THERMOCHEMICAL ENERGY STORAGE SYSTEM (TESS)-INTEGRATED WITH SOLAR THERMAL ENERGY: A CASE STUDY OF A BUILDING IN MALAYSIA

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ABSTRACT

Cooling or heating of buildings produced using conventional vapour compression cooling systems uses ozone-depleting refrigerants such as chlorofluorocarbons (CFCs). Notwithstanding, the development of less or zero ozone-safe alternatives such as the hydrochlorofluorocarbons (HCFCs) and the hydrofluorocarbons (HFCs), still contributes to the undesirable effect of global warming. Furthermore, such cooling or heating systems utilize electricity and fossil fuels as their driving sources. As the cooling demand for climate control and refrigeration ascends in the future, it will be a frontrunner in the increase of energy consumption. This instinctively leads to a faster depletion of known fossil fuel reserves, more carbon dioxide emissions, and a higher peak of electricity demand. Such environmental issues have intensified research efforts on the development of environmentally benign refrigerants and energy saving on cooling technologies and renewed interest in air-conditioning applications. Thermochemical adsorption cooling systems based on Thermochemical Energy Storage Systems is thought out to be an alternative to the conventional vapour compression systems. These systems could store thermal energy in terms of cooling without using any pumping system. Therefore, the systems could alleviate high dependency on using the electricity for generating the compressor in the conventional air-conditioning systems. To analyse the cooling load, building simulation was entailed to estimate the energy usage of the building using the various conventional cooling systems such as chiller systems in the building. The IESVE (Integrated Environment Solution-Virtual Environment) is employed in this simulation. After simulation results are given and discussed, thermochemical materials and the corresponding solar panel will be sized based on required space cooling load via calculation and software respectively.

Keywords: Thermochemical Energy Storage, Adsorption Cooling, Solar Thermal, Building Simulation

1 INTRODUCTION

Renewable energy technologies such as wind turbines, biomass boilers, and solar PV/Thermal systems were widely being investigated on to overcome the problems related to the scarcity of fossil fuel, global warming, and climate change. While the energy resources of these technologies are theoretically inexhaustible and abundant, there is often a large barrier to their successful implementation, namely a mismatch between the production of and demand for the energy they generate [1]. Consequently, solar energy is currently seen as one of the most promising alternatives to more conventional energy resources, however it requires some energy management. The use of solar thermal energy has been broadly researched, accepted publicly and adopted for heating, ventilation and air-conditioning in both domestic and commercial buildings [2]. The global raising pattern in buildings energy consumption, both residential and commercial, has ascended steadily; reaching figures between 20% and 40% in developed countries [3]. Furthermore, cooling account is up to nearly 60% of the world's total energy consumption and are highly dependent on conventional energy sources generated by fossils fuels. The conventional air-conditioning systems using a vapour compression will contribute to global warming due to the use of CFC, HCFC, such as cooling refrigerant. Hence, the integration of solar thermal and Thermochemical Energy Storage Systems (TESS) based on thermochemical adsorption cooling systems is proposed to be an alternative to the conventional vapour compression systems. Furthermore, TESS is a promising technology that would be able to solve the mismatch between seasonal heat supply and demand as a typical problem for temperate climate zones. Adsorption heating/cooling was extensively investigated on to compete with the conventional vapour compression systems. These systems could store thermal energy in terms of cooling without using any pumping system. Therefore, these systems could alleviate high dependency on the use of electricity for generating the compressor in the conventional systems. To analyse the cooling load, building simulation was entailed to estimate the energy usage of the building using the various conventional cooling systems in the building such as direct expansion or Chiller System. The concept of saving and storage of the energy of

TESS is by using solar thermal for the regeneration/charging during the daytime, the excessive cooling energy will be stored and discharged according to building load demand shown in **Figure 1**. The heat pump will be used as the backup system during lower solar insolation. The AHU (Air handling unit) will distribute the cooling to the building and the cooling tower will reject the air from the condenser before the next process of cooling.

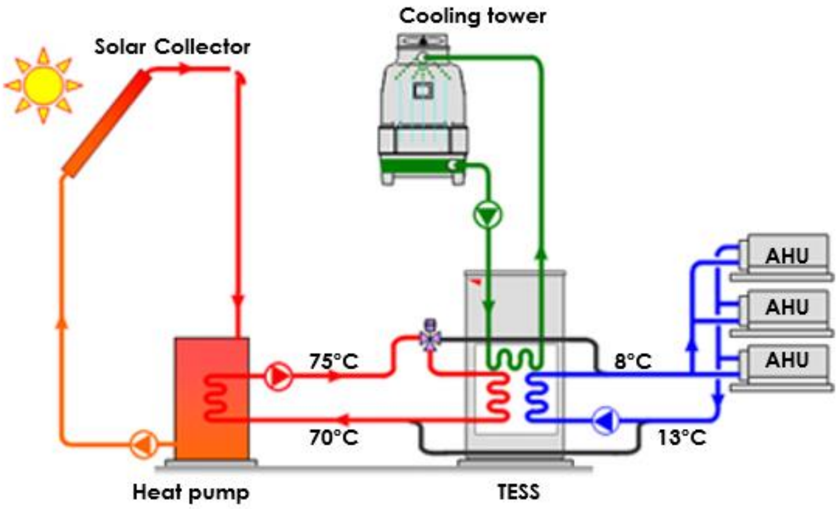

Figure 1: Working Principle of TESS

In order to propose and build a state of the art TESS, a modelling of a case study laboratory building is presented by the IESVE building thermal analysis software. The TESS is proposed to integrate with a roof solar collector, therefore in the actual implementation of TESS, acceptable space requirements and low construction cost are crucial to being considered during the design stage. Hence, the optimization of space requirement and size of collector need to be thoroughly investigated to avoid unnecessary high initial cost in the early stage of the project.

2 MODELLING A CASE STUDY BUILDING

2.1 Introduction to Laboratory Building

The laboratory will be built in the University Campus in the Selangor State of Malaysia and the main function will be in the research laboratory for applied science research. The building gross floor area is 3059 m^2 which comprise of laboratories, postgraduate offices, multipurpose rooms, and toilets. The building was considered to be operating at 12 hours per day and 5 days a week. The laboratories and offices will be fully air-conditioned, however some areas such as toilets and storeroom will be non-air-conditioned.

2.2 Simulation Software and Setting

Building simulation software consists of mathematical models calculated with the aid of a computer to determine the interaction of thermal loading within a building. They would be able to take different approaches such as steady state (the model's parameters are considered constant and do not differ with time) and dynamic models (parameters differ with time, and the calculation represents the behaviour of the building over a chosen period). There are many building simulation software available for the designer, architecture or academic to use for their interest area in analysing the building performance. Software such as IESVE, TAS, Ecotect, Energy Plus, and Design-Builder are widely used to analyse various aspects for building fabric simulation to the HVAC (heating ventilation and air conditioning) plant simulation. However, the accuracy of this software depends on the capabilities on the simulation of the details of each component or design strategies. For this study, IESVE is selected to simulate the cooling load of the building. IESVE is a unique tool for estimating building thermal behaviour, it creates a virtual environment where

HVAC and lighting system of the building are evaluated with a relative version of retrofitted strategies. Furthermore, IESVE has an updated software which includes the embedding of the analysis from ASHRAE Heat Balance Method for the detailed analysis of thermal and plant simulations. Core parameters settings in IESVE software includes year calendar, local weather, zoning of the building, construction materials, internal conditions of each zone and operation schedules. **Figure 2** shows the 3D model of the Laboratory Building in IESVE.

Calendar: The calendar in IESVE used in this simulation was set as no holidays due to the fact that there was no calendar for Malaysia in the library of the holiday template. However, the working days has been set at only 5 days a week.

Construction Material: The construction material has been set as default from IESVE and the U values and thickness of the building fabric are shown in **Table 1**.

Table 1: Detail materials' layers and corresponding thermal properties

Description	U value (W/m^{2}K)	Thickness (mm)
External Wall	0.26	208.9
External Window	1.68	24.0
Ground/Expose Floor	0.23	268.2
Internal Ceiling Floor	1.07	282.5
Internal Partition	1.86	75.0
Roof	0.18	317.0

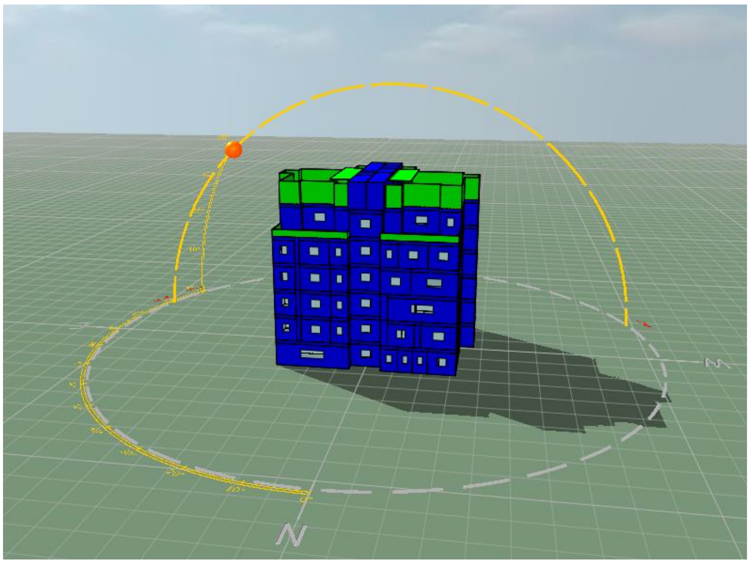

Figure 2: The IES VE model for the laboratory building

2.3 Simulation Analysis and Discussion

In this project the building is located in the Selangor region, therefore the nearest located weather station is in Kuala Lumpur, Malaysia as indicated in the ASHRAE design weather database. **Figure 3** indicates the Thermal comfort zone for the building according to ASHRAE 55. The comfort temperature of a building under a moderate climate in the range of 22°C to 26°C has been recommended by [4, 5]. Figure 3 shows the simulation results of the ambient temperature for the selected climate location. The comfort zone spot was scattered at 22°C to 26°C (see Figure 4) and complied with the recommended range as mentioned above. Other than that, Department of Mechanical Engineering, PWD uses the Malaysian Standard Code of practice MS 1525 (Energy efficiency and use of renewable energy for non-residential buildings) [6] for the design specification which also have the same temperature range as stated above. Hence, the results from this simulation can be used as the acceptable range for the room comfort level.

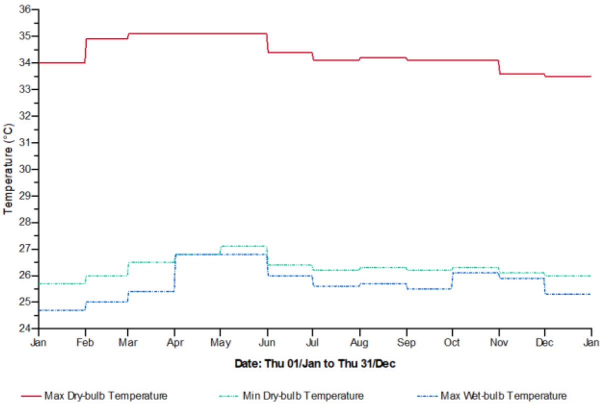

Figure 3: Ambient temperature of the simulated building

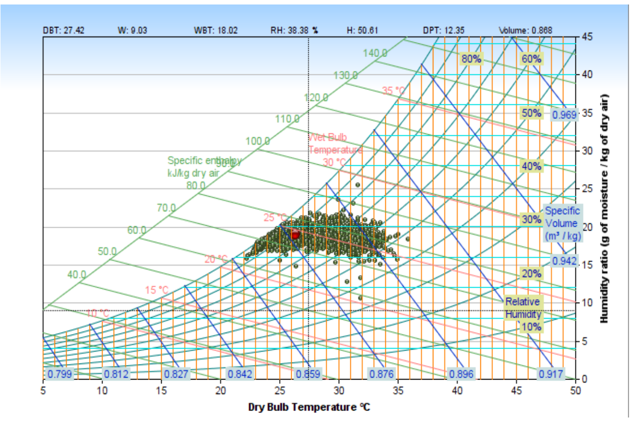

Figure 4 : Thermal comfort zone for the building

3 NUMERATION OF TESS/ADSORPTION COOLING

3.1 Thermochemical Energy Storage/Adsorption Cooling Materials Sizing

There are lists of potential materials for Thermochemical Energy Storage (TES) which are commercially available in the market. However, due to the special working principle in the proposed system, the material selected should be able to satisfy the following four requirements [7, 8];

i. A high thermal storage density, which leads to less amount of material to store the same required heat.
ii. Heat storing in a hydration reaction and releasing in a dehydration method.
iii. Temperature of heat absorption reaction occurring more than 35°C.
iv. A low price. A Large amount of storage material will be required, and inexpensive material can save cost.
v. Environmentally friendly.

An analysis of the storage volume of several possible TES materials are shown in Table 2. The storage density information are obtained from the material synthesizing of previous studies [2, 9, 10]. The maximum storage required occurs in the month of December with a high demand of 49000 kWh needed monthly. These results indicates that vermiculite/$MgSO_4$ has the lowest storage volume of 18.06 m^3 for daily cooling demand. The composite of vermiculite has the storage of 18 m^3 to 25 m^3. This is considered as a relatively low storage volume than that of silica gel/$LiN0_3$ which is 35.3 m^3. Thus, this result shows that the TCMs has lower storage volume compared to sensible storage systems. Other than that, integration using solar thermal energy will make the systems more economical. The TESS contribution with cooling load for Malaysia Climatic condition can be seen in **Figure 5**. The sensible thermal storage of water doubled the volume of TESS. The analysis was carried out using 1m^3 storage for all energy storage materials.

Table 2: *Thermal Energy storage materials for daily cooling demand*

	Storage Density	Daily Storage (m^3)											
Material/Heating Demand	kWh/m^3	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cooling Demand (kWh) (Monthly)		44700.00	43000.00	49700.00	45300.00	45300.00	47500.00	47300.00	47200.00	47400.00	44900.00	47100.00	49000.00
Vermiculite + $MgSO_4$	113.06	16.47	15.85	18.32	16.70	16.70	17.51	17.43	17.40	17.47	16.55	17.36	18.06
Vermiculite+$CaCl_2$	103.89	17.93	17.25	19.93	18.17	18.17	19.05	18.97	18.93	19.01	18.01	18.89	19.65
Parafin wax	87.30	21.33	20.52	23.72	21.62	21.62	22.67	22.58	22.53	22.62	21.43	22.48	23.39
Vermiculite+$LiNO_3$	81.39	22.88	22.01	25.44	23.19	23.19	24.32	24.22	24.16	24.27	22.99	24.11	25.09
Silica Gel + $LiNO_3$	57.84	32.20	30.97	35.80	32.63	32.63	34.22	34.07	34.00	34.14	32.34	33.93	35.30
Zeolite+$CaCl_2$	50.56	36.84	35.44	40.96	37.34	37.34	39.15	38.98	38.90	39.07	37.01	38.82	40.38
Water	50.00	37.25	35.83	41.42	37.75	37.75	39.58	39.42	39.33	39.50	37.42	39.25	40.83
Concrete	28.02	66.47	63.94	73.91	67.36	67.36	70.63	70.34	70.19	70.49	66.77	70.04	72.86
Rock	22.40	83.15	79.99	92.45	84.26	84.26	88.36	87.98	87.80	88.17	83.52	87.61	91.15

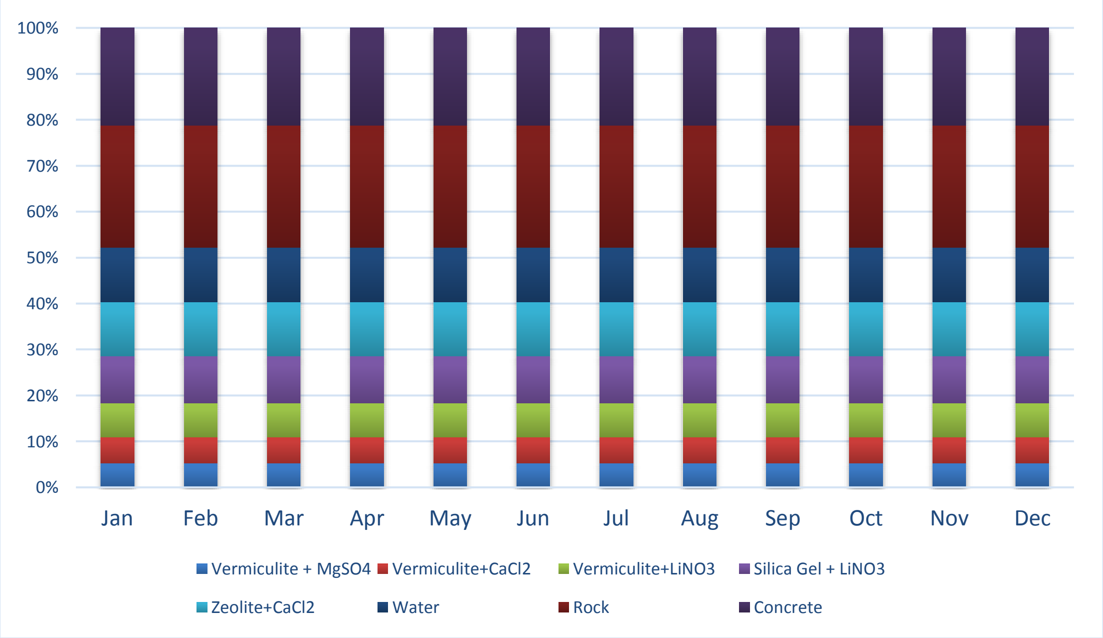

Figure 5 : Contribution of cooling storage to cooling load for different type of energy storage systems

3.2 Solar Thermal Contribution Analysis

Calculation of the buildings solar thermal heat gain in accordance to equation 1 is done by using the data obtained from the European Commission's web site (http://www.photovoltaic-software.com/). The values used in the thermal analysis of solar collectors were demonstrated in Table 3 . The instantaneous heat gain of collectors is calculated as:

$$Q_u = A_c \cdot F_r \cdot [(\frac{H_t}{h_s} \cdot (\tau\alpha)_{net} - U_L \cdot (T_f - T_a)] \qquad (1)$$

Where Q_u is the heat gain (W), A_c is the collector area (m^2), H_t is the solar radiation per m^2 (kW/m^2), h_s is the radiation time (s), $\tau\alpha$ is the absorption-transmission coefficient of solar collectors, U_L is the heat loss coefficient of solar collectors (W/m^2 °C), T_f is the collector surface temperature and T_a is ambient temperature. For the solar collector area assumptions made for the monthly solar thermal gain, the collector area is 500m^2. The roof area is sufficient for the installation of a solar collector as illustrated in **Figure 6**. The properties of the solar collector are according to **Table 3** and the solar thermal energy was calculated using the global solar radiation from the simulation results as illustrated in **Figure 7**. **Figure 8** illustrates the analysis carried out for the solar power that could regenerate the solar adsorption chiller. Nearly halved of the power to generate the electrical chiller can be offset by the solar adsorption chiller. Therefore, from this result, the availability of solar power could reduce by nearly 50% of the conventional electrical chiller in the building.

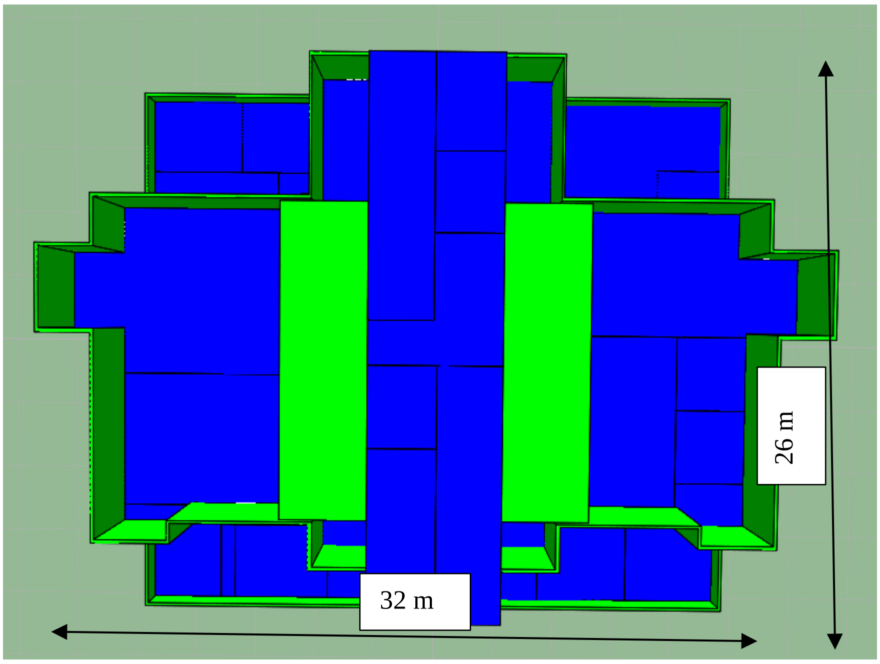

Figure 6: Roof area for the building

Table 3: Properties of the assumed collector

Constant	Symbol	Value
Total Collector Area	A_c	500m^2
Collector heat exchanger efficiency	F_r	0.86
Absorption – Transmission Coefficient	$\tau\alpha$	0.8
Heat loss coefficient	U_L	6.9 W/m^{2}K

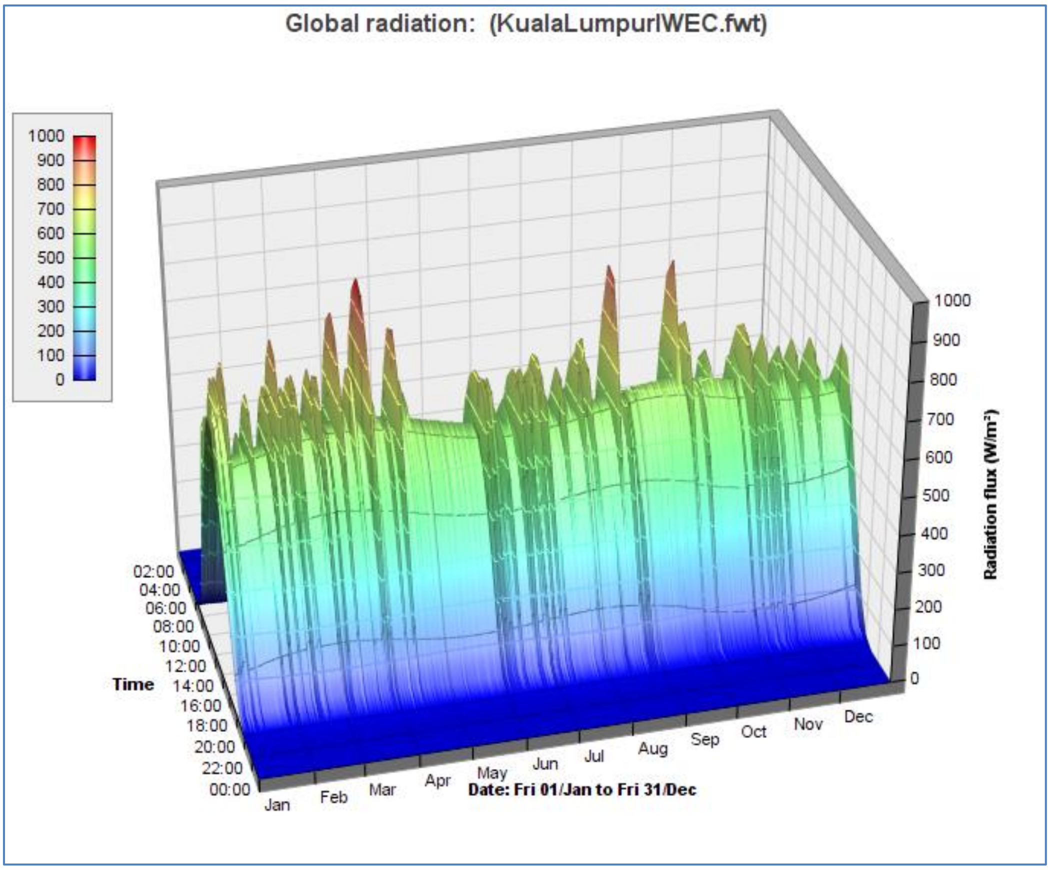

Figure 7 : Graph showing the Global Radiation for Kuala Lumpur based on International Weather for Energy Calculation (IWEC)

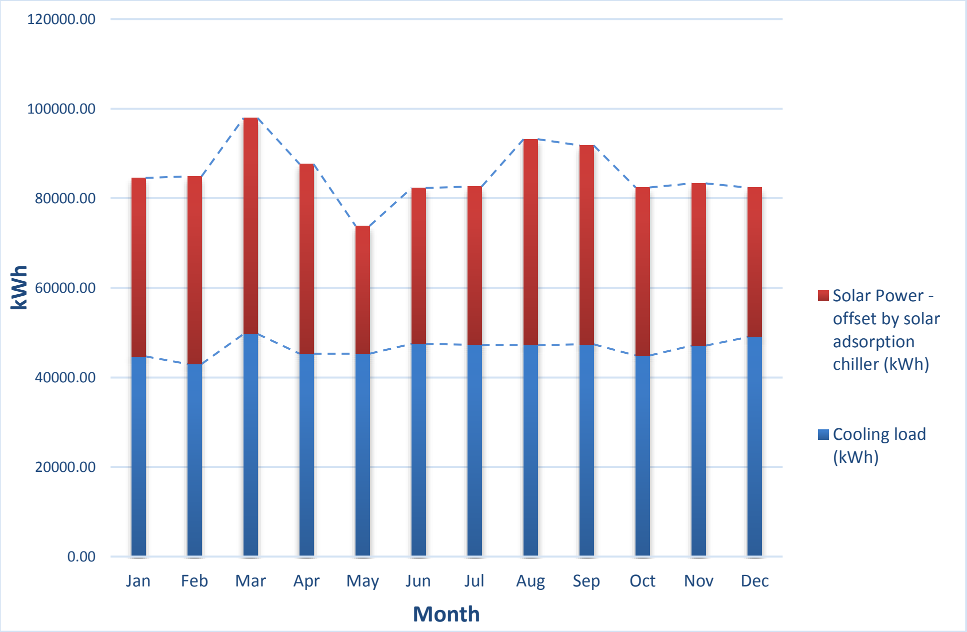

Figure 8 : Monthly cooling load estimated to be offset by solar adsorption chiller

4 CONCLUSION

Theoretical analysis and building simulation of this case study building have indicated that the monthly total energy demanded for cooling are approximately at a maximum of 49000 kWh. In terms of storage volume, TESS with host matrix of vermiculite are in the range of 18 m^3 to 25 m^3. This is considered low when compared to the latent and sensible storage system. This building simulation suggests that solar thermal energy could provide cooling storage in the range of 20000 kWh to 40000 kWh in a month. Furthermore, solar thermal storage could also assist the TESS systems to meet the demands for cooling. Other than that, the analysis of storage volume suggested that the thermochemical materials have lesser storage volume compared to sensible and latent storage systems. Thus, this may indicate that TESS is more compact, economical and sustainable to be adopted in the future and more importantly could reduce the $C0_2$ from fossils fuel.

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