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# Transient Cooling Load Characteristic of an Academic Building, using TRNSYS

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**Abstract:** One of the major energy consumers in any commercial building, in hot and humid area is the air conditioning system. Therefore matching between Air Conditioning (AC) systems strategies with the cooling load characteristic is crucial to ensure effectiveness. Previous researches have been done to determine cooling load characteristic for offices and residential buildings. However, same research for academic buildings is rare and still need further development. The occupancy schedule in office and residential buildings are significantly different with academic buildings and so does the cooling load characteristic. Due to that the paper aims to provide transient cooling load characteristic for academic building through simulation using TRNSYS. The results showed that the major contributor to the cooling load was heat gain from building envelope which was counted up to 52.57% of the total cooling load in a year. The result also implied that cooling energy wasted during peak and off-peak period was approximately 50% of the total cooling load. Once transient cooling load characteristic was presented, three possible solutions were applied to the system to find best solution in reducing the cooling load. The result showed that the AC system with adjustable room temperature set point would have lowest cooling load. This solution would reduce the cooling load by 27.4%.

**Key words:** Transient cooling load, air conditioning system, energy building simulation, TRNSYS

## INTRODUCTION

In recent years, efforts to reduce the energy consumption for air conditioning systems have been growing since the system consume more than 50% of the total energy used in a building. Improvements of the system are needed to reduce energy consumption by enhancing the performance of air conditioning system or increasing the efficiency of the system. It has also been stated that comfort, health and energy saving are recent research topics and the direction of air conditioning related research in the future (Yu *et al*., 2009).

One of the major energy consumers in any commercial building, in hot and humid area, is the air conditioning system. Due to this; cooling load characteristic is a vital part on improving any Air Conditioning (AC) system to meet indoor comfort level with high efficiency.

The characteristics of space cooling load and indoor humidity control using Room Air Conditioner (RAC) with an equipment Sensible Heat Ratio (SHR) for residences in the subtropics (Hong Kong) has been investigated by (Li *et al*., 2006). SHR is ratio between sensible cooling load and total cooling load. The investigation found that most standard RACs with equipment SHR (value at 0.7-0.8) are not applicable for all operating months, due to cooling load characteristic in Hong Kong which have SHR value at 0.56-0.68. Another result from their work showed that indoor furnishings affect on indoor Relative Humidity (RH) level at less than 2% RH, especially at Day-time Operating Mode (DOM) condition and can therefore be neglected for practical calculations in residential building (Li *et al*., 2006). Furthermore, in hot and humid area, Mazzei *et al*. (2005), found that allowing natural dehumidification at the cooling coil to deal with the latent cooling load will be not sufficient (Mazzei *et al*., 2005).

For residential building (bedroom) in subtropical Hong Kong, the cooling load characteristic had been investigated by Lin and Deng (2004). They found that using 1h and 2h longer cool-down period in sizing the RACs, would reduces its cooling capacities by 20 and 25%. Due to this, The RACs would operate with minimum number of off cycles and therefore, have high efficiency (Lin and Deng, 2004).

In most office building located in hot and humid area, heat gain from envelope and ventilation are the major heat gain. Typically office building is occupied during the day and unoccupied during the night. Therefore, it is possible to use night ventilation to release heat absorbed by buildings thermal mass on day time. Yang and Li (2008)

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**Corresponding Author:** Petrus Tri Bhaskoro, Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia found that cooling load in office building can be reduced effectively up to 60%, by using thermal mass which have time constant between 400-1000 h (Yang and Li, 2008). Another investigations found that lightweight aluminum roof using polyurethane insulation with white painted surface color, thermal insulation on walls, urban form and $CO_2$ concentration control can be used to reduce cooling load (Han *et al*., 2009; Leung and Steemers, 2008; Congradac and Kulic, 2009; Aktacir *et al*., 2010).

Existing studies have described transient cooling load characteristic in hot and humid area with various ways to reduce the cooling load regarding to the cooling load characteristic. However, these studies were mostly conducted for office and residential buildings with concrete walls while the study for mechanical workshop in academic buildings with large glazing area is still rare. Unlike office and residential buildings, the workshops are used for practical/research works by the students and staffs (lectures or technicians) who have higher degree level of activity and unique occupancy pattern due to academic schedule.

Therefore, this study aims to provide cooling load characteristic and get best solution for the AC system to reduce cooling load in a mechanical workshop at UTP through simulation using TRNSYS. The workshop is located in Tronoh, Malaysia with -100.98° of longitude and 4.42° of latitude.

## MATERIALS AND METHODS

**Building description and activity schedules:** The workshop is facing southeast with large window glazing area (nearly 100% of glazing area) and on 32 m above sea level. It has 598 $m^2$ of area and 8m of height. Floor lay out for the block can be seen from construction drawing (Control Room, 2009).

As a mechanical workshop, it has machines, computers and artificial lights to support practical/research works by the students and staffs. Material used for walls on the workshop, conductivity and U-values of each material were described in Table 1 and 2. Detail of machines and electronic devices in the workshop were described in Table 3 while schedule for the students and staffs are described in Table 4 and 5.

Activity schedule between the students and staffs are different. For staff, activity schedule is based on UTP working days and working hours which have 5 working days (Monday-Friday) with nine working hours for each day (08.00-17.00) and some of Malaysian's national holidays. For students, activity schedule is based on academic schedule. Activities in the workshop which have no specific schedule were not considered in this simulation.

Table 1: Building material specification of block 16

| Building construction | Details (thickness-thermal conductivity) |
|---|---|
| External Wall | Steel (5 mm-54 kj hmK$^{-1}$),<br>Air gap (0.047 hm$^2$ k kJ$^{-1}$),<br>Steel (11 mm-54 kj hmK$^{-1}$) |
| Partition Wall | Plasterboard (25 mm-0.576 kj hmK$^{-1}$),<br>Air Gap (92 mm-0.047 hm$^2$ k kJ),<br>Plasterboard (25 mm-0.576 kj hmK$^{-1}$) |
| Flooring | Tile (5 mm-3.6 kj hmK$^{-1}$), Cement mortar (5 mm-5.04 kj hmK$^{-1}$), Common concrete (100 mm-7.56 kj hmK$^{-1}$), Compacting earth (for ground floor only)<br>(500 mm-5.4 kj hmK$^{-1}$) |
| Window | Optiwhite glass (12 mm-0.98 kj hmK$^{-1}$) |
| Roofing | Aluminum (1 mm-846 kj hmK$^{-1}$),<br>Rockwool (25 mm-0.162 kj hmK$^{-1}$),<br>Aluminum foil (1-846 kj hmK$^{-1}$),<br>Common concrete (10 mm-7.56 kj hmK$^{-1}$) |

Table 2: U-values of walls for block 16

| Type | U-values (conduction) ($W/m^2K$) | U-value (Overall) ($W/m^2K$) |
|---|---|---|
| Floor | 2.567 | 1.787 |
| Roof | 1.785 | 1.369 |
| Partition Wall | 2.076 | 1.534 |
| Window | 0.272 | 5.390 |
| External Wall | 66.667 | 5.405 |

Table 3: Machines, lighting and computers in the workshop

| Description | Type | Power (kJ/h) | Qty |
|---|---|---|---|
| Machines | CNC Milling | 108,000 | 1 |
| | CNC Lathe | 180,000 | 1 |
| | CNC laser | 720 | 1 |
| PC with monitor | | 1,440 | 3 |
| | | 1,800 | 1 |
| Lighting | Fluorescent | 129.6 | 12 |
| | Halid | 1,440 | 21 |

Table 4: Students academic schedule 2009

| | Month | | | | | |
|---|---|---|---|---|---|---|
| Week | Jan. | Feb. | Mar. | Apr. | May. | June |
| I | B | S | S | S | E | B |
| II | B | S | S | S | E | B |
| III | S | S | B | S | E | B |
| IV | S | S | S | S | E | B |
| V | - | - | S | S | - | B |
| | July | Aug. | Sep. | Oct. | Nov. | Des. |
| I | B | S | S | S | E | B |
| II | B | S | S | S | E | B |
| III | S | S | S | S | E | B |
| IV | S | S | B | S | E | B |
| V | - | - | S | S | - | B |

Table 5: Practical schedule for mechanical workshop

| | Practical session | | | |
|---|---|---|---|---|
| Days | I | II | Students | Staff |
| Monday | 12.00-13.30 | - | 15 | 3 |
| Tuesday | 11.00-12.30 | 14.00-17.30 | | |
| Wednesday | 10.00-11.30 | - | | |
| Thursday | 12.00-13.30 | 15.00-18.30 | | |
| Friday | 15.00-16.30 | - | | |
| Saturday | - | - | - | - |
| Sunday | - | - | - | - |

**Air conditioning system at UTP:** Centralized AC system with Absorption chiller was used to deal with the cooling load from all UTP's academic blocks. Each block has 3 levels and each level have two wings of group zones (left and right wing). The buildings are fully sealed and fresh air is supplied by the Air Handling Unit (AHU) on each floor only. There are two Air Handling Unit (AHU) on each level. AHU 1 is used to provide chilled air to the right wing while AHU 2 is for the left wing.

In each room, there is a Variable Air Volume (VAV) to control chilled air flow rate enter the room (2 room max) and a temperature sensor which is placed in each room to monitor room temperature (Control Room, 2009). The AC system was operated from 7 am till 7 pm every Monday to Saturday.

**Cooling load in the workshop:** Heat Gain From Machines (QMCH), Heat Gain From Lighting (QLIGHT), heat gain from electronic equipments and heat gain from building envelope (QENV) would contribute to sensible cooling load (QSEN). Heat gain from occupants (QPERSON), heat gain from ventilation (QVENT) and heat gain from infiltration (QINF) would contribute to both latent (QLAT) and sensible cooling load. Convective and radiative fraction for heat gain from computers and QMCH were 0.7 and 0.3 while for artificial lights, the values were 0.6 and 0.4 (Spitler *et al.*, 1997).

**Calculation:** Heat balance method is used by TRNSYS as a base for all calculations. For conductive heat gain at the surface on each wall, TRNSYS use Transfer Function Method (TFM) as a simplification of the arduous heat balance method (TRNSYS Group, 2003):

$$q_{s,i} = \sum_{k=0}^{n_{bs}} b_s^k T_{s,o}^k - \sum_{k=0}^{n_{cs}} c_s^k T_{s,i}^k - \sum_{k=1}^{n_{ds}} d_s^k q_{s,i}^k \tag{1}$$

$$q_{s,o} = \sum_{k=0}^{n_{as}} a_s^k T_{s,o}^k - \sum_{k=0}^{n_{bs}} b_s^k T_{s,i}^k - \sum_{k=1}^{n_{ds}} d_s^k q_{s,o}^k \tag{2}$$

Heat gain through radiation and convection were calculated using:

$$q_{s,\,i} = q_{comb,\,s,\,i} + S_{s,\,i} + \text{Wall-gain} \tag{3}$$

$$q_{s,\,o} = q_{comb,\,s,\,i} + S_{s,\,i} \tag{4}$$

where, $q_{comb,s,i/o}$ is combined convective and long wave radiation of inside/outside surface:

$$q_{comb,s,i} = \frac{1}{R_{equiv,i} \times A_{s,i}} \left(T_{s,i} - T_{star}\right) \tag{5}$$

$$q_{comb,\,s,\,o} = q_{c,\,s,\,o} + q_{r,\,s,\,o} \tag{6}$$

with:

$$q_{c,\,s,\,o} = h_{conv,\,s,\,o} \left(T_{a,\,s} - T_{s,\,o}\right) \tag{7}$$

$$q_{r,s,o} = s\,e_{s,o} \left(T_{s,o}^4 - T_{fsky}^4\right) \tag{8}$$

Latent heat gain from ventilation/infiltration air is calculated using (Wang, 2000; Cengel and Boles, 2008):

$$qit = V\alpha\, \rho_O \left(\omega_O - \omega w_\gamma\right) h_{fg,\,32} \tag{9}$$

The amount of heat gain per occupant is based on ISO 7730 table. Degree level of activity was inputted to get the portion of sensible and latent heat from the table.

**Building simulation and assumptions:** Design temperature and RH were based on ASHRAE where 25°C of operative temperature and 50% of RH needed for a comfort zone (ASHRAE, 1995). In practical, the operative temperature should be kept below the design temperature. The reason was that operative temperature is approximately the mean value of indoor air temperature and mean radiant temperature (ASHRAE, 1995) and the mean radiant temperature is usually higher then indoor air temperature (Lin and Deng, 2004). In this simulation 24°C of operative temperature and 50% of RH were chosen for the workshop. Ventilation rate of 7.5 $L^{-1}$ sec per person as required by ASHRAE (2001) standard is supplied by the AHU. Infiltration rate were based on door openings and leakage air which was assumed to be 3% in this fully sealed workshop. Temperature of ambient air, RH of ambient air, wind velocity, wind direction and global solar radiation data were provided by weather data collected from Ipoh weather station.

During practical session, all machines were operated at full power for half session time. All students and technician were standing and doing light work or walking slowly during the session. Influence of indoor furnishing to indoor RH was neglected since most of the furnishing are made from steel, hence has low moisture content and absorption. The simulation was done for a year with one hour time step. Due to the building construction, shading factor for external wall facing southeast and southwest was 0.9 and 0.8.

For deeper analysis, the simulation was separated into two periods of times; peak period (study week period) and off-peak period (examination and break periods). The cooling load in March (as representative of peak period) and December (as representative of off-peak period) were chosen for the analysis. In order to give better visualization, the graphs were presented on 48h based (Monday and Tuesday). Three solutions to reduce the cooling load were presented. First solution added external shading devices for the window and external wall with shading factor equal to 1 (Zero transmission). Second solution changed the window from single window glazing to double window glazing. Third solution Adjusted room temperature set point from 24 to 28°C during unoccupied period. Temperature of 28°C was chosen because the ambient temperature is usually above 28°C during daytime.

**TRNSYS software:** TRNSYS was used to carry out the simulation, since TRNSYS is a transient system simulation program which can be used to solve complex energy system using heat balance method. Simple or complex systems are provided by TRNSYS to help the users in modeling the system in question. The advantages of this software are its ability to insert new equation and mathematical model from other software like matlab, excel, etc. TRNSYS also allow the users to create new component from other engineering software to model their own component. These advantages make TRNSYS flexible to solve any energy system and to develop the system in question into more complex system (Crawley *et al*., 2008).

Due to this, the software was used to simulate cooling load characteristic for the workshop.

## RESULTS AND DISCUSSION

**Total cooling load and cooling load characteristic:** An energy building simulation had been performed using TRNSYS software to demonstrate transient cooling load characteristic in the workshop for a year. The result showed that, QENV was the highest contributor to the cooling load which contributes 52.57% followed by QMCH 23.68%, QVENT and QINF 1.92%, QLIGHT 5.22%, QPERSON 0.84% and QLAT 15.77% of the total cooling load. Calculated sensible and latent cooling load was 58.54 and 10.37 MWh. Breakdown of monthly cooling load from January till December are shown in Fig. 1 and 2.

**Cooling load characteristic during off-peak month (December):** Breakdown of cooling load in the zone during off-peak month (December) is shown in Fig. 3 and calculated hourly cooling load characteristic during this period is shown in Fig. 4. The graph showed that QENV contribute 77.01%, QINF contribute 2% and QLAT contribute 20.99% of the total cooling load. Calculated sensible and latent cooling load in this month was 2.32 and 0.60 MWh.

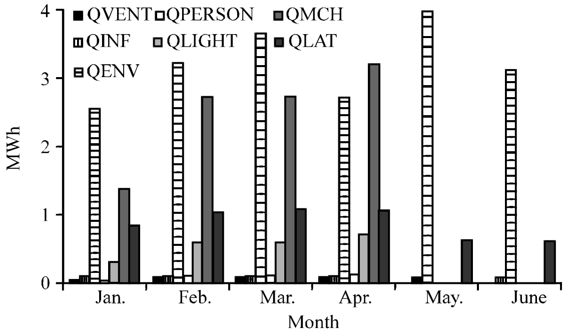

Fig. 1: Monthly cooling load in a period of january till June

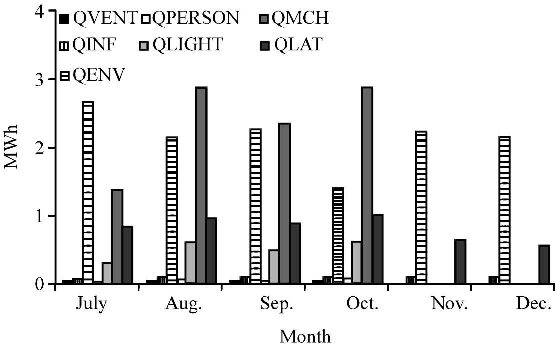

Fig. 2: Monthly cooling load in a period of july till december

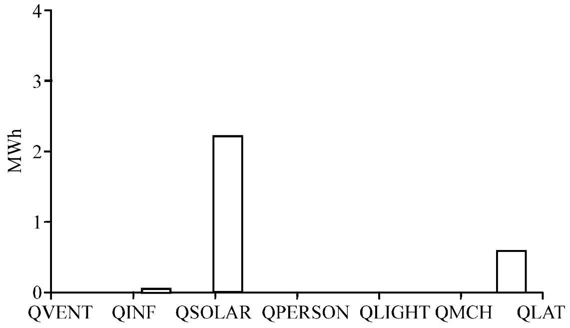

Fig. 3: Cooling load in the workshop during the month of december (off-peak)

**Cooling load characteristic during peak month (March):** Breakdown of cooling load characteristic in the zone during peak month (March) is shown in Fig. 5 and calculated hourly cooling load characteristic during this period is shown in Fig. 6. In March, as a highest cooling load, the cooling load is dominated by QENV which contributes for 45.06% of the total cooling load followed by QMCH 31.53%, QINF and QVENT 2.02%, QLIGHT

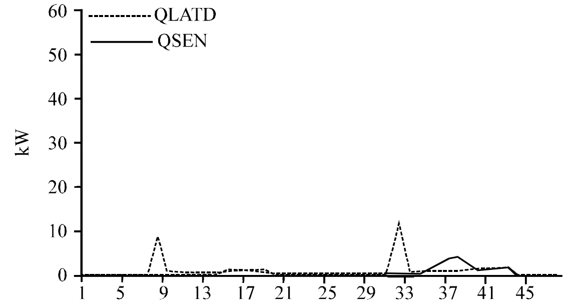

Fig. 4: Hourly cooling load characteristic in the workshop during the month of december (off-peak)

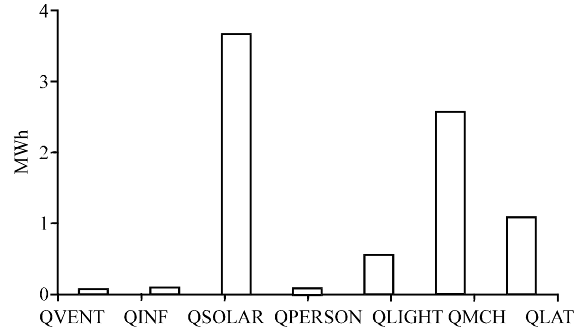

Fig. 5: Cooling load in the workshop during the month of march (peak)

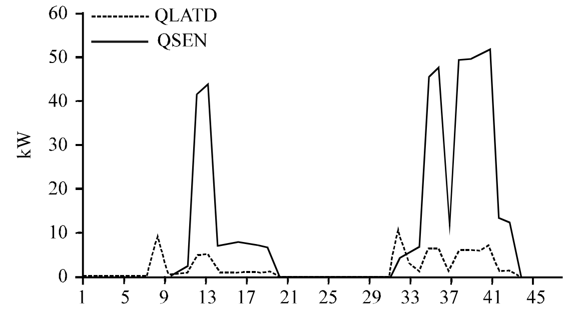

Fig. 6: Hourly cooling load characteristic in the workshop during the month of march (peak)

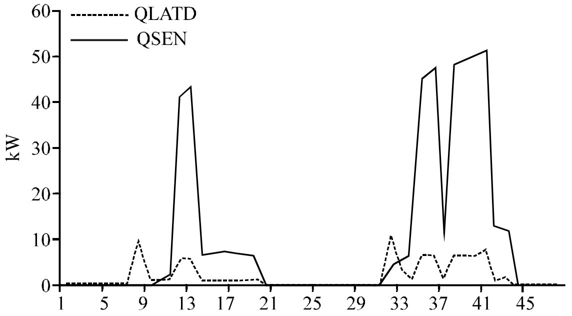

Fig. 7: Hourly cooling load characteristic in the workshop during the month of march with external shading device

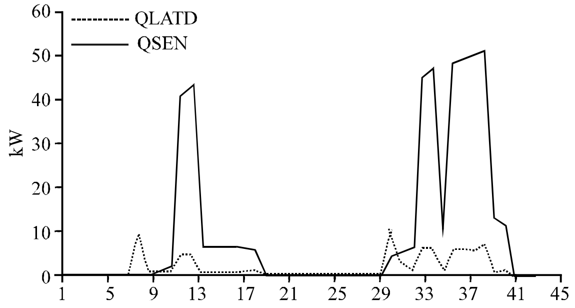

Fig. 8: Hourly cooling load characteristic in the workshop during the month of march using double window glazing

6.95%, QPERSON 1.12% and QLAT 13.32%. Calculated total sensible and latent cooling load in this month was 7.05 and 1.08 MWh.

**First solution**

**Cooling load characteristic during peak month (march) with external shading devices for the wall:** External shading device for the external walls and windows with shading factor equal to 1 was applied in the simulation during peak month (March) and the result was presented in Fig. 7. The result showed that calculated total sensible and latent cooling load in this month was 6.57 and 1.07 MWh.

**Second solution: Cooling load characteristic during peak month (March) using double window glazing:** The window of the workshop was changed from single window glazing to double window glazing and the result during peak month was shown in Fig. 8. The result showed that there were only small cooling load different before and after double window glazing was applied. Calculated total sensible and latent cooling load in this month was 6.88 and 1.11 MWh.

**Third solution**

**Cooling load characteristic during peak month (March) with adjustable room temperature set point:** AC system with adjustable room temperature set point was applied in the simulation during peak month (March) and the result was presented in Fig. 9. The result showed that calculated total sensible and latent cooling load in this month was 4.9 and 1.00 MWh. The reduction was mainly caused by higher room temperature during unoccupied period.

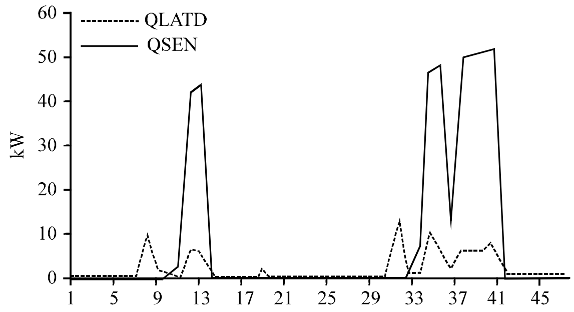

Fig. 9: Hourly cooling load characteristic in the workshop during the month of march with adjustable room temperature set point

## DISCUSSION

During peak and off-peak period, it was clear that QENV was the main contributor to the cooling load. With external glass wall, the workshop might use solar light as natural light which would reduce QLIGHT. However, the reduction would not significantly affect to the total cooling load since for a year QLIGHT contributes only 5.22% of the total cooling load.

During off-peak period, air conditioning system could not be turned off since fresh air is supplied by AHU only and possibility that there were staffs doing their research in the workshop. Due to this, cooling energy was wasted when there were no activities by the staffs in the workshop. With off-peak period up to 5 months in a year, the energy wasted would burden the operational cost of the workshop.

For a day, during peak period, there was only one or two practical session. Each session only had one up to three hours duration and there was one up to 4 h time gap between first session and next session where the cooling energy was wasted. The simulation result implied that cooling energy wasted during peak and off-peak period could be up to 50% of the total cooling energy used if there was no research activity by the staff during unoccupied period.

Three possible solutions to reduce the total cooling load were presented. With first solution, the cooling load was reduced by 6%. The reduction was mainly due to fact that heat gain from building envelope was minimized. With second solution, the cooling load was reduced by 1.7%. The reductions were mainly due to lower direct solar heat gain to the zone. With third solution, the cooling load was reduced by 27.4%. The reductions were mainly due to higher room temperature set point (28°C) during unoccupied period. Hence, third solution is the best solution to be applied in the workshop to reduce the cooling load and the cooling energy wasted during unoccupied period.

Table 6: Percentage of cooling load

| | Total cooling load on march | | |
|---|---|---|---|
| Effect of proposed solution | QSEN (Mwh) | QLAT (Mwh) | Reduction (%) |
| Shading devices | 6.57 | 1.08 | 6.0 |
| Lightweight concrete | 6.88 | 1.11 | 1.7 |
| Adjustable room temperature | 4.90 | 1.00 | 27.4 |

## CONCLUSION AND FURTHER WORKS

The cooling load characteristic in a mechanical workshop has been performed using TRNSYS and reported in this paper. The result showed that QENV was the main contributor to the cooling load. Reducing QLIGHT by using solar light would not significantly affect to the total cooling load since for a year QLIGHT contributes only 5.22% of the total cooling load. With off-peak period up to 5 months in a year, the simulation result implied that cooling energy wasted during peak and off-peak period could be up to 50% of the total cooling energy used if there was no research activity by the staff during unoccupied period.

During peak month (March) the total QSEN and QLAT were 7.05 MWh and 1.08 MWh. Three solutions were applied to reduce the cooling load. The percentage of cooling load reduction from the solutions was presented in Table 6.

The results showed that the third solution gives highest cooling load reductions. Therefore, third solution is the best solution to be applied for AC system in this type of workshop. Real design of control system for the AC system and experimental study for the solution will be carried out for further research and will be presented in the future.

## ACKNOWLEDGMENT

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