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最適空調設計に向けたマレーシアにおける建築省エネルギーの現状調査

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九州大学大学院人間環境学府空間システム専攻 : 博士後期課程

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最適空調設計に向けたマレーシアにおける建築省エネルギーの現状調査

Investigation of Current Situation of Building Energy Conservation in Malaysia for Optimal Air-conditioning Design

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This paper reviews the current situation in Malaysia relating to energy consumption, indoor thermal comfort and air-conditioning system design in a hot and humid country of Malaysia. It is observed that the guideline towards low energy building was already in place. The research pertaining to comfort temperature seems to dominate the thermal comfort research while the analysis of humidity was lacking. It is observed that the air-conditioning design was made so that the system operates in relatively low temperature and humidity. The low temperature also will increase the building energy consumption. Air-conditioning design was intentionally oversized which would prevent the system running at full load and best efficiency. Simulation of building energy consumption was not carried out and leads to the selection of system merely based on equipment cost without considering the energy.

Keywords: *Energy efficiency, Policies, Design standards, Thermal comfort, Energy conservation*
エネルギー効率，　政策，　設計基準，快適感，省エネルギー

1. Introduction

1.1 Background

As one of the leading developing countries in Asia, Malaysia's urban growth is continuing to rise. The urban growth could be physically seen by the rapid increase of rural buildings and premises in the cities across the nation. However, the nation's economy development has resulted in the increase of energy consumption of the whole country as well. In order to tackle this issue, implementation of effective energy conservation and management system needs to be carried out accordingly. Also, efforts are greatly needed to reduce the energy consumption through innovative strategies.

On the other hand, reducing the energy consumption of a building should not compromise the thermal comfort of the occupants inside the premises. Thermal comfort is defined as the condition of mind which expresses satisfaction with the thermal environment[1)]. The significance of maintaining well indoor climate is self-evident due to the fact that a large number of work forces in Malaysia are as the occupants in buildings. It is important to note that thermal comfort directly affects the occupant's health and productivity.

Air-conditioning is an important system in buildings especially in Malaysia which has a hot and humid climate throughout the year. The buildings are exposed to excessive amount of solar heat during daytime occupancy. In addition to the heat gain from the sun, there is also internal heat source from the equipment inside the building. Cooling is needed and thermal comfort is satisfied by supplying enough air colder than the room temperature. However, it is known that air-conditioning equipment is the main energy consumer in a commercial building. Therefore, more attempts should be focused on the improvement related to the usage and operation of the air-conditioning system.

1.2 Objective

The overall research is to propose an energy efficient air-conditioning system which is suitable for Malaysian climate by way of optimizing the indoor humidity without compromising the indoor thermal comfort. The objective of this paper is to investigate the current situation in Malaysia in terms of energy, thermal comfort and current practice of air-conditioning design and operation. After assessing the existing situation, the potential approach to lower the building energy consumption is proposed to be carried out in the next stage of the research.

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2. Situation of Energy

2.1 Overall energy consumption

Lately, there have been growing concerns about energy consumption in Malaysia and its implications to the environment. High economic growth has led to an increase in energy consumption in recent years. The contribution from buildings towards energy consumption has steadily increased especially in a developing country of Malaysia. This scenario is due to the attempt of reaching a higher standard of living among the occupants. Hence it is very important to consider new measures for energy conservation in developing nations.

For the sake of argument, the energy consumption in Japan is shown together in Figure 1[2] for comparison between both countries. It is observed that since 1981, the total energy consumption for Malaysia had increased at a constant rate until 2009. The value of energy in kWh was always less than Japan, to the justification that Malaysian economy was far smaller. But the alarming note is that the energy consumption per capita in kWh/person is increasing from year to year basis. In other words, people in Malaysia are consuming more and more energy at a higher rate than before. Actions must be taken to curb this trend as it will increase the level of carbon dioxide emission in Malaysia as well.

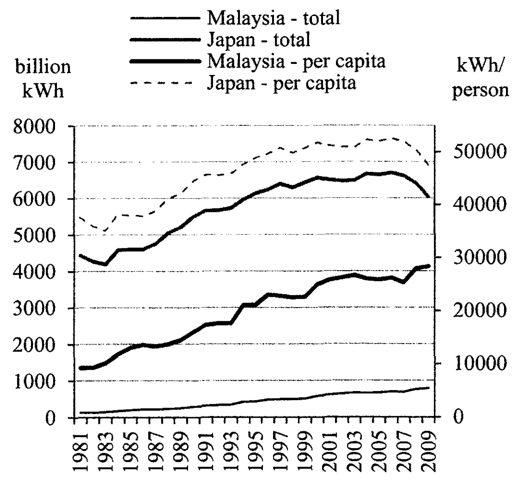

Fig.1 Energy Consumption

2.2 Building energy guideline

In promoting energy efficiency to the public, it is important for the authorities in Malaysia to come up with a strategic guideline and regulation pertaining to the issue. In the present ruling for instance, there is a clause under the Electricity Supply Act 2008 which states that any installation that consumes 3 million kWh over a period of 6 months is required to engage a registered energy manager for the building. The appointed energy manager is responsible to analyze the energy consumption of the building through continuous monitoring of all system including air-conditioning. In addition, he/she would advise on the development and implementation of measures to ensure efficient management of building energy and to supervise the effectiveness of the measures taken.

A significant development towards establishing a comprehensive guideline of sustainable buildings in Malaysia is the introduction of MS1525 Code of Practice on Energy Efficiency for Non-Residential Buildings[3]. The standard is applicable to the building that has at least 4,000 m^2 of indoor air-conditioned space. The standard was initially published in 2001 by a group that consists of academician and industry players who involved in building services and management. The purposes of establishing MS1525 are to:

i. encourage the design, construction, operation and maintenance of new and existing buildings in a manner that reduces the use of energy without constraining building function and the comfort or productivity of the occupants.
ii. provide the criteria and minimum standards for energy efficiency in the design of new buildings, retrofit of existing buildings and methods for determining the compliance.
iii. provide guidance for energy efficiency design to comply with minimum standards.
iv. encourage the application of renewable energy in new and existing buildings to minimize reliance on non-renewable energy sources, pollution and energy consumption whilst maintaining comfort, health and safety of the occupants.

There are 7 main areas covered by the MS1525 code of practice as shown in Figure 2. It has to be noted that the standards set out only the minimum requirements and designers are encouraged to practice beyond the stipulated standards. The first topic in MS1525 is the architectural and passive design strategy which focuses on the design and construction of a building taking optimal advantage of its environment. The important factors that should be considered are building orientation, configuration, geometry, room depth, floor to ceiling height, location of pillars, building façade, internal layout, fenestrations, building materials, roof design, roof colour, shading, day lighting and natural ventilation.

1. Architectural & passive design strategy
2. Building envelope
3. Lighting
4. Electric power & distribution
5. Air-conditioning & mechanical ventilation system
6. Energy management control system
7. Building energy simulation method

Fig. 2 Code of practice covered in MS1525

Building envelope is another area covered in the standard. The envelope is referred to wall, window, door and roof and is used to reduce heat gain from coming into the buildings via conduction and solar radiation. The heat gain constitutes a substantial share of cooling load in air-conditioned building. In order to quantify the design criterion for building envelope, overall thermal transfer value (OTTV) concept has been adopted. The calculation of OTTV includes the parameter of window-to-wall ratio, solar absorptivity, thermal transmittance (u-value) and shading coefficient. In addition, there is also a calculation mentioned as roof thermal transfer value (RTTV) for roof with skylights. Lastly, the MS1525 requires the submission of the u-value for roof assembly and the OTTV and RTTV calculation for the building.

The code of practice for lighting is mainly focused on the usage of efficient lamps and luminaires. The recommended level of illuminance in unit lux is listed for several building space applications. Maximum allowable lighting power for different building types is also provided as well as lighting control in terms of automation and accessibility.

The electric power and distribution clause applies to the energy efficiency requirements of electric motors, transformers and distribution systems of buildings except for those required for emergency purposes. All electrical power distribution equipment should be selected for their energy efficiency, capital cost and the cost of energy over the equipment life time. The classification of high efficiency electric motors is provided for designer's reference. The guidelines for cable, wire, transformer and inverter are clearly explained. Lastly, the MS1525 requires the installation of electrical energy meters at strategic load centers to facilitate the monitoring of energy consumption and management.

The Malaysian Standard recommends that load calculation method should be determined in accordance with the procedures described by ASHRAE (American Society of Heating, Refrigeration and Air-conditioning Engineers) or other equivalent publication. MS1525 also suggests the design conditions of an air-conditioned space for comfort cooling in Malaysia as follows:

i. indoor design dry bulb temperature of 23 - 26 °C.
ii. indoor design relative humidity of 55 - 70 %.
iii. indoor air movement of 0.15 - 0.50 m/s.
iv. outdoor dry bulb temperature of 33.3 °C.
v. outdoor wet bulb temperature of 27.2 °C.

According to the standard, oversizing is not recommended and the air-conditioning system and equipment shall be sized to provide no more than the space and system load being calculated. In addition, the usage of efficiency devices such as multi compressors, variable speed drive and high efficiency motor is encouraged. Also included in MS1525 are the guidelines for automation control, fan power rating and piping/ ducting insulation and leakage checking. For factory-assembled package and unitary air-conditioning system, the minimum coefficient of performance (COP) is listed according to system capacity. There is also standard rating and specification for water chiller and heat-operated absorption system. The standard requires the submission of schematic drawing and operation manual as well as the scheduling of periodic maintenance.

Energy management control system is another important aspect described in the Malaysian Standard. The control and monitoring of equipment are for the purpose of improving the efficiency by providing:

i. real-time information of running equipment.
ii. historical data of equipment.
iii. abnormal equipment condition.

iv. analysis tool and diagram for a study purpose.

The application of energy management control system should be used for time scheduling to match occupancy pattern and chiller optimization program. The system could be further utilized for controlling the cooling coil valve, fan speed and the on-off mechanism for other equipment such as the lighting system. In order to enable energy monitoring, data logging facilities shall be provided for the air-conditioning system, lift, escalator, water pump, power supply and lighting.

The last code of practice is for building energy simulation method. It is a performance-based approach to compute the predicted energy use of buildings. MS1525 specifies that the computer-based simulation program should have a minimum of 8,760 hours of time step per year. Subsequently, a report of the simulation shall be produced according to ASHRAE or British CIBSE (Chartered Institution of Building Services Engineers) format for submission.

2.3 Green building certification

An added effort to promote sustainable building in Malaysia is the establishment of the Green Building Index (GBI) in 2008. GBI is an assessment tool to certify energy efficient building and is comparable to Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan. GBI certification started from the year 2009 with the Green Energy Office (GEO) building, shown in Figure 3, as the first building to be certified. Building energy intensity (BEI) of GEO is measured at 65 kWh/m^2/year based on the secondary power supply, which is the most energy efficient building in Southeast Asia. It has to be noted that the average BEI for Malaysian building is currently at 250 kWh/m^2/year.

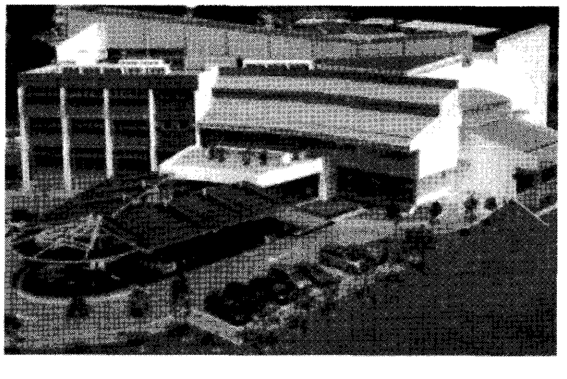

Fig. 3 GEO (Green Energy Office) building[4)]

The success of GEO building in pioneering the concept of green building has opened the door for more subsequent GBI certification. As shown in Figure 4, the accumulation of buildings being certified has increased rapidly to 4 units in 2010, 23 units in 2011 and 57 units in 2012. The certification would last for 3 years before a re-assessment is required to ensure that the buildings are well maintained and environmentally friendly. The positive development on the number of certification shows that more premise owners in Malaysia are aware of the needs towards building energy conservation.

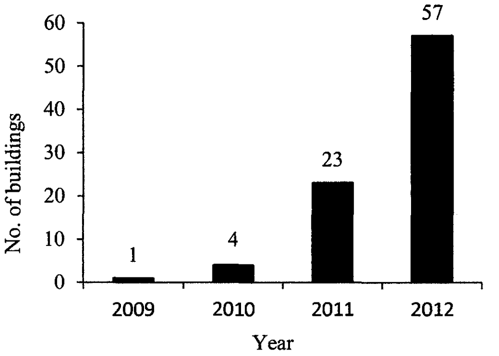

Fig.4 Number of certification

The main idea of green building is basically based on the concept of consuming less energy and resources but at the same time generate less waste to the surroundings. Therefore, GBI is based on six main assessment criteria as shown in Figure 5. Energy efficiency is the most

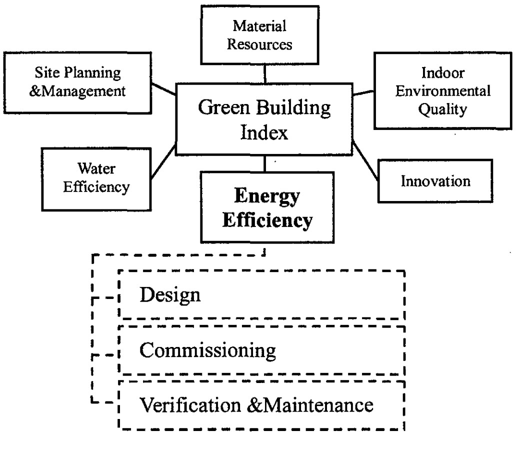

Fig. 5 Green Building Index assessment criteria

significant factor with 35% score of the overall evaluation followed by indoor environmental quality (21%), site planning & management (16%), material resources (11%), water efficiency (10%) and innovation (7%).

With the highest provision of score percentage, energy efficiency proves to be the most important factor towards green buildings and within the criteria, there are three sub-assessments available namely design, commissioning and verification & maintenance. The requirements stipulated under the design sub-assessment are the building envelope index, building energy management system, usage of renewable energy and building energy index achievement. GBI assessment demands that a proper commissioning being carried out for the building energy system during the design stage, installation and 12 months after initial operation. Lastly, under the verification & maintenance sub-assessment, energy consumption should be continuously monitored as well as the scheduled preventive maintenance exercise.

With the comprehensive environmental rating system offered by GBI, Malaysia is totally committed in the development of sustainable buildings in the country. In order to maintain the relevancy of the index, GBI criteria are reviewed annually by architects and engineers for continuous improvement.

3. Situation of Thermal Comfort

3.1 Characteristics of tropical climate

Malaysia is located in Southeast Asia and very close to the 0° equator line. Therefore, the country is experiencing tropical climate which is hot and humid throughout the year. Unlike Japan, there is no winter or summer season in Malaysia. Figure 6 shows the difference between Kuala Lumpur and Fukuoka in terms of ambient temperature and humidity. During the summer season in Japan, the temperature in both cities is almost equal to each other but the humidity in Kuala Lumpur is still slightly higher than Fukuoka during the same period. This phenomenon happens due to the long daytime and short nighttime interval in Japan during the summer whereas in Malaysia the day and night period is almost consistently similar about 12 hours each throughout the year.

In terms of daily weather, the temperature in Malaysia normally builds up in the morning and peaks beyond 30 °C in the early afternoon. Figure 7 shows the ambient temperature and humidity measured on top of a building in Kuala Lumpur on Sept 23, 2012. In Malaysia, the precipitation is generally high due to frequent downpour normally occurring in the afternoon. As the measurement shows in the figure, there was a short rain, happening about 20 minutes at 16:00 hours which cooled down the temperature and raised the humidity instantly. In the evening, the temperature started to subside to a more comfortable level than in the daytime. But the drop in temperature brings an inherent effect of increased humidity to about 80 %. Should there be any rainfall in the evening; the humidity would shoot up until saturation at 100 %. On the other hand, the precipitation is higher than average at the end of the year due to the monsoon rain coming from the South China Sea.

3.2 Local research on thermal comfort

The issue of thermal comfort in Malaysia is mainly due to the outdoor hot and humid climate and its consequence to the indoor space. The perception of comfort varies from someone to another since there many factors affecting the thermal sense of a human. The key

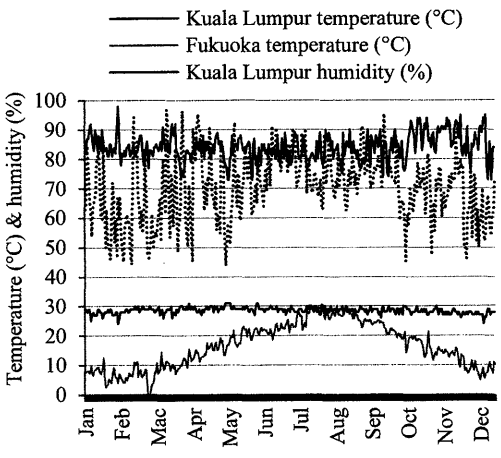

Fig. 6 Yearly typical weather

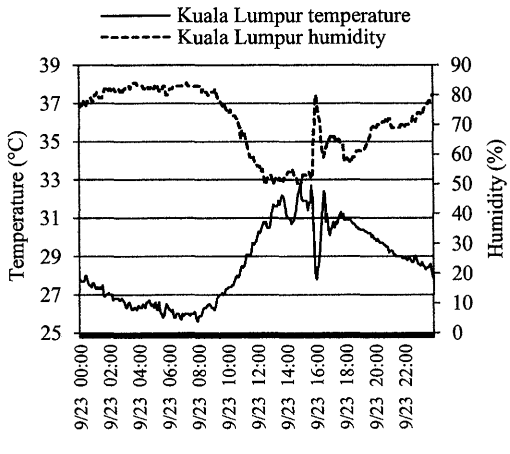

Fig. 7 Weather on 2012-09-23

parameters involved are temperature, humidity, air speed, physical activity, clothing worn and duration of occupancy. The difference in cooling requirement will affect the preferred air temperature of the occupant. It is well known that the human body normally cools itself by sweating as the evaporation process will absorb heat from the body. However, a higher relative humidity reduces the evaporation rate because of the higher vapor content. If the air is at 100 % saturation relative humidity, sweat will not evaporate into the air. As a result, a person will feel much hotter than the actual temperature.

Past studies of research on thermal comfort in Malaysia is shown in Table 1. Generally, the research was mainly focused on the temperature comfort with little attention given to humidity factor. Most of the researchers argument was that the recommended thermal comfort condition mentioned in the ASHRAE Standard 55 were not matched to the findings in the actual research being carried out. The researchers concluded that the comfort temperature zone in Standard 55 was too low and Malaysians have adapted to a higher comfort temperature region.

Table 1 Past studies of thermal comfort

	Researcher	Neutral value	Comfort range
Comfort temperature for space with air-conditioning			
1	R. Daghigh et.al[5]	26.1 °C	25.8 - 26.3 °C
2	Y.H Yau et.al[6]	26.4 °C	25.3 - 28.2 °C
3	Y.H Yau et.al[7]	25.3 °C	23.8 - 26.6 °C
4	F. Azizpour et.al[8]	26.6 °C	24.6 - 27.6 °C
Comfort temperature for space without air-conditioning			
1	I. Hussein et.al[9]	28.4 °C	
2	S.R.S. Wafi et.al[10]	28.5 °C	
Comfort humidity for space with air-conditioning			
1	A.R.M Rebi et.al[11]	54.9 %	50 - 60%

There were also studies to determine the comfort temperature of spaces without air-conditioning. It is observed that the neutral temperature for naturally ventilated room was higher than the spaces with air-conditioning. However, there was only one research pertaining to humidity being carried out, in which the indoor comfort humidity was estimated to be 54.9 %. In that research, comfort humidity zone was not comprehensively measured or calculated. The proposed comfort range of 50 - 60 % was merely suggested by the researchers. In conclusion, the main point in discussing about thermal comfort in Malaysia is the temperature itself and the effect of humidity was apparently not as important to the researchers. The lack of research specifically on humidity was evident as the findings were observed to be incomprehensive.

3.3 Thermal comfort guideline

The thermal comfort guideline was presented in the first issue of Malaysia Standard MS1525 in 2001 which defined the indoor comfort temperature and humidity as 23 - 26 °C and 60 - 70 % respectively. In the revised copy of the standard issued in 2007, the temperature range remains while the comfort humidity has been amended to 55 - 70 %. Therefore, as the standard suggests, the air-conditioning system should be designed and operated according to these recommendations, which in return not only provide thermal comfort to the occupants but would reduce its energy usage during the operation.[1]

Another guideline widely renowned in Malaysia for its performance criteria of thermal comfort is the ASHRAE Standard 55. Initially produced in 1966, the standard's purpose and definitions clearly show that it is established based on 80% acceptability[3]. In other words, even if the criteria in the standard are met, all occupants may not be mutually satisfied with the indoor condition. The discrepancy is inevitable due to the individual preferences and thermal sensitivity. Standard 55 has undergone several revisions in the year 1974, 1981, 1992, 1994 and 2004 to improve its definition on thermal comfort. In the latest revision, the standard's comfort boundaries for summer zone are defined within the effective temperature of 23 - 26 °C. While the humidity ratio of 0.012 kg/kg dry air is chosen as the upper limit, there is no lower limit being defined for humidity.

4. Situation of Air-Conditioning Design

4.1 Management system in building construction

The construction of a new building requires a few parties to be directly involved starting from the design stage. Therefore, the installation of air-conditioning system in a building demands detail planning and systematic management from the blueprint period and during the construction work. Furthermore, such complicated work requires co-ordination between related parties that involved in the project. In Malaysian practice, an architect firm is appointed by the building owner to act as the leader in a building construction project. The architect will also design the shape and aesthetic features of the building. As shown in the organization chart in Figure 8, the architect will assign three other parties namely civil & structural engineer, mechanical & electrical engineer and quantity surveyor to complete the management team.

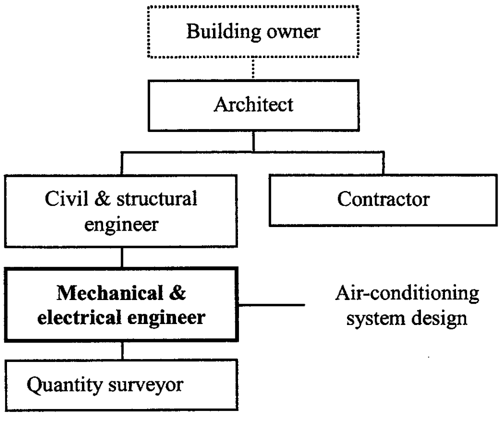

Fig. 8 Organization of building construction

The mechanical & electrical engineer is the party which provides consultation in terms of air-conditioning design to be used in the building. The design includes the determination of cooling load, the sizing of equipment and schematic drawings of the air-conditioning system. During the construction stage, mechanical & electrical engineer works closely with the appointed contractor to ensure that the air-conditioning equipment is installed correctly and ready to be used after building completion. The engineer is also responsible in ensuring the initial commissioning exercise being carried out smoothly before the air-conditioning system being handed over to the building owner.

4.2 Cooling load calculation and equipment sizing

The initial stage of designing the air-conditioning system is the determination of building cooling load. The load calculation requires the input of building heat gain from external and internal sources. The skill and technique of determining the right cooling load and subsequently the accurate air-conditioning equipment sizing requires extensive training and years of experience in order to come out with a satisfactory design. As shown in Figure 9, Al-Mofleh et.al stated that the design and choice of air-conditioning system is one of the key factors in building energy performance. Cooling load determination may be carried out using manual calculation with the aid of a spread sheet form. Usually, the spread sheet is provided by the equipment manufacturer but the guidance of calculation is minimal and depends a lot to the designer's own knowledge and technical know-how in air-conditioning. With the introduction of software in computer application, cooling load calculation can be more easily and accurately being determined. In using software as a tool, the experience level of the user is less important than that of using manual calculation.

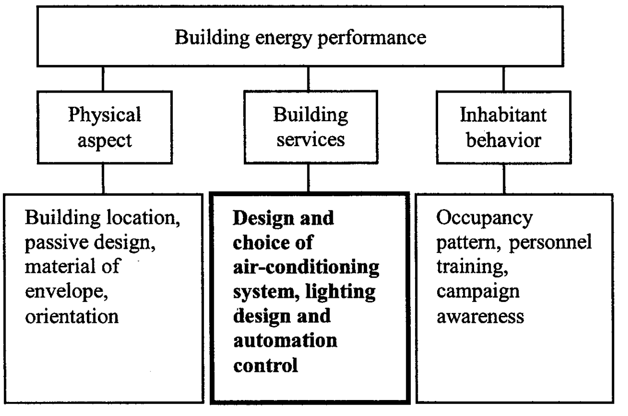

Fig. 9 Factors related to building energy[12)]

In order to seek further clarification on the current air-conditioning design practice in Malaysia, an interview session was held with a credible air-conditioning designer from a mechanical & electrical engineering consultant firm as shown in Figure 10. The approached designer had a work experience of over 16 years related to air-conditioning. Throughout that period, numerous air-conditioning systems had been designed by him mainly for office building, retail premises, shopping mall and academic institution in the country. In addition, the air-conditioning designer was a certified Professional Engineer. Under the Malaysian law, only a certified engineer is legally authorised to endorse construction drawings for building projects.

During the interview, the designer revealed the process of sizing the air-conditioning equipment was assisted by utilizing the Carrier E-20 software. According to him, the software was not only used in his consulting firm, but also popular among other designers in Malaysia due to its reliable accuracy and easy-to-use. Furthermore, the software was acquired for free by the equipment manufacturer. Therefore, most of the air-conditioning designers in Malaysia have ditched out the traditional method of manual calculation as the thing in the past.

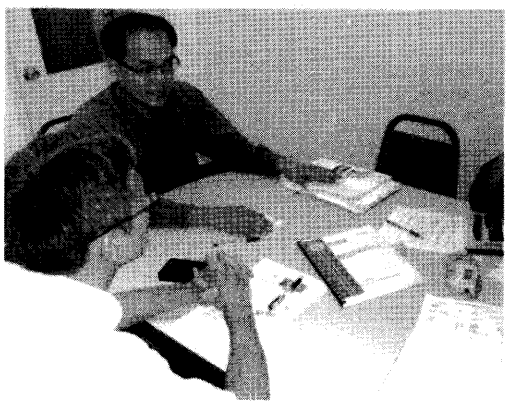

Fig. 10 Session with air-conditioning designer

A sample of calculation for actual air-conditioning system sizing was provided by the designer. The calculation revealed that the indoor design temperature was chosen as 23.0 °C. Sensible heat ratio was determined to be 0.586. Sensible heat ratio is the fraction of sensible heat load over total heat load. Supplied air was determined to be 12.5 °C and the resulting humidity of the conditioned space was 56 %. In addition, 10% of oversizing was given the whole system. According to him, the reason for oversizing is for any future room expansion or modification inside the building that requires larger air-conditioning system. The air-conditioning designer also confirmed that there was no assessment of building energy consumption being carried out at the moment.

It is observed that the calculation was made so that the air-conditioning system operates in relatively low temperature. It is difficult to obtain good energy consumption with such a low temperature set point of air-conditioning system. A reduced sensible heat ratio exaggerates the dehumidification process at the cooling coil of air handling unit. As more moisture being taken out of the conditioned space, the indoor humidity will also become too low. In such design set-up, thermal comfort of the occupants is affected and resulting in unnecessary dry condition.

Furthermore, the design is intentionally oversized, forcing the chiller to run at partial load more often than normal. The oversizing is not necessary as the MS1525 recommends that the equipment size should be determined according to the calculation.

In another words, oversizing is prohibited in order to avoid the air-conditioning system running at partial load more often than full load. In running at partial load, the efficiency of the air-conditioning is reduced and will affect the building energy consumption.

The clause for the requirement to perform building energy simulation is newly included in the first revision of MS1525 as it was not available in the initial issue. The simulation is necessary to predict the energy consumption in the buildings where the air-conditioning designer could opt for a more efficient system based on the simulation results. However, the exercise to predict building energy consumption through software-assisted tool is relatively new in Malaysia, and this may be the reason of the practice was not being carried out. It is hoped that the new clause in MS1525 regarding building energy assessment will be adhered in the future.

4.3 Air-conditioning system selection

As the technology gets better, air-conditioning manufacturers around the world race among themselves to produce the most efficient equipment for the benefit of the consumer. In a typical Malaysian commercial building, there are several types of air-conditioning system being the most popular; the conventional chiller system, variable refrigerant volume (VRV) system, package system and unitary system. Each system has its own characteristics due to the variance in design.

The function of a chiller is to produce chilled water and distribute it to the whole building. The chilled water will reach the air handling unit or fan coil unit where the cooled air is produced for the conditioned space. In VRV system, the cooled refrigerant is distributed to the building spaces instead of chilled water. On the other hand, the package system is a factory-assembled unit of air-conditioner and unitary system is the smallest type using direct expansion coil to produce cooled air.

The air-conditioning designer explained that choosing the type of system to be installed in the building was purely due to the equipment initial cost, as far as the practice in Malaysia is concern. An energy efficient air-conditioning system would obviously cost more than the conventional type of equipment. Hence, convincing the building owners to acquire air-conditioning system which provide energy conservation but cost more capital investment is a difficult task. Such scenario occurred may be due to the fact that the building energy consumption was not being estimated in the first place. Without a proper prediction of long term energy saving, building owners hesitated in investing monies for an unknown return in the future. As a result, the type of air-conditioning system was chosen based on merely equipment cost but not energy-saving reason.

Using the monetary currency of Ringgit Malaysia (RM) as the basis, the rule of thumb for the costing of air-conditioning system was explained by the designer. The VRV system was valued at RM 5,000 / ton refrigerant and for the chiller system, RM 6,000 / ton refrigerant. At a glance, the VRV system seems to be the preferred choice. However, unlike the chiller system which is suitable for high rise building, VRV system was limited to a 20-storey building or smaller. It has to be noted that there was no rough calculation available for the maintenance cost for both system. The air-conditioning designer pointed out that most of the other players in the industry are practicing an almost similar approach in terms of air-conditioning design and selection.

5. Conclusion

This paper presents the review of current situation in Malaysia relating to energy consumption, indoor thermal comfort and air-conditioning system design. It is observed that the guidelines towards low energy building and the platform for green buildings are already in place with the establishment of Malaysian Standard MS1525. The research pertaining to temperature seems to dominate the thermal comfort research while the analysis of humidity is lacking. It is observed that the air-conditioning design was made so that the system operates in relatively low temperature. Subsequently, the low temperature will have an inherent effect by lowering the humidity too much as well. Apart from affecting the thermal comfort, the low temperature also will increase the building energy consumption. In addition, the air-conditioning equipment was observed to be purposely oversized and this would prevent the system from running in full load and obtaining the best efficiency. Simulation of building energy consumption was not practiced accordingly as an energy saving tool. As a consequence, the selection to choose the air-conditioning system was merely based on the equipment cost. Energy cost was never in consideration.

Further research is required to understand the current indoor thermal comfort condition of temperature and humidity in Malaysian building. The outcome of the study will be helpful in designing the air-conditioning system that reduces the building energy consumption while improving the thermal comfort.

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