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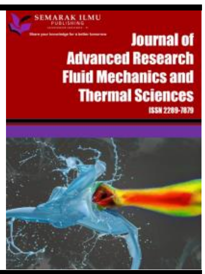

Indoor Climates and Energy Consumption by Air Conditioning System in a Learning Resource Centre in Malaysia

Chang Choo Khean[1,*], Zulkiflle Leman[2], Nor Mariah Adam[2], Eris Elianddy Supeni[2]

[1] HVAC&R Section, Universiti Kuala Lumpur, Malaysia France Institute, 43650 Bandar Baru Bangi, Selangor, Malaysia
[2] Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Malaysia

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ABSTRACT

A Learning Resource Centre is a type of library that houses books and all other media facilities as well as daily newspapers and journal articles. Indoor climates such as the indoor dry bulb temperature and relative humidity must be controlled at the recommended level in a Learning Resource Centre in order to keep the collections and archival materials in good condition. Based on the ASEAN Energy Organization report, 50-60% of the total energy consumption of a building goes to Heating, Ventilating and Air Conditioning (HVAC) systems operation. As such, energy savings for HVAC systems is crucial and should be studied, especially after climate change has taken place. In this paper, the author installed data loggers in the Resource Centre for a period of a month to monitor the indoor climate changing trend. Due to the lack of cooling and dehumidification processes when the HVAC systems were turned off, there were peaks in both indoor dry bulb temperature and relative humidity during the night. The ambient high relative humidity had caused an increase in the indoor relative humidity at night. At the same time, the energy consumption simulation of the HVAC systems was run using the Transient Energy System Simulation Tool (TRNSYS). Different operating modes were set in the simulations to obtain the comparison of energy consumption for the different operating modes of the HVAC systems under four different weather elements, namely the present-day, 2020's, 2050's and 2080's time scenarios. Electricity bills for the different scenarios based on current electricity tariffs were analyzed. The results show that a significant saving can be obtained if the HVAC systems were operated under the All-day Operating Mode.

1. Introduction

A Learning Resource Centre (RC) is a type of library that has books and all other media facilities as well as daily newspapers, journal articles, software and audio/visual materials. There are 21 public universities and 60 major private universities and colleges in Malaysia. All these universities provide a RC or library for their students to obtain information and references for their studies. Besides these, there are 14 state and public libraries and a National Library in Malaysia. There are hundreds of

* *Corresponding author.*
E-mail address: chang@unikl.edu.my

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thousands of materials and archival information in the libraries. It stores the human heritage, like ideas, facts, thoughts, and evidence of human development. As such, they must be conserved in a proper environment to prevent any decay. But, are the RC owners concerning about the indoor dry bulb temperature and relative humidity requirement for these valuable archives? This research studied the HVAC systems' performance in achieving the RC indoor climate requirements under four different weather files time scenarios. According to the British Standard [1], the dry bulb temperature in the RC should be maintained between 16 - 19°C with a tolerance of 1°C on either side, but ranging neither below the minimum nor above the maximum. Note that the relative humidity should be set between 45 - 60% with a tolerance of 5% on either side, but ranging neither below the minimum nor above the maximum. Whereas the Northeast Document Conservation Center (NEDCC) recommends that the room dry bulb temperature range should be 15 – 21°C while the room relative humidity range should be 30 - 50% [2]. It's essential to regulate the temperature and relative humidity for archival collections. The degradation of materials is dramatically accelerated by either at inappropriate levels. Heat speeds up chemical processes that degrade media. Low relative humidity can cause desiccation and embrittlement, whereas high relative humidity can promote the growth of mould and the activity of pests. 35-65°F and 30-50% relative humidity are the acceptable environmental standards for paper-based collections (RH). But other materials might call for various criteria [3]. Cornell University Library suggested the ideal indoor dry bulb temperature must be closely monitored and maintained at 20°C to 21°C in the books or archival materials storage areas, as for the indoor relative humidity, it is recommended to control it within the range of 30 and 50%, and it is aligned with the recommendation from NEDCC [4]. It is obvious that the maintenance of printed materials in libraries depends heavily on indoor climate management and air quality. While high temperatures and relative humidity can speed up the deterioration of paper, poor air quality can make pages brittle and yellow. In order to preserve library collections, it is crucial to maintain a suitable interior climate as agreed by Forde [5] and Bankole [6]. Is the cooling capacity sufficient to sustain the indoor climatic needs in the 2020s, 2050s, and 2080s for those libraries built in the 1970s to 2010s and fitted with an air conditioning system that was designed based on that time meteorological data?

In 1986, Clements [7] conducted a survey on 300 archives and 550 libraries worldwide. From the 417 replies, he revealed that indoor climate control and monitoring were neglected in most of the surveyed institutions. In a 1999 survey conducted by the Girdler-Brown [8] from National Archives of Hungary, it was discovered that indoor climate control and building maintenance were not effectively carried out. In a different study, Fenn and Muir [9] found that the major challenge in preserving library resources was indoor temperatures and environmental management in their survey. There is a lack of research related to indoor climate control in preserving library materials and archives in Malaysia. As such, the HVAC systems play an important role in creating and maintaining the stringent indoor climates in order to keep the collections in tip-top conditions. Unfortunately, the installation and operation of the HVAC systems are costly due to the high energy consumption, and are difficult to operate and maintain to achieve the recommended appropriate indoor climate as mentioned by Kerschner and Baker [10]. In fact, studies in Africa have shown that HVAC systems are responsible for 50% of the total power consumption in a building [11]. In the US alone, HVAC systems contribute almost 31% of the power consumption by households [12]. From the Asean Energy Organization report by Listijone [13], 50 - 60% of the total energy consumption of a building goes to HVAC systems operation. And it is forecasted the air conditioning system will consume about 40% of the electricity in Southeast Asia in 2040 [14]. Since 1990, the amount of energy used for space cooling has more than tripled, with major effects on electrical grids. One of the seven warmest years on record was 2021. The last seven years have also been the hottest on record. The demand for space cooling grew at the fastest rate among all construction end uses in 2021, making for approximately 16% of the sector's total final power consumption (about 2000 TWh) [15]. According to current estimates, electric fans and air conditioners in buildings account for about 20% of the world's total electricity usage. Additionally, the world's urbanisation, industrialization, climate change, and rising standards of living are all predicted to result in an increase in the electricity consumption for cooling, with some estimates predicting a triple of the current electricity demand for cooling [16]. Therefore, energy savings for HVAC systems are crucial and should be investigated completely, especially after the change in climates has taken place. The operation modes are studied in the current research.

Literature review reveals that there is very limited research done on the RC in terms of the indoor climates and energy consumption, especially in the tropics. For this purpose, the main aim of the present paper is to examine the energy consumption for the Air Conditioning (AC) system under different AC operating modes and weather data for different time scenarios, namely, the present-day weather data, 2020's, 2050's and 2080's. The research is also to study the impact of different operating modes of AC systems on energy consumption without impairing the indoor climate requirement in the RC. It was simulated a saving ranging from 10% to 20% of cooling energy if the cooling mode is set on hybrid ventilation with fixed schedules, and a bigger savings about 65% will be expected on hybrid ventilation with variable schedules [17]. Therefore, the operation mode plays an important role in energy savings. The TRNSYS calculates the annual electricity consumption for HVAC systems to provide human comfort in the building. Note that the electrical energy usage can be extracted directly from the TRNSYS in kWh.

2. Methodology

In the present work, the RC at the Institute in Kuala Lumpur, Malaysia was identified as the building to be studied. There were two main activities performed in the present study. The first activity was the site measurement of the indoor climates in the examined building. The second activity was the computer software simulation on the building thermal load and energy consumption. The authors carried out some field measurements in the center and computer software simulations had been run to study the building's thermal load and energy consumption for the AC system for the studied RC.

2.1 Field Measurement

The RC is situated on the 2nd floor of a 3 storey academic building. The total floor area is 581 m^2 (6,258 ft^2). The centre is divided into 6 zones. The walls facing South and West are exposed to sunlight. Figure 1 illustrates the layout of the RC.

In the present study, six (6) Kimo data loggers were used to measure the indoor dry bulb temperatures and relative humidity. The data loggers were mounted at the ceiling for each Zone in the RC as illustrated in Figure 1 for a period of 26 days, which was commenced on the 25 July 2019 till 19 August 2019. The indoor climate data was recorded hourly. The changing trend, minimum and maximum of the dry bulb temperature and RH in the Resource center were analyzed. In this regard, the existing AC system can be determined in terms of its cooling capacity to achieve the required indoor climate set points. There are no heating and ventilation systems installed in the RC.

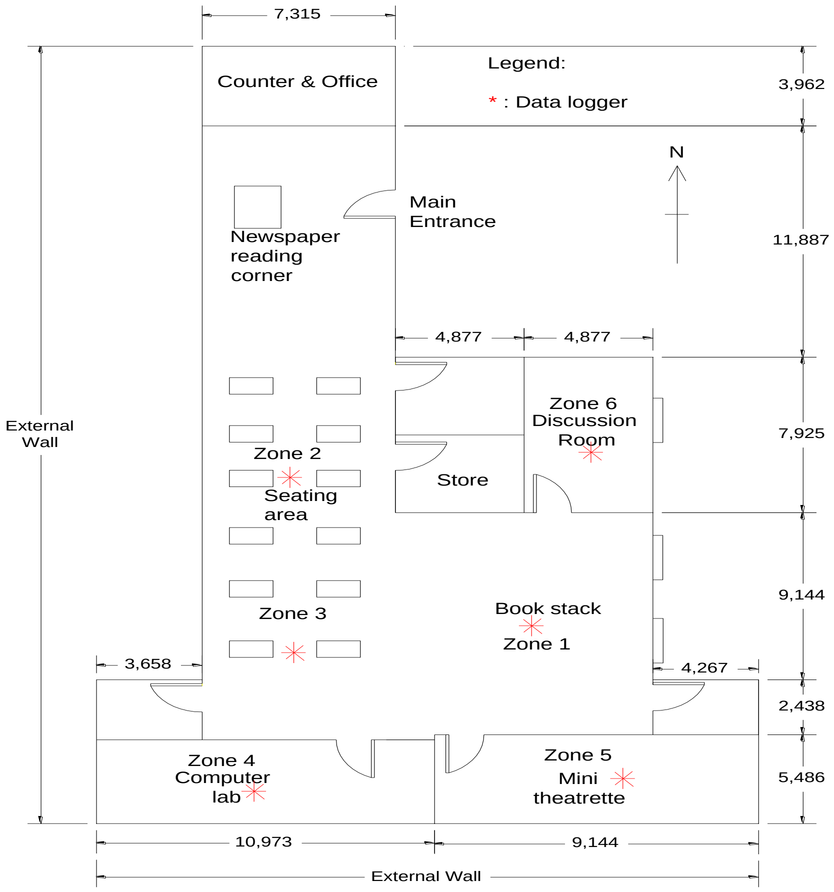

Fig. 1. Learning resource centre layout

2.2 TRNSYS Model Simulation

The RC is a totally enclosed envelope building. There is no window on the wall. The only main entrance is a single glazed 2-leaf door exposed to the corridor. There are five computers for students' usage placed at Zone 1, and a photocopy machine installed at the newspaper reading corner. An air-handling unit (AHU) room is located adjacent to the Resource center. The AHU is designed to deliver 16,990 m^3/h (10,000 cfm) of airflow rate and 40 TR (480,000 Btu/hr) cooling capacity for the RC. It is a centralized ducted air conditioning (AC) system. The AC system is operated from 8.00 am to 10.00 pm on weekdays and from 8.00 am to 1.00 pm on Saturdays. For Sundays and Public holidays, the AC system is switched OFF. There is no heating system incorporated in the AC system as mentioned above. The room thermostat is set at 25°C. Therefore, the existing AC system will not be able to control the indoor relative humidity. TRNSYS was used to simulate the building cooling energy for two different AC system operating modes (Normal office hour operating mode & All Day operating mode), and four different climate weather files with different time scenarios, namely present, the 2020s, 2050s, and 2080s weather files. The two different operating modes will determine the difference in energy consumption of the AC system. The room dry bulb temperature and RH were set at 25°C and 40% respectively for every simulation run. The yearly energy consumption of the AC system was analyzed for the said time scenarios with two different operating modes. The simulation results and the actual measured readings were compared in order to determine the sustainability of the existing AC system in maintaining the required indoor climate set points. On the other hand, the energy consumption resulting from the different operating modes of the AC system was studied to justify the best operating practice to yield the least energy consumption for the RC.

3. Results

The field measurement was discussed first in sub-section 3.1. The TRNSYS simulation model was illustrated later in sub-section 3.2.

3.1 Field Measurement

Figure 2 and Figure 3 demonstrate the changing profile of room dry bulb temperature and relative humidity captured by the data loggers during the testing period.

Basically, there was at least 50% of the monitoring time; the room dry bulb temperature was above the set point. On the other hand, the room relative humidity was almost 100% above the set point. The AC system was running under the Normal Office Hour operating mode. Based on the results, the indoor dry bulb temperature and RH cannot be maintained at the recommended set points. The conditions were fluctuating daily which are shown clearly in the Figure 2 and Figure 3. There was a peak for the relative humidity daily at night when the AC system was switched off and the ambient relative humidity was high. Besides, Figure 2 and Figure 3 have also revealed the high dry bulb temperature and relative humidity over the weekends. The maximum room dry bulb temperature occurred in the evening of the Sunday after the AC system was switched off for one day. The radiant heat from the wall after exposure to sunshine from Saturday afternoon till Sunday evening increased the indoor dry bulb temperature. Note that the heat was kept as sensible heat in the furniture, carpet and books, etc. Therefore, it took a much longer time to cool down the indoor environment on each Monday morning in comparison to the other working days. In other words, the AC system has to work much harder in order to achieve the thermostat set point, which was at 25°C. The result strongly suggested that the existing AC system is not sufficient to produce acceptable thermal comfort to the RC users, and achieve the indoor climate requirement for the books and collections for preservation.

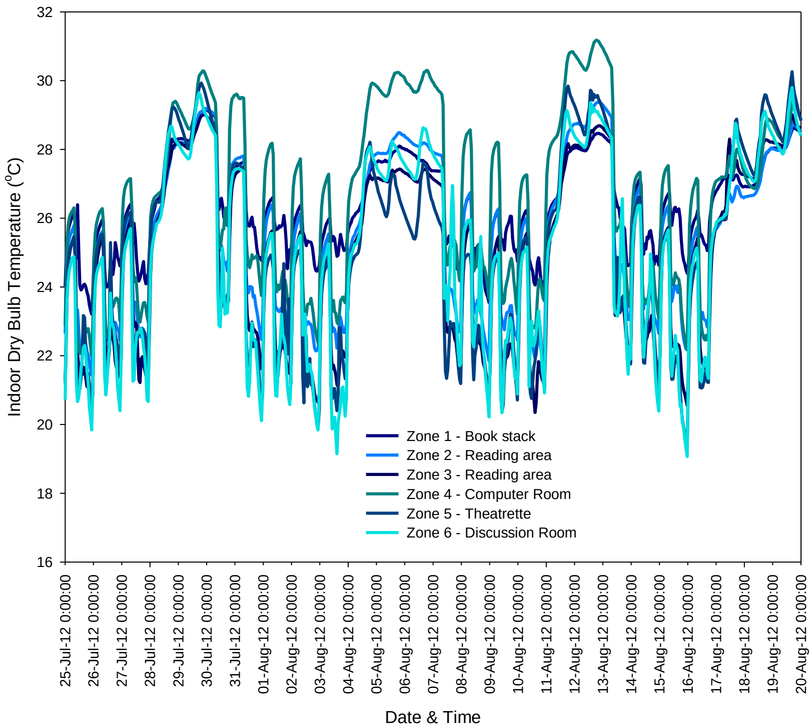

Fig. 2. Room Dry Bulb Temperature vs. Date

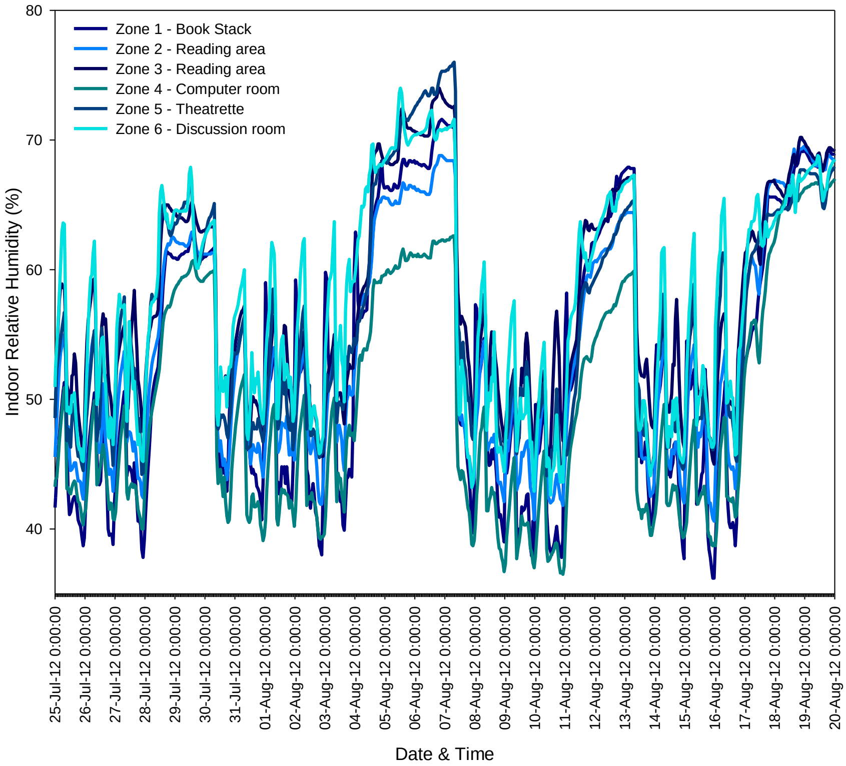

Fig. 3. Room Relative Humidity vs. Date

3.2 TRNSYS Simulation Model

Simulations were run with four different weather files, namely the present-day weather file as adopted from ASHRAE [18], and also, the climate change adapted versions of weather files for 2020's, 2050's and 2080's. It is important to highlight that simulation results required 42TR (505,000 Btu/hr) cooling capacity to achieve the indoor climate set points at 23°C and 40% for the dry bulb temperature and relative humidity respectively based on the present weather data. The existing AHU's cooling capacity, which is 40TR, is unable to perform the duty. The simulation result has proven that the existing AC system is not sufficient to produce acceptable thermal comfort to the RC users, and achieve the indoor climate requirement for the books and collections for preservation as just mentioned in sub-section 3.1. It is clear from Figure 2 and Figure 3 that the data loggers' readings showed that the indoor climate conditions were not stable throughout the day. The minimum room dry bulb temperature was above the set point at 23°C. The fluctuating conditions will inevitably cause biological or fungal growth [19-23]. Therefore, it is strongly recommended that the operating AC system work for 24 hours daily throughout the year in order to keep the environment stable and suitable for the preservation of books and archival materials. Table 1 shows the summary of yearly energy consumption for the AC system installed at the RC for different weather files and operating modes. The result indicates an increasing trend for both operating modes. The result displays that the energy consumption increases due to climate change implications to the building load. For example, for the Normal Office Hour AC system operating mode, it shows the yearly energy consumption increases 14,600kWh or about 3% from the present-day time scenario to 2020's time scenario. It is expected that the percentages will increase at 6.5% and 11.6% in 2050's and 2080's scenarios respectively. However, if the AC system's operating mode is switched to All-Day operating mode, the yearly energy consumption for the AC system reduces to about 50% for each different time scenario as indicated in Table 1.

Table 1
AC System Yearly Energy Consumption

Operating mode	Weather files			
	Present-day	2020's	2050's	2080's
Normal office hour / kWh	504,800	519,400	537,000	563,500
All day / kWh	255,500	273,700	294,500	323,300

Figure 4 and Figure 5 imply the monthly electricity consumption trend with different time scenarios and different AC system operating modes. It is important to mention that Figure 4 and Figure 5 indicate that February consumes the least electrical energy to produce the required indoor climate, i.e., 23°C and 40% RH, whereas January requires the highest energy to provide acceptable comfort indoor climates for the RC. There is a large saving (about 50%) if the AC system is switched from Normal Office Hours to the day operating mode, and at the same time, the indoor climates can be maintained at the required set points. Figure 4 and Figure 5 reveal with the change of the operating mode, a significant amount of energy can be saved because the centre is cooled down to the required set points, and thus, less energy is needed in comparison to the Normal Office Hour operating mode, where the cooling and dehumidification processes are switched off after office hours for weekdays, and after 1pm for Saturday as well as for the whole day for Sunday. Again, from Figure 4 and Figure 5, it is obvious that Malaysia has to prepare itself to face the climate change implications on the high electrical energy consumption for the AC system in the future because the building AC system cooling capacity is significantly affected by the weather data. The higher ambient temperature will inevitably cause a higher AC system cooling capacity. Note that this study is conducted on a room for which the volume is just about 1,743 m^3 (62,580 ft^3) or the floor area is about 581 m^2 (6,258 ft^2).

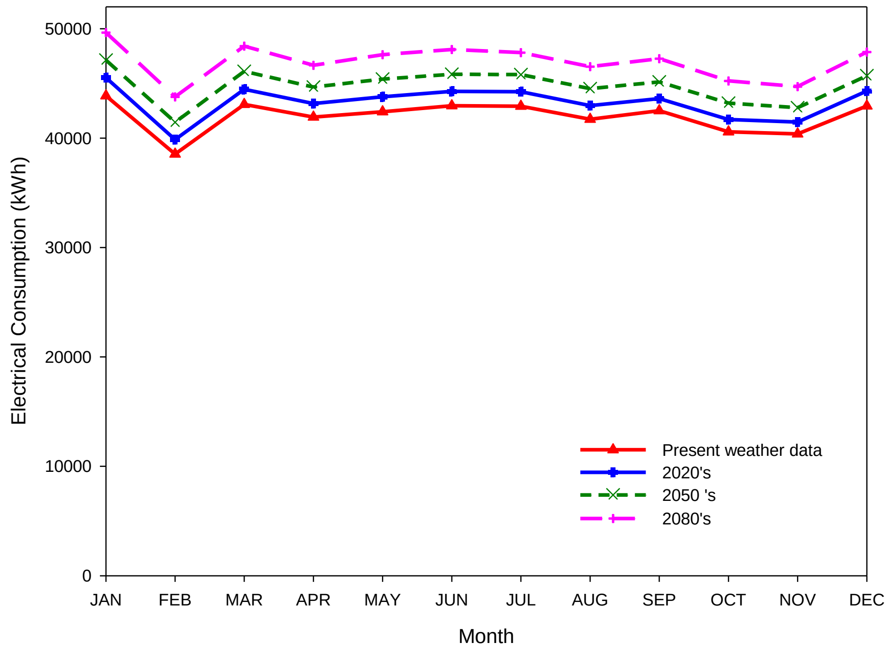

Fig. 4. Electrical Consumption vs Month for Different Time Scenarios with AC System Normal Office Hour Operating Mode

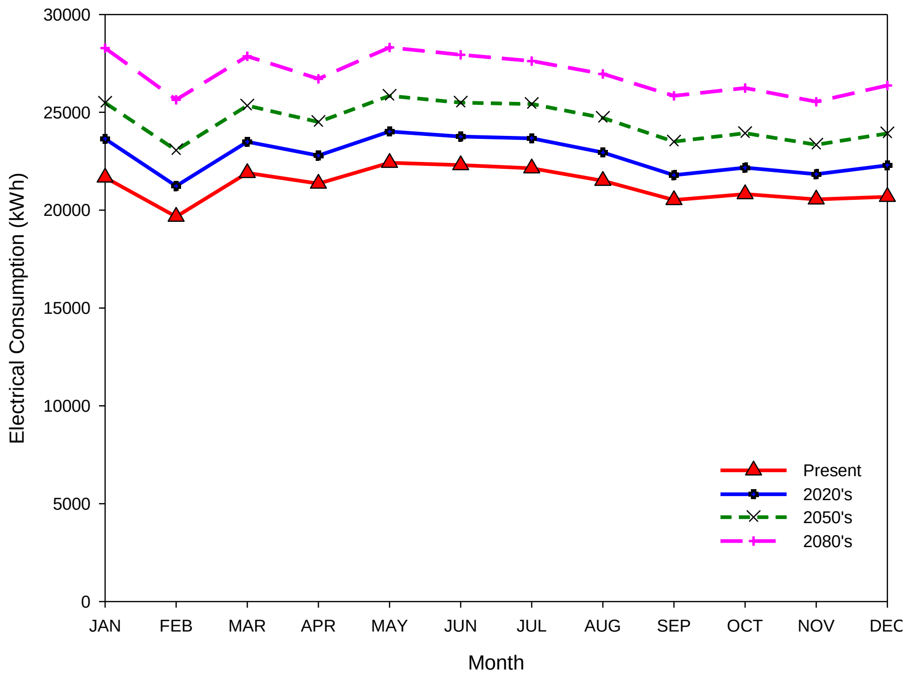

Fig. 5. Electrical Consumption vs Month for Different Time Scenarios with AC System All-Day Operating Mode

4. Conclusions

The investigation on the energy consumption for the Air Conditioning (AC) system under different AC operating modes and weather data for different time scenarios has been conducted successfully in a RC in Malaysia. The results can serve as an important guide for HVAC engineers and building owners for the optimization of energy savings for AC systems in library buildings in the tropics.

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