

Similar to overhangs, active shading devices were applied to north window and south windows. The variation was done on the solar set point, with the aim of observing the shading effect on an exact value of solar power each square meter. Solar set point is the set point for activating window shading (DesignBuilder 2006b). The unit used in this case was W/m^2, which means that shading is on if beam plus diffuse solar radiation incident on the window exceeds the set point in W/m^2. The evaluation of weather data shows that in Surabaya the maximum incident solar radiation is 811 W/m² for south surface and 702 W/m² for north surface. These values subsequently are used as the initial value for the solar set point in the base case. The sensitivity analysis was done based on the reduction of solar incidents on the south surface and north surface. The simulation results concerning the shading effect is illustrated in Figure 66.

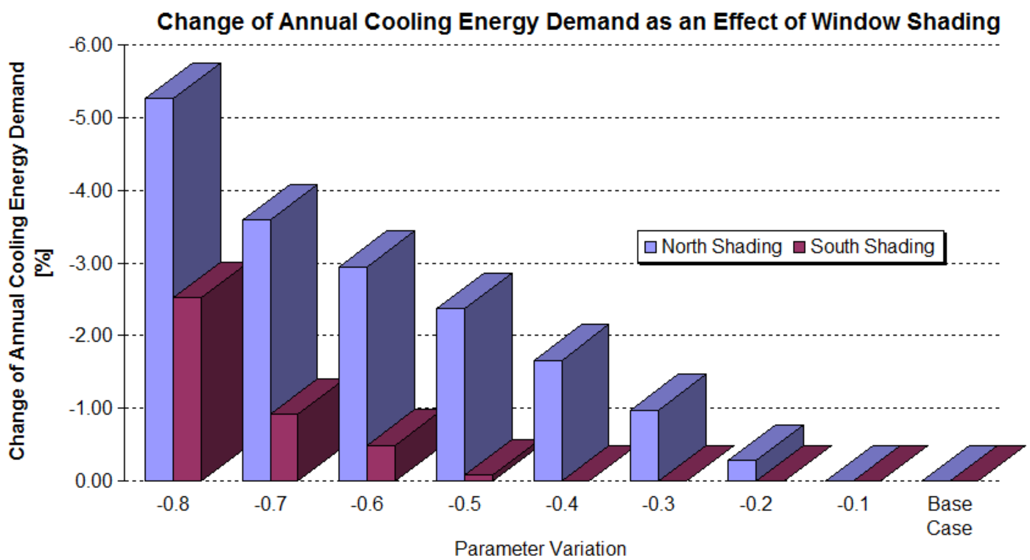

Figure 66. Effect of Shading Device

It can be seen that obviously, north shading gives important impact on reducing cooling energy in the office building compared to those of south shading. On average, the difference of the reduction in the cooling energy as an effect of shading position concerning the orientation is considerably higher. Figure 66 describes that by reducing the solar set point by 40% for south windows (or decreasing the solar set point to 487 W/m²), there is no change on the cooling energy, whereas north shading gives the reduction of 1.66%.

IMPROVED BUILDING DESIGN

Based on the previous simulations on changing the parameters that contribute significant on cooling energy, a new conditioned office building was designed that is expected to be a low energy building. The parameters chosen in this model are shown in Table 6. The simulation shows a reduction on annual cooling energy demand of 37% compared to the base case, (i.e. 69.70 kWh), with the equivalent to the Specific Cooling Demand (= annual specific cooling energy demand per square meter conditioned area) of 74.95 kWh/m²/year.

Table 6. Parameter variation of modify office building

Parameter	Value	Variation from base case	% change of Cooling Energy Demand
Thermal Mass	508.8 m²	No	0
North wall to window ratio	32%	-0.2	5.08
South wall to window ratio	36%	-0.1	1.90
East wall to window ratio	7%	-0.3	1.77
G Value	0.594	-0.2	7.55
Overhangs	All windows North & South		14.57
North shading (solar)	492W/m²	-0.3	0.97
South shading (solar)	487 W/m²	-0.4	0
Temperature Setpoint (°C)	26	0.08	12.90
Sum of percentage reduction for all individual parameter			44.74
Combined effect of all parameters			37%

According to the standard of Energy Consumption Intensity of Electricity for Indonesia, the recommended magnitude for office/commercial building is 240 kWh/m²/year (Ayuni 2004). If the cooling energy is assumed as accounting for 40% of total electricity in the building, it means that this reference building has the energy consumption intensity of 187.4 kWh/m²/year, which is about 20% lower than the recommended value.

CONCLUSIONS

There are nine different parameters varied in the simulation of a reference three-storey office building using the weather data of Surabaya, Indonesia. The results show that increasing the indoor air set point temperature gives the most valuable effect of the cooling energy demand, followed by the variation of percentage of north window to wall ratio and the SHGC value of glazing material. In addition, the shading devices situated on the north windows also contribute to a considerable reduction of cooling energy demand, followed by overhangs. Thermal mass, the ratio of window to wall for south and east orientation, U-value of glass, and south shading give only little effects on the percentage change of cooling energy demand. By simulating an optimized building based on the previous simulation results, the cooling energy demand decreases 37% compared to the base case. It is also found that the U value of the building components also contributes to the change of cooling energy demand.

5.2.2 Typical Shophouse in Jakarta

Shophouse comes from two words, shop and house. It is a type of building, most often with two storeys, of which its ground floor is used as a shop (or other kind of business) and the upper floor is used as a house. The construction of the shophouse is nowadays becoming an ‘epidemic’ for cities in Indonesia, as the development of the city also leads to the change of the living style, which is more practice, effective, and efficient. This causes the rapid increase of shophouse construction as the alternative living place, which offers simplicity and practice to accommodate small-scale activities as well as time efficiency as dwelling function mixed with working place, therefore, will saving money and time as living and working can be done in the same or nearby place (Wahyuasih 2007). It is usual that the buildings' developer build shophouses as mass constructions, as shophouses have similar design of floor plan, dimension, materials and finishing. In addition, mass constructions economically benefit to the developer concerning time consumption and materials' expenditure. This simulation was done using the proposed model of a shophouse in Jakarta, designed by PT. Jaya Real Property, Tbk, in Jakarta (Jaya Real Property, PT.Tbk. 2008b). In this simulation, the sensitivity analysis was performed in order to obtain the appropriate strategies dealing with the reduction of cooling energy demand.

5.2.2.1 The Reference Building

Figure 67 shows the site plan of the shophouses which are located in the western part of Jakarta.

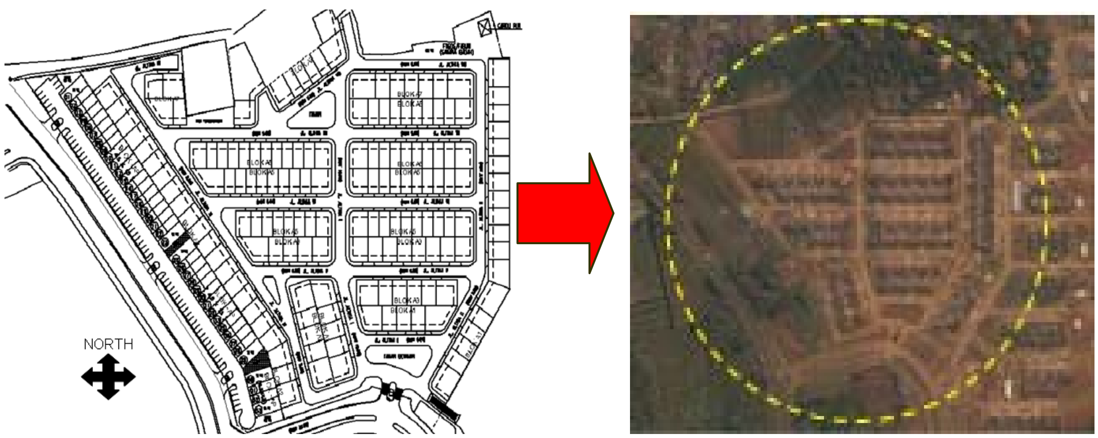

Figure 67. Site Plan of the Shophouses (Jaya Real Property, PT.Tbk. 2008b)(www.earth.google.com.)

There will be some building blocks built and each block has a different orientation such as north, south, southwest and northwest. The building face to the north is used as the reference building.

Figure 68 shows the perspective drawing of this block of shophouse buildings. It can be seen that the main difference of this block of shophouses is only on the façade design, and typically the design of the floor plan for attached buildings is mirroring. Usually, the shape of these shophouses is longwise to the back and attached to each other. Consequently, there are no window on its two sides. This causes a low level of natural lighting penetration (Andarini et al. 2009). Furthermore, the natural ventilation depends only on the movement of the air through the doors and windows in the front and backside. In attached buildings, normally a sidewall belongs to two buildings therefore in this simulation the walls that attached to other buildings are assumed to be adiabatic. The drawing depicts that the model building is designed with a number of glass façade. Obviously, this will contribute high heat gain through the windows.

Figure 68. Perspective Drawing of Shophouses (Jaya Real Property, PT.Tbk. 2008b)

The details of the drawing in Figure 69 show the front view and side views of the building. The area of the ground floor is 34.4 m² and of the upper floor 27.9 m². This smaller area of the upper floor is due to the stairs that connects both floors. The height of ground floor is 3 m and upper floor is 3.23 m. The total volume of ground floor is 103.2 m³ and upper floor is of 131.6 m³, and it is assumed that each floor has one zone. There is also a roof space above the upper floor, which is unoccupied and unconditioned, except its constant infiltration rate is assumed with 0.5 air change per hour due to the leakage. The area of this roof space is 25.9 m², and its volume is 13.75 m³.

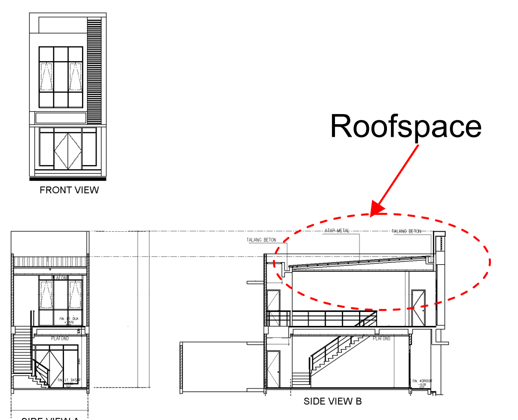

Figure 69. The Drawing of the Shophouse (Jaya Real Property, PT.Tbk. 2008b)

The assumption for the building is that both ground floor and upper floor have the rate of infiltration due to leakages of the building envelope of 0.5 air change per hour. The consideration on determining this high value of infiltration as the lower floor of this building is used as a shop that cause people always move in and out of the building. In addition, as there is stairs connecting lower floor and upper floor, the upper floor will also have a similar value of air changer per hour. There is also natural ventilation for hygienic air exchange depending on the occupancy in the ground floor and upper floor of 7.5 l/s/person, respectively.

Figure 70. The Geometry of the Shophouse (generated using DesignBuilder)

Based on the architectural drawing, then the geometrical building generated by DesignBuilder is shown in Figure 70, with an assumption that the sidewalls are adiabatic.

5.2.2.2 Constructional Properties

The materials for the building envelopes such as wall, floor, floor slab, roof, ceiling and window glazing were defined based on the design by the planners of this building (Jaya Real Property, PT.Tbk. 2008b). This building uses construction materials which are commonly available in Indonesia. The wall is made of brick covered by plaster on its both side and finished with painting. This constructional material will result to the U value of the building envelope as shown in Table 7.

Table 7. U Value of Reference Building

Component	U Value (W/m^2K)
Wall	2.235
Ground Floor	3.916
Floor Slab	1.315
Roof Slab	4.411
Sloping Roof	3.201
Glazing	6.189

The glazing material is single glass, with the SHGC value of 0.816 and light transmission of 0.883. The solar radiation absorption coefficient of the sloping roof that is made from metal was set to 0.3.

5.2.2.3 Internal Gain

It is assumed that the internal gains of this reference shophouse consist of occupancy, computers, and lighting. Occupancy density is assumed to be 0.12 people/m² for each floor, or in the case of full occupancy this assumption results to a total of 4 people being simultaneously present in each floor. As there are different functions of each floor, hence the activity schedule are also different. The ground floor which is functioned as shop or small office has an occupancy schedule of Monday to Saturday from 08.00 to 18.00 and based on ISO – 7730 standard (ISO 1994) one person will dissipate heat to the surroundings at a rate of 100 W. This value also refers to activity "seated at rest", where one person dissipates sensible heat of 60 watts and 40 watts for latent heat.

The occupancy schedule for the upper floor is set as a domestic family weekday, which is Monday to Saturday; the people presence is from 07.00 to 09.00 during the day, and from 16.00 to 23.00 during the night From 23.00 to 07.00 it is assumed that the activities of the occupants are sleeping. On Sunday the occupancy schedule is set to be from 07.00 until 23.00, and after 23.00 until 07.00, it is also assumed that all occupants are sleeping. The internal gains due to the computers and other electrical equipments such as television and cash register assumed to be 4 W/m² in the ground floor and 1.7 W/m² in the upper floor. Lighting will contribute to the heat dissipation of 15 W/m² and 10 W/m² in the ground floor and upper floor, respectively. Both follow the occupancy schedule of the respective floor.

5.2.2.4 Simulation Result and Analysis

The simulation result for the base case of reference shophouse is graphed in Figure 71. It shows the heat balance of the reference shophouse.

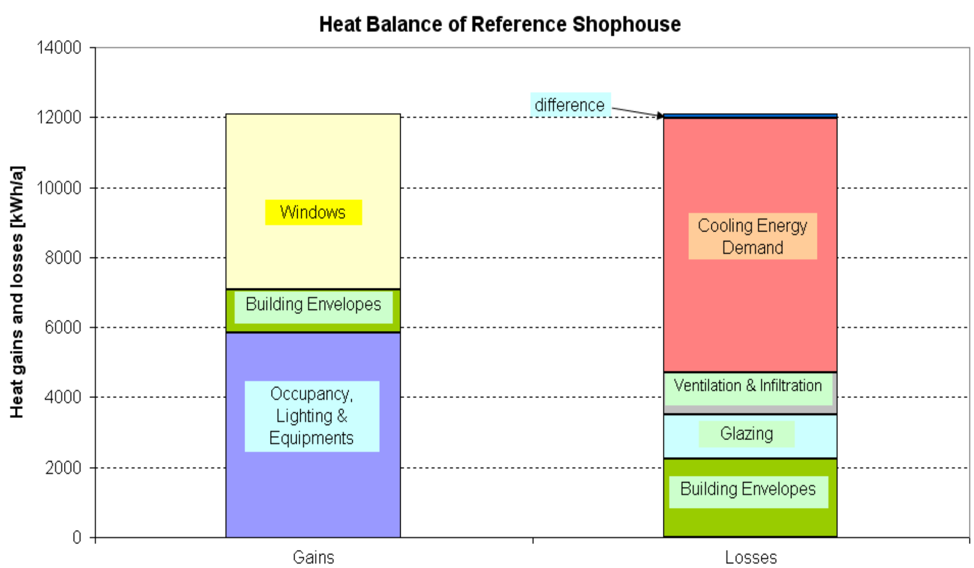

Figure 71. Heat balance of reference shophose

It is found that the internal heat gain such as occupancy, lighting, and equipments contributes 48% of the total heat gain followed by windows that contributes 42% of the total heat gain. The other building envelope component causes only 10%

heat transmitted into the building. The graph also presents that there are losses through the window glazing due to the shading effect, noted about the same as the heat gain through the building envelope.

After obtaining the energy performance of the reference base case, the sensitivity analysis is performed in order to investigate the effect of parameters variation to the change of cooling energy demand. The parameters chosen in this analysis consists of roof insulation and it's position, the building orientation, the SHGC value of the glazing material, the operating time and the power of the cooling device. In addition, the effect of the existence of the roof space will also be investigated.

Effect of Roof insulation

Applying roof insulation intends to reduce the heat entering the room by solar radiation absorbed in the roofspace, hence it is assumed that it will decrease the heat transferred to the lower zone.

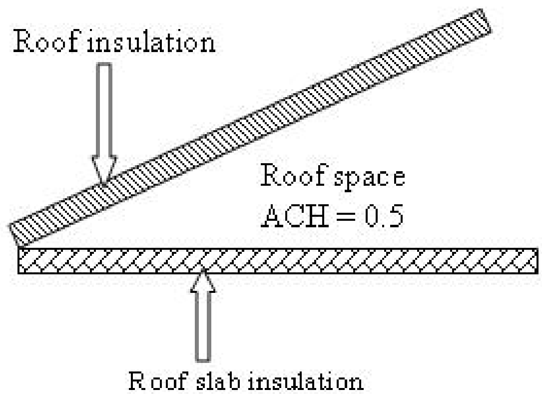

Figure 72. Roof Insulation Installation

The simulations were done by assuming two difference strategies of insulation placement, those are inserting the insulation just below the inclined surface of the roof (hereafter is called as 'roof insulation') and applying insulation above the ceiling of the upper floor, which is then called as 'roof slab insulation', as depicted in Figure 72. The material of the roof insulation was assumed similar for both installations, that is glass wool with the thickness of 5 cm. It is found that using the insulation will cause the U value of the roof decreased by 77.5%. The new U value changed, from 3.201 W/m²K, to 0.719 W/m²K. Meanwhile, the U value of slab changed from 2.381 W/m²K to 0.599 W/m²K, or decreased by 74.8%.

Figure 73 shows the temperature profile inside the roof space taken for only three days as an illustration. The graph shows the comparison of the hourly air temperature inside the roof space while there is no roof insulation, inserting roof insulation, and applying roof slab insulation. The graph describes that installing roof insulation will decrease the temperature during the day compare to the case without insulation. This is because the roof insulation reduces the U value; hence less heat will be transferred into the roof space during the day. Nevertheless, during the night, less heat is released as heat is trapped inside roof space as an effect of installing roof insulation that makes heat is less transferred to the environment. Therefore, the benefit of installing roof insulation is reducing temperature of roof space during the day.

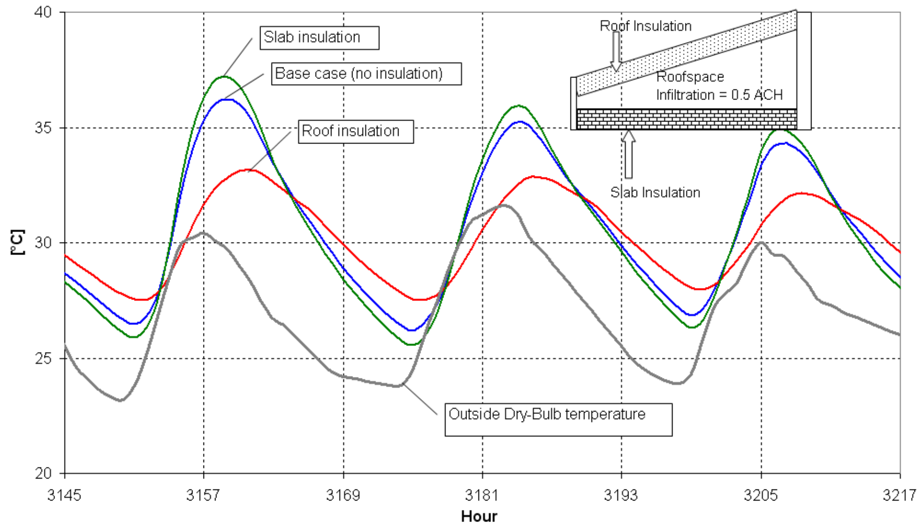

Figure 73. Temperature Profile Inside Roofspace

Applying roof slab insulation will cause a high heat gain of the roof space during the day as there is no insulation on the roof layer. However, there is not too much heat entering the lower zone as there is insulation between these two zones that is placed above the roof slab. Yet it also releases significant amount of heat to the cool-night air during the night. It means that installing roof slab insulation will benefit in releasing warm air to the ambient during the night.

The comparison of hourly roof heat gains as an effect of constructing roof insulation is depicted in Figure 74.

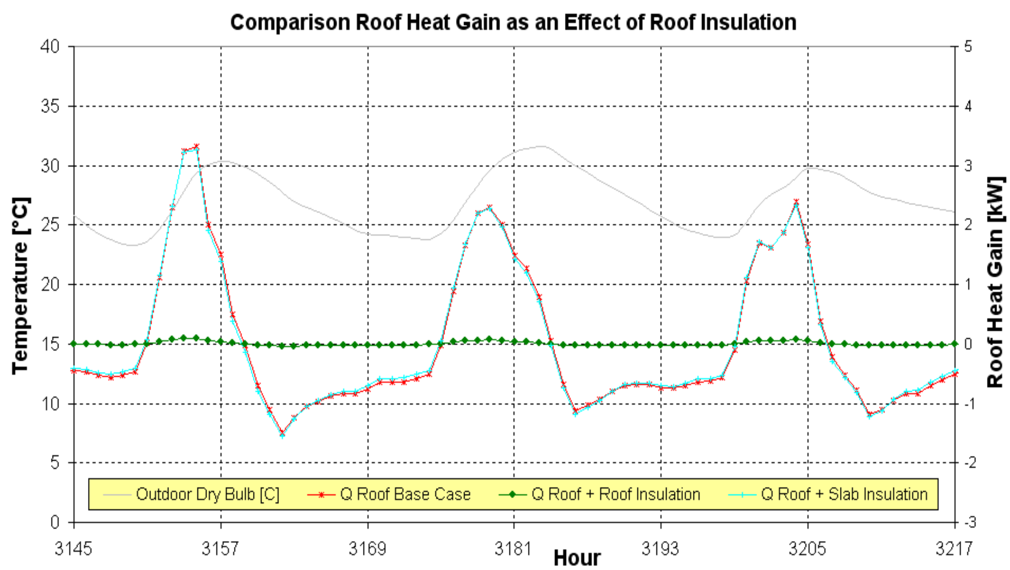

Figure 74. Comparison Roof Heat Gain as an Effect of Roof Insulation

The roof heat gain is presented in the positive value, and the negative value means heat losses. It can be seen that the roof heat gain is reduced considerably when roof insulation is installed on the inclined roof. The roof heat gain of the base case is the same as that of roof slab insulation. Obviously, this occurs, as during the day both of the roofs have no insulation and the roof surfaces receives high level of solar radiation, and the insulated roof is capable to prevent the transmitted solar radiation. Conversely, during the night when the surrounding temperature is lower, the inclined roof apparently almost does not release the heat to the environment, while the roofs that are not insulated releases a considerable amount of heat to the environment. In summary, to reduce roof space temperature significantly during the day and maintain the temperature lower than the ambient air during the night could be achieved by installing roof insulation during the day and using roof slab insulation during the night. In the following, the influence of the roof insulation in the occupied zone is analysed.

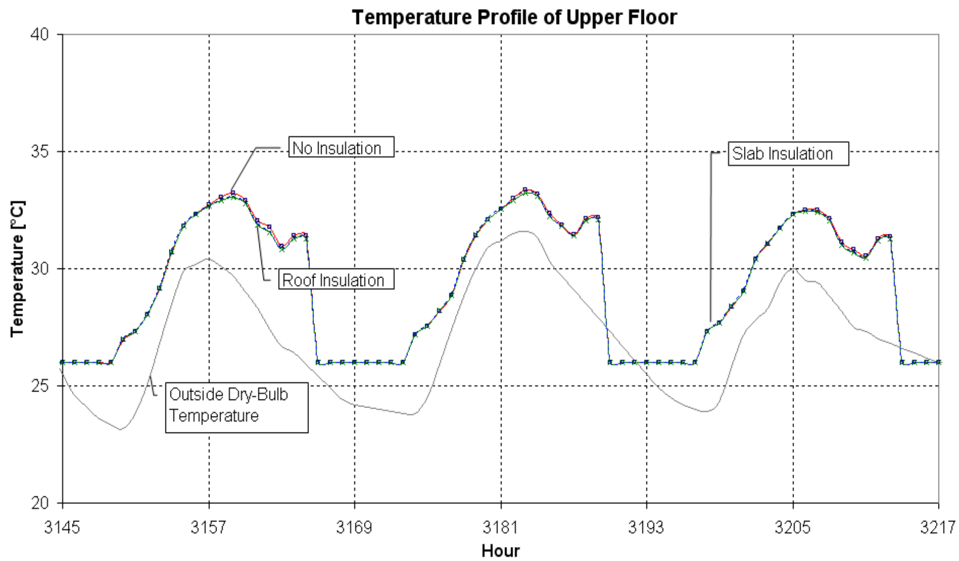

Figure 75. Temperature Profile of Upper Floor

Figure 75 shows the temperature profile inside the upper floor as an effect of installing roof insulation and roof slab insulation. It can be seen that there is no significant influence in the temperature reduction during the day and night either by applying roof insulation or roof slab insulation. This means that roof insulation only is of benefit in decreasing the roof space temperature during the day, but not the underneath temperature. Furthermore, the roof slab insulation which can reduce the roof space temperature during the night apparently has similar influence as the roof insulation. This result satisfies the finding from previous research concerning the effect of roof and ceiling insulation in tropical climate. The installation of insulation at the inclined roof will only reduce the temperature inside the roof space during the day. Furthermore, the ceiling insulation has no significant benefit (Zakaria et al. 2008).

Further investigation will be focused only on the thermal behaviour of the upper floor, as from previous analysis, there is no influence on the indoor air temperature of the upper floor as an effect of roof and roof slab insulation. For that reason, the thermal behaviour of the lower floor regarding the effect of roof and roof slab insulation will not be analysed. The effect of applying roof insulation and roof slab insulation to the profile of the cooling energy demand of the upper floor is depicted in Figure 76. As there is no significant difference of hourly air temperature in the upper floor as an effect of either installing roof insulation or roof slab insulation, accordingly, the cooling energy demand of the upper floor will also not be influenced. This means, the installation of roof and roof slab insulation will not benefit to the change of cooling energy demand of the building. It only reduces the roof space temperature significantly. Whereas in Indonesia, it is not common to use the roof space as a living space, therefore normally roof space is unoccupied.

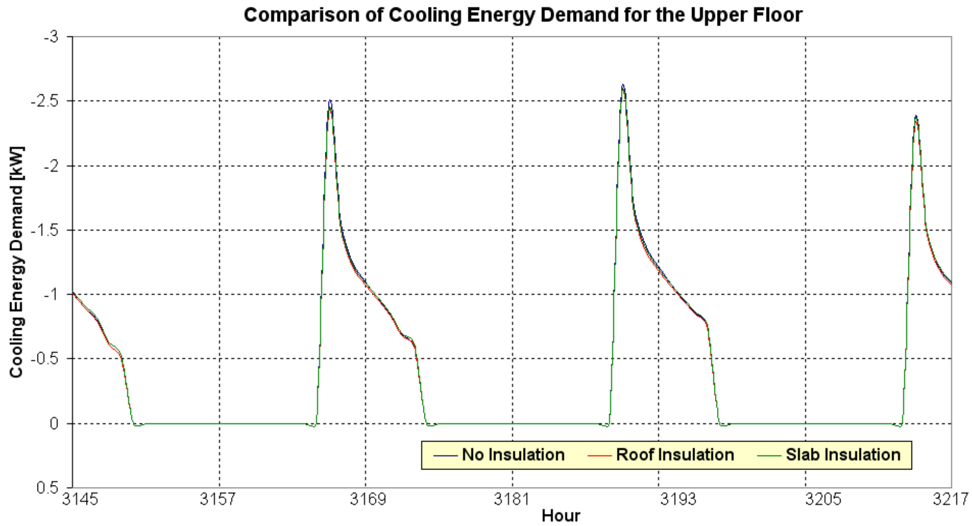

Figure 76. Comparison of cooling energy in the upper floor

Figure 77 shows the comparison of the maximum, minimum, and average roof space temperature for a yearly simulation. It can be seen that installing roof slab insulation will give the highest maximum temperature compare to base case and roof insulation. However, its minimum and average temperature are the lowest compare to the others cases.

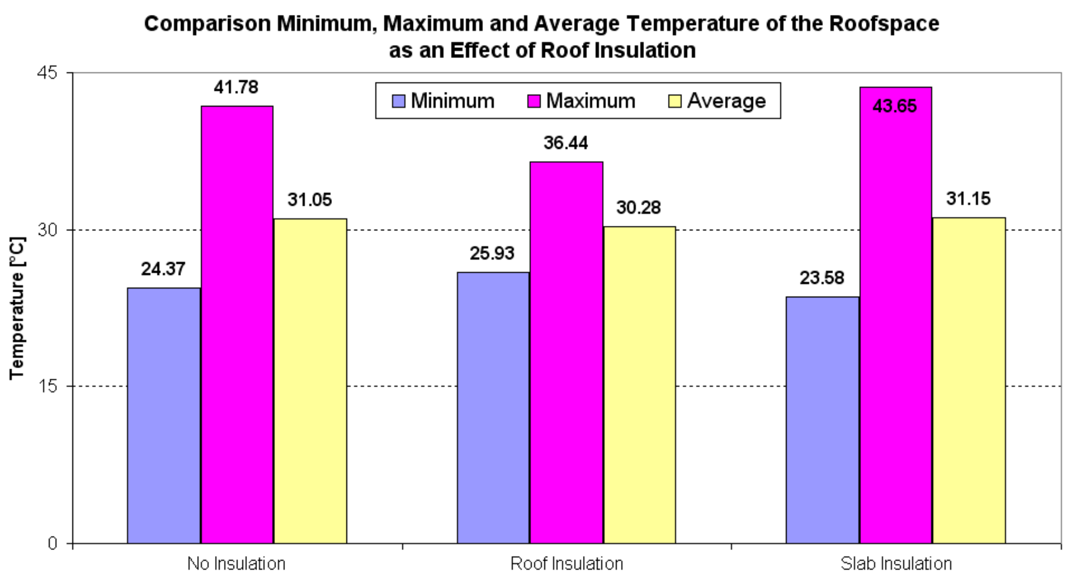

Figure 77. Comparison of minimum, maximum and average temperature inside roof space

In general, applying roof insulation and roof slab insulation will only give effect to the temperature reduction of roof space, but not to the reduction of the building's cooling energy demand. This would be different if no roof space is available, and this analysis will be presented afterwards.

Building orientation

Another parameter that influences the cooling energy demand is the building's orientation. These simulations were done by rotating the reference building model to three different orientations based on the site plan. The base case orientation is 0°, or building faces to the north. As mentioned before, the planner has designed a building complex which consists of several building blocks, and each block faces to different orientation such as south (180°), north east (45°), and south west (225°). As this type of building is attached to other buildings, it is assumed that sidewalls are adiabatic.

Figure 78 shows the percentage difference of the cooling energy demand compared to the base case for different orientations. It can be seen that buildings facing to the south will have less cooling energy demand than base case buildings that is facing to the north.

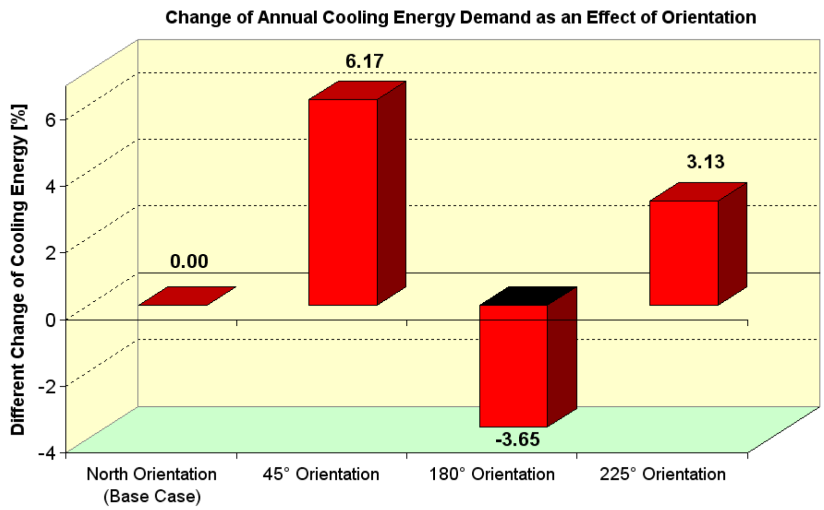

Figure 78. Effect of building's orientation to the cooling energy demand.

This is because Jakarta is located in the tropic of which solar radiation available through the year, and has very high solar angle, thus the dominant source of solar gain is at the north windows than south windows. Therefore, a building facing to the south will have less solar gains on the north wall, and as results, heat gain through north wall will be smaller than buildings facing to the north. In addition, refers to the diagram of solar position (see Figure 51), it can be seen that east and west surfaces will be exposed to the higher solar radiation in all year than north and south surfaces. As a result, this is disadvantage to construct a building with east or west orientation. Thus, the simulation results confirm that buildings facing to the northeast and southwest require significantly higher annual energy demand than those buildings that facing to the south and north.

A factor that significantly influences the difference of cooling energy demand for different building's orientation is the heat transfer through the building envelope as shown in Figure 79. The positive value means the heat transmitted into the building and the negative value represents the heat transferred from the building to the surrounding. It is found that roofs and windows contribute to the high amount of solar heat gain. Conversely, walls, floor, ground floor and glazing are able to release the heat to the environment. Consequently, in order to reduce the cooling energy demand, it is essential to prevent the solar heat gain transmitted through the windows and roofs by means of installing roof insulation and utilizing low SHGC value of the glazing material.

As it is mentioned before, solar gains are very high for buildings facing to northeast and southwest, which is described in Figure 79, even higher if the building is facing to the east and west. Overall, buildings which face to northeast have the highest heat gains compare to other buildings. In contrast, buildings which face to the south have the highest heat losses. With the change of building orientation, it is noticeable how buildings' envelopes contribute to the change of heat gain and heat loss through the buildings. This, of course, influences the annual cooling energy demand.

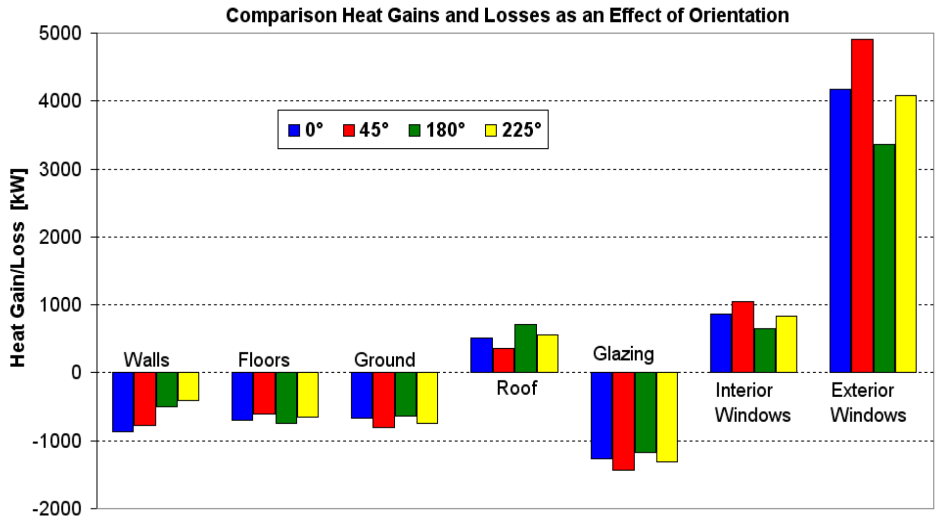

Figure 79. Heat transfer through building envelopes for different building orientation

From the site plan of these buildings' complex, there are also some shophouses that situated on the corner, therefore, one of its sidewall is exposed to the environment, and adiabatic wall is not possible in this case.

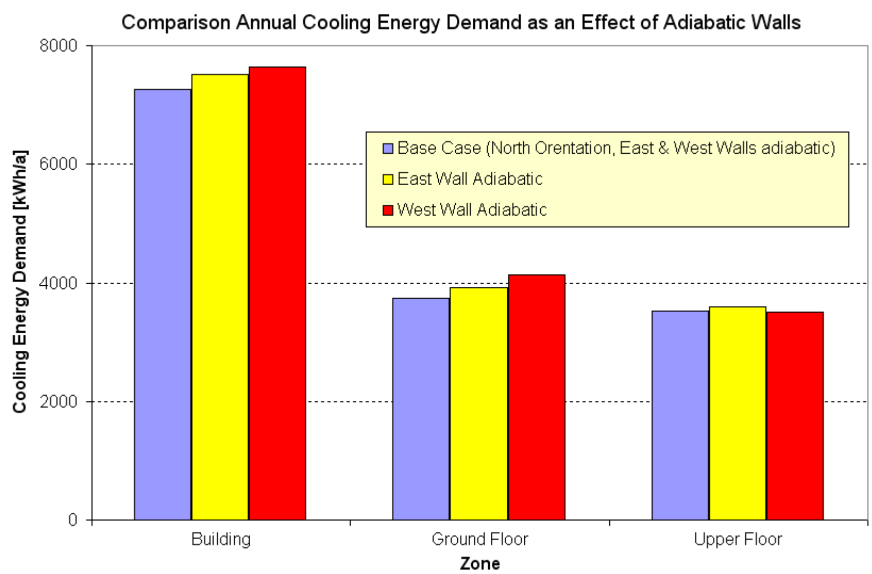

Figure 80. Comparison Annual Cooling Energy Demand as an Effect of Adiabatic Walls

Simulations have been carried out in order to observe the effect of adiabatic wall. The north orientation is still used as the base case, and suppose that in one scenario the east wall is non-adiabatic and for the other scenario the west wall is non adiabatic. The influence of this adiabatic wall is illustrated in Figure 80. In general, the results show that non-adiabatic wall causes the annual cooling energy demand increases. This is because non-adiabatic wall causes additional heat transmitted through the sidewall. The scenario of west wall being non adiabatic causes the highest increase of the annual cooling energy demand. It is calculated that when the east wall is non adiabatic, the annual cooling energy demand of the building increases by 3.5%, and 5% for the non adiabatic of west wall. This increase is mainly contributed by the additional cooling energy demand of the ground floor, those are 4.8% in the case of non adiabatic east wall and 10.6% for the west wall is non adiabatic. Both the building and the ground floor show the similar tendency of annual cooling energy demand as an effect of adiabatic wall, however, the upper floor shows that when the west wall is adiabatic, the annual cooling energy demand has similar value to the base case.

Figure 81 shows the comparison of annual heat gain through the building envelope as an effect of adiabatic wall.

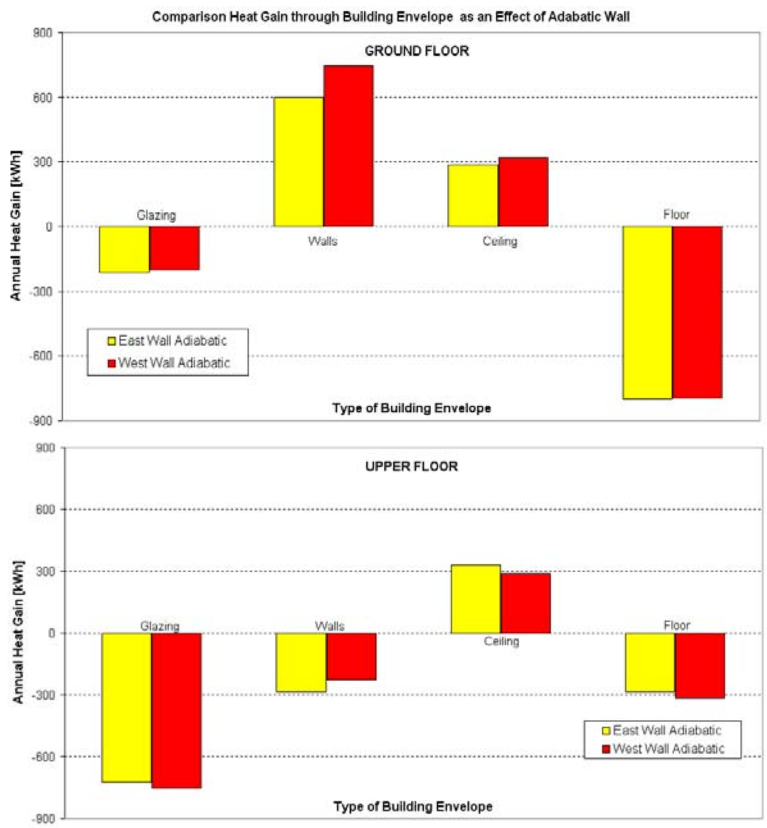

Figure 81. Comparison Annual Heat Gain via Building Envelope as an Effect of Adiabatic Wall for Ground Floor and Upper Floor

It can be seen that for the ground floor, the building with west wall adiabatic the wall losses less energy and gains more energy than that with east adiabatic wall. As a result, the ground floor's annual cooling energy demand of the building with west adiabatic wall is higher compared to that with east adiabatic wall. The main contributor is the heat transmitted through the wall.

Figure 82 shows the amount of solar incident at the external surface of the east wall (west wall adiabatic) and the west wall (east wall adiabatic). It explains that in one day the east wall receives substantial amount of solar radiation than the west wall.

Consequently, the heat transmitted through east wall is higher compared to the west wall.

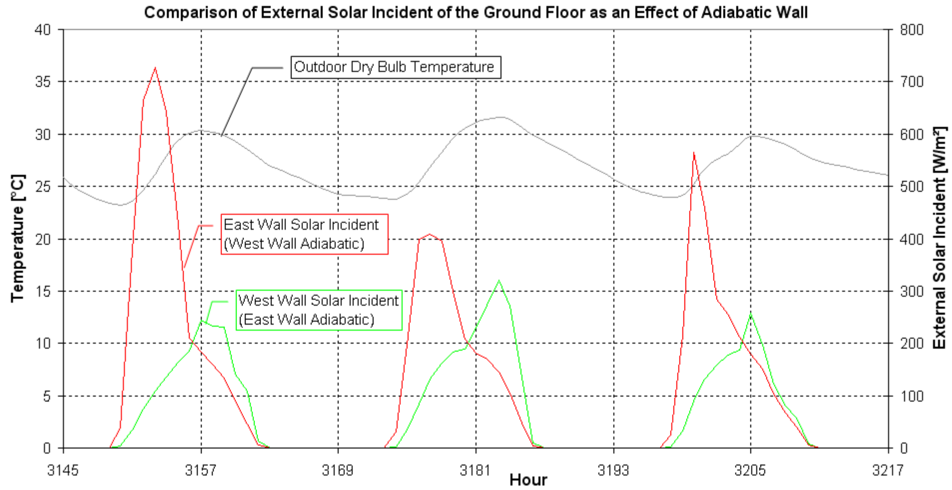

Figure 82. Comparison of External Solar Incident of the Ground Floor

For the upper floor, there is no significant difference of heat gains and losses through the building envelope. However, it is found that all together, the building with east adiabatic wall gains more heat 5% higher than that of west adiabatic wall.

Again, this evidences that east and west surfaces cause higher high solar transmitted to the building compared to other orientation. Hence, to overcome this problem, buildings facing to the east or west should be avoided, however, when this is not possible, it is recommended that these two surfaces should be shaded.

SHGC value of glazing material

The SHGC value is a coefficient that represents energy (solar radiation, heat dissipated from inner glazing) transmitted by a certain type of glazing material. The value range from 0 to 1, of which a lower value representing less energy transmitted, consequently there will be less solar energy entering the building. For buildings in tropical climate, it is recommended that glazing material should have low SHGC value but a high light transmission value, as it will cause less heat gain entering the building but still transmits high level of natural light during the day.

The simulations in order to observe the effect of the SHGC value to the reduction of cooling energy demand were performed by decreasing the base SHGC value of by 50% in five steps for all of the windows. Figure 83 depicts the simulation results of varying the SHGC value.

By lowering the SHGC value of the glazing material, the annual cooling energy demand of the shophouse considerably decreases. It is found that reducing the SHGC value by 50% will cause a reduction of the annual cooling energy demand by 8.3%. Therefore, the chosen of glazing material will improve the thermal performance of the building.

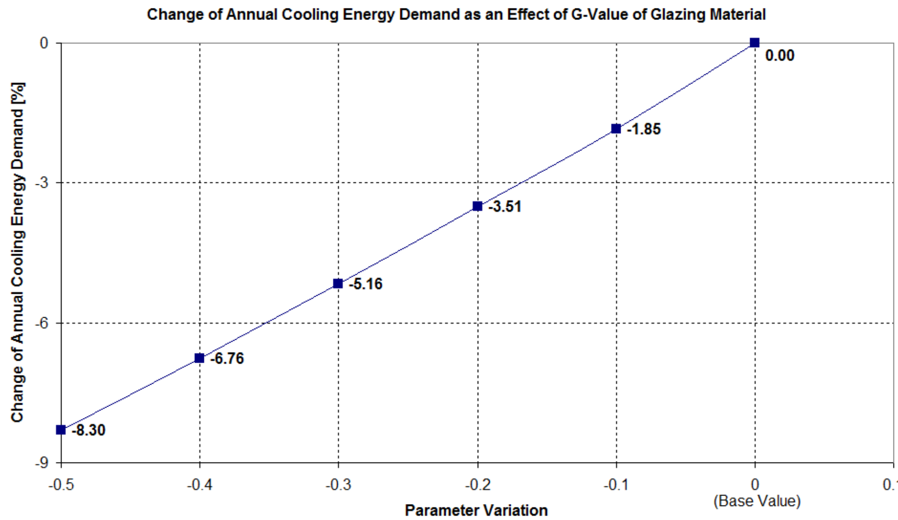

Figure 83. Change of Annual Cooling Energy Demand as an Effect of SHGC Value

Effect of limited power and operational time of cooling device

Limiting power of cooling equipment means reducing the investment cost. From the thermal building simulation of the base case, it is found that the maximum power was 3.9 kW, which occurred in the upper floor and for the lower floor, the maximum power was 1.9 kW. The simulation was performed by limiting the power of the cooling equipment to 2 kW only, for both upper floor and lower floor.

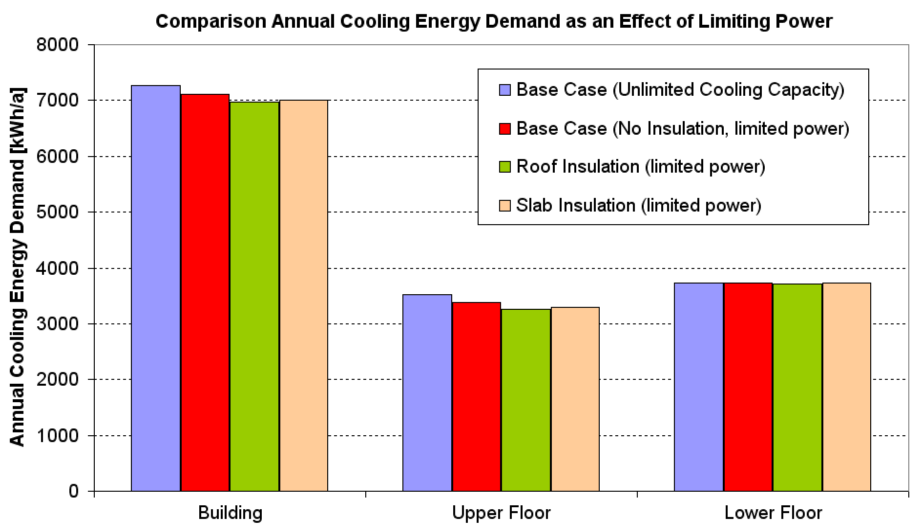

Figure 84. Comparison of annual cooling energy as the effect of limited power of the cooling device

Figure 84 shows simulation result and the comparison of the annual cooling energy demand of limited power of the cooling device. It can be seen that there is no significant difference of annual cooling energy demand when the power is limited into 2 kW. In the case of no roof insulation, the 2% reduction of annual cooling energy demand of the building is mainly contributed by the slight decrease of upper floor’s annual cooling energy demand. As the lower floor has already a maximum power of 1.9 kW, therefore, by limiting power of the cooling equipment will not give effect to the reduction of annual cooling energy demand. Further investigation on the effect of limiting power was done for the roof space with roof insulation and slab insulation respectively.

The simulation results show that there is 7.5% reduction of the cooling energy demand of the upper floor as the influence of roof insulation and 6.6% for slab insulation compare to the base case of unlimited cooling power and no roof insulation. Even though no significant difference, it is found that roof insulation causes more reduction on the cooling energy demand than slab insulation. In case of limiting power, it is found that roof insulation will reduce the building's annual cooling demand by 1.9%, and 1.4% for the installation of slab insulation compared to the base case of limiting power and no roof insulation.

Further analysis will be focused on the upper floor. The effect of power limitation of the cooling device to the cooling energy demand is depicted in Figure 85. The graph shows the hourly cooling energy demand in the period of which the peak load was occurred. It presents that by limiting the power, the maximum reduction of the cooling energy for the cases of no roof insulation is about 1.5 kW, or equals to 36.4%. However, it has been calculated that there are only 358 hours, or 4.1% occurrence in a year that the cooling device deliver the cooling power more than 2 kW. Hence, this causes a reduction of the annual cooling energy demand which is not significant.

In case of limiting power, it is found that roof insulation has 1.4% peak cooling load lower than the case of no roof insulation, and the peak cooling load for slab insulation is 1.5% lower than the case of without insulation. Again, it is found that roof insulation and slab insulation have no significant effect to the reduction of annual cooling energy demand.

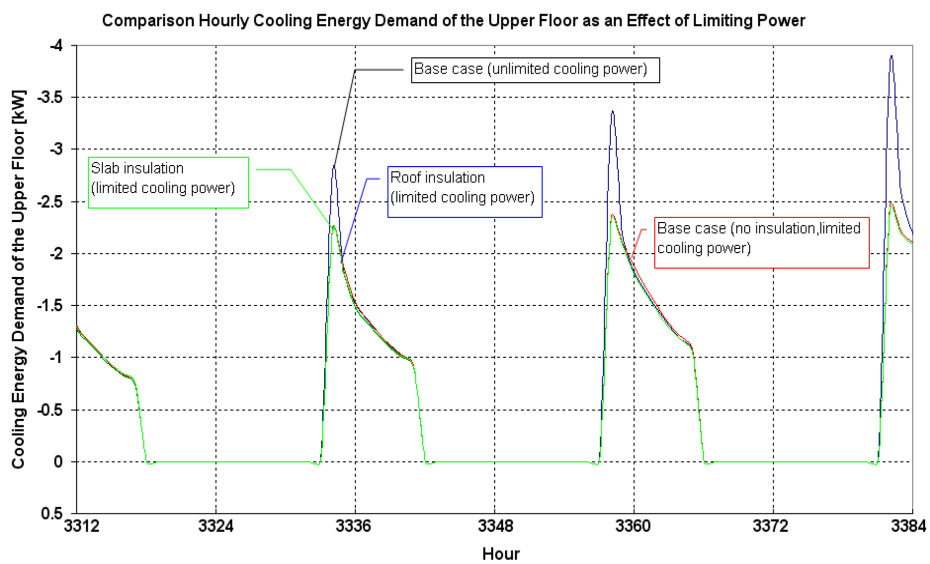

Figure 85. Comparison of hourly cooling energy demand of the upper floor as an effect of limiting power of the cooling device and the insulation

In addition, limiting the power of the cooling device does not influence the increase of indoor air temperature in the upper floor during the peak load period. Figure 86 shows the corresponding indoor air temperature of the upper floor as the effect of limiting the power of the cooling device.

The graphs explain that the main influence of limiting power to the hourly temperature profile is that there is a time retard to reach the indoor set point temperature compared to the case of unlimited power.

Therefore, limiting cooling power should be applied as it reduces the investment cost as well as operational cost. In addition, it is also recommended to turn on the cooling device earlier in order to achieve the set point temperature faster. Obviously, this will result in small additional operational hour, however, this will benefit to the significant decrease of peak cooling load that requires higher operational cost than additional operating hour.

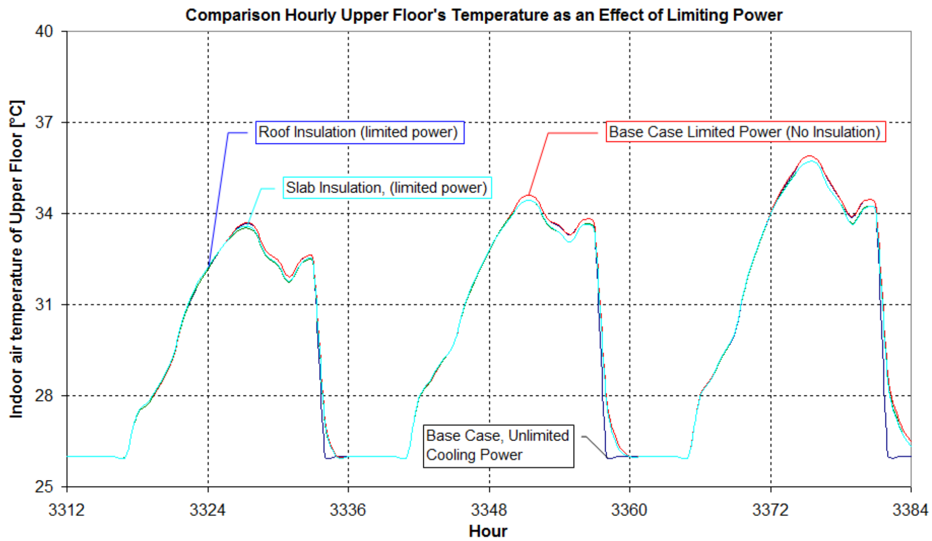

Figure 86. Comparison of Hourly indoor air temperature of the upper floor as an effect of limiting power of the cooling device and the insulation

Other simulations were done in order to observe the effect of operational time of the cooling device to the annual cooling energy consumption. The simulations were done by setting on the operational time of cooling device in the upper floor for 24 hours. The annual cooling energy consumptions between scheduled operational as set in the base case and setting on for 24 hours were compared. Subsequently, the effectiveness of installing roof insulation when the cooling equipment in the upper floor operates for 24 hours is compared.

The results in the Figure 87 show that there is significant increase of the building's annual cooling energy demand when the cooling device in the upper floor operates for 24 hours. In comparison of installing roof insulation and roof slab insulation, it also can be seen that there is a decrease on cooling energy on the upper floor compare to that without insulation. Conversely, there is a small decrease of the cooling energy demand in the lower floor compared to the base case, as the effect of continuously operation of cooling device in the upper floor. This is because, with the continuous operation of the cooling device in the upper floor, the upper floor's temperature will be constant at 26°C, hence will provide cooling effect to the lower floor. As a result, the cooling energy demand in the lower floor decreased.

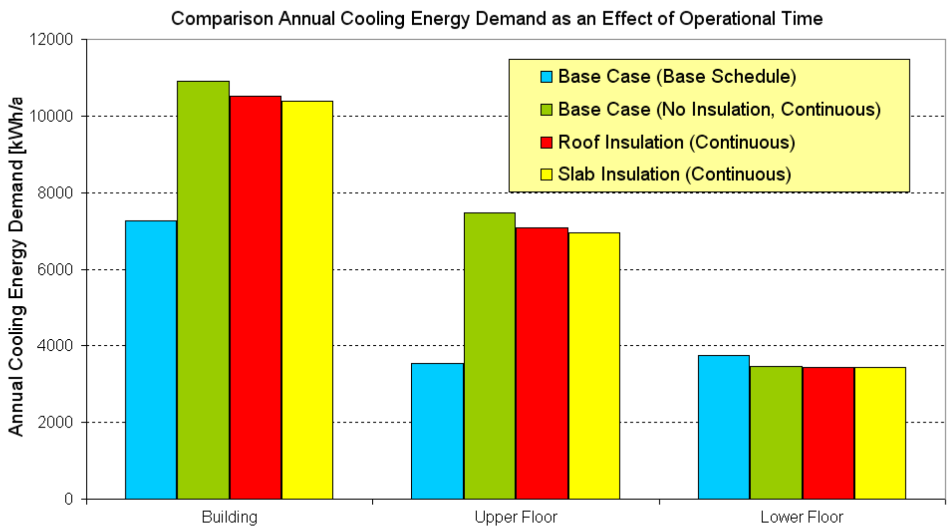

Figure 87. Comparison of annual cooling energy as the effect of operational time of the cooling device

Comparison with flat roof

The assumption of flat roof design was also simulated in order to see the effect of applying roof insulation on the cooling energy demand. The construction of flat roof means that there is no roof space available. Figure 88 shows the comparison of annual cooling energy between sloping roof and flat roof.

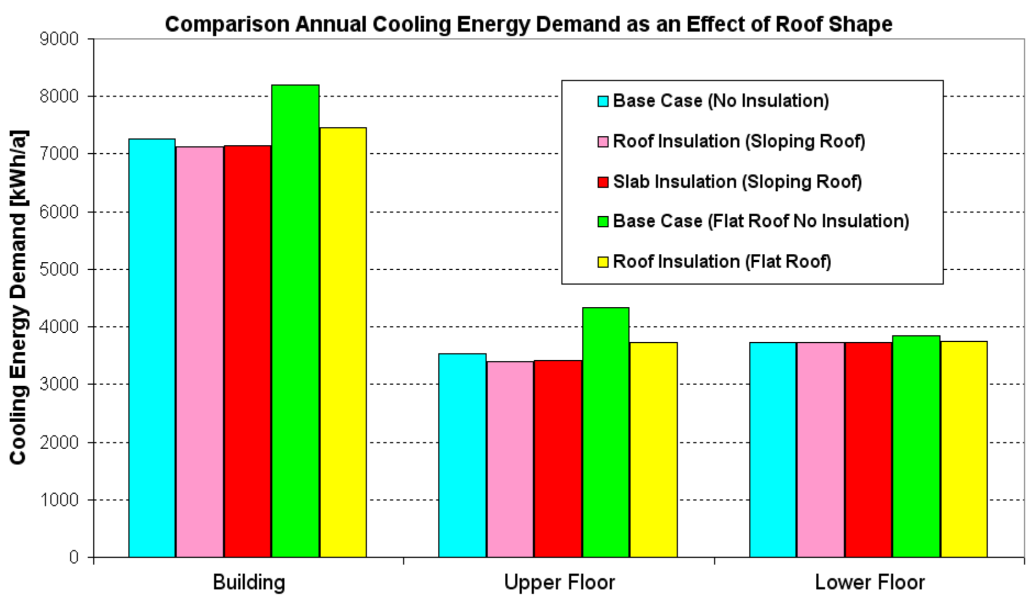

Figure 88. Comparison Annual Cooling Energy Demand as an Effect of Roof Shape

Since there is no roof space above the ceiling, solar heat transmitted directly onto the building. As a consequent, the heat transmitted into the building is higher than that of sloping roof. It is noted that the solar heat gain transmitted through the flat roof is 4 times higher than that of the sloping roof. However, when the flat roof is insulated, the transmitted solar heat into the building decreases significantly by 82%. The graph reveals that in the case of flat roof construction, insulated flat roofs will reduce the annual cooling energy demand significantly, and it gives approximately the same effect as sloping roof, which is indicated by the similar value of annual cooling energy demand.

This reduction obviously, will influence only in the upper floor, and it is found that for the lower floor there is no significant reduction of the annual cooling energy demand. In summary, there are two possibilities to reduce the solar heat gain through the roof, either constructing sloping roof hence there is a roof space, or by constructing flat roof with additional insulation.

Conclusion

From the thermal simulation and cooling energy sensitivity analysis for the shophouse, it is found that the buildings orientation gives substantial impact to the change of energy consumption. Buildings facing to the south give 3.65% less cooling energy demand than the reference building which has north orientation. It is found that the building with south orientation has the lowest annual cooling energy demand compared to other buildings, which have north orientation, north-east orientation and south-west orientation. Decreasing SHGC value by 50% will reduce the annual cooling energy demand by 8.3%. It is also found that for a ventilated sloping roof construction, applying roof insulation has no significant effect on the reduction of annual cooling energy demand, except for the case that the schedule of the air conditioning in the upper floor is 24 hours always on. By limiting the power of the cooling device to 2 kW which means reducing the investment cost, will reduce annual cooling energy demand by 2.07% of the building without roof insulation. In the case of flat roof construction, insulated flat roof will give approximately the same effect as sloping roof.

5.2.3 Single Family House

In this simulation, the strategies of reducing cooling energy demand for single-family house are analysed. The reference house is based on the design proposed by PT. Jaya Real Property, Jakarta, Indonesia.

5.2.3.1 Building Reference

The building reference is a single-family house, which is named as Emerald Garden (Jaya Real Property, PT.Tbk. 2008a). Similar to the previous thermal building simulation of the shophouse, this single-family row house will also be constructed in a real estate region, which means that, there will be mass construction of the type of this building. The site plan of the location of these houses is shown in Figure 89.

Figure 89. Site Plan of the Single Family Houses (Jaya Real Property, PT.Tbk. 2008a)

The model of the single-family house is shown in Figure 90.

Figure 90. Model of Single Family House (Jaya Real Property, PT.Tbk. 2008a)

It describes that the form of the house is mirroring from its neighbour, and for the reference building, it is assumed that there is no shading effect due to plantation or other buildings from the front side of the house. This type of house consists of two floors, the ground floor has one conditioned bedroom and the upper floor has three conditioned bedrooms. The total area of each house is approximately 150m², and the total occupied area is 110.5m².

The floor plans of this single-family house are illustrated in Figure 91 for the ground floor and the upper floor is depicted in Figure 92.

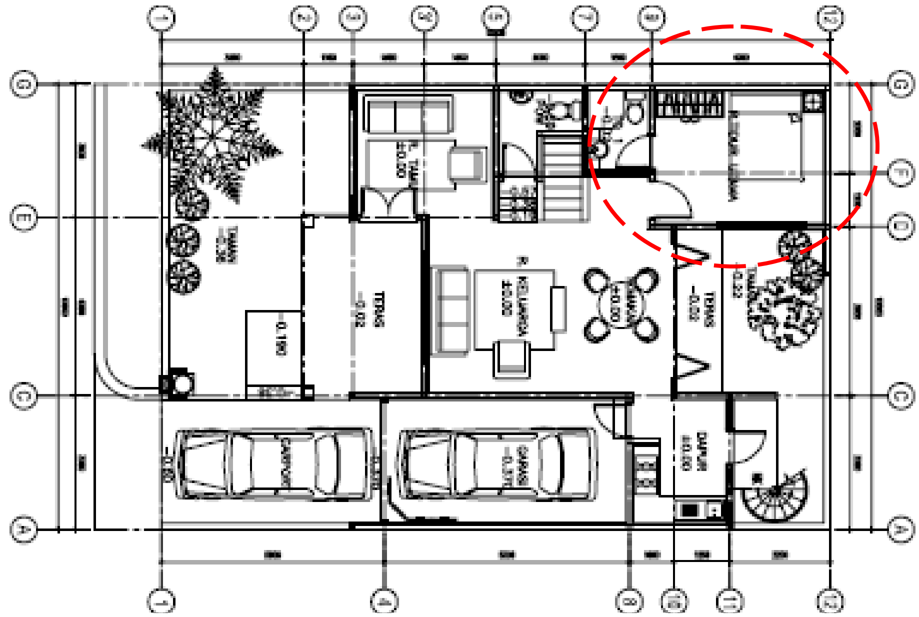

Figure 91. Floor Plan of Ground Floor (Jaya Real Property, PT.Tbk. 2008a)

In the ground floor, there is a garage on the front part of the house, which is in the simulation assumed unoccupied and unconditioned. There is also an open terrace in the front and the back of the house. In the base case, the position of the conditioned bedroom is in the backside, or on the south side of the house, marked with red circle named R.Tidur Utama. The gross area of R. Tidur Utama is 12 m². There is also common room called R.Tamu in the front side of the house that is usually used as a space to receive guests. In the middle part of the ground floor there is a living room and dining room as well as a kitchen. Behind the R. Tamu are the stairs that connect ground floor with upper floor. In this floor, the zones other than R. Tidur Utama are unconditioned.

In the upper floor, the three conditioned bedrooms located in the front side of the building, or in the reference base case is on the north side. The rooms are named R.Tidur I, R.Tidur II, and R.Tidur III with the gross area of 9.6 m², 17.2 m² and 9.6 m², respectively. In the middle part behind these bedrooms, there is an unconditioned living room, which is called as R. Duduk. At the backside of the upper floor, there is an unconditioned room and toilet for the servant of the family. There is also a roof space on the top of this house, this roof space is unoccupied and unconditioned except the assumption of ventilation available with the rate of 5 air exchange per hour.

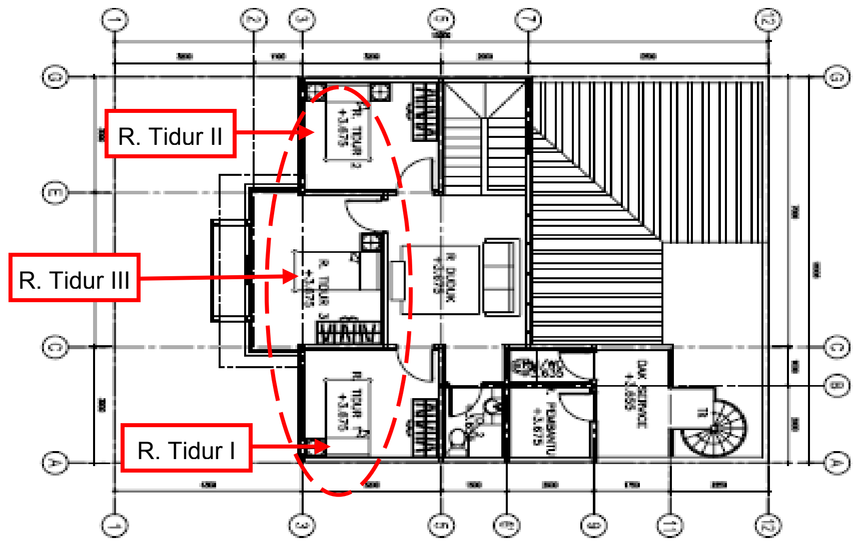

Figure 92. Floor Plan of the Upper Floor (Jaya Real Property, PT.Tbk. 2008a)

The perspective drawing of the single-family house in DesignBuilder, is visualized in Figure 93. The reference single-family house is oriented to the south. As shown in Figure 90, the house is attached to other houses, therefore, in the simulation, the walls that are connected to other houses are assumed as adiabatic walls.

Figure 93. Perspective Drawing of the Single Family House

As an additional information, it is usual that in the design of row houses, the sidewalls belongs to two different houses.

5.2.3.2 Constructional Properties

The constructional material of the single-family house is given by the building designers (Jaya Real Property, PT.Tbk. 2008a), and the material properties are shown in Table 8.

Table 8. U Value of Reference Single-Family House

Component	U Value (W/m^2K)
Wall	0.716
Ground Floor	5.394
Floor Slab	3.467
Roof Slab	5.000
Sloping Roof	5.221
Glazing	6.219

In the base case, the glazing G value is assumed 0.82 with the light transmission of 0.88. Thereafter, the sensitivity of using low G value will be done using the G value of 0.6, or 72% lower than the initial value, and light transmission of 0.74.

5.2.3.3 Internal Gains

The internal gains of the single-family house consist of occupancy, equipments, and lighting. This single-family house is assumed to be occupied by five persons. Based on ISO – 7730 standard (ISO 1994), one person will dissipate heat to the surroundings at a rate of 100 W with the activity “seated at rest”. One person dissipates sensible heat of 60 watts and 40 watts for latent heat. As it was explained, basically determining the occupant behaviour is not simple as there are a lot of uncertainty in daily living such as the schedule in each room. Therefore, it is assumed that schedules are consistent. The schedule of the presence of the people is based on the domestic family activities, on weekday and weekend. During weekday, the presence of the people is between 6.00 and 9.00 in the morning and from 17.00 to 6.00. During weekend, it is assumed that the people are present in the house in the whole day. Lighting is contributing to the heat dissipation of 3 W/m^2 for each bedroom and 2 W/m^2 for the bathrooms and garage. For the common room such as living room and dining room light contribute 5 W/m^2. There are also appliances that contribute heat gains of 15 W/m^2 in the living room and dining room, 10 W/m^2 in the R. Tidur Utama and computer in the R. Tidur I delivers heat dissipation of 5 W/m^2. All these appliances have a radiant factor of 0.4, which means that 40% of long-wave radiant heat dissipated in the zone, and 60% by means of convective heat transfer.

It is also assumed that there is an infiltration rate of 0.7 air exchange per hour. The consideration in defining the value of the infiltration rate is because it is common that in Indonesia the doors and windows are always opened day and night in order to have more comfort condition. This habit apparently benefits during the night but provides less comfortable condition during the day (Ekasiwi & Hokoi 2006) (Soebarto & Handjarinto 1998). During the sleeping time the conditioned rooms’ window and doors are closed. In addition, the ventilation rate is depending on the occupancy, which is 30 m^3/h/person.

5.2.3.4 Simulation Results and Analysis

The simulation result of the base case is shown as heat balance (Figure 94). It presents that windows contribute to the high-transmitted gains to the building, followed by the other building envelopes, such as roof, walls and floors. Yet, the building envelope is also useful in releasing heat to the environment, with higher magnitude than the heat gain.

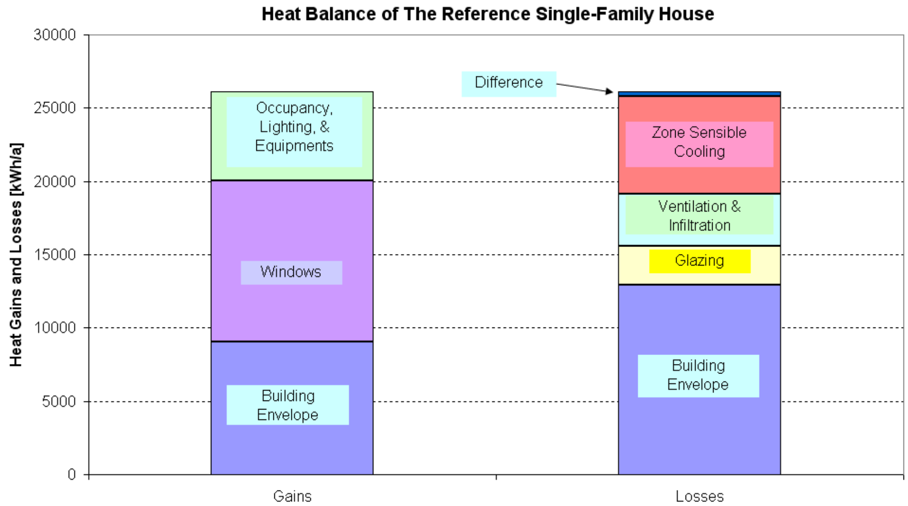

Figure 94. Heat balance of Reference Single-Family House

The subsequent step in order to obtain the optimum design concerning the cooling energy demand for this single-family house is by performing a sensitivity analysis. It was performed based on the parameter variation such as building orientation, shading effect, limiting power of the cooling equipment, the installation of roof insulation, the SHGC value of the glazing material and the effect of window blinds.

Effect of Orientation

Based on the site plan of these row houses, the single-family houses will be constructed in this area with different orientation. The reference base case of the single family house is oriented to the south. Figure 95 depicts the comparison of annual cooling energy demand as an effect of orientation.

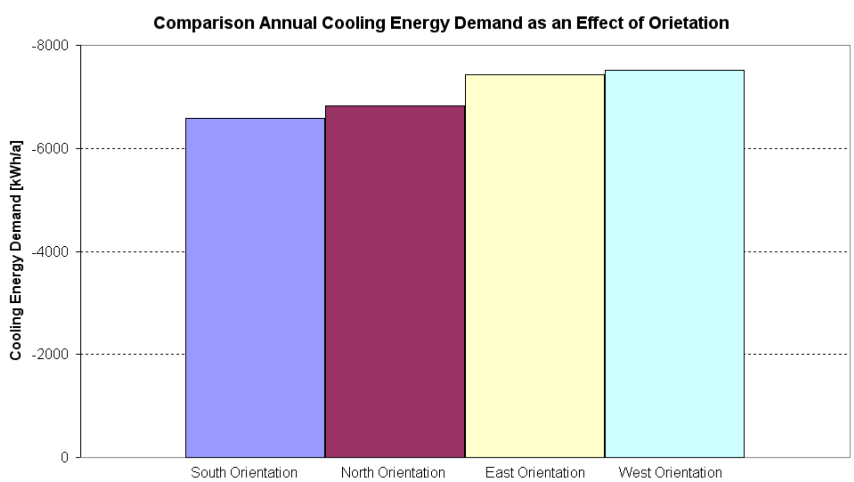

Figure 95. Comparison Building Cooling Energy Demand as an Effect of Orientation

It shows that south orientation as the base case gives the lowest cooling energy demand compared to other orientations. This confirms the result of the previous simulation that building with south orientation requires less cooling energy demand compared to other orientations as well as refers to the fact concerning the position of Jakarta in the tropical region.

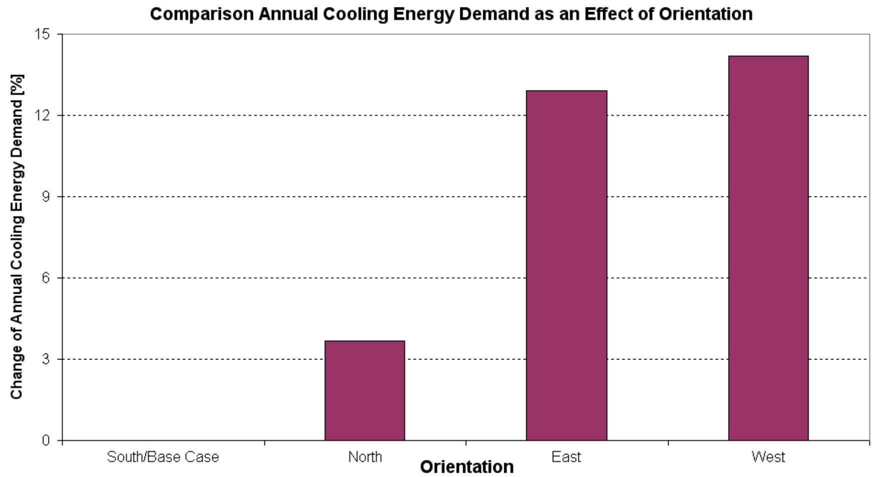

Figure 96. Percentage Difference of Annual Cooling Energy Demand

According to the building orientation, the percentage difference of the annual cooling energy demand is illustrated in Figure 96. It shows that east and west orientation give considerable difference compared to the south orientation, those are 13% and 14%, respectively. The north orientation apparently requires 3.5% higher annual cooling energy demand compared to the south orientation. The factor that causes the difference in the cooling energy demand concerning different orientation is the building envelope. The difference of heat gains and heat losses for each orientation is shown in Figure 97.

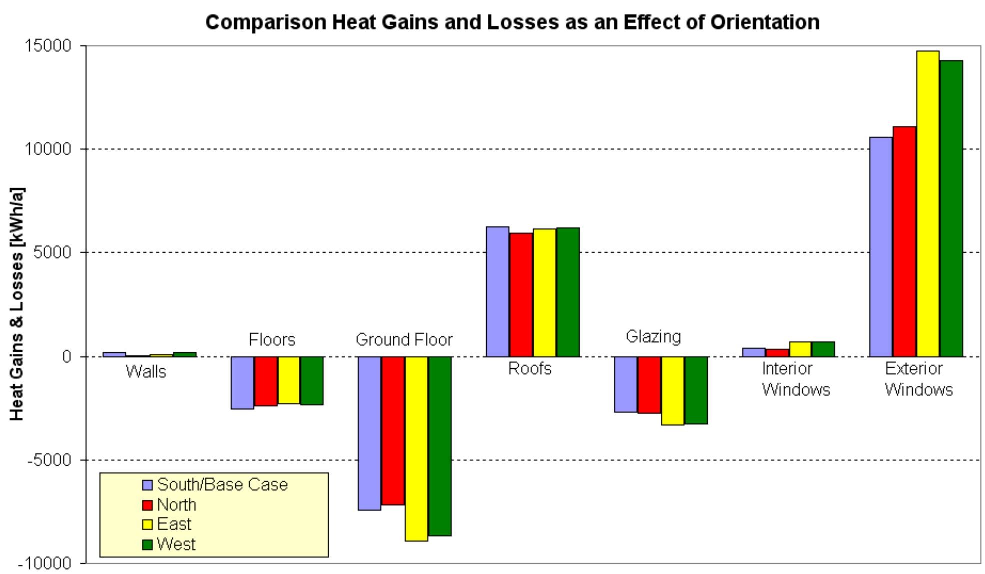

Figure 97. Comparison Heat Gains and Losses as an Effect of Orientation

The main contribution to the high heat gains are due to the exterior windows, specifically for the east orientation followed by the roof. Apparently, walls do not notably contribute to the heat gain, as two sidewalls are adiabatic. Conversely, ground floor releases heat to the environment.

Following is the analysis of the influence of building orientation to the indoor air temperature in the R.Tamu and living room and dining room as the unconditioned spaces in the ground floor. Figure 98 shows that during the day, the temperature in the R. Tamu behaves similar to the outside dry bulb temperature for all of building orientation. However, the west and east orientations cause the temperature of R. Tamu higher than that of other orientations. As R. Tamu is located in the front part of the house, obviously, this satisfies the hypothesis that east and west orientation will result to the higher heat gain than other orientations. During the night the temperature of R. Tamu is approximately 3°C higher than ambient temperature. Again east and west orientations cause the air temperature of R. tamu to be higher than that of other orientations, even though not too significant.

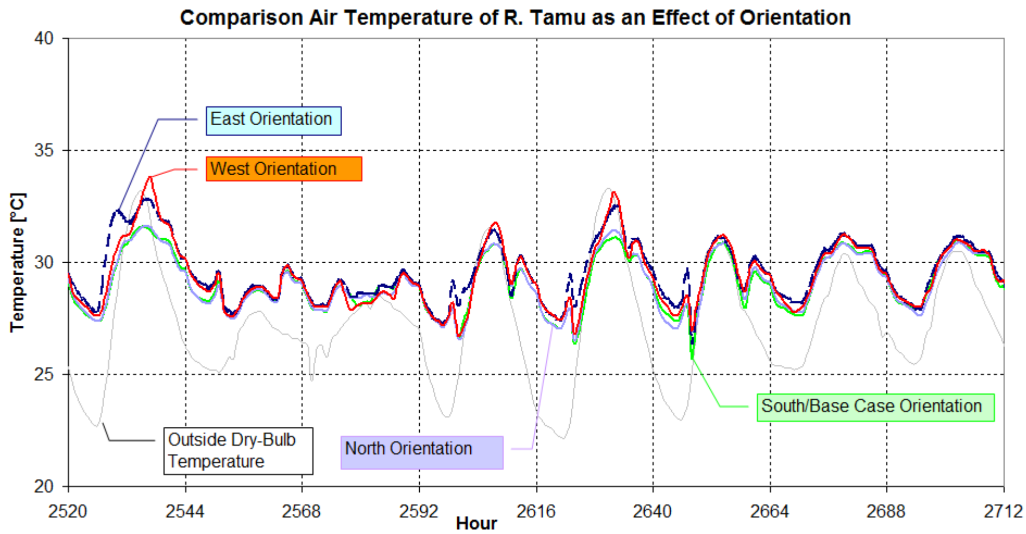

Figure 98. Comparison Air Temperature of R. Tamu as an Effect of Orientation

Figure 99 shows the hourly air temperature of the living room and dining room which is located behind the R.Tamu in the middle part of the ground floor. Thereafter, the living room and dining room will be mentioned as dining room.

It is found that the temperature in the dining room is close to the temperature of R. Tamu, except that the temperature for the west orientation is slightly lower than that of R. Tamu. This is because the position of dining room is in the middle of the house, therefore, this room receives less solar radiation than R.Tamu. It is predicted that because dining room is close to the stairs (which is in the simulation modelled as hole), consequently, there is probably more air movement in this area compared to the R. Tamu. The temperature profiles for both of R.Tamu and dining room fluctuates between 27°C and 34°C.

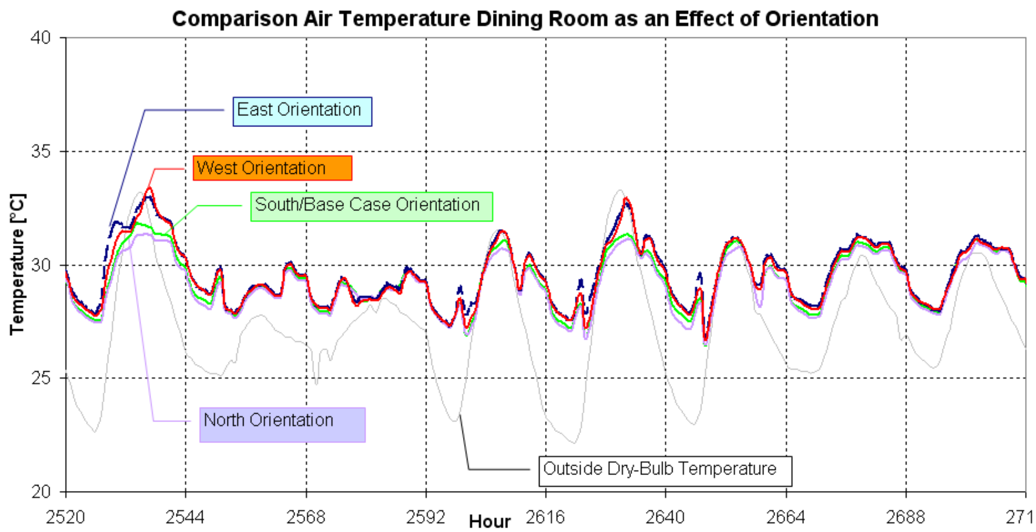

Figure 99. Comparison Air Temperature Dining Room as an Effect of Orientation

Effect of Shading

The effect of shading to the orientation as depicted in Figure 100 shows that there is no important influence of shading. It is found that the shading for south orientation is able to reduce the annual cooling energy demand by 2%, and less than 1% for the other orientations.

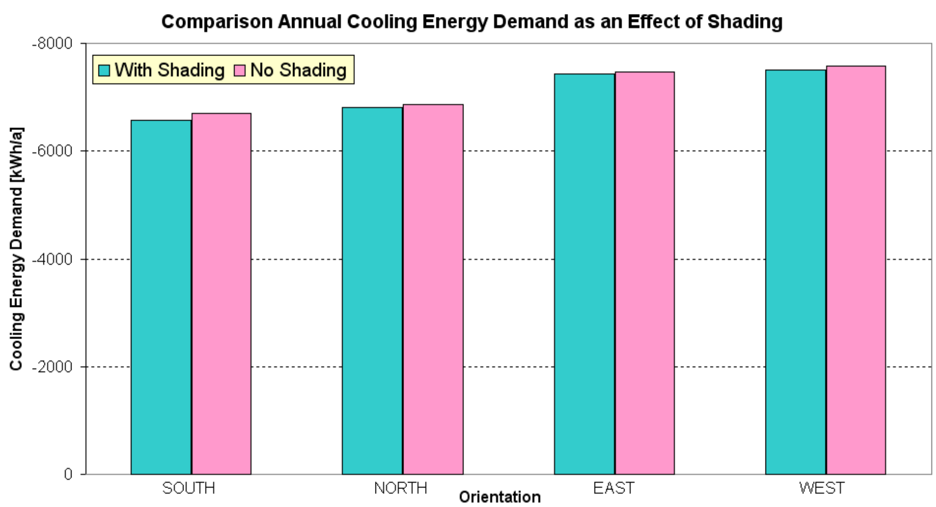

Figure 100. Building Cooling Energy Demand as an Effect of Orientation and Shading

This slightly effect on the annual cooling energy demand can be explained by the drawing of the shading's position as shown in Figure 101. The construction of the shading in front of R.Tidur III is expected to give an effect to the solar transmitted to this room. Apparently, the difference of the transmitted solar to this zone as an effect of shading is not significant.

This is because the area of the shading device is less than half of the glazing area of this room, in addition, the distance between the window and the shading device is about 0.5 m, which lead to the unimportant influence of the shading to the reduction of the annual cooling energy demand.

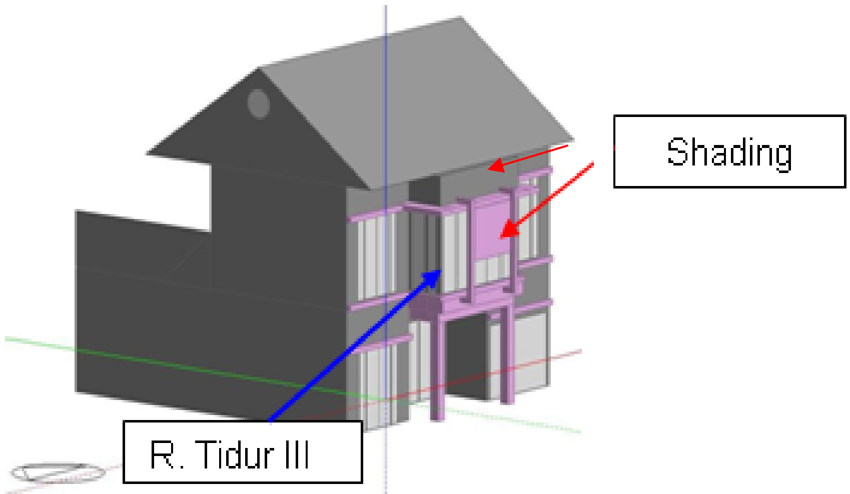

Figure 101. Construction of Shading

Furthermore, the upper part of the glazing area has already a horizontal shading construction, which prevents the solar radiation directly penetrate to this room. This is shown by the graph of hourly solar transmitted as described in Figure 102.

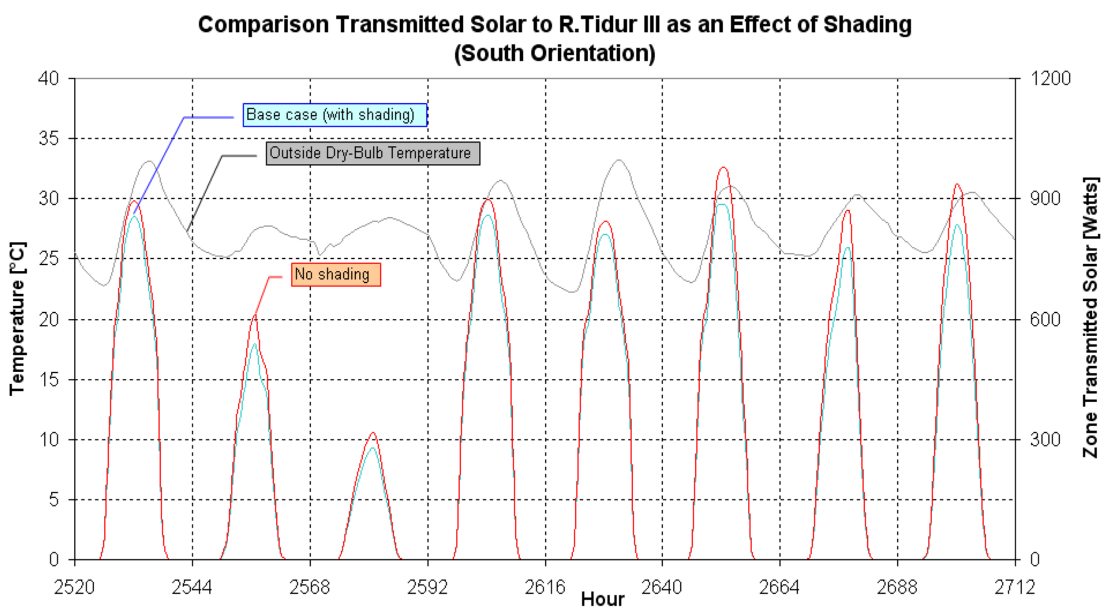

Figure 102. Transmitted Solar of R.Tidur III as an Effect of Shading (South Orientation)

The graph of hourly-transmitted solar radiation to the R.Tidur III in Figure 103 shows that the shading device reduces only a small amount of solar radiation penetrating the zone. Therefore, there is no significant reduction on the annual cooling energy of R.Tidur III.

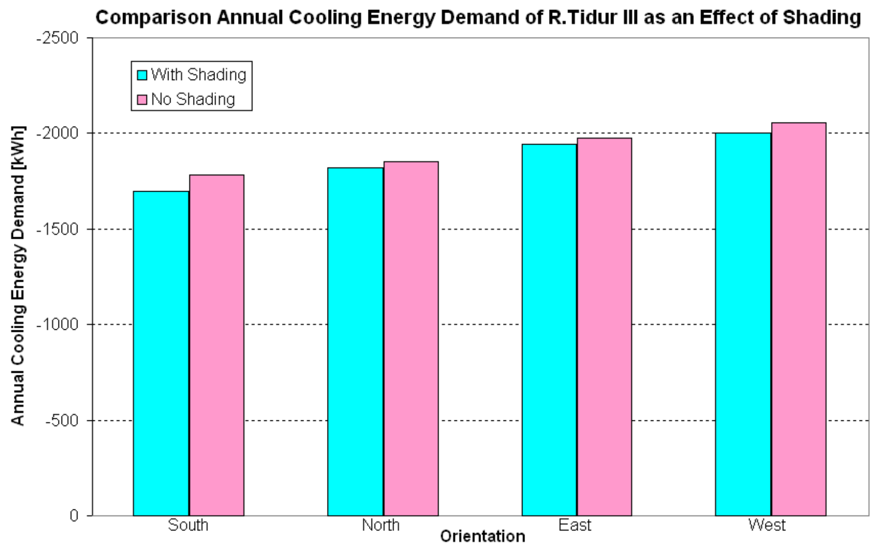

Figure 103. Annual Cooling Energy Demand as an Effect of Shading (R.Tidur III)

Effect of Limiting Power of Cooling Equipment

Limiting power means also reducing the operational and investment costs of the building. In this simulations, there are two scenarios introduced, those are limiting the power of cooling equipment into 1 kW and 0.5 kW. All setting were done for all conditioned rooms, those are R.Tidur Utama, R.Tidur I, R.Tidur II and R. Tidur III.

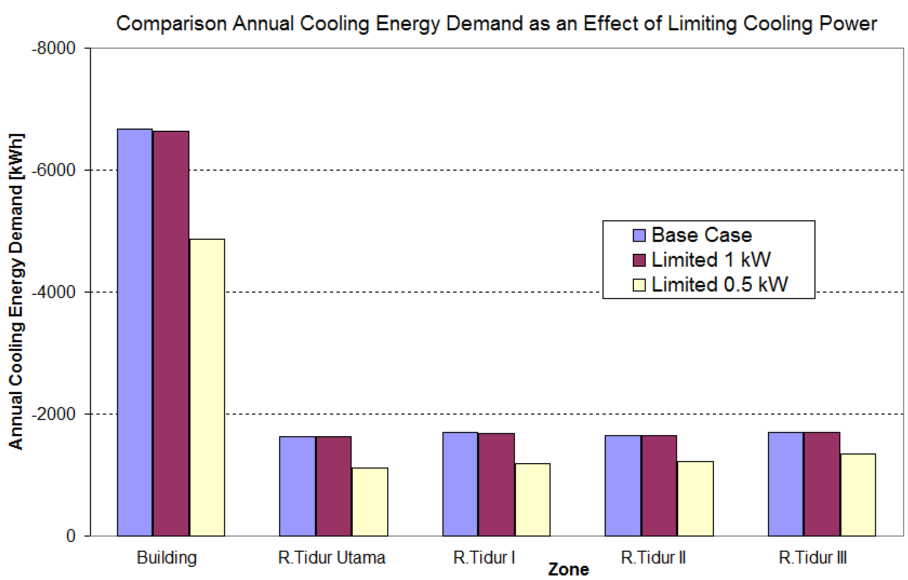

Figure 104. Comparison Cooling Energy Demand as an Effect of Limiting Power

The simulation results show that limiting power gives an effect to the reduction of cooling energy demand. Figure 104 illustrates that by limiting the power of the cooling equipment to 1 kW, there is no significant impact to the reduction of the cooling energy demand. This is because, in the base case, the peak cooling energy required is almost 1 kW for each conditioned rooms. Nevertheless, by limiting the power of the cooling equipment to 0.5 kW causes a considerable decrease of annual cooling energy demand of the building as all the conditioned rooms experience the reduction. It is found that the decrease of the building's cooling energy demand is 27%, of which R.Tidur utama contributes the highest reduction that is 32%. Thereafter, the analysis will be focused only for R. Tidur Utama.

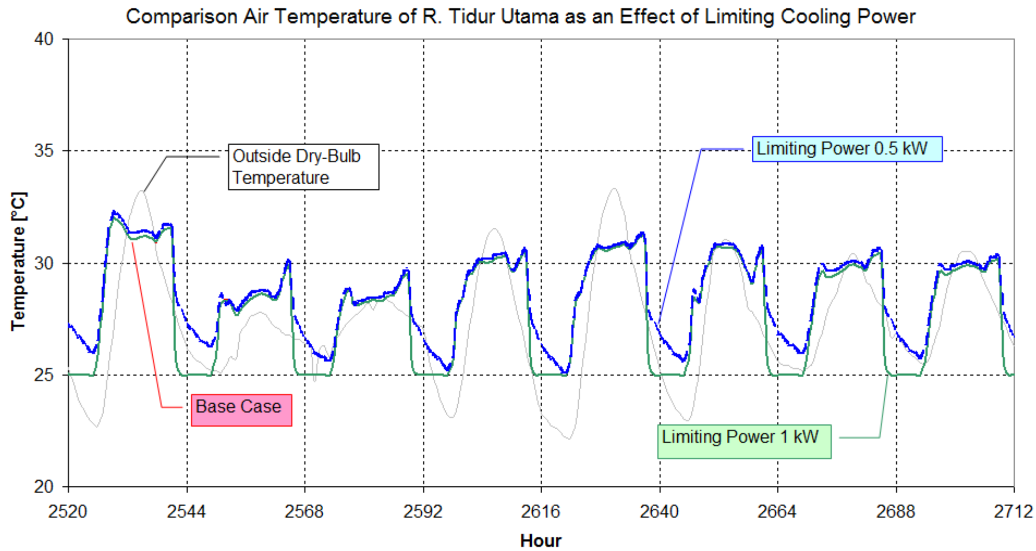

Figure 105. Comparison Air Temperature of R.Tidur Utama as an Effect of Limiting Power

The comparison of hourly temperature as an effect of limiting power, represented by air temperature of R. Tidur Utama as the zone contributes the highest reduction of annual cooling energy. The graph is shown in Figure 105. There is no significant difference of the air temperature inside the R.Tidur Utama during the day when the cooling device is switched off. During the night, the set indoor air cannot be reached with the limited power. However, it is shown that the temperature lies between 27°C and 25°C, which is still close to the range of comfort. The low cooling energy demand are due to the high indoor temperature.

It is known that limiting the power of the cooling equipment will reduce the annual cooling energy demand. However, reducing the cooling energy demand does not mean disregard the thermal comfort of the occupant. One of the side effects of limiting power is that the occurrence of indoor air temperature of which higher than the set point temperature.

Figure 106 shows the number of hours and the number of occurrence of the indoor air temperature in certain temperature ranges. There are hours at which the temperature exceeds the indoor set point temperature as an effect of limiting the power. Limiting the power into 1 kW causes no significant influence on the presence of excess temperature compared to the base case. However, there is considerable difference of the temperature occurrence in a specific range as an effect of limiting power into 0.5 kW.

The charts in Figure 106 show that in the temperature range below 26°C, limiting power into 0.5 kW results in a smaller number of hours, yet in the range of temperature between 27°C and 28°C, there are more. This is not giving significant effect for the comfort temperature, as the number of hours at which temperature is higher than 28°C are almost similar to the other cases. Further explanation concerning this excess temperature will be presented by the following graph.

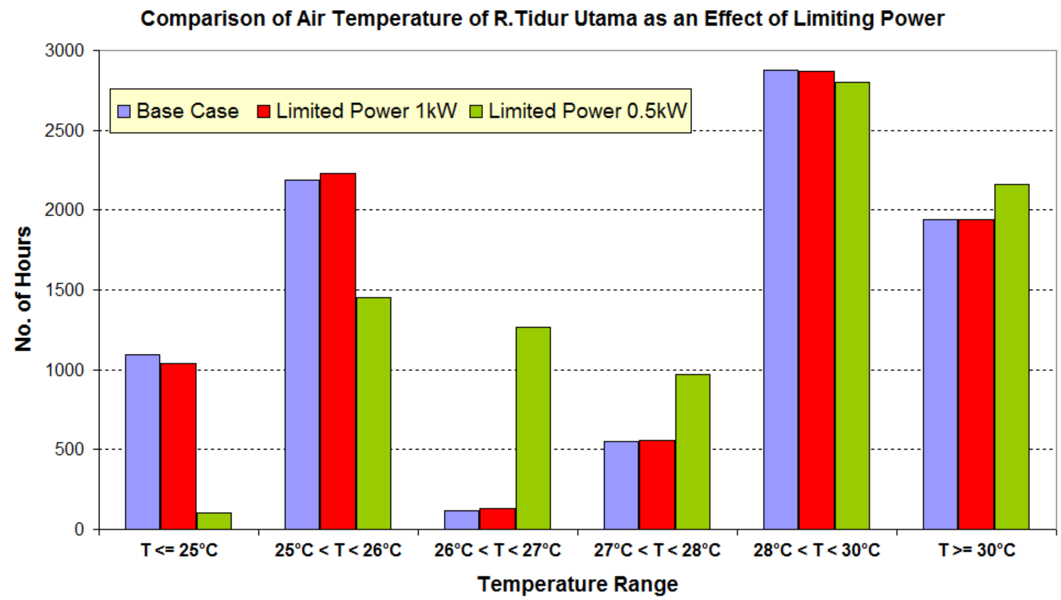

Figure 106. Number of hours concerning temperature excess as an Effect of Limiting Power

Figure 107 shows that for these three cases the temperature distributions are similar concerning the number oh hours that the indoor air temperature ranged between below and equals to 25°C and 28°C.

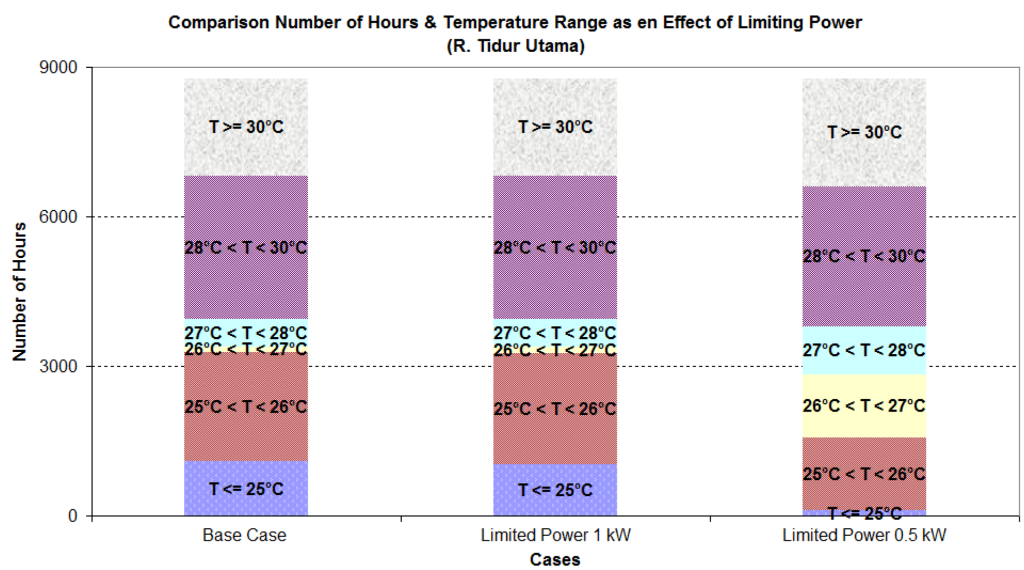

Figure 107. Comparison No. of Hours & Temperature Range as an Effect of Limiting Power of R. Tidur Utama

For the base case and the scenario of limiting the cooling power to 1 kW have approximately the same distribution for the four temperature ranges between below and equals to 25°C and 28°C. However, in the case of limiting the cooling power to 0.5 kW, the temperature distribution is far smaller in the range of below and equal to 25°C as well as in the range of 25°C – 26°C. The distribution is more in the temperature range of 26°C – 27°C and 27°C – 28°C. Those differences in the number of hours concerning the temperature distribution are clarified in Figure 108. It shows the hourly air temperature of

R. Tidur Utama as an effect of limiting power of cooling equipment, and the profile of the occupant.

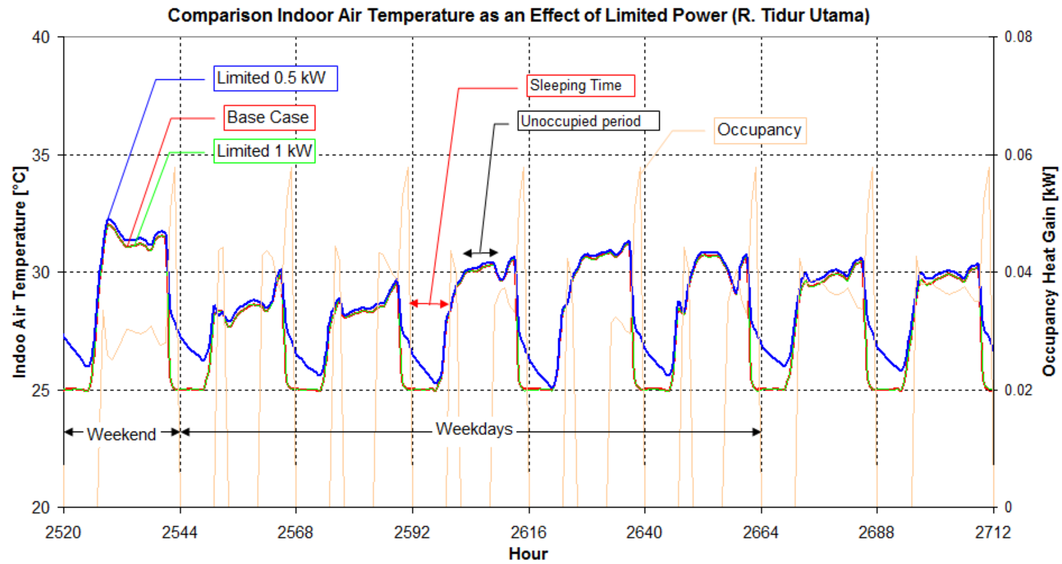

Figure 108. Comparison Indoor Air Temperature of R. Tidur Utama as an Effect of Limited Power, analysis of Occupancy Time

It can be seen that both the base case and the case of limiting the power to 1 kW have approximately the same temperature profile. Consequently, refers to previous diagram (see Figure 107) the number of hours concerning the distribution of indoor air temperature are similar. The graph also shows that during the day there is no important difference of indoor air temperature as an effect of limiting cooling power, since the cooling device is not working. Hence (refers to Figure 107) the number of hours for these three scenarios are nearly the same for the temperature range above 28°C.

However, during the night (sleeping time) when the cooling device is operated, it is found that for the case of limiting power to 0.5 kW, there is a delay to reach the indoor set point temperature, moreover, it is shown that some days and during the weekend, the temperature can not reach the indoor set point temperature, or approximately reach . 26°C or 27°C. Hence, the temperature distribution in Figure 107 shows that he number of hours for the temperature range between 26°C and 27°C is more in this case than the other cases. In addition, the number of hours in the temperature range of 27°C – 28°C is also moderately higher that other scenarios.

Figure 109 shows the comparison of the hourly cooling energy demand in the R.Tidur Utama, as an effect of limiting power. It can be seen that for limiting power of 1 kW, there is no effect to the change of hourly cooling energy demand. Its hourly cooling energy profile is approximately the same as the base case. However, there is substantial difference for the scenario of limiting the cooling power into 0.5 kW. Even though the hourly cooling demand for limiting power 0.5 kW is only about half of the base case, yet the temperature is only influence moderately. It means that by operating the low capacity of cooling equipment, there is no essential influence on the increase of indoor air temperature during the operational time. Furthermore, it reduces the annual cooling energy demand significantly which means reducing the operational cost.

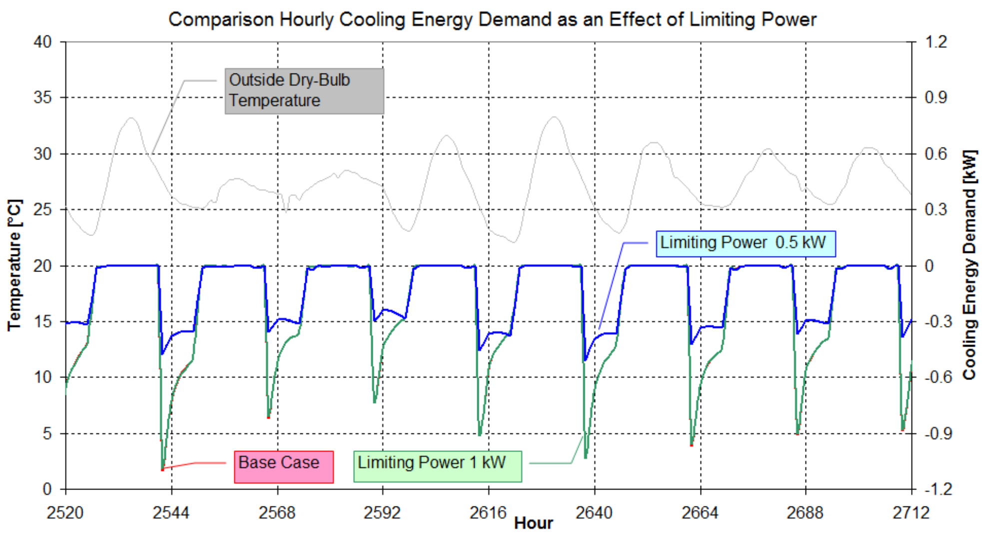

Figure 109. Cooling Energy Demand of R. Tidur Utama as an Effect of Limiting Power

In addition, by limiting the power will also diminish the high peak load, which causes essential reduction in term of operational cost. In order to achieve the set point temperature, it is suggested to switch on the device earlier. This is obviously will put additional operating hour, however, still provides lower operational cost. In conclusion, it is recommended to use low capacity of cooling equipment as it reduces significantly not only the investment cost, but also the operational cost. Moreover, it is still able to provide the thermal comfort condition.

Effect of Roof Insulation

The simulations in order to investigate the effect of roof insulation to the reduction of cooling energy demand were performed by installing two different thicknesses of insulation, of 2 cm and 5 cm. With the insulation thickness of 2 cm, the U value of the roof decreased by 74%, and 88% for the thickness of 5 cm. It is expected that with this low U value will reduce the transmitted solar heat to the house through the roof.

Figure 110 shows the comparison of annual cooling energy demand of the house as well as the conditioned bedrooms as an effect of installing roof insulation. It can be seen that there is a slight decrease of the cooling energy demand as an effect of roof insulation. It reveals that, for the roof with an insulation thickness of 2 cm, the reduction of annual cooling energy demand is 5.4%, and for the 5 cm roof insulation it amounts a decrease of 7.6%. These reductions are due to the cooling energy reductions of rooms in the upper floor, such as R. Tidur I, R. Tidur II and R. Tidur III. There is no reduction of cooling energy demand for the R.Tidur Utama as this room is located in the ground floor, therefore, there is no important influence of the roof insulation.

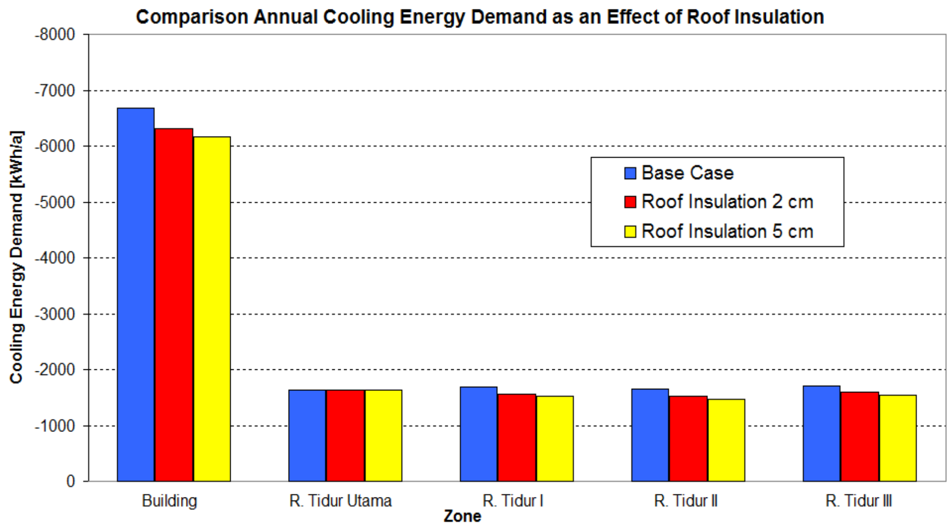

Figure 110. Comparison of Cooling Energy Demand as an Effect of Roof Insulation

The comparison of the roof heat gain as an effect of roof insulation is graphed in Figure 111.

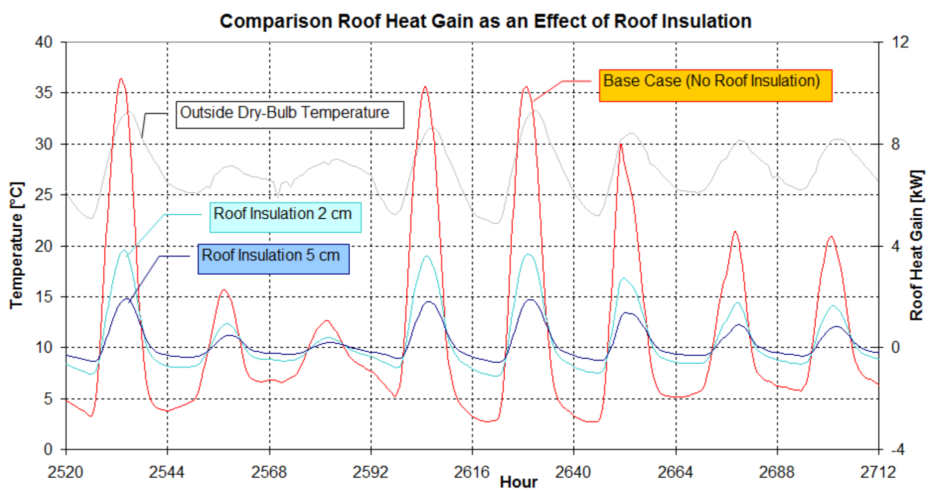

Figure 111. Comparison of Roof Heat Gain as an Effect of Roof Insulation

There are significant reductions of the roof heat gain as an effect of roof insulation. During the day, a roof insulation of 2 cm is able to reduce 60% of solar heat gain, and 80% for the insulation thickness of 5 cm. Conversely, during the night the heat release to the environment not as high as that without insulation. In general, the amount of the heat that is absorbed by the roof material and transmitted into the house during the day is approximately only 20% released to the environment during the night by the roof. This is because the roof insulation, which acts as a resistant, prevents the solar heat gain being transmitted to the roof space, however, during the night the insulation traps the heat inside the roof space. In addition, as the ambient temperature during the night is not significantly low in the tropical climate, therefore, the temperature difference between inside and outside roof space is not considerable, thus, also no important heat transferred to the environment occurs.

The confirmation concerning the influence of the roof insulation to the temperature profile inside the roof space is depicted in Figure 112. It can be seen that the insulation on the roof gives considerable effect to the reduction of roof space temperature. Figure 112 illustrates that the uninsulated roof causes the air temperature inside the roof space sometime approaching 10°C higher than ambient temperature during the day and during the night, the difference decreases to 5°C.

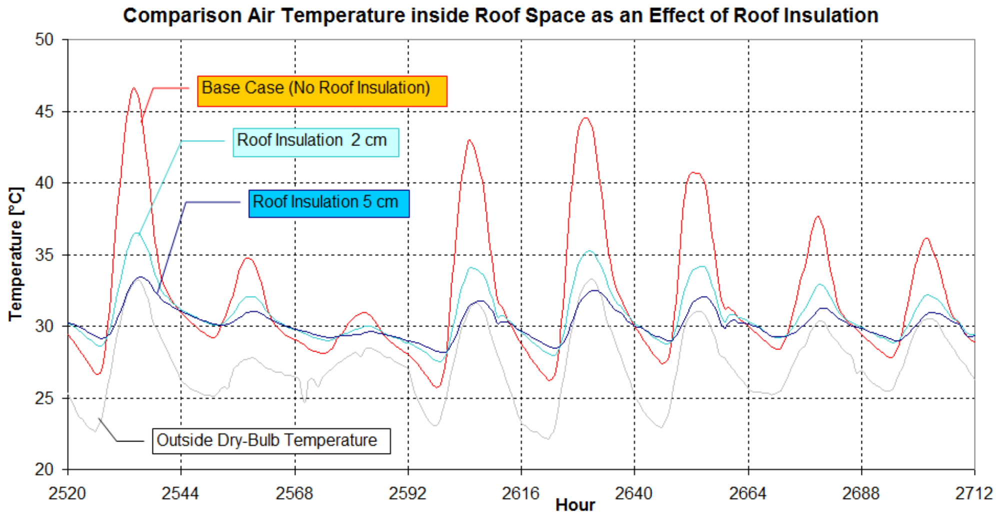

Figure 112. Comparison of Roofspace Air Temperature as an Effect of Roof Insulation

With the additional roof insulation, the temperature inside the roof space significantly decreases, yet during the night there is no important difference with that of no roof insulation. Moreover, it is shown that the uninsulated roof has lower roof space temperature than insulated roof.

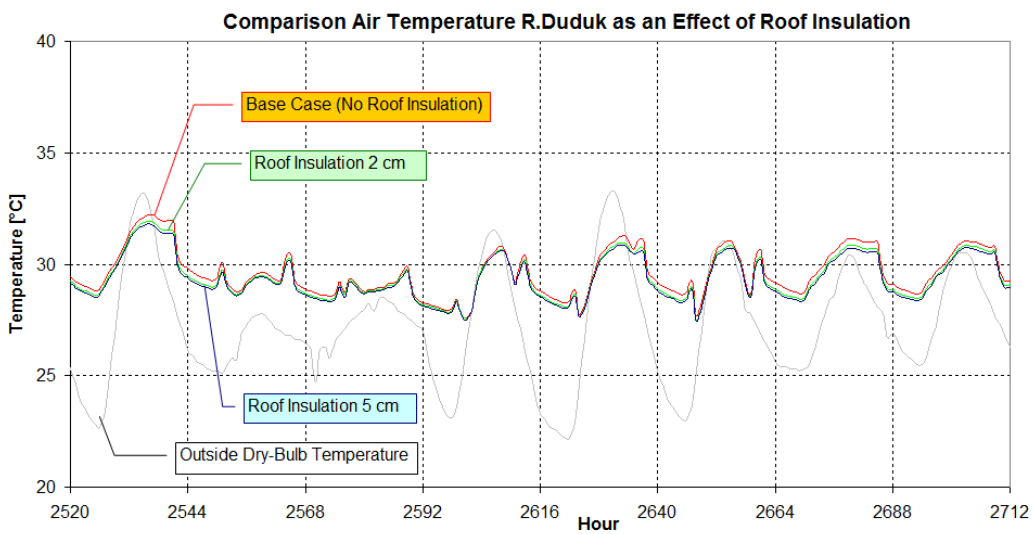

Figure 113. Comparison of Upper Floor Air Temperature as an Effect of Roof Insulation

The above graph shows the comparison of indoor air temperature of R: Duduk as an effect of roof insulation. R. Duduk is the unconditioned area of the house, which is located in the upper floor. Hence, it is expected that there will be an important influence of the roof insulation to the reduction of indoor air temperature.

As it is depicted in Figure 113, the air temperature in the upper floor is not changing significantly and only slightly decreases as the effect of the roof insulation even though the roof space temperature is substantially decreases. This occurrence conform the same condition that existed in the previous simulations of shophouses.

Effect of SHGC value of the Glazing

The simulations in order to study the effect of the SHGC value of glazing material to the reduction of annual cooling energy demand were performed in two different scenarios. The first scenario was by choosing a single glass material with low SHGC value, and the second one is using a double glass window with an approximately similar SHGC value as the first scenario. Both single glass and double glass material have the SHGC value of 72% lower than the SHGC value of the base case, except the U value, that single glass has 61% U value higher than the double glass.

The simulation results is shown in Figure 114. A low SHGC value for single glass results in a higher reduction of the annual cooling energy demand compared to that of a double glass. It is revealed that the building's cooling energy demand reduces into 5.9% as the effect of low SHGC value with single glass and 3.2% with double glass.

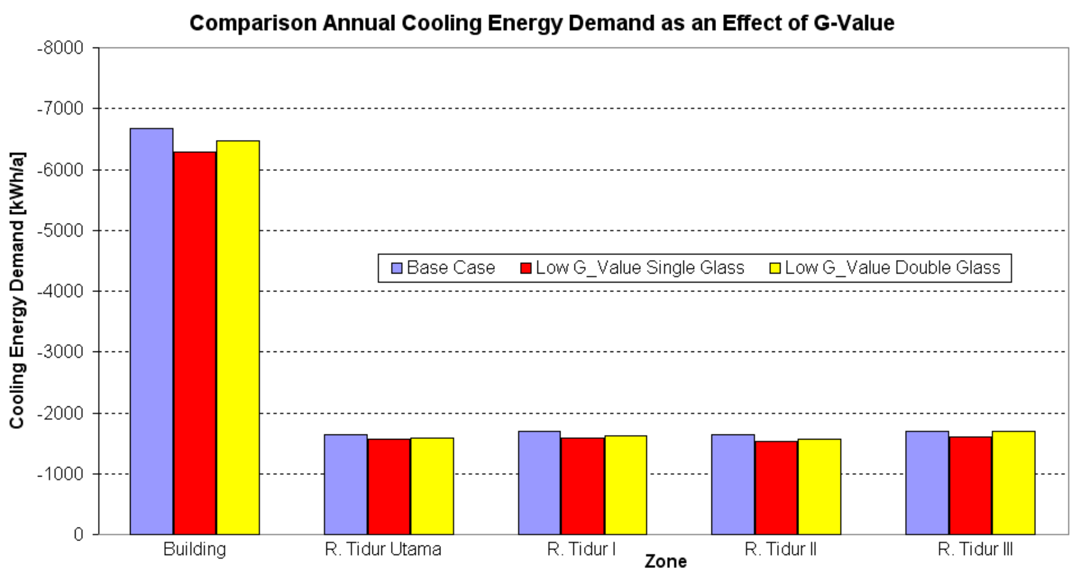

Figure 114. Comparison of Cooling Energy Demand as an Effect of G Value

The detailed explanation regarding the results is shown in the following graph, which describes the hourly heat transmitted through the window as an effect of SHGC value. Figure 115 presents that using low SHGC value causes lower solar heat transmitted into the building through the window. However, with the same SHGC value but different type of glazing, it is found that double glazing will absorb more solar heat than single glazing even though the difference is not significant. This is because double glazing window has gas filling between its two layers, and gas is known as a material with poor conductivity. As a result, double glazing 'traps' the solar radiation into the double façade and it is heated up during the day, and keep the warm during the night time. It is found that double glazing gives advantage when it is combined with ventilation or applied in a high rise building which is designed with stack effect (Hien et al. 2005)(Yellamraju 2004).

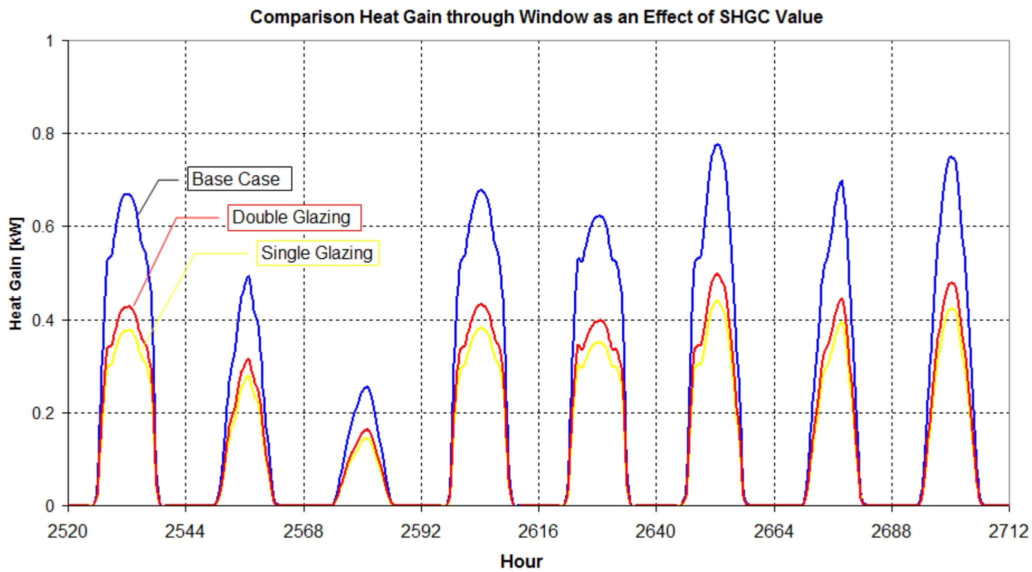

Figure 115. Comparison Hourly Heat Gain through the window as an Effect of SHGC Value

The other consideration should be taking into account when using the double glazing in tropical region is the high price compared to the single glazing. A double glazed window is more beneficial to be applied for the building design in the region other than tropical regions. It provides good thermal insulation, hence reducing the heat loss to the environment during cold period. In addition, with double layers of glasses, it is tighter and acts as a good insulation. As a result, it will decrease the heating demand. Moreover, normally double glazed is aimed more for acoustic purpose.

Effect of Installing Window Blinds

The scenarios of installing window blinds were done in order to observe its effect on the reduction of cooling energy demand. There are two differences scenarios, those are placing the window blinds inside the room and outside the room. The arrangement of window blinds was done by assuming windows were shaded by the blinds between 06.00 and 21.00.

The simulation results present that installing window blinds apparently give no substantial influence on the reduction of annual cooling energy demand. Figure 116 shows the comparison of annual cooling energy demand as an effect of installing window blinds. It is found that for the whole building the decrease is only 3.8% when the blind is installed inside and 5.4% for blind placed outside the windows. The highest reduction occurred in R.Tidur I and R.Tidur II, those are 4.5% and 4.6%, respectively when the blinds is installed inside the window. For outside blind, the annual cooling energy demand of R. Tidur I and R. Tidur II decreased by 6.1% and 6.3% accordingly. This is because the house is facing to the south, and the position of R. Tidur I and R. Tidur II is on the south east and south west of the house (refers to Figure 92). It can be summarized that the position of the window blinds gives no considerable effect to the reduction of cooling energy demand and placed the blind outside the window will reduce more cooling energy demand than inside blind. This will change significantly when the orientation of the building would be more to east or west.

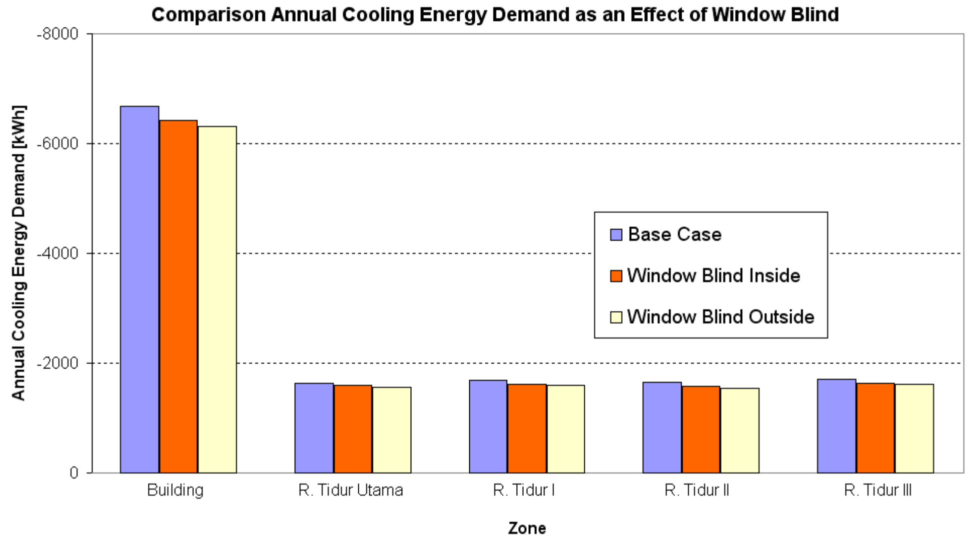

Figure 116. Comparison Cooling Energy Demand as an Effect of Window Blinds

Figure 117 shows the annual solar heat gain transmitted through the window and glazing.

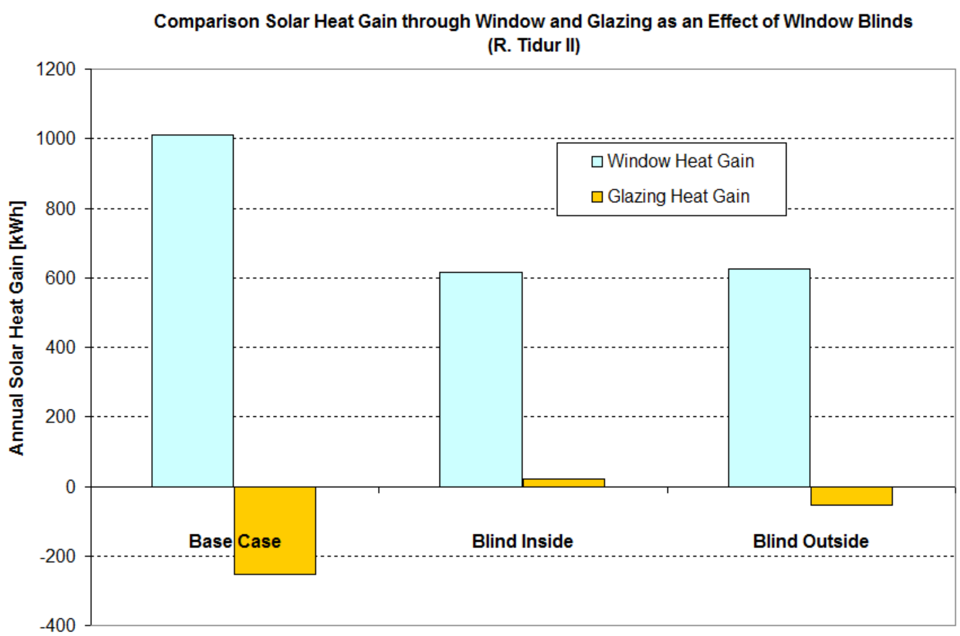

Figure 117. Comparison of Annual Solar Heat Gain through Window and Glazing as an Effect of Window Blinds (R. Tidur II)

It can be seen that there is a substantial decrease in the solar heat gain through the window as an effect of window blinds. However, there is no significant difference as the effect of blind position either blind is inside the window or is outside. The charts also describes that the window without blinds will release more heat to the environment than that of with blinds. This is because there is no obstacle close to the window, therefore the heat will be more easily released to the environment. Moreover, the heat losses via the glazing occur during the night, while the cooling equipment is switched on. The effect of blinds position reveals that placing window blinds outside the window will release heat to the environment, conversely, the blinds inside the window will gain heat.

Placing blind inside the window is expected to reduce the heat gain transmitted to the room, however as the heat will be repelled already inside the room hence it will keep the gap between the window and the blind warm. On the other hand, a blind that is positioned outside the window will prevent the heat before it enters the room.

Figure 118 shows the comparison of annual cooling energy demand of the base case, the scenario case of using window blind and the case file of using low SHGC value of the glazing. In overall, there is no valuable decrease of the annual cooling energy demand as an effect of using low SHGC value as well as installing window blinds. For the whole house, it can be seen that installing window blind outside gives similar result as using low SHGC value with single glass. In addition, installing the window blind outside gives a comparable influence as using low SHGC value with double glass. It means that there is the possibility to choose, either to invest for the window blind and placing it outside the window or using the single glazing with low SHGC value in order to reduce the cooling energy demand of the building.

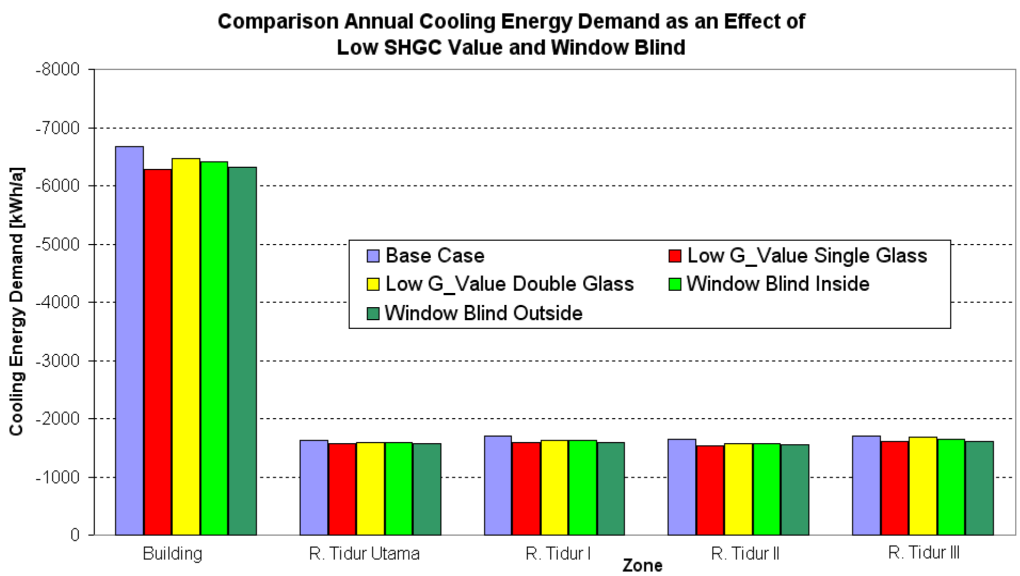

Figure 118. Comparison Annual Cooling Energy Demand as an Effect of Window Blind and Low G_Value of Glazing

The difference results of annual cooling energy demand are mainly contributed by the solar heat gain trough the window and glazing. Figure 119 shows the comparison of annual solar heat gain through the window and Figure 120 shows the comparison of annual solar heat gain through the glazing. Overall, the base case shows that there is a high amount of solar energy transmitted through the windows compared to those of other cases. However, the glazing counteract this heat transfer by releasing high amount of heat to the environment compared to other cases, therefore this results to the similar level of cooling load of the house.

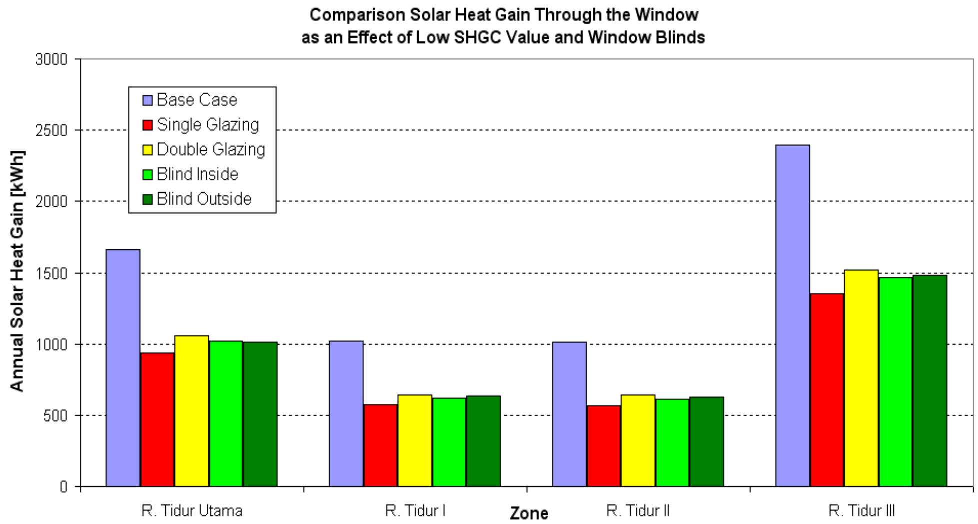

Figure 119. Comparison of Annual Solar Heat Gain through the Window as an Effect of Low SHGC Value and Window Blinds

It is also found that for all zones, placing the window blinds inside the room apparently will always results to heat transmitted to the room, therefore, this strategy should be avoided.

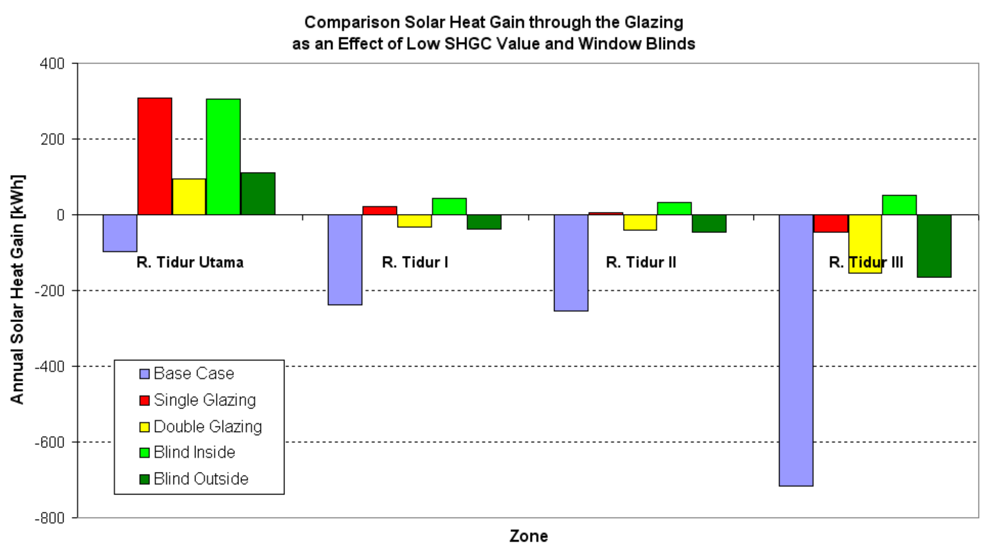

Figure 120. Comparison of Annual Solar Heat Gain through the Glazing as an Effect of Low SHGC Value and Window Blinds

Conclusion

There were six different parameters analysed in order to find the potential strategies in reducing the energy consumption, especially in terms of cooling energy demand, for a single-family house. Those parameters consist of building orientation, shading of window, roof insulation, limiting the power of the cooling equipment, the SHGC value of the glazing material and the window blind. It reveals that limiting the power of the cooling equipment gives the most significant impact to the reduction of annual cooling energy demand. Moreover, the lower capacity of the cooling equipment lowers the investment cost as well as operational cost. Similar effect would have taken place with increasing of set point indoor temperature.

In addition, for the case of single-family house, another strategy to reduce the cooling energy demand is by using roof insulation. User behaviour also influences the energy savings such as opening the windows and the door in the early morning to provide natural ventilation. Hence, the low outside air temperature will cool the indoor air temperature in the morning while the cooling equipment is off.

5.2.4 Puri Kahuripan

In this simulation, the thermal simulation results of high-rise office building in Surabaya will be presented.

5.2.4.1 The building reference

The simulations were undertaken using a high rise office building named Puri Kahuripan, which is designed by Dpavilion Architects, Surabaya, Indonesia (Dpavillion Architects 2008). The building is located in Sidoarjo, regency adjacent to Surabaya, Indonesia. Therefore, in this simulation the weather data of Surabaya will be applied.

Figure 121. Perspective Drawing of Puri Kahuripan

Figure 121 shows the view of the office building studied. The reference building simulated is a nine-storey office building, of which its ground floor is used as a lobby, the first until the eighth floors are used as office areas, which are rented to the tenants, and the ninth floor is used as a penthouse only for the management of the building. The figure depicts that this office building is designed with a big portion of the front façade glazed. The purpose of this design is that the designer wanted to expose the interior of the office to the public as this building is the highest building in this complex and it is facing to the highway in Surabaya.

Figure 122 shows the site plan of the building. It can be seen that the building is designed together with other buildings in a building complex, which will be constructed in the future.

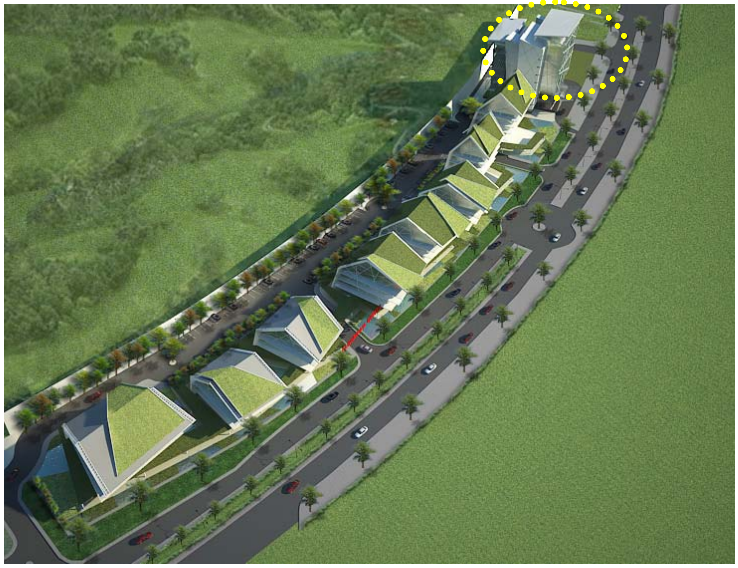

Figure 122. Site Plan of Puri Kahuripan

As it is described, this building is designed along the east-west axis and its front façade oriented to the east, whereas, according to previous research (Andarini et al. 2008), east orientation will gain the highest solar energy radiation. The other disadvantage of the available plan is that the building is designed as the highest building amongst the others; therefore, there will be no shading effect from other buildings.

Figure 123 shows the three-dimensional drawing of the building, generated by DesignBuilder. The floor space on one level including the areas covered by internal walls and access facilities amounts to 812.7 m², of which almost 85% of this space, are used as offices area. This area is equal for the first floor and the second floor, but then increases on the third floor up to the eighth floor as the wall façade has an inclination about 92°. For the eighth floor, there are two separate floor areas - the front of which covers an area of 400 m², and the rear area is 165.5 m².

At the south side of the building as shown in Figure 123, there will be a perforated steel sheet constructed to prevent the heat from this building rejected to the neighbouring buildings, and to reduce solar radiation achieving the south wall. In the simulation, this perforated steel sheet then will be modelled as steel sheet with opening on the bottom and top part.

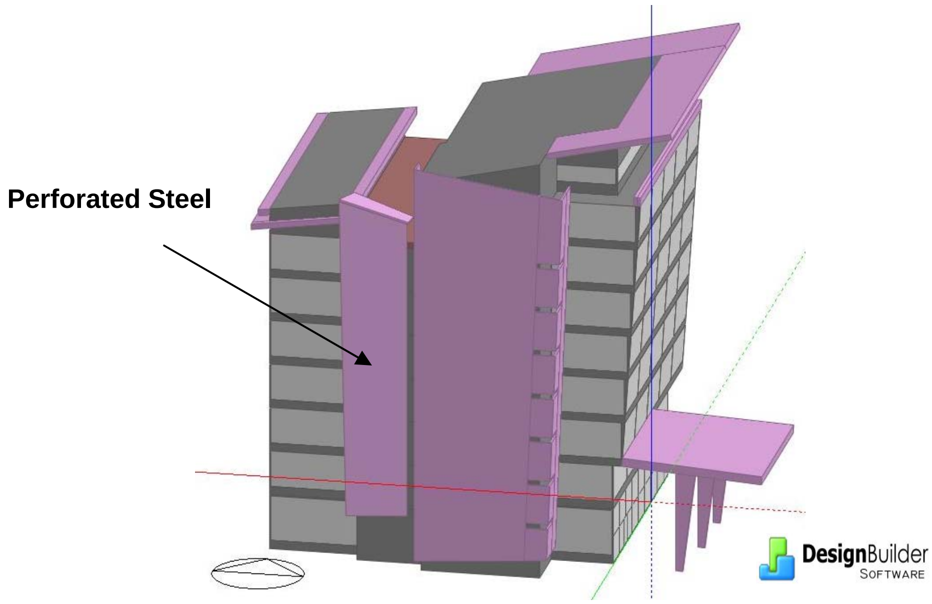

Figure 123. Drawing of the Building (generated by DesignBuilder)

The north side view of the building as depicted in Figure 124 shows that the north wall is not fully glazed, and on the top floor there is penthouse which has an area smaller than the other floors.

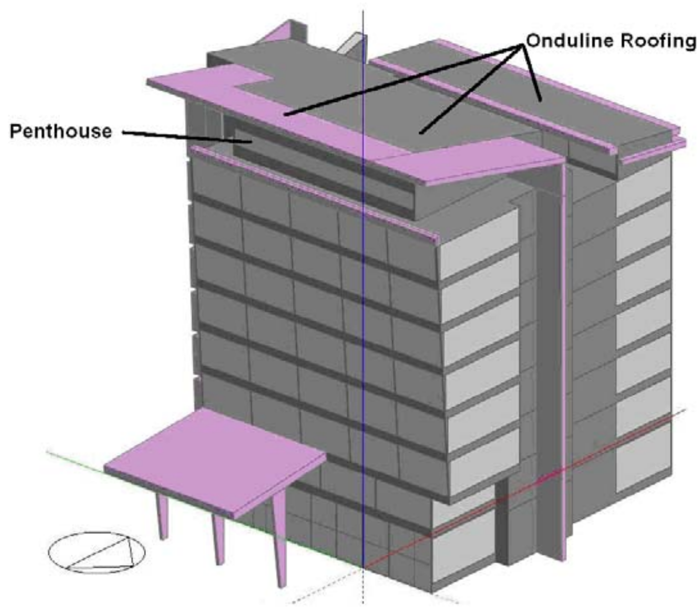

Figure 124. Drawing of Building from the North Side and the Penthouse's position

This penthouse is also shaded by a building block, which is constructed from a material manufactured from organic fibre called onduline. Onduline is a lightweight metal material especially for roofing which is tough and flexible to be mounted. It also provides high value of thermal insulation, therefore, it is an appropriate energy efficient material (www.compositeglobal.com/onduline.htm). The other consideration of using onduline as the roofing material is that this material does not reflect the light. This building is located nearby the International Airport in Surabaya, Indonesia, and there is a regulation from the Government, that due to the air traffic safety, all high-rise buildings must use non-reflective material and red colour for their roof. Therefore, onduline was chosen as the roof material for the roof of this building.

5.2.4.2 Constructional Properties

The constructional material of this building consists of material commonly used in Indonesia, such as brick wall finished with light colour painting, reinforced concrete, and so on. The slabs construction is made of concrete, air gap, and gypsum board ceiling. The air gap aims to provide space for the water, electricity, and ducting for air conditioning system as well as hydrant installation. The gypsum board ceiling was chosen as it is useful as noise protection.

Table 9 shows the U value of the thermal characteristics of reference office building's envelope, based on the suggestion by the architects.

Table 9. U-Value of the Reference Office Building's Envelope

Component	U-Value
External Wall	1.642
Roof	4.244
Floor Slab (ground floor-basement)	5.428
Floor Slab	3.933
Ceiling	7.116

As shown in Figure 125, there are side walls at the north and south orientation which is made of alucobond. Alucobond is a light composite material consisting of two aluminium cover sheets and a core made of plastic. The U value of alucobond ranges between 5.3 ~ 5.6 W/m²K, and it has a wide range of temperature resistance, that is between -50°C and +80°C (www.alucobondusa.com).

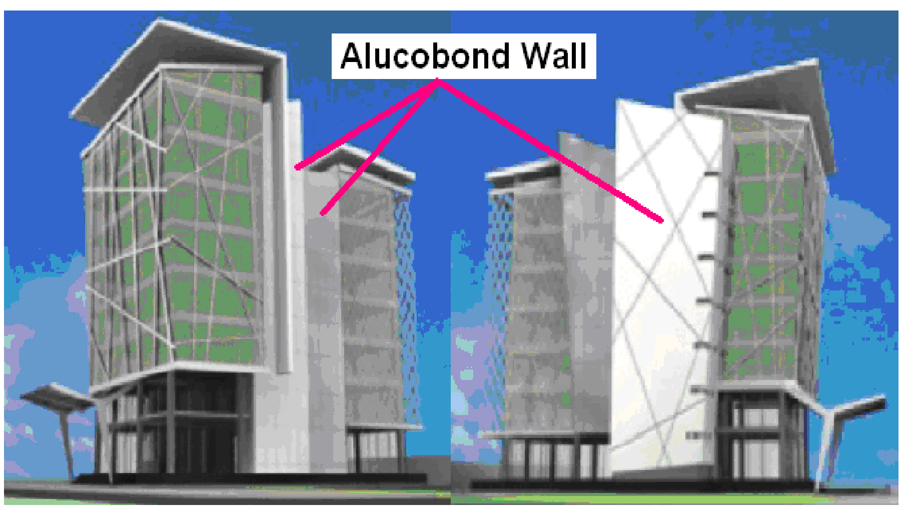

Figure 125. Position of alucobond wall

The properties of glazing material as suggested are shown in Table 10, and this glass material is used for the whole building.

Table 10. Glazing Characteristics

Characteristic		Value
Thermal	Thickness	8 mm
	Conductivity	0.9 W/m.K
Solar	Solar Transmittance	0.26
Visible	Light Transmittance	0.52
SHGC		0.434
U value		6.056

Later on, on the west side, the architects plan to put in a plantation in order to reduce solar heat gain transmitted through the building. In this simulation, this shading effect from the plantation will be simulated as a lower SHGC value of glazing material.

5.2.4.3 Internal Gains

The internal gains of the reference office building consist of occupancy, computers, and lighting. In the office areas and rooms for customer reception, one person per 15 m² floor area is assumed. In the case of full occupancy, this assumption results in 48 people being simultaneously present in each floor of the building, except in the penthouse. Based on ISO – 7730 standard (ISO 1994), one person will dissipate heat to the surroundings at a rate of 100 W with the activity “seated at rest”. One person dissipates sensible heat of 60 watts and 40 watts for latent heat. It is assumed that people work only from Monday to Friday, and there are no people assumed to be inside the building on weekends. Lighting in the offices area will contribute to the heat dissipation of 10 W/m². All internal gains follow an operational schedule of working hours. It is also supposed that there is an infiltration rate of 1 air change per hour due to leakages in the first floor as a lobby area, and for other office area, the infiltration rate is assumed 0.3 air change per hour. However, this is only the design value, and the DesignBuilder will calculate the exact infiltration value based on the temperature difference of inside and outside air. In addition, the ventilation rate is depending on the occupancy, which is 30 m³/h/person. The indoor air temperature was set to 26°C.

5.2.4.4 Simulation Results and Analysis

Figure 126 shows the heat balance of the base case building. It can be seen that the heat gain is dominated by the solar heat transmitted through the windows and glazing. Moreover, roofs also contribute to the considerable amount of heat gain.

As an office building, it is obvious that lighting, computers and equipment contribute a significant amount of heat gain, as well as the occupancy gains. The charts also inform that there are only ceiling and ground floors that released heat to the environment. Apparently, there is almost no influence of natural ventilation, therefore, this building requires an essential amount of cooling energy.

A sensitivity analysis has been carried out in order to find the parameters that give the most significant impact in reducing the cooling energy demand of the building. Some designed scenarios were simulated and the results were compared to the results of the base case. The parameters chosen for the simulation were the window shading on the west side of the building, a perforated steel sheet on the south side, G value of the glass, and the roof insulation of the penthouse.

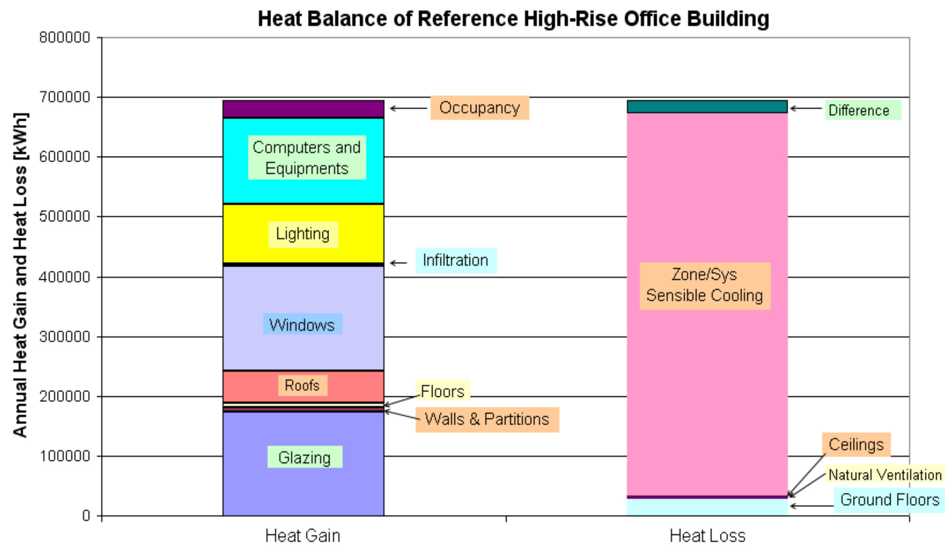

Figure 126. Heat Balance of Reference High- Rise Office Building

Effect of Window Shading

The window shading here means the overhang construction made of reinforced concrete, which is in design will be used as a place to grow plantation. This shading will be constructed at the west side or the back wall of the building.

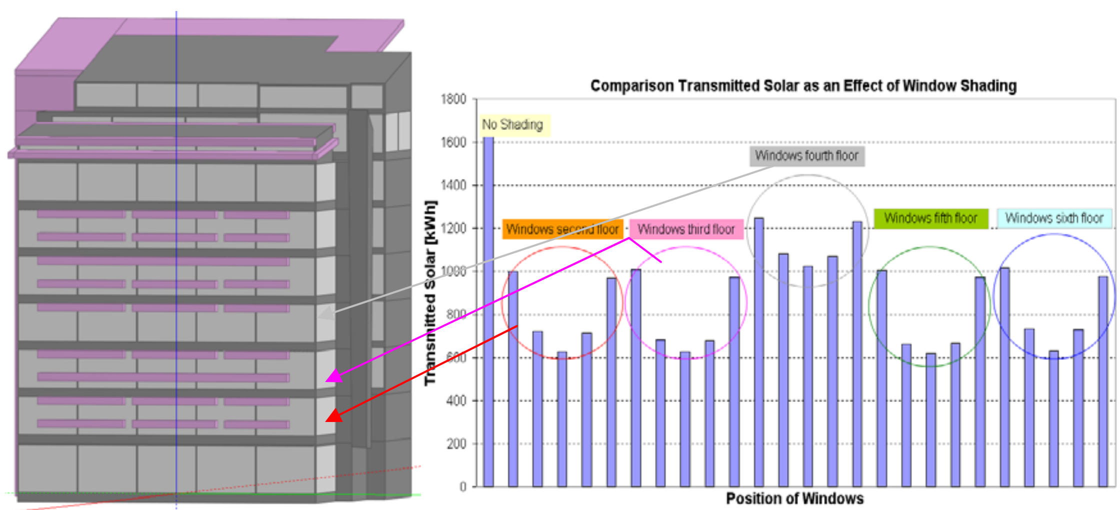

Figure 127. Effect of Shading on the West windows

Figure 127 shows the comparison of solar energy transmitted through the window without shading and the transmitted solar energy through the windows of the second floor up to the sixth floor, as there is no shading component on the first floor, seventh floor, and the eighth floor. It can be seen that a window without shading will transmit almost the double the amount of solar energy into the building. The profile of the solar energy transmission follows the positions and the dimensions of the window shading.

A decrease in solar energy transmitted obviously reduces the cooling energy demand. The simulation results show that despite the lower solar transmission, the decrease of the cooling energy demand in each of those floors is rather small. The cooling energy demand of the whole building decreases by 5% compare to the base case. This is because the solar energy transmitted through the window of the west side is only 12% comparing to the total heat gains of the building.

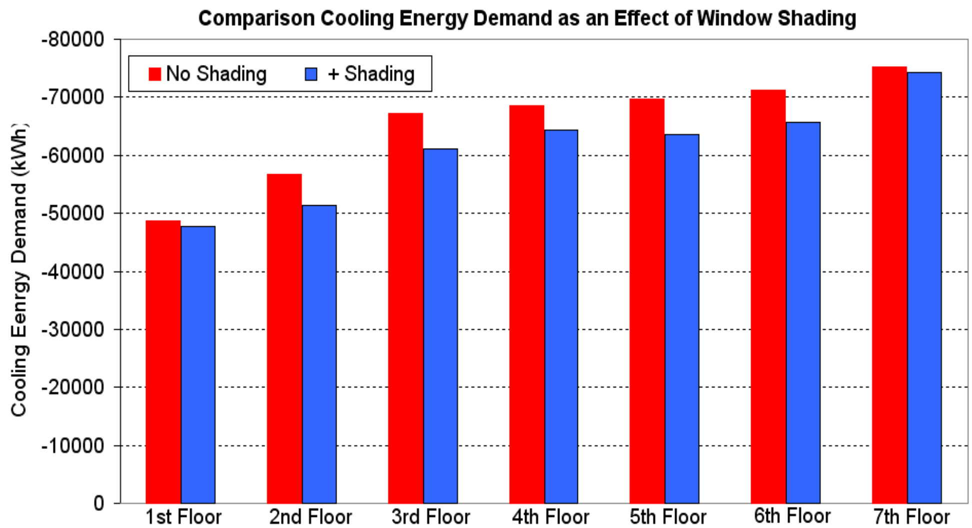

Figure 128. Comparison of Cooling Energy Demand as an Effect of Window Shading

Figure 128 shows the comparison of the cooling energy demand for each floor, from the first floor until the seventh floor, with and without window shading. The cooling energy demand for each of the second floor up to the sixth floor is reduced by about 8% and for the first floor and the seventh floor, it is decreased only about 1.5% as there is no window shading installed on these two floors.

Effect of Perforated Steel

As mentioned before, the construction of a perforated steel sheet on the south side of the building should act not only as a shading measure that reduces the heat gain at the south wall of the building, but also reduces the heat rejected into the environment.

As on its early design, the south side of the building will be used as the HVAC room and utilities which will produce heat, whereas with reference to Figure 122 some lower buildings will be constructed on the south side. The arrangement of the air movement inside the gap between outside building wall and the perforated steel sheet is shown in Figure 129. The analysis of the temperatures will be focused on the wall inside and outside temperature, the temperature of the gap or temperature between the outside wall and the perforated steel, as well as the temperature of the perforated steel sheet.

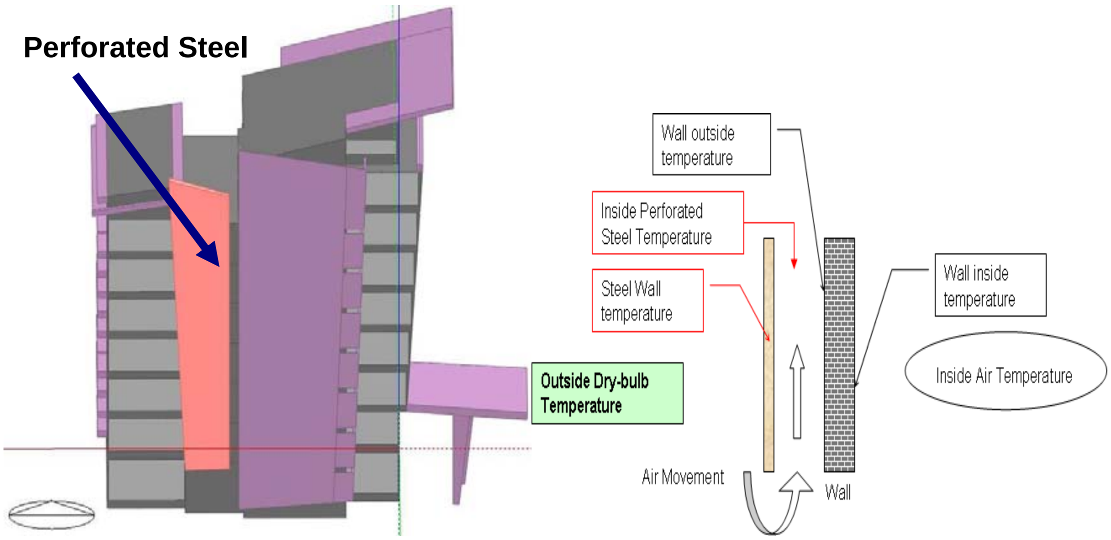

Figure 129. Construction of Perforated Steel and Temperature Analysis

In order to investigate the effect of the perforated steel sheet, there are several scenarios calculated. Firstly, it is assumed that the building is unconditioned which means that the cooling equipments are always off, and then the temperature inside the building and the temperature inside the gap between the south wall and the perforated steel are compared.

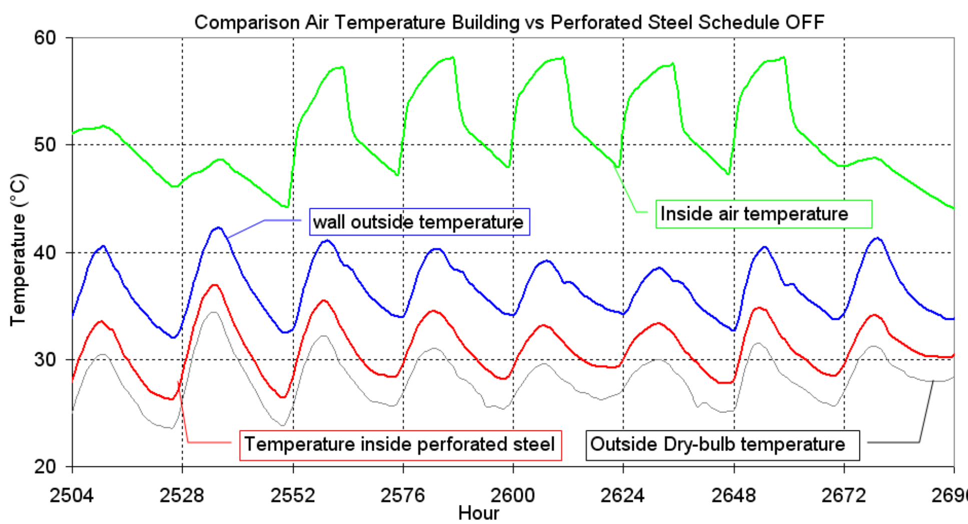

Figure 130. Air Temperature of Building and Perforated Steel, AC Schedule OFF

Figure 130 shows the comparison of the hourly indoor air temperature of the building and the wall outside temperature as well as the air temperature inside perforated steel, when the air conditioning is off.

The graphs describe that in the case of no cooling equipment in the building, the indoor air temperature is about 25°C higher than the outdoor dry bulb temperature, as there are high internal gains of the building as well as solar radiation transmitted into the building. However, the outside wall temperature is about 15°C lower than indoor air temperature moreover, with the addition of the perforated steel sheet the temperature can be decreased further, so that the temperature inside the gap of the perforated steel is only about 1°C higher than the ambient temperature. In summary, the perforated steel is able to prevent the high temperature of the building being transmitted to the environment.

In the second scenario, the cooling equipment schedule inside the building is always set on. Here the indoor air temperature is maintained to be always 26°C during occupation. The simulation results are depicted in the Figure 131 and Figure 132, which show the temperature profiles when there is no perforated steel and when the perforated steel is constructed on the south wall, respectively.

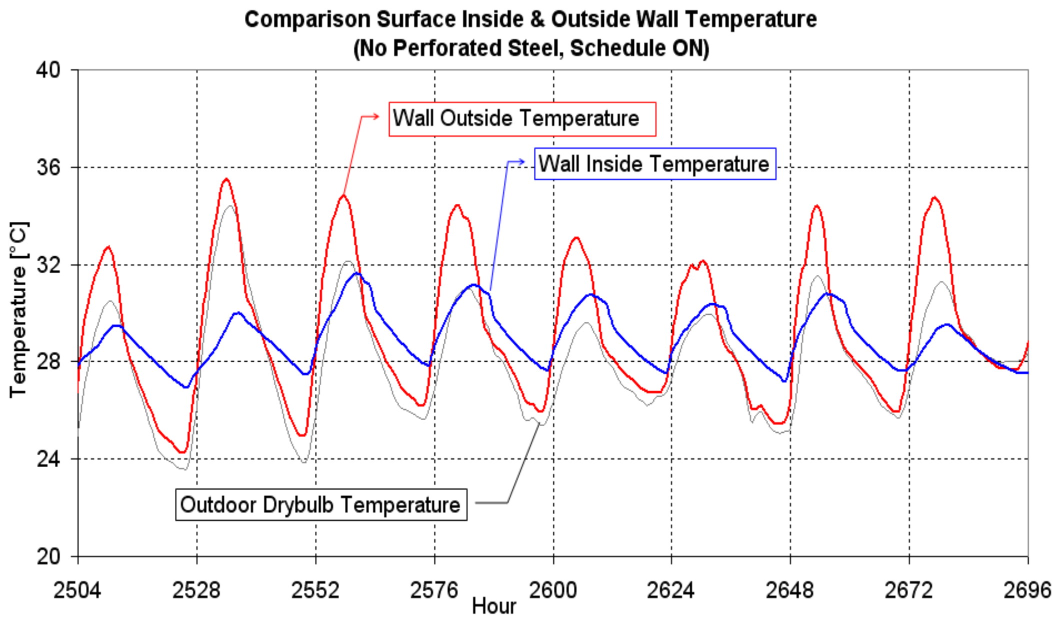

Figure 131. Comparison of Temperature Inside and Outside Wall without Perforated Steel, AC Schedule ON

In the Figure 131, it can be seen that during the day, the temperature profile of the surface inside the wall is about 5°C higher than the indoor air temperature, which is set to 26°C, and the outside wall temperature is nearly the same as the ambient temperature. This is because the inside wall temperature does not represent the indoor air temperature but the radiant temperature, which is highly influenced by the interaction with the internal gains and transmitted gains. During the night, the temperature difference between indoor air temperature and the inside wall temperature decreases to 2°C and the outside wall temperature is still similar to the ambient.

The effect of constructing a perforated steel wall on the south side as shown in Figure 132 explains that the temperature outside the wall is 4°C higher than that without perforated steel. During the day, the temperature of the steel wall is about 5°C higher than the ambient temperature and the air temperature inside the gap is 3°C lower than the steel wall temperature. During the night, the difference between the steel wall temperature and the ambient temperature decrease to only 3°C and the air temperature inside the gap is only 1°C higher than the ambient temperature. These differences occur as the absorption value of the perforated steel is higher than that of the building's wall material; therefore, the steel wall absorbs more heat and consequently, the outside wall temperature is higher than that of without perforated steel.

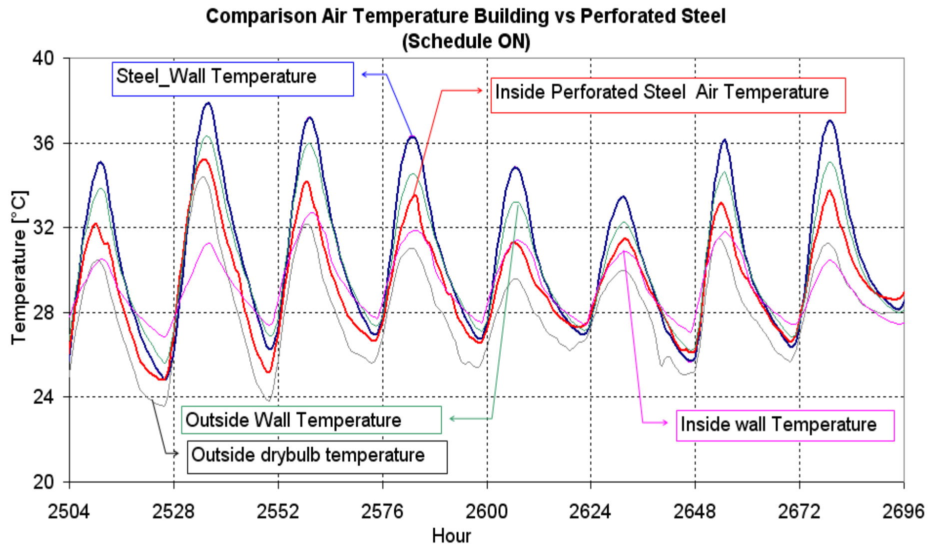

Figure 132. Temperature Inside and Outside Wall with Perforated Steel, Schedule ON

In conclusion, the construction of perforated steel gives no considerable effect in reducing the cooling energy demand of the building. It is found that there is only 0.4% reduction of annual cooling energy demand as an effect of construction using perforated steel. This is because the position of the perforated steel is on the south wall and south wall gives no significant effect in gaining the solar energy radiation (Andarini et al. 2008). However, this perforated steel gives the benefit in reducing the energy transmitted from the building into the environment in case that there is no cooling equipment in the building.

Effect of G Value of the Glazing on West Side (assumed as plantation)

The SHGC value also has a definition of the fraction of external solar radiation that is radiated on a transparent surface (e.g. a window or skylight) both directly transmitted, and absorbed and subsequently released inward (www.daviddarling.info/encyclopedia/S/AE_solar_radiation.html.). The simulation was done by reducing the SHGC value by 65%, from 0.43 to 0.284 for the west window. As it is introduced before, this simulation represents the plantation that will be placed at the back wall with the aims to reduce the heat transmitted to the building from the west side. The simulation result shows that the cooling energy demand decreases only 4%. It means that there is no significant impact of the lowering the SHGC value to the reduction of cooling energy demand, as in the basic design, the glazing already has a low SHGC value and high light transmission.

Effect of Installing Roof Insulation of the Penthouse

The scenario of installing roof insulation for the penthouse has been done in order to investigate its effect on reducing the cooling energy demand. The roof insulation was assumed to be made of 5 cm stone wool, mounted below the tilted roof construction. The simulations results show the difference of solar gain on the roof surface, as well as the air temperature inside the penthouse and the cooling energy demand of the penthouse compared to the entire building.

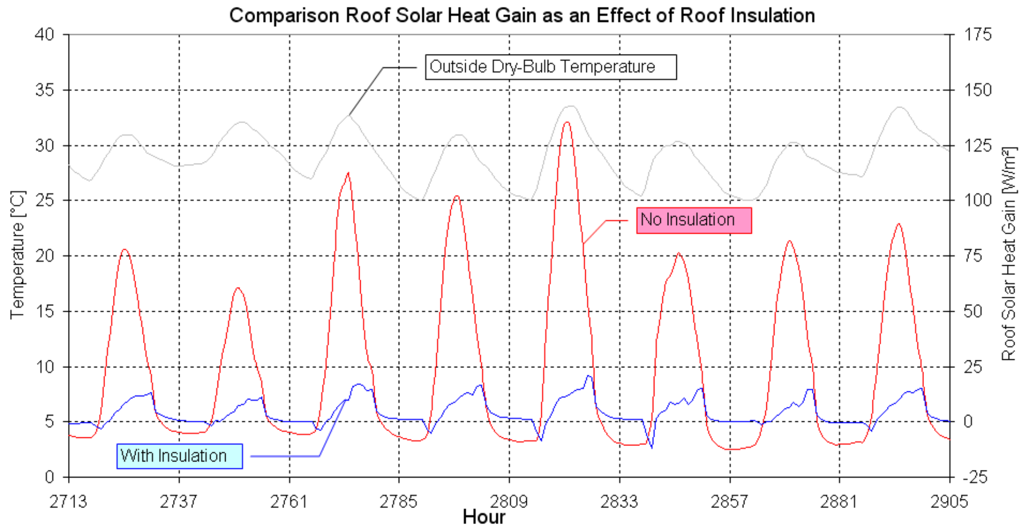

Figure 133. Comparison of Roof Heat Gain of the Penthouse

Figure 133 shows the comparison of heat gain through the roof of the penthouse per square meter of roof area. The positive sign shows that there is heat transmitted from the outside environment into the building, and the negative sign indicates the heat releasesd to the environment. It can be seen that by installing roof insulation will reduce approximately 125 W/m² or about 82% of heat will be reduced being transmitted to the building. The influence of this reduction to the indoor air temperature will be analyzed based on the following graph.

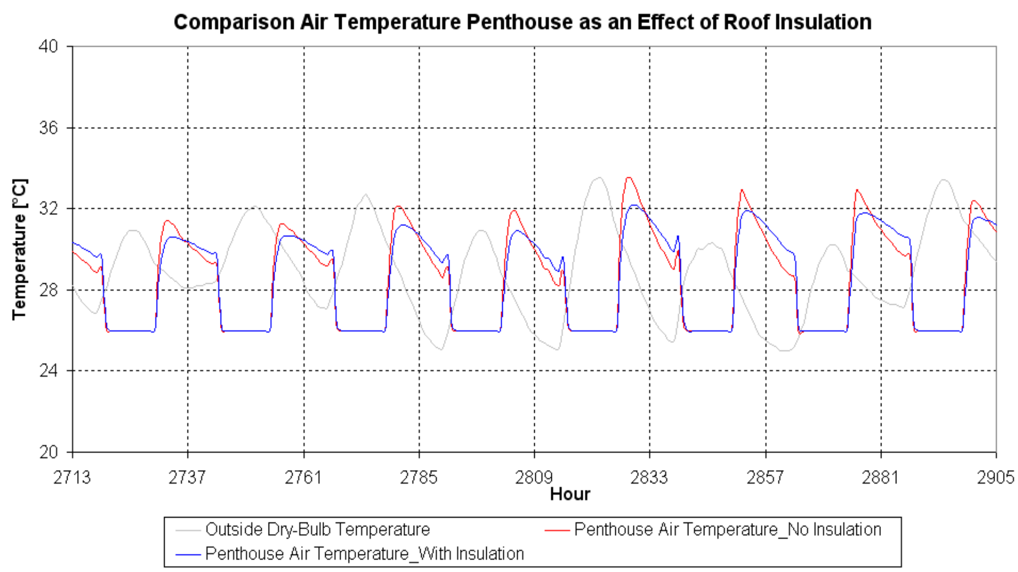

Figure 134. Comparison Inside Air Temperature

The effect of installing roof insulation in the penthouse in reducing the inside air temperature is described in Figure 134. It shows the comparison of inside air temperature of the penthouse when there is insulation on the roof and no roof insulation. During the day, when the penthouse is conditioned, there is no change of the inside air temperature as an effect of roof insulation. However, during the night while the cooling equipment is not working, the inside air temperature of the penthouse in average decreases by 2°C in the case of insulated roof. This is because the roof insulation traps the heat in the building although there is potential to release the heat to the environment as the ambient temperature is considerably lower than indoor air temperature. Obviously, this has an affect on the morning temperature, which is higher with insulation but needs less cooling energy demand during the day and will therefore lead to the reduction of cooling energy required by the cooling equipment. On average, the cooling energy demand of the penthouse during the day decreased to about 0.17 kWh of penthouse area, from 0.44 kWh/m² to 0.27 kWh/m².

Further analysis was done in order to observe the effect of installing roof insulation on the penthouse to the lower floor that is the eighth floor. Figure 135 shows the comparison of the air temperature in the eighth floor when there is no insulation and the roof of the penthouse is insulated. The graph shows that there is no important effect on the indoor air temperature in the eighth floor as an effect of installing roof insulation. During the day while the cooling equipment in the eighth floor is operating, there is no effect of the roof insulation.

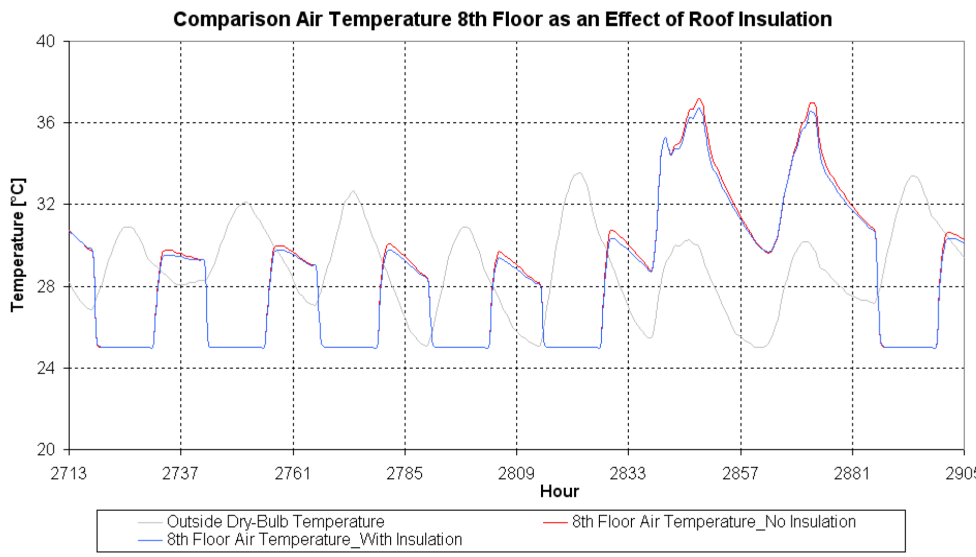

Figure 135. Comparison Indoor Air Temperature of 8th floor as an Effect of Roof Insulation of the penthouse

Additionally, during the night when the cooling equipment does not work as well as on the weekend, there is slight decrease in the indoor air temperature of the eighth floor as the result of installing roof insulation. Thus, installing roof insulation in the penthouse only has a slight influence on the indoor air temperature of the penthouse during the night, and almost no effect for the floor beneath.

Figure 136 shows the comparison of hourly cooling energy demand as an effect of installing roof insulation on the penthouse. As explained before, there is substantial decrease of solar heat gain through the roof of the penthouse as an effect of roof insulation. This reduction of the solar heat gain apparently does not influence the indoor air temperature, however, the hourly cooling energy demand of the penthouse decrease significantly. It is found that the annual cooling energy demand of the penthouse decreases by 40% as an effect of installing roof insulation.

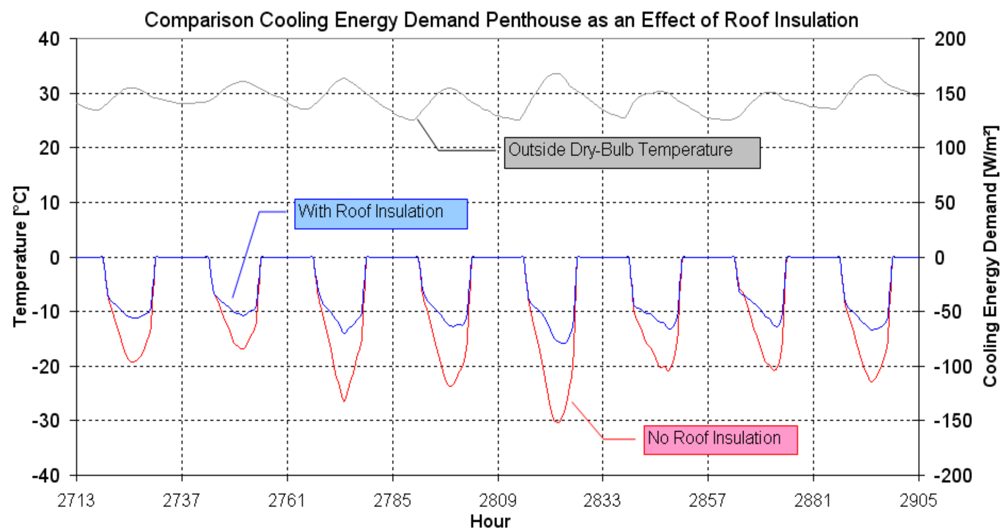

Figure 136. Comparison of Cooling Energy Demand of the Penthouse

Figure 137 shows the comparison of the cooling energy demand of the whole building and the penthouse. It is found that the hourly cooling energy demand of the penthouse is only about 9% compared to the cooling energy demand of the whole building. Therefore, even though the hourly cooling energy demand of the penthouse considerably decreases when the roof is insulated, the cooling energy demand of the whole building is only slightly decreased.

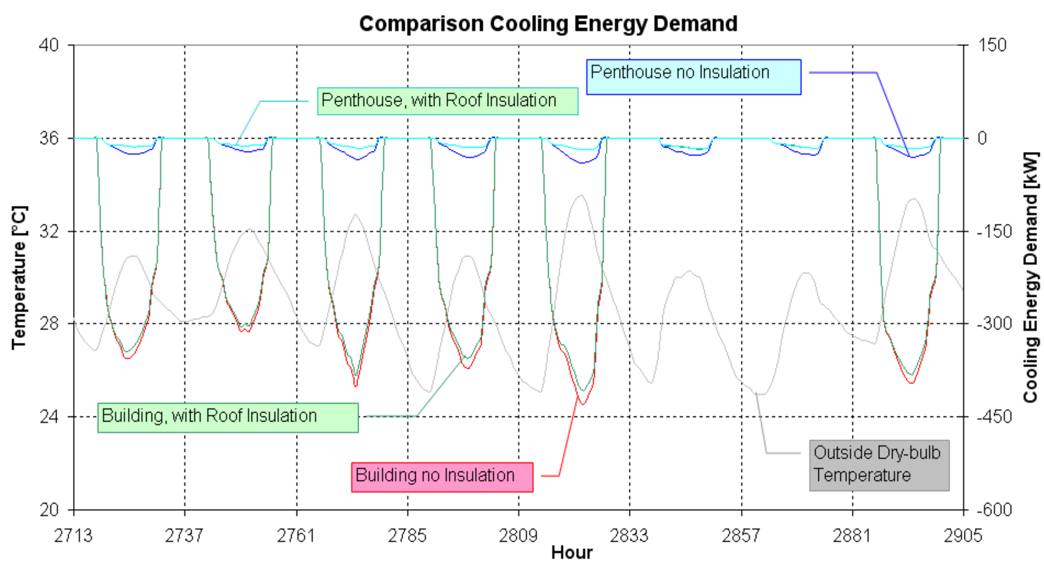

Figure 137. Comparison Hourly Cooling Energy Demand Building and Penthouse

Overall, the annual cooling energy demand of the whole building reduced about 3.8% as an effect of installing roof insulation on the penthouse.

Optimised Building

The simulation of optimised building was done in order to obtain the reduction of annual cooling energy demand of the building based on the parameter variation that has been simulated. The designed optimised building simulated consists of the additional perforated steel sheet on the south side, south shading made of alucobond wall, and west window shading with an assumption of plantation on this side, as simulated with lower glazing SHGC value. The roof insulation of the penthouse with the thickness of 5 cm is also considered. The simulation result shows that the cooling energy demand of the optimised building is 17% lower than the reference base case of office building.

Conclusion

The sensitivity analysis in order to obtain the parameter that contributes to the reduction of annual cooling energy demand of the nine-storey office building was done with the variation of four parameters. These parameters consist of window shading on the west wall, constructing perforated steel sheet on the south side of the building, applying lower SHGC value of the glazing material for the south windows in order to assume the plantation, and installing a roof insulation for the penthouse. It is found that the construction of the shading on the west wall causes the highest decrease of the annual cooling energy demand that is 5%, followed by the use of low SHGC value for the west glazing, that cause 4% reduction. Installing roof insulation of the penthouse, found the potential to decrease the annual cooling energy, demand of the penthouse by 40% apparently can only decrease the annual cooling energy demand of the building by 3.8%. The construction of perforated steel sheet indeed reduces the annual cooling energy demand only 0.4%, however, it is of benefit to prevent the heat rejected into the environment when the building is unconditioned.

CHAPTER 6: GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR ENERGY EFFICIENT BUILDINGS IN INDONESIA

With the background of the energy crisis indicated by the high price of oil as well as its limited availability, it is important to consume energy more wisely. The building sector in Indonesia is evidenced as the major contributor of energy consumption, and has high dependency on the electricity and buildings also contribute on high level to GHG emissions. Therefore, the energy efficient building is a crucial importance in a context where building's constructions are booming in Indonesia.

Towards the realization of energy efficient buildings, it is important to provide well-established regulation and standards, which elaborate the guidance on how a building should be designed, occupied and evaluated. It is also required to develop a calculation method to asses the energy performance of a building. The realization of regulations and standards must also be followed by the implementation, and it is important to set them into force as a mandatory. The current situation in Indonesia shows that the regulation does not persistently describes the obligation for the building management, and no penalty for inefficient buildings has to be paid. Moreover, the available standards are still adopted from international standards which are not appropriated to be applied in Indonesian climate. Consequently, it is crucial that the Indonesian standards are developed based on the situation and conditions in Indonesia, as well as adapt to the local culture and people's behaviour. Additionally, it is also important to learn from the experiences of Austria in implementing the EPBD towards the energy efficient and sustainable buildings. The LEED rating system is the current system adopted in Indonesia, however, this requires high budget hence causes this building certification is less interesting to the building owners.

Some examples of vernacular architecture in Indonesia show that the traditional designs are more appropriate to the climatic condition and have higher durability to the natural hazard compared to the modern design. Therefore, the building designers have to improve their awareness to apply the bioclimatic principle in designing a building towards low energy building. The lesson learned from Austrian experiences dealing with integrated energy concept in building's design should be implemented in Indonesian practices.

In order to promote energy efficiency building, the ASEAN Energy Centre has implemented a competition on the regional level since 2001. The definition of energy efficient building as mentioned in ASEAN Energy awards yet is not clear. There is no specification of the type of buildings, such as residential category, hospital, etc, as this categorisation will influence to the user behaviour as well as occupancy time and energy consumption. Moreover, the evaluation guidance pointed out that the set point indoor air temperature should be between 21°C and 26°C which is not in accordance to the survey. People in the tropical climate are more tolerance in accepting higher indoor air temperature at about 28°C. As a result, the judgement of 'energy efficient building' is presumed less acceptable as it requires more evaluation and validation.

6.1 Conclusions

Thermal building simulation is a powerful tool to asses the energy performance of a building. The simulation is recommended to be integrated during the design phase of a building. During this stage, there are more opportunities to influence the design of the building and to change the design as it is far cheaper to change the design rather than the real building. Moreover, various numbers of scenarios can be modelled in order to obtain the most optimum design, not only on the physical design, but also the operational scenario. However, the application of thermal building simulation in Indonesia as well as in neighbouring countries is not widely used. In this dissertation, the importance of thermal building simulation towards energy efficient building is presented.

Four different types of building are simulated in this thesis. The buildings consist of three storey office building, a shophouse, a single-family row house, and a high-rise office building. The climatic data used in the simulation refers to that of Jakarta and Surabaya. The simulated buildings are based on the design drawings of the architects, except for the three storey office building which was based on the proposed design in the IEA SHC TASK 25. The constructional material chosen for the Indonesian buildings are based on the common materials used for the construction in Indonesia. In addition, the user behaviour is also assumed in line with the habits available in Indonesia. The simulation results show that in general, the factors that give significant influence to the reduction of cooling energy demand consist of the indoor set point temperature, building's orientation, shading device, overhangs, window blinds, SHGC value, roof insulation, and possibility to reduce the power of the cooling equipment.

Increasing the indoor air temperature is the parameters that gives significant reduction of the cooling energy demand. Therefore, it is important that the building's owner or management maintain the indoor air temperature at about 25°C to 27°C, as this range is not only still comfortable for the occupants, but also requires less cooling energy delivered. Concerning the building's orientation, it is recommended to design a building facing to the south or north, and if possible the east and west orientation is to be avoided or the window on the east and west surfaces should be at least minimised. Another possibility to reduce the solar energy radiation exposing the window glazing is either by installing window shading or overhangs, as well as window blinds. These will be more effective for the unavoidable east and west windows. Additionally, choosing a window glass material with low SHGC and high light transmission value is found valuable in minimising the heat gain of the building but maximising the use of natural lighting. Roof insulation in unoccupied and ventilated roof space is apparently effective in reducing the indoor air temperature of the roof space, however, there is no significant effect to the room below. For the shape of the roof, the flat roof without roof space is not recommended as it will be directly transmitted the solar energy radiation into the building. In this situation, a thermal insulation is necessary. A tilted roof with a roof space is highly recommended because it will prevent the solar radiation directly penetrate the building. This was also usually done in the traditional building designs in Indonesia. Other than the calculated cooling design of the building, the power limitation of the cooling equipment is found beneficial in reducing the energy consumption of the building. Therefore, the design of cooling capacity is important to be considered in order to obtain the optimum installation of the cooling equipment.

The results from the thermal building simulation of the simulated Indonesian buildings unfortunately cannot be compared to those of existing buildings, as these buildings are still in the design phase. However, these results are valuable for the designers as they are still able to alter the building designs.

6.2 Recommendations for Future Works toward Energy Efficient Buildings in Indonesia

There are some limitation in this work, therefore future research should be performed, such as including the design of system plant in the simulation and the analysis of the CO_2 emission. Moreover, the elaboration of the life cycle analysis should also be considered in the future research.

Based on the conclusion of this research, follow up work should be carried out. The post occupancy evaluation is an important step to be conducted. The evaluation should elaborate field measurements and surveys dealing with the energy consumption of the simulated buildings, in order to obtain the validation of the simulation results and to monitor whether its behaviour is similar or close to the simulation results. There is still a lot more to do dealing with the building thermal simulation and parameters measurement of traditional building in Indonesia.

In term of sustainable development, it is hoped that this research will contribute to the improvement of urban design regulation/building codes regionally and nationally in Indonesia. Therefore, promoting the importance of integrated building thermal simulation during the design phase as well as in the energy certification process is essential. In addition, embedding thermal building simulation as a tool in the energy auditing would be also valuable.

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