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ASSESSMENT OF CLIMATE CHANGE IMPACT ON THE REQUIRED COOLING LOAD OF THE HOSPITAL BUILDINGS

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Abstract

The impact of climate change on the energy performance of the Heating, Ventilation and Air Conditioning (HVAC) systems was studied in this research. The present research employs the Transient System Simulation Software (TRNSYS) to study the hour-by-hour influence of the climate change scenario on a HVAC system performance by modeling the system in the TRNSYS software as the base line model. To this end, a HVAC system operating in a hospital as a high energy demanding building was selected for data collection, analysis and simulation. Three sets of predicted Typical Meteorological Year (TMY) data for the region are used for simulation in the TRNSYS to analyze the established indoor air conditions and yearly required cooling loads by the building. Based on the predictions and comparison of the findings with the year 2000, it can be estimated that the yearly required cooling load for 2020 and 2050 would be increased by 4.66% and 7.3%, respectively.

Keywords: Climate change, Cooling load, Heating, Ventilation and Air Conditioning system, TRNSYS.

1. Introduction

It was predicted that the world energy consumption will increase by about 56% from 2010 to 2040 [1]. It can be anticipated that the energy consumption even has a faster growth in developing countries. In addition, buildings section is responsible for about 40% of the total energy demands [2]. In buildings section

Abbreviations

AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
HVAC	Heating, Ventilation and Air Conditioning
RH	Relative Humidity
TMY	Typical Meteorological Year
TRNSYS	Transient Systems Simulation Software

itself, Heating, Ventilation and Air Conditioning (HVAC) systems are responsible for approximately 60% of the total energy consumption [3].

Besides the energy aspect, the global warming as a challenge for the scientists and policy makers is a truth, which is mainly occurred by human activities and needs to be tackled immediately. The phenomenon has become a new challenge for the engineers and scientists who are involved in the HVAC system designing. The designers need to design a compatible cooling system, which is able to deal with the yearly increase of the ambient temperature. Therefore, in order to provide the desired indoor air conditions, the HVAC systems are expected to consume more energy in upcoming years. This expected behavior should be carefully addressed by the designers for a long terms operation.

In hot and dry regions, the HVAC systems normally need higher cooling load capacity. Moreover, in order to establish energy conservation measures, the higher rate of air change per hour is required for the HVAC systems in these regions. Therefore, designing a suitable HVAC system for the upcoming years needs to estimate the future climate required cooling capacity. This estimation can be made by applying a computer simulation program. The simulation can help the designing engineers to design a HVAC system compatible for future requirements with reasonable costs. However, to prevent under-sizing or over-sizing of the HVAC systems, proper estimations are needed.

The literature survey shows some predictions have been made on the world climate change using computational estimations and its effect on energy consumption. For instance, Michael and Jacob [4] revealed that the global temperature is expected to increase by 3.98 $^{\circ}C$ due to high emission scenario at 2080.

The impact of climate change on the energy demand has been reported by some researchers [5-21]. For instance, Isaac and van Vuuren [5] explored the effect of climate changes on future heating and cooling loads in the context of climate change. The study showed that the heating energy demand could decrease by 34% worldwide by 2100. Moreover, the study indicated that the energy demands by the air-conditioning systems are expected to increase by 72% for the same year. Furthermore, it was found that at the regional scale considerable impacts expected to happen, particularly in South Asia, where energy demand for residential air conditioning is predicted to increase by about 50% due to the climate change. The effect of climate change on the CO_2 emissions for both heating and cooling was also reported. It was reported that CO_2 emissions will increase about 12%. In another study, Yau [6] investigated the effect of climate change on the maximum needed cooling loads for a large building in the tropics on the climate change scenario. The study showed that the cooling load required with the building HVAC system needs to be increased by about 4.8% and 11.8% for the years of 2020 and 2050, respectively to establish the desired indoor air conditions. Cooling and heating energy consumption of an office building during 1971-2010 was explored by Li et al. [7]. The study was considered two emission scenarios namely, low emission and medium emission. The study showed that compared with 1971-2010, the average multiannual energy loads of the office buildings in 2011-2050 are about 10% less for heating, about 12% more for cooling and over 2% more for total energy consumption under the studied scenarios.

Wong et al. [8] investigated the influence of heat gain through the buildings envelopes in the residential sector in subtropical Hong Kong on the future trends of cooling loads. For this purpose, the predicted monthly weather data from five general circulation models were obtained and analysed. It was observed that the average annual cooling load during the 2009–2100 period would be 6.1% and 9.8% more than that during 1979–2008, respectively. Moreover, the study showed that for the last 30 years (2071–2100) the percentage increase would be much larger at 12.3% and 21.6%. Furthermore, four energy conservation measures namely, raising the indoor temperature, thermal insulation, double glazing and tinted glass were also investigated. The study revealed that raising the indoor temperature has the best mitigation potential because of growing awareness and recognition of adaptive thermal comfort and it was recommended to be applied to both existing and new buildings at no extra cost. In another study, the impact of climate change on the energy consumption of the buildings in the United States was explored by Haojie and Qingyan [12]. To this end, the HadCM3 Global Circulation Model was employed to generate weather data for future typical meteorological years, such as 2020, 2050, and 2080. In this research, a residential and commercial building were selected and simulated by the Energy Plus. Based on the study, a geographical dependency of the impact of climate change on future energy demand was determined. Moreover, it was found that that by the 2080 passive cooling would not be suitable for San Diego buildings because of global warming, while it would still be acceptable for San Francisco and Seattle buildings.

Kristi et al. [18] investigated the energy demand of a typical detached house in Finland in the observed recent and anticipated future climatic conditions. The hourly reference weather data (2030, 2050, and 2100) were employed as the input data for the building simulation purposes. The study showed that the annual energy demand for heating of the spaces and ventilation supply air decrease by 20–40% by 2100. In addition, it was found that the energy demand for cooling increases by 40–80%. Based on the simulations, the annual sum of delivered energy consumed in heating and cooling was predicted to be decreased by 20–35% by 2100. Furthermore, a long-term economic analysis taking into account the energy consumption in buildings showed that the net present value of households' energy costs in 2100 would be 5–10% lower than without climate change case.

Literature survey indicated that numerous research studies on the subject for different regions of the word have been conducted to prove the climate change impacts on the buildings required energy in upcoming years. However, research works employing the Typical Meteorological Year (TMY) data for the Southeast Asia, especially on the hospital buildings as a high energy demanding space and 24 hour running HVAC systems are limited at least in Malaysia, Singapore, Indonesia and Brunei. Therefore, this study was carried out and the main purpose is to examine the yearly required cooling load of a hospital building and established indoor air conditions due to the climate change effects for the years of 2000, 2020, and 2050.

2. Method

In the present research, fieldwork study was conducted first to determine the performance of the operating HVAC system in the building. For this purpose, the space physical data such as: supply duct air, indoor air and amount of supply air and return air into the building space were measured and recorded. Air Handling Units (AHUs) technical specifications, ducting systems layout, and building architecture information were obtained.

The considered building has a zone volume of 3,785 m^3 and includes a total of 57 patient beds, 26 beds in Wing-A and 31 beds in Wing-B. The chiller plant is located in the ground floor and one chiller provides the chilled water to the building. There are four units of air-cooled cooling towers at the back of the chiller plant. Figures 1 and 2 show the building and the plan view of the space.

Two AHUs, namely, AHU-A and AHU-B, provide the conditioned air into the space. The AHUs consist of three rows of tubes, four passes with 46 tubs in every row [22]. The ducting system has been designed in such a way that the return air is mixed with fresh outdoor air and no heating device has been placed in the system. Therefore, the cooling coil off air directly enters into the space. Figures 3 and 4 show the schematic diagram of the space HVAC system and air states in the Psychrometric chart, respectively.

Fig. 1. Overview of the building.

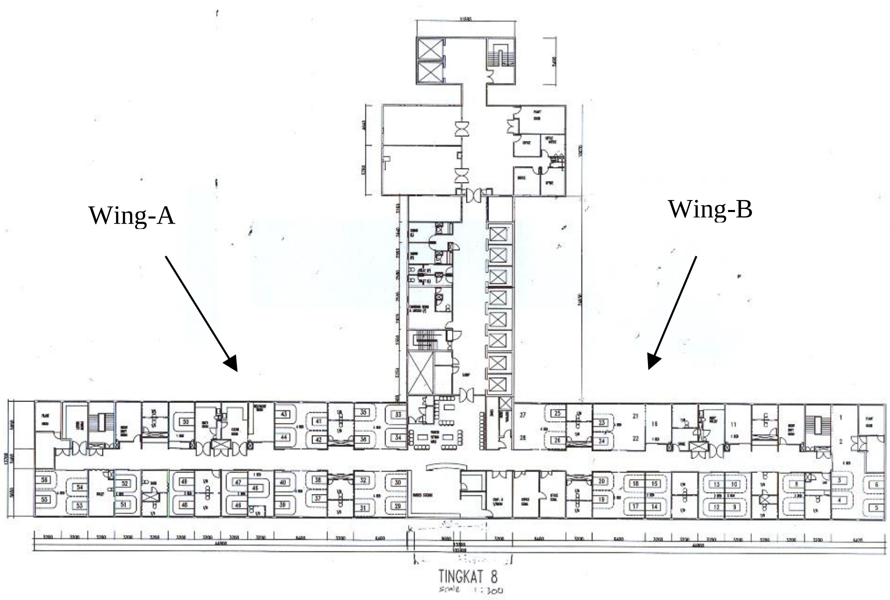


Fig. 2. Plan view of the space.

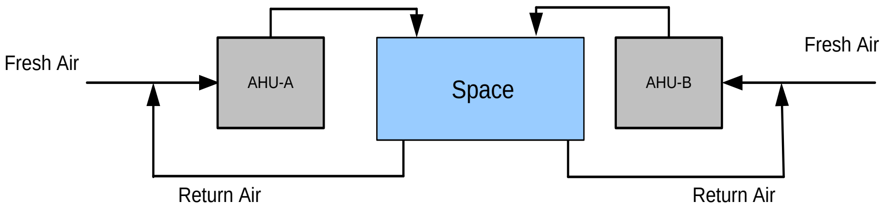


Fig. 3. Schematic diagram of the HVAC system.

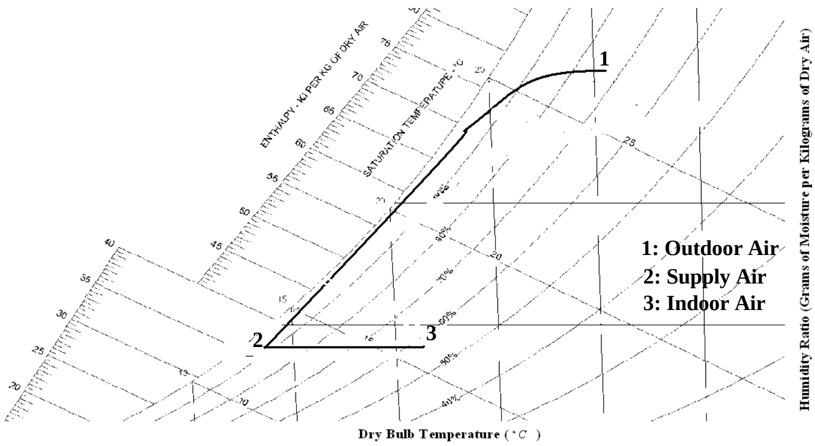


Fig. 4. HVAC system performance in the psychrometric chart.

A hot wire anemometer was used to record the supplied air and indoor air temperature and Relative Humidity (RH), air velocity for the diffusers and return grills. In order to measure the off-coil data, the measuring instrument was located at the first diffuser, which is the nearest point to the AHUs. The indoor air measurements were taken one meter above the floor, as this is the approximate distance intended for a person recommended by ASHRAE [23].

The recorded mean values for the supply and indoor air were tabulate in Table 1. The recorded values indicate that the mean indoor temperature and RH were 21.8 $^{\circ}C$ and 61.9%, respectively, which is out of the range recommended by ASHRAE [24] and the space was overcooled. Moreover, the recorded supply air RH also revealed that the RH value was 92.2%, which is much higher than the 70% recommended for the supply duct air [25].

Table 1. Spot measured air conditions and simulated results for the space [22].

	Supply air DBT (°C)	Supply air RH (%)	Indoor air DBT (°C)	Indoor air RH (%)
Spot measurement results	14	92.2	21.8	61.9
Simulation results	13.6	92.7	21.7	57.4
Deviation (%)	2.8	0.53	0.45	7

3. Baseline System Simulation in TRNSYS

The baseline HVAC system of the building was simulated using the TRNSYS software. TRNSYS is transient system simulation software with a modular structure and is employed in the present research to model the HVAC system of the building. For this purpose, the building geometry and its HVAC equipment must be defined in the studio. The modular structure of the program enables the users to represent the non-standard equipment as the defined components into the TRNSYS library and being used in the software. (Note: to define the non-standard components, the performance of the equipment needs to be written in FORTRAN language and be added in the software library).

As illustrated in Fig. 1, the considered space consists of two wings as: Wing-A and Wing-B, and since the wings have not been separated, the space is considered as a single thermal zone for the simulation purposes.

Type 52a component represents the building and to this end, the architectural design as well as the internal conditions needs to be considered to define the Type 52b component. As already mentioned in the paper, two AHUs as AHU-A and AHU-B were operating in the space HVAC system to provide the desired indoor air condition. Type 52b as the standard cooling coil component in the software library, which represents the detailed type of chilled water coil performance was used to model the AHUs in the system. The operating chiller as the full load and 24 hour running chiller was defined as the component Type 215 and added to the simulation studio. The HVAC system simulation layout in the TRNSYS studio was illustrated in Fig. 5. Table 2 describes the components and functions in Fig. 5.

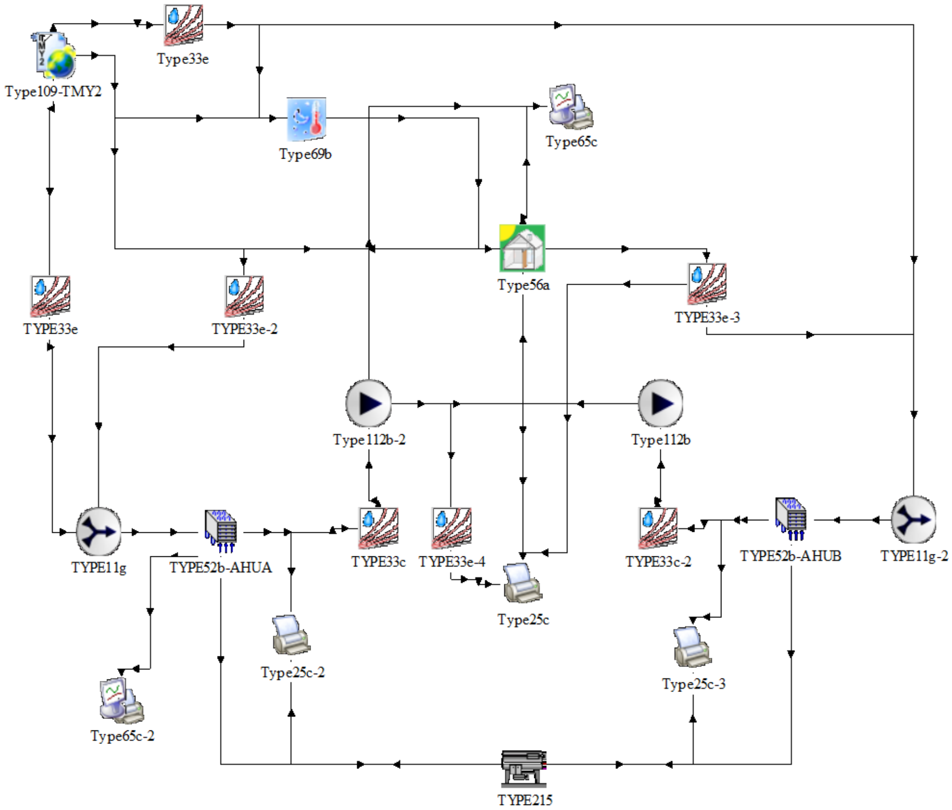
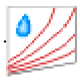


Fig. 5. Simulation layout of the building HVAC in TRNSYS environment.

In order to further investigations, the modelled HVAC system needed to be examined and validated. To this end, the simulation results and the collected data were compared and the deviations were determined. Then, the effect of climate change on the indoor air conditions and required yearly cooling loads were estimated for years 2000, 2020 and 2050 with the climate change weather data files using TRNSYS simulation. The simulation was conducted using the yearly predicted weather data files (TMY2) as the input file to the software. The following assumptions were adopted for the simulations:

- The return air temperature was considered equal to the indoor air temperature.
- There is no air leakage from the ducts.
- The number of occupants, equipment, and lightings were recorded through the field work survey.
- The material properties of the outer structure were obtained from the available references.

Table 2. The processes and functions in Fig. 5.

Code or label in Fig. 5	Description of the components	Function
 Type109-TMY2	Region weather data	This component reads TRNSYS TMY2 format weather file to determine the outdoor condition
 Type56a	Building (Space)	This component takes the inlet DBT, RH and air flow and calculates the space DBT and RH
 TYPE52b-AHUA	Cooling coil	This component takes the inlet air properties to calculate the cooling coil outlet air properties
 Type112b-2	Blower	This component takes the inlet air DBT and RH to calculate the leaving air DBT and RH
 TYPE11g	Air mixer	This component takes the air properties at branches one and two to calculate the mixed air properties
 TYPE215	Chiller	This component takes the total load of the AHUs to calculate the power consumption
 Type33	Psychrometric calculator	This component takes any two properties of moist air to calculate all other properties of moist air
 Type65c	Online plotter	This component illustrates the simulated data on the screen and saves them into a specified file

4. Results and Discussion

The results of existing system simulation as the baseline model will be discussed in Section 4.1 and the effect of climate change scenarios on the systems will be explained later in Section 4.2.

4.1. Baseline model simulation outcomes

Before estimating the effect of climate change on the indoor air conditions and yearly required cooling load, the existing HVAC system performance needed to be determined and validated. The exiting HVAC system hourly performance was determined and the simulation results were presented in Fig. 6.

Based on the simulation results illustrated in Fig. 6, the supply duct air temperature varied in the range of 12.9ºC- 14.8 ºC with an average value of 13.8 ºC. Moreover, the simulation results showed the variation from 91.3% to 93.9% with an average value of 92.7% for the supply duct air RH.

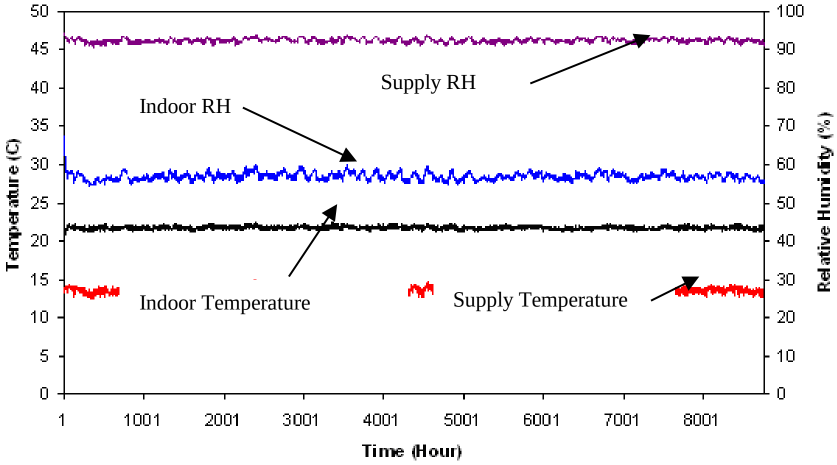


Fig. 6. Simulation results for the HVAC system.

According to the simulations results, the indoor temperature ranges between 21.3 ºC - 22.4 ºC with the average value of 21.8 ºC. In addition, the RH value fluctuates between 55.4% and 60% with a mean value of 57.4%. The deviation between the simulation results and the space recorded data were tabulated in Table 1. It is shown an acceptable agreement between the spot measured data and the simulated values with the maximum deviation of 7%.

4.2. The climate change implication results

Before examining the climate change influence on the performance of the HVAC system, the predicted TMY weather files for the region needed to be analyzed.

Three predicted TMY weather data files for Kuala Lumpur, Malaysia, where the building is located, were utilized to simulate the climate change effects on the HVAC system. The employed TMY files have been developed in the UK based on the Malaysia tropical weather profiles with the methodology explained in [26]. The 'morphing' methodology published by the Chartered Institute of Building Services Engineering was used as a baseline for transforming current CIBSE test reference years into climate change weather years. The predicted TMY files were applied in the TRNSYS studio to determine the HVAC system responses throughout a year. The predicted TMY files for the years of 2000, 2020 and 2050 were illustrated in Figs. 7-9 [6].

Figure 7 shows the hourly weather data for the 2000. Based on the Fig. 7, the ambient temperature and RH varied in the range of 21.4 ºC - 35.38 ºC and 40.5%-100%, respectively. Figures 8 and 9 illustrate the predicted yearly weather data for the region in 2020 and 2050, respectively. It can be seen that in the 2020 the ambient temperature fluctuates between 22.6 ºC and 36.18 ºC, while the ambient air RH fluctuates in the range of 39.8–100%. However, according to the estimations for the year 2050, these parameters are going to vary in the range of 23.4 ºC - 37.48 ºC and 33.4%-100% for the temperature and RH, respectively. A comparison between the predicted weather data for the years 2020 and 2050 with the year 2000 indicates an increment of 0.98 ºC and 2.38 ºC for ambient temperature and decrease of 1% and 3% for the ambient RH. For more convenient, the year and the external conditions are presented in Table 3.

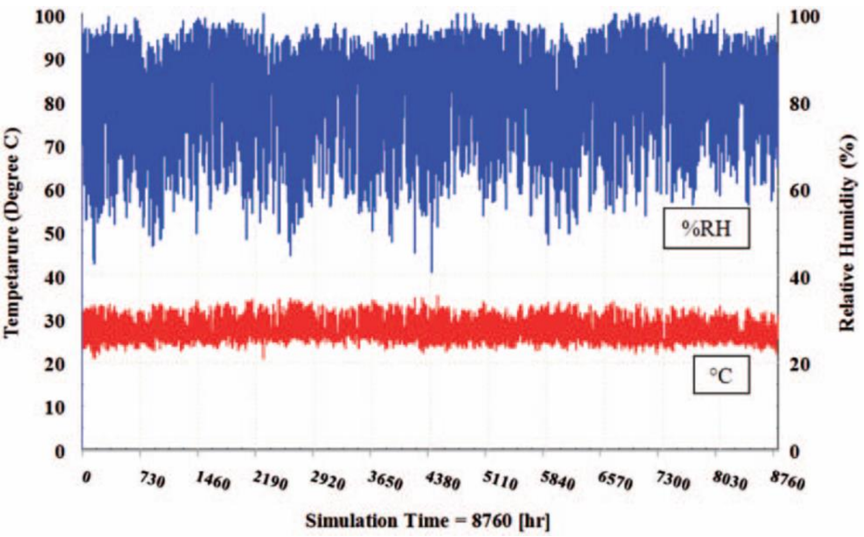


Fig. 7. The predicted weather file for the region, (2000) [6].

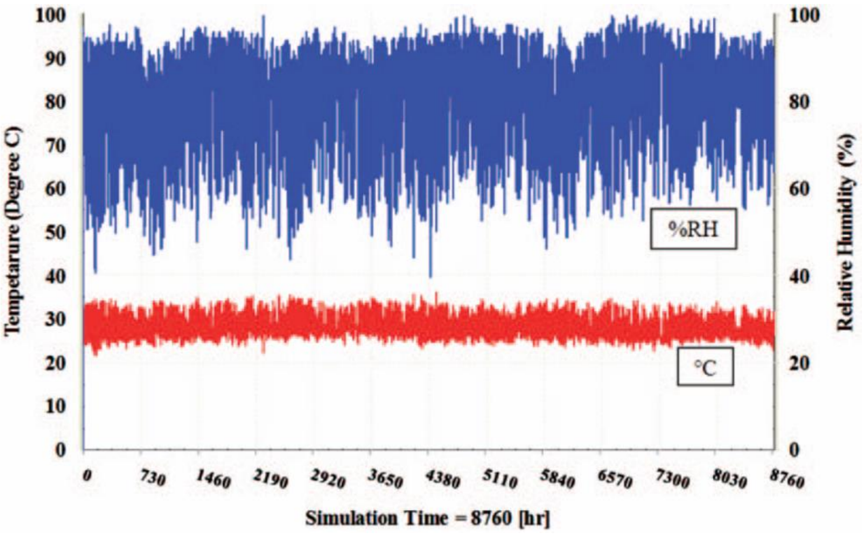


Fig. 8. The predicted weather file for the region, (2020) [6].

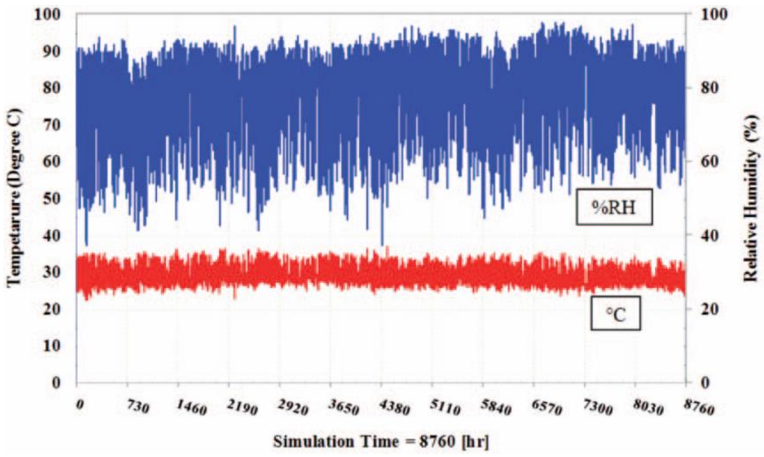


Fig. 9. The predicted weather file for the region, (2050) [6].

Table 3. The year and external conditions.

Year	**Temperature variation (°C)**	**Relative humidity (%)**
2000	21.4-35.3	40.5-100
2020	22.6-36.1	39.8-100
2050	23.4-37.4	33.4-100

In order to compare the effect of climate change on the indoor air conditions, the simulation results for the year of 2000 were determined first. Figure 6 illustrates the indoor air conditions for the space. In this figure, the results were shown for the whole year of operation. The indoor physical data fluctuations were discussed in Section 4.1. This is performed to understand the actual condition of the system to find out the HVAC system performance and the yearly required cooling load of the system.

The needed cooling load for a space is estimated as the total heat gain inside the space. However, the total heat gain can be categorized as the sensible and latent heat gains, which the air handling units are designed to remove from the space. The sensible heat gain consists of the elements, which affect the sensible temperature of the space; however, the latent heat gain is related to the moisture of the space. In order to keep the designed humidity ratio, water vapour needs be removed from the space at a rate equal to its addition into the space.

According to the estimation for the baseline model, the 433.7 MWh and 455 MWh amount of energy are used for sensible cooling in AHU-A and AHU-B, respectively, and 263.5 MWh and 256.5 MWh of energy are used for latent cooling with the AHU-A and AHU-B, respectively. Therefore, HVAC system consumes the total amount of 1409.5 MWh energy in a year (see Table 4).

Based on the simulation results for the year of 2020, the indoor temperature varies in the range of 18.9 °C - 22.4 °C with the mean value of 21.9 °C and the space RH varies in the range of 52.8%-66.7% with the mean value of 57.6%. Moreover, the predictions indicate the fluctuation between 18.9 °C to 22.5 °C for indoor air temperature and 52.8% to 67.1% for the space RH for the 2050, see Fig. 10. The mean values of 22 °C and 57.9% establishes in this situation.

Table 4. Sensible, latent and total cooling rate for the AHUs for the entire year.

Baseline system	Sensible load (MWh)		Latent load (MWh)		Total load (MWh)	
	AHU-A	AHU-B	AHU-A	AHU-B	AHU-A	AHU-B
	433.7	455.8	263.5	256.5	697.2	712.3

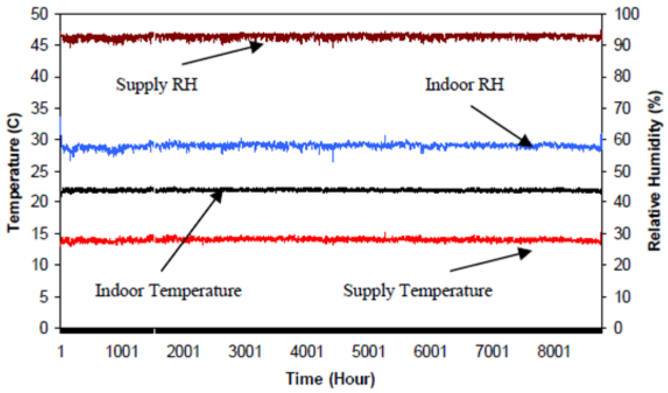


Fig. 10. Simulation results for the HVAC system, (2050).

In order to estimate the yearly required cooling load for the years of 2020 and 2050, the provided indoor air conditions were compared with the established situation in 2000. The hour-by-hour needed cooling loads to bring the provided conditions to the established conditions by the baseline model were determined using the Psychrometric chart. Predictions showed that the system require a total amount of 1475.25 MWh and 1512.405 MWh energy to provide the desired indoor air conditions in 2020 and 2050, respectively. Therefore, in comparison to the year of 2000, the cooling load required in 2020 increases by 4.66% or 65.74 MWh and 7.3% or 102.905 MWh in the 2050 for the studied building (see Table 5). Figure 11 illustrates the hourly cooling loads of the system for 2050 as the representative of the years studied.

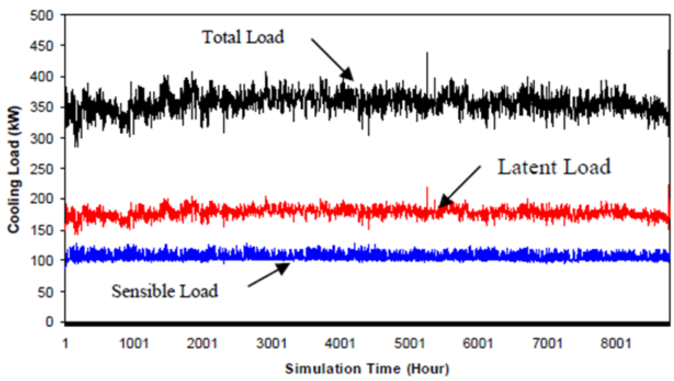


Fig. 11. The yearly required cooling load for the HVAC system (2050).

Table 5. Yearly required cooling load for the HVAC system.

Year	Total load(MWh)	Increment (%)
	1409.5	-
2020	1475.25	4.66%
2050	1512.405	7.3%

The required total cooling load by the buildings in the region and upcoming years could also be obtained by a correlation recommended using tabulated data in Table 5. Based on Fig. 12, the recommended correlation was obtained with the highest goodness of fit value (R^2). In the recommended correlation *y* parameter represents the total cooling load and *x* parameter presents the year.

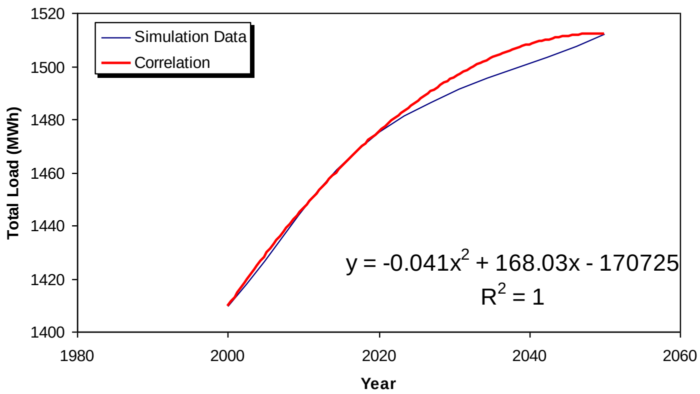


Fig. 12. The correlation between the total load of the building (*y*) and the year (*x*).

5. Conclusions

In the present research, the influence of climate change on the established indoor air conditions and yearly cooling load of the HVAC system was investigated. For this purpose, an operating HVAC system in a high energy demanding building was chosen as the case study. The building HVAC system was successfully modelled via TRNSYS software as a baseline model to understand the yearly performance of the system in terms of indoor air conditions and cooling loads. Three sets of TMY weather files predicted for the years of 2000, 2020, and 2050 were utilized as input data to estimate the yearly cooling loads for the 2000, 2020 and 2050. The following conclusions are drawn from the research and can serve as a general guide for the building HVAC designers to design the future HVAC systems in buildings especially in South East Asia:

- The simulation results for the year of 2020 showed the mean values of 21.9 ^{o}C and 57.6% for the indoor air temperature and RH, respectively.
- The predictions for the year of 2050 indicated the mean values of 22 ^{o}C and 57.9%, for the indoor air temperature and RH, respectively.
- The hour-by-hour needed cooling loads to bring the provided indoor air conditions to the established conditions by the baseline model were evaluated using the Psychrometric chart and estimations showed that the system

requires a total amount of 1475.25 MWh and 1512.405 MWh energy to provide the desired indoor air conditions in 2020 and 2050, respectively.

- The yearly required cooling load needed to be increased by 4.66 % and 7.3% for the years of 2020 and 2050 or 65.74 MWh and 102.905 MWh, respectively to establish the desired indoor air conditions in the space.

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