Abstract— This paper aims to estimate intermittent transient cooling load characteristics in an academic building with large glazing area using TRNSYS. Simulation and experimental studies have been done in the past to estimate cooling load characteristic and to find strategies to reduce the energy used by the centralized HVAC system in various ways. However, these studies were mostly conducted for a building with simultaneous occupancy pattern. Since occupancy pattern in a university is intermittent, the cooling load characteristic would be different with that with simultaneous occupancy pattern. The building thermal and simulation model was first built and validated by comparing the results with experimental results. The validated model was then used to estimate the cooling load characteristic on a year basis. In addition, the effect of the occupancy pattern were also analyzed and discussed. The results showed that the ratio of cooling loads at minimum and maximum were 0.52, 0.54, and 0.68 for the workshop, classroom and office due to the occupancy pattern. This would reduce the energy wasted during unoccupied period.

Index Terms— Keywords: Building simulation, intermittent transient cooling load characteristic, centralized HVAC system, academic glazed building

I. INTRODUCTION

Recently, efforts to reduce energy usage are doubled due to global warming and energy source shortage. With the fact that HVAC system is the major energy consumption in office buildings in Malaysia (up to 64% of the total energy consumed) [1] and a trend of higher cooling energy usage due to climate change [2], strategies to reduce the cooling load is highly needed.

Davis III and Nutter found that occupancy pattern in a university differ from that in many office and residential buildings [3]. Since cooling load in those building is mostly driven by the occupancy pattern, the difference will result in different cooling load characteristics. In office or residential buildings, the room is usually occupied during cooling period even though the number of occupants may be changing over the period [4,5]. In a university, there are occupied and unoccupied hours during cooling period [6]. Due to this, the cooling type is likely to be continuous load for office or residential buildings and intermittent load for a university. The types of rooms are also found to be more various in a university than that in office or residential building.

Simulation and experimental studies showed that external window glazing could have significant effect on indoor thermal comfort and energy consumption. Due to the glazing constructions and properties, more shortwave solar radiation will be transmitted into the zone while long wave solar radiation from internal heat sources will be trapped inside the zone. On the other hand, it will reduce heat gain from artificial lighting during daytime and release the heat buildup during daytime easily during nighttime [7,8,9,]. These results indicate that there is a trade-off between thermal comfort, lighting need and energy consumption.

Simulations and experimental studies to study cooling load characteristic have been done in the past by taking into account internal (occupant, lighting, etc) and external (wall heat gain, window heat gain and solar radiation heat gain) cooling load. The building thermal model was first constructed based on physical and operation characteristic of the building [4,9,10,11]. The model was then validated by comparing simulations results with experimental results before it is used for further analysis. From the simulations results, it was found that for office and residential buildings, heat gained from building envelope and lighting are the major cooling load [4,9]. The previous studies of cooling load characteristics, however, were mostly conducted for office and residential building.

Therefore, the objective of this work is to do simulation study of intermittent transient cooling load characteristic of an academic building with large glazing area using transient system simulation software TRNSYS. A building thermal and
simulation model was first constructed and validated by comparing the results with experimental results. The validated model was then used to simulate the hourly intermittent transient cooling load characteristic for a year. In addition, the effect of usage factor and the occupancy pattern on the energy consumption and the HVAC system performance were analyzed and discussed.

II. BUILDING THERMAL AND SIMULATION MODEL

A transient building thermal and simulation model for the academic block was developed using energy building simulation software TRNSYS. The building thermal and simulation model was developed based on the following:

- Building construction detail and occupancy schedules
- List of indoor lights, equipments and machines
- Centralized HVAC system in the building
- Cooling load types in the building

Nomenclature

- \( T_s \): Surface temperature, \( ^\circ \text{C} \)
- \( T_{\text{star}} \): Artificial temperature node, \( ^\circ \text{C} \)
- \( A_s \): Surface area, m²
- \( R_{\text{equiv}} \): Equivalent resistant between the walls with a node, h m² K kJ⁻¹
- \( q_{c,s} \): Convection heat flux an the surface of the wall, kJ h⁻¹
- \( q_{r,s} \): Long wave radiation heat flux on the surface of the wall, kJ h⁻¹
- \( h_{\text{conv},s} \): Convective heat transfer coefficient on the surface of the wall, kJ h⁻¹ m⁻² K⁻¹
- \( \sigma \): Stephan-Boltzmann constant
- \( \epsilon_s \): Long-wave emissivity of the surface
- \( T_{\text{sky}} \): Ambient temperature, \( ^\circ \text{C} \)
- \( T_{\text{sky}} \): Fictive sky temperature, \( ^\circ \text{C} \)
- \( q_{\text{comb}} \): Combined convective and radiation heat transfer, kJ h⁻¹
- \( \text{RH} \): Relative humidity, %

Superscripts:

- \( i \): inside
- \( o \): outside

A. Building thermal details and occupancy schedules

An academic block located at Universiti Teknologi PETRONAS (UTP) was chosen for the study. The block is facing east with large window glazing area (nearly 100% of glazing area) and on 32m above sea level. It has three levels with 4m height on each floor. Floor lay out for the block was detailed on construction drawing [12].

As an academic block, it has offices, classrooms and workshop 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. Student academic schedule was described in Table 3 while staff schedule was based on UTP working days (Monday-Friday), working hours (08:00-17.00) and Malaysia national holidays.

Activity schedule for each workshops in block 16 are based on practical schedule of each subject. Numbers of equipment used and usage factors of the equipments in each type of rooms were based on observation data and discussion with the technician/staff. Activities in the workshop with no specific schedule were not considered in this simulation.

B. Centralized HVAC system in the building

Centralized AC system with absorption chiller was used to cover the cooling load from all the 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. There are two air handling unit (AHU) on each level. AHU 1 is used to provide air supply to the right wing while AHU 2 is for the left wing. A variable fan speed and a
regulating valve were used in the AHU to give variable supply air and chilled water flow rate.

The HVAC system use variable air volume (VAV) system to control supply air flow rate enter the room according to the cooling load. A temperature sensor is placed in each room to monitor room temperature [14]. The AC system was operated from 7 a.m till 7 p.m to keep indoor temperature set point (24°C). Indoor relative humidity was kept floating depend on the indoor temperature.

C. Cooling Load in the Building

Heat gain from equipments (QEQUIP), heat gain from lighting (QLIGHT), heat gain from electronic equipment and heat gain from building envelope due to solar radiation (QSEN) would contribute to sensible cooling load. 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. These heat gains were considered in the simulation.

The heat balance method is used in 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 [15]. Heat gain through radiation and convection within the zone were calculated using the star network given by Seem:

\[ q_{\text{comb,ref}} = q_{\text{e,ref}} + q_{\text{r,ref}} = \frac{1}{R_{\text{equiv}}} \left( T_{\text{a,ref}} - T_{\text{star}} \right) \]  

Heat gain through radiation and convection for external surface were calculated by:

\[ q_{\text{comb,ref}} = q_{\text{c,ref}} + q_{\text{e,ref}} \]  

\[ q_{\text{c,ref}} = h_{\text{conv,ref}} \left( T_{\text{a,ref}} - T_{\text{ref}} \right) \]  

\[ q_{\text{r,ref}} = \sigma e_{\text{ref}} \left( T_{\text{a,ref}}^4 - T_{\text{ref}}^4 \right) \]

Convection heat transfer coefficient for inside and outside walls were set 11 kJ/hm²K and 64 kJ/hm²K as recommended by the software [15]. Minimum ventilation rate required in each room is calculated based on ASHRAE standard [16]. Degree levels of activities were based on the types of activities in each room and it was inputted to get the portion of sensible and latent heat from ISO 7730 table. Heat gains from the equipments were calculated based on rated power, usage factor, load factor and its efficiency. Convective and radiative fraction for these heat gains were 0.7 and 0.3 while for artificial lights, the values were 0.6 and 0.4 [17].

III. ASSUMPTIONS AND STANDARDS

Building and occupant ventilation components were considered based on ASHRAE standard [16]. Building ventilation component is at rate 0.3 L/s/m² and occupant ventilation rates per person are 2.5 L/s per person. Infiltration air exchange due to door openings and leakage air was assumed to be 0.05/h during AC operation and 0.15/h during non-AC operation.

For calculation simplification, influence of indoor furnishing to indoor RH can be neglected since indoor furnishing will affect on indoor RH level at less than 2% RH, especially during daytime operating mode condition [2]. Occupant activity level in classroom and office was set at level 4 with sensible and latent heat values 269kJ/hr. Level 5 of activity level was applied for workshop where practical work existed. The sensible heat value is 332.33kJ/hr and the latent heat value is 342.88kJ/hr. These values are based on ISO 7730 table.

IV. EXPERIMENTAL DATA MEASUREMENTS

Indoor and outdoor experimental measurements were done for 2 weeks for validation purposes only. Indoor temperature, indoor relative humidity, supply air flow rate and supply air temperature were measured to get indoor environmental and supply air conditions. Supply air flow rate and temperature measurements are performed under the maintenance department supervision. Scheduled calibrations were performed by the department to maintain the accuracy of the equipments.

Ambient temperature, ambient relative humidity, global solar radiation, wind speed and wind directions measurements were done to get outdoor environmental conditions. The first three outdoor parameters measurements were done every 5 minutes by Firmanda [18] while wind speed and wind direction were not measured on this locations due to technical difficulties. These measurements data were collected from nearby weather station at Ipoh.

V. COMPARISON OF EXPERIMENTAL AND SIMULATION RESULTS

The comparison of indoor temperature between experimental measurement and simulation model is shown in Fig. 1 and 2. 81.25% of the simulated temperature values were found to be within ±1°C with the measured values. The difference occurs may be due to climatic difference between building area and outdoor experiment area.
Indoor relative humidity comparison between experimental measurement and simulation model is shown in Fig. 3. 72.5% of the simulated relative humidity values were found to be within ±5% compared to measured values. It may be due to influence of indoor temperature which will amplify the difference.

The simulation model was then used to calculate intermittent transient cooling load characteristic of the building for a year. The result was then used to investigate the effect of usage factor and the HVAC system performance.

VI. INTERMITTENT TRANSIENT COOLING LOAD CHARACTERISTIC

Intermittent transient cooling load for a year was calculated by the software using hourly climatic weather data collected from Ipoh weather station. The characteristics for typical workshop, classroom and office in the building during peak and off-peak period were shown in Fig. 5 to Fig. 10.

In the workshop, during peak period, the sensible and latent heat rise due to occupancy and practical activity. It can be seen that peak cooling load during peak period occur during occupied hours. However, the occupant exists only for several hours and become empty after that. The peak cooling load during peak period and off-peak period were counted up to 73 MJ and 39 MJ.

In the classroom, sensible and latent heat rise due to occupancy and more ventilation air needed. Similar to workshop, the peak cooling load during peak period occur during occupied hours. However, occupancy in the classroom was more frequent compared to that in the workshop. The peak cooling load during peak period and off-peak period were counted up to 51 MJ and 25 MJ.
Figure 7. Intermittent transient cooling load characteristic of classroom in the academic building during peak period.

Figure 8. Intermittent transient cooling load characteristic of classroom in the academic building during off-peak period.

Figure 9. Intermittent cooling load characteristic of office in the academic building during peak period.

Figure 10. Intermittent cooling load characteristic of office in the academic building during off-peak period.

It can be seen that usage factor plays important roles on daily total cooling load. Usage factor is the ratio of unoccupied hours to total HVAC operating hours. Higher usage factor will result in higher total cooling load and vice versa.

VII. CONCLUSION

Simulations to determine intermittent cooling load characteristic for typical workshop, classroom and office in an academic building have been presented and discussed. The building has been modeled and has been validated (through comparison between experiment and simulation results). The result showed that the model behave closely to the real building. 81.25% of the simulated temperature values were found to be within ±1°C with the measured values. The difference occurs may be due to climatic difference between building area and outdoor experiment area. 72.5% of the simulated relative humidity values were found to be within ±5% compare to measured values. High difference for the indoor relative humidity was due to fact that relative humidity is influenced by the temperature so that the difference on indoor temperature would amplify the difference of indoor relative humidity.

The cooling load was found to be fluctuated according to the occupancy pattern (occupant’s driven cooling load). The results showed that the ratio of cooling loads at minimum and maximum were 0.52, 0.54, and 0.68 for the workshop, classroom and office. Due to the occupancy pattern, several problems occur on the current HVAC system:

- During unoccupied hours, the HVAC system could not be turned off due to the centralized ventilation system and fact that the system serves more than one room with specific occupancy pattern for each room.
- There is a minimum supply air flow rate according to the ducting design and sizing. The cooling energy will be wasted when the supply air flow rate needed is lower than the minimum supply air flow rate. It was the reason why indoor temperature sometimes falls below the set point.
- Occupancy pattern for each room cannot be fixed because it is specific and can be changed. Due to the occupancy pattern and occupant’s driven cooling load,
additional equipment is needed by the current system to track the occupant and control the HVAC system based on the occupancy.

Strategies to solve the problems and handle the intermittent load by taking into account usage factor and occupancy pattern for each type of room will be discussed and presented in the near future.

REFERENCES


[12] Construction drawing, Universiti Teknologi PETRONAS


[14] Air conditioning and ventilation drawing, University Teknologi PETRONAS

[15] TRNSYS 16 manual

