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The design of solar power thermoelectric radiant panel as cooling system in small buildings under tropical climate

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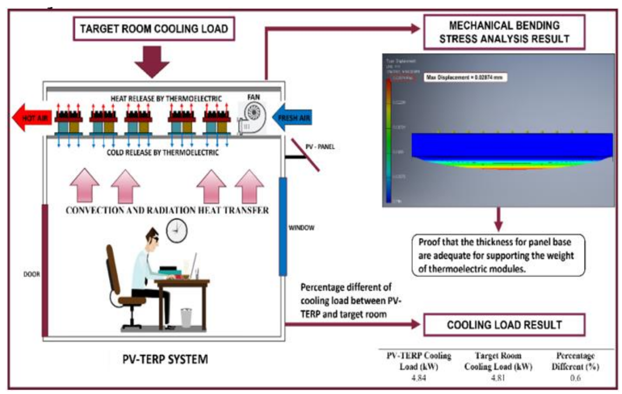
Abstract



The usage of an air–conditioning (AC) system in any building is necessary to maintain its indoor thermal comfort and health. However, this system consumes a lot of energy, while the usage of refrigerant causes irreversible damage to the ozone layer. To solve this problem, a solar thermoelectric radiant panel (PV-TERP) system has a high potential in replacing conventional AC system because it requires no refrigerant and easier to be controlled due to the absence of moving and mechanical parts such as water pumps, compressors, including auxiliary and hydronic pipes. Meanwhile, the usage of solar energy in the PV-TERP system can also help reduce fossil energy consumption and carbon emissions. The main objective of this work is to design a new PV-TERP system for replacing conventional AC systems in buildings located in tropical climate countries, like Malaysia. It is found that the designed PV-TERP system can provide up to 4.84 kW of cooling power, which is about 0.6% higher than the cooling load of targeted rooms. Here, the targeted rooms operate under indoor parameters within the acceptable range of ASHRAE standard-55. The obtained results clearly show that the new design is applicable to be used as a cooling system for the targeted building. In the future, it is then essential to understand the thermal properties and mechanism of the design via simulation process, followed by experimental validation to support the design feasibility. In conclusion, this new design of PV-TERP will lead the path toward expanding renewable energy applications for cooling purposes in sustaining and preserving the environment.

Keywords: Thermoelectric; Radiant panel; Solar energy; Cooling system; Renewable energy

1. Introduction

The usage of air-conditioning (AC) systems in buildings, especially in hot climate regions, consumes high energy. For instance, in tropical countries, the AC system accounts for approximately 50% to 70% of the energy loss in the building [1]. Besides, refrigerants used to operate this system have high ozone depletion potential (ODP) and global warming potential (GWP). Furthermore, if refrigerant leakage occurs during this system manufacturing, operation, servicing, and disposal at the end of life (EOL) process, it will cause irreversible damage to the ozone layer and global warming [1 – 17]. Furthermore, since most AC systems are electrically powered, the increase in AC system usage results in higher energy demands, which can increase the consumption of non-renewable energy sources (fossil fuels such as coal, natural gas, and oil), which are generally environmentally hazardous [1, 5, 11, 14, 16, 18, 19].

Concerns over significant energy consumption in the building and the environment have prompted research into environmentally friendly cooling technologies. The solar thermoelectric radiant panel system (PV-TERP) is one of the technologies that has been considered for replacing the conventional AC system. This system removes the sensible heat from the conditioned zone through the panel and releases the heat to the outdoor via radiation, conduction, and natural convection based on the Peltier effect [2 – 4, 6 – 8, 11, 20 – 22]. Furthermore, in this system, the thermoelectric module (TEM) can be directly attached to the radiant panel's surface without requiring additional equipment such as a heat exchanger and hydraulic pipe. Besides, TEM used in the PV-TERP system brings a lot of benefits, including refrigerant-free; easy to control; no major mechanical parts; no moving parts; absence of auxiliary and hydraulic pipes; lightweight; portable; compact in size; no noise; no vibrations; fast response; high durability; high reliability; high density of cooling; long life span (15 – 20 years); and powered by direct current (DC) electric sources [2 – 16, 19 – 26]. Furthermore, this system uses solar energy to operate which can decrease both fossil fuels consumption and carbon emissions to the greatest extent possible [10, 11, 14, 19, 27, 28].

The major challenge in applying PV-TERP system in real buildings is outdoor conditions such as ambient temperature, relative humidity, and solar radiation since these conditions are likely to vary based on the weather conditions and geographic coordinate [10, 14, 19, 27 – 29]. Excessive solar radiation and temperature might degrade the efficiency of the photovoltaic (PV) panels while low solar radiation can lead to low electrical power production [10, 14, 27 – 29]. Therefore, it is essential to analyze the PV-TERP system application, performance, and working conditions before using it for cooling purposes. Otherwise, this system may have an impact on indoor thermal comfort, and its cooling performance may not be fully utilized.

Despite the fact that there are many studies on the application of PV panels in cooling systems, there are not many studies on the utilization of PV panels in TERP systems because TERP systems are still relatively new in the cooling industry, especially in tropical countries like Malaysia, Singapore, Indonesia, and Thailand. Consequently, the main purpose of this study is to assess the design of the PVTERP system as a cooling system for a building application in a tropical country (Malaysia) under indoor parameters within the acceptable range of ASHRAE Standard-55, ensuring this system is applicable for building in a tropical country as a cooling system.

2. Materials and Methods

In this research, the cooling load of the target room must first be determined, followed by the PVTERP system design process. The design’s cooling load is recommended within 5% of the target room cooling load. Significant parameters to be considered including the hot temperature of the hot side of TEM and thermal resistance of the heat sink.

Target Room Cooling Load

As shown in Fig. 1, the chosen target room is located at Malaysia-Japan International Institute of Technology (MJIIT), University of Technology Malaysia (UTM), Kuala Lumpur (KL). This room is 4.76 m in length, 3.52 m in width, and 2.83 m in height, with a total area of 16.8 m2. This room is illuminated by four fluorescent tubes and is fully operational on weekdays from 9 AM to 5 PM. There are no electrical appliances or equipment that generate heat in this room. The PV-TERP system is expected to serve the target room without a ventilation system or even a dehumidifier. This system assists in maintaining the indoor temperature and relative humidity of 21 °C and 50%, respectively at outdoor conditions based on ASHRAE handbook [29]. Here, the indoor temperature and relative humidity is within the acceptable range of ASHRAE standard-55 [30]. This system also is expected to be fully operational on weekdays from 9 AM to 5 PM. It is assumed that this room accommodates one occupant with resting activity on weekdays from 9 AM to 1 PM and 2 PM to 5 PM. Table 1 shows the obtained cooling load of the targeted room. It should be noted that Hourly Analysis Program (HAP) software is used to calculate the targeted room cooling load.

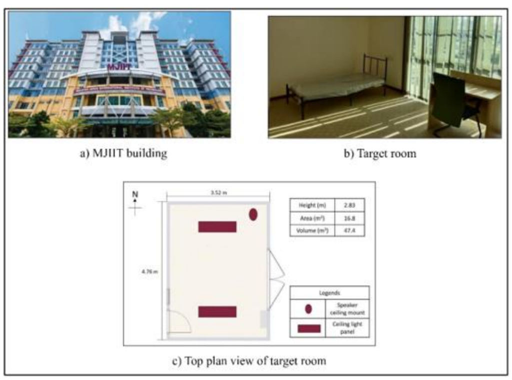


Fig. 1 Target room.

Table 1 Cooling load of the target room.

Conduction Loads	
Building Façades	**Sensible Load (W)**
Wall	3084
Ceiling	994
Door	94
Window	271
Solar Loads	
Building Façades	**Sensible Load (W)**
Window (East wall)	248
Window (West wall)	0
Internal Loads	
Internal Loads	**Sensible Load (W)**
People	44
Lighting	77
Equipment	0

PV-TERP Design

The PV-TERP system design is based on the cooling load of the targeted room. Fig. 2 shows the overall flow of designing the PV-TERP system. Firstly, the thermoelectric module (TEM) is designed, followed by the radiant panel base. Then, the PV panels are added to the system to form a whole PVTERP system.

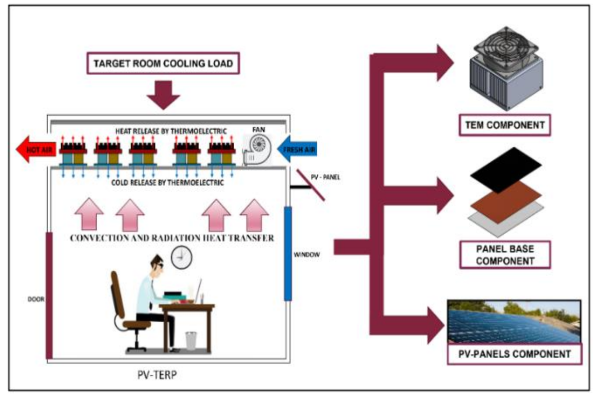


Fig. 2 PV-TERP system.

TEM Design

As shown Fig. 3, the TEM consists of a thermoelectric (TE) Peltier plate, a heat sink with an exhaust fan, and a fan bracket. The heat sink helps to dissipate heat from the TE to the outdoor environment. In order to maintain the heat sink's thermal resistance, the exhaust fan is needed to provide forced convection to the heat sink, where the fan bracket is used to connect the heat sink with the exhaust fan. Here, a heat sink, exhaust fan, and fan bracket are connected by the bolting method, while the TE Peltier plate and the heat sink are bonded by using heat paste (thermal adhesive), since there is no place for bolting between these components. It should be noted that the heat paste is used to lower the contact resistance between these two components.

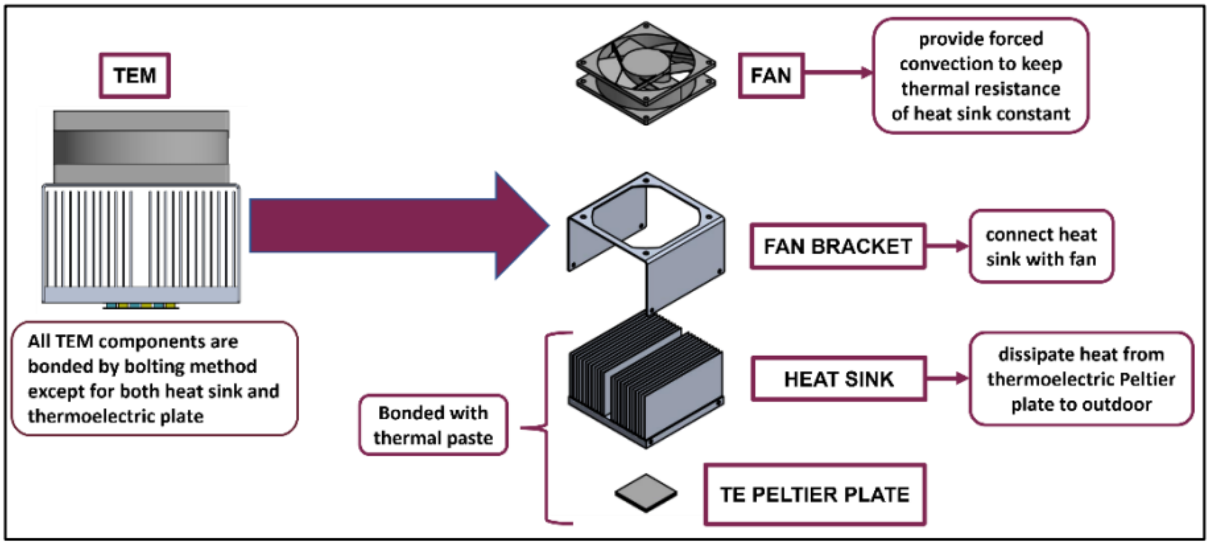


Fig. 3 TEM components.

As shown in Fig. 4, the TE Peltier plate is selected from the cooling performance graph provided by the manufacturer [31]. From this graph, the temperature of the hot side of the plate must be selected between 30, 50 and 70 °C as provided by the manufacturer. In this study, 30 °C is selected as the hot side to reduce the temperature difference between both sides. This is because, higher coefficient of performance (COP) value of TEM will be obtained as the temperature difference gets lower. The cold side temperature of the plate is set to 11 °C, which is 0.5 °C higher than the dew-point temperature of the targeted room to prevent condensation on the surface of the PV-TERP system. Then, from the graph, an adequate TE Peltier plate with the necessary cooling load can be selected based on the temperature difference between both hot and cold sides, including its voltage input.

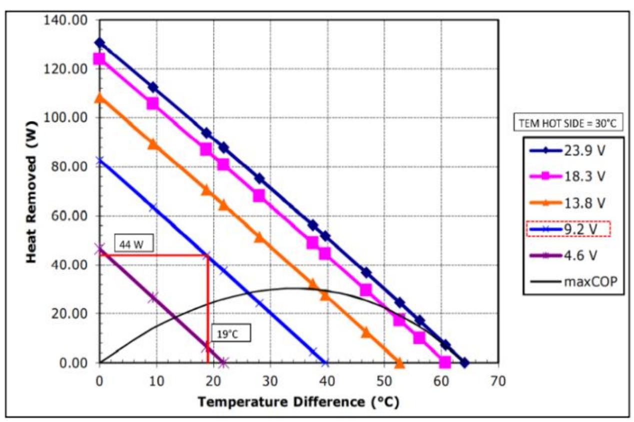


Fig. 4 TE Peltier plate cooling performance graph [32].

Meanwhile, the heat sink with 0.1 °C W^{-1} thermal resistance is selected for the TEM design. As shown in Fig. 5, the airflow volume (CFM) of exhaust fan is selected based on thermal resistance of heat sink graph [32]. Here, quantity for heat sink, exhaust fan, and fan bracket must be equal to the quantity of TE Peltier plate.

Radiant Panel Base and PV Panel Design

The radiant panel design consists of a panel base, a substrate, and insulation layer.

A substrate is needed to improve the structural stability of the radiant panel design because mechanical bending stress can occur on the panel base due to the weight of TEM. An insulation layer is needed to avoid unnecessary heat transfer between the TEM and the radiant panel. In this study, aluminium is used as a panel base due to its low cost and high heat conductivity, while copper is used as a substrate because it conducts heat well and is more denser than aluminium. This can improve the structural stability of the radiant panel design without increasing the thermal resistance of the PV-TERP system [2].

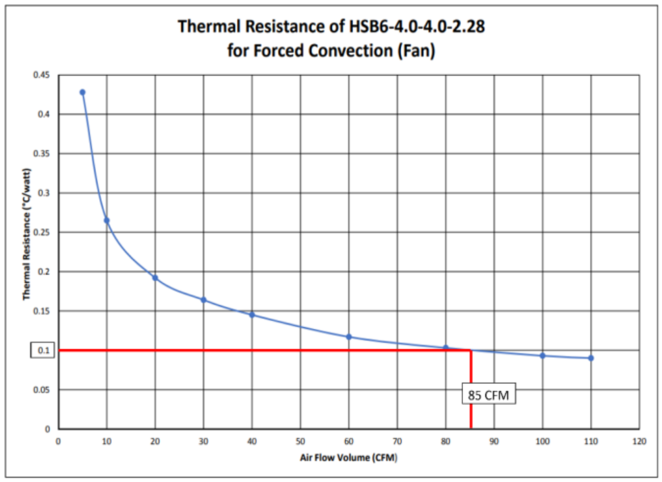


Fig. 5 Heat sink thermal resistance vs fan air flow volume graph [33].

In Fig. 6, in the assembly of radiant panel base with TEM, the bolting method is used to attach the substrate to the panel base while the heat paste (thermal adhesive) is used to attach the substrate to the TE Peltier plate. Here, the heat paste can lower the contact resistance between substrate and panel base [2]. In addition, the substrate's top surface is insulated to avoid unnecessary heat transfer between the TEM and the radiant panel. Due to the ease of the bolting method, the chosen thickness for the aluminium and co pper is 2 mm and 3 mm, respectively. As for insulation, the flexible polymeric barrier with 0.034 W m^{-2} thermal conductivity and a thickness of 7 mm is selected. The simulation in terms of mechanical bending stress is done to demonstrate the chosen thicknesses for radiant panel and substrate are adequate for supporting the weight of TEM by using Autodesk Inventor software.

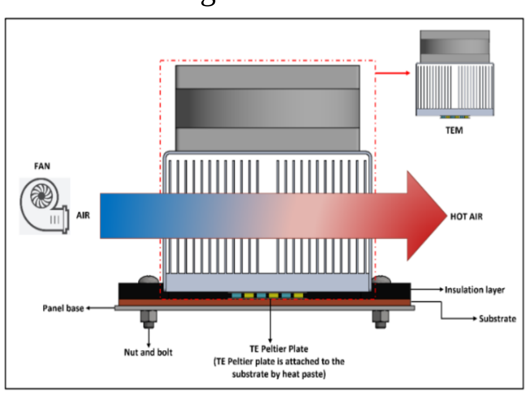


Fig. 6 Radiant panel base components.

The dimension of the PV-TERP system depends on the quantity of the TEM and the dimension of the target room. The dimensions of the designed TERP system are 0.5 m in length and 2.4 m in width. A rectangular shaped plenum with a height of 0.15 m is added to the panel base to trap the heat generated by the heat sink. Here, the trapped heat is rejected to the outdoor environment through the 84 mm in diameter flanges installed at the plenum inlet and outlet with the help of a fan/blower. Finally, the PV panels are added to the design becoming a whole PV-TERP system.

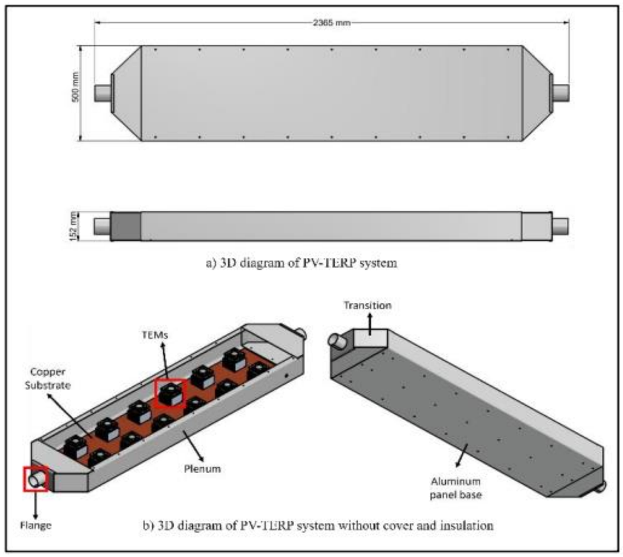


Fig. 7 Dimension of PV-TERP.

3. Results and Discussion

From Fig. 4, at an applied voltage of 9.2 V and a temperature difference of 19 °C at the TE Peltier plate, a plate with 44 W of cooling power is chosen. As shown in Fig. 8, 110 units of the chosen plate are required to be installed in the PV-TERP system to provide a cooling load equal to the targeted room cooling load. However, to avoid heavy load due to large number of TEMs in a single PV-TERP, the quantity required for PV-TERP to cool down the targeted room is 10 units, each with 11 TEMs. In the given configuration, all units of PV-TERPs can provide up to 4.84 kW of cooling power, which is about a 0.6% percentage difference from the cooling load of the targeted room. Here, each PV-TERP can provide up to 484 W of cooling power. This clearly shows that the new design is applicable to be used as a cooling system for the targeted room.

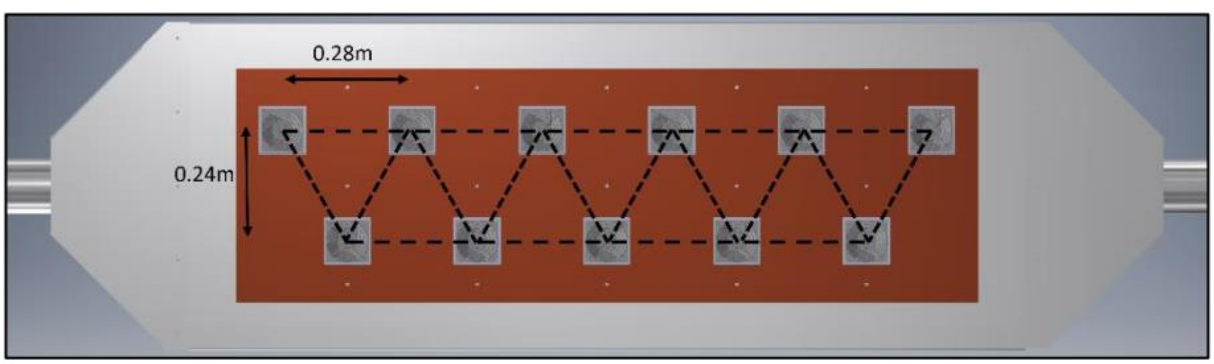


Fig. 8 TEM configuration in PV-TERP system.

Table 2 Cooling load comparison between the PV-TERP and target room.

PV-TERP Cooling Load (kW)	Target Room Cooling Load (kW)	Percentage Different (%)
4.84	4.81	0.6

Besides that, in the mechanical bending stress analysis, the effect of TEMs' weight on the displacement of the base panel bolting with substrate is very low, which is about 0.02874 mm. This clearly demonstrates that the thicknesses of both panel and substrate are adequate for supporting the weight of TEMs. It should be noted that the weight of single unit TEM is 0.755 kg.

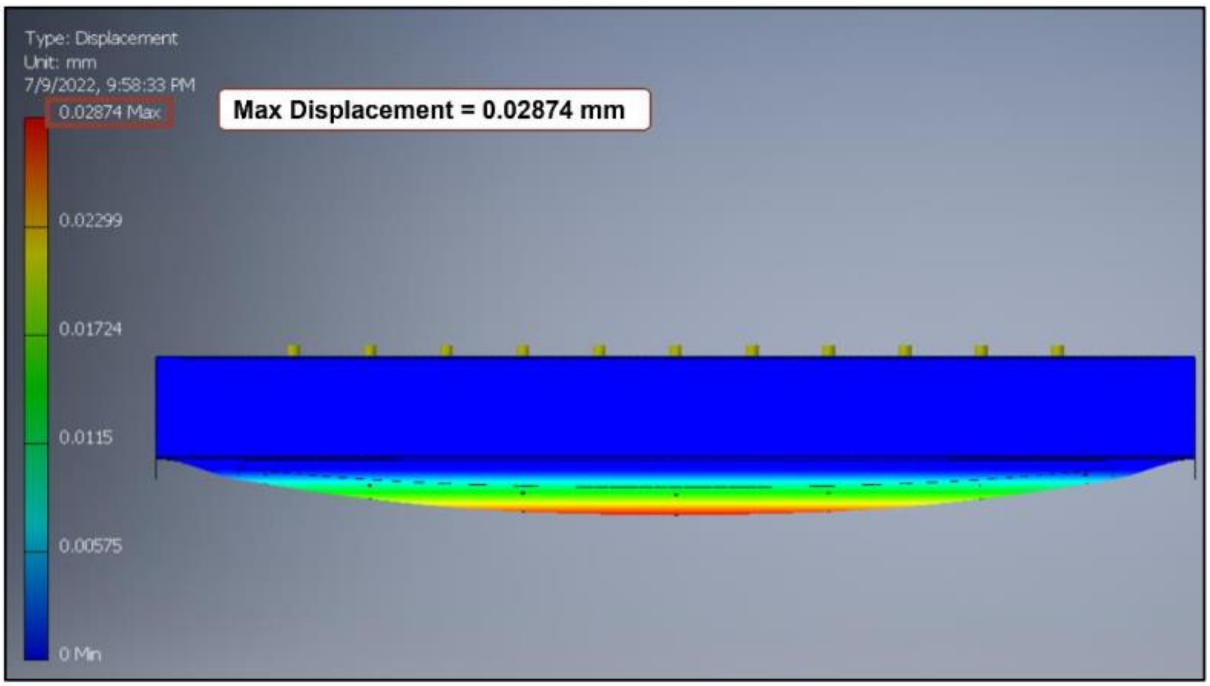


Fig. 9 Mechanical bending stress analysis on PV-TERP.

4. Conclusion

In cooling system design, it is important to estimate the total cooling load required to condition the targeted building under usual weather conditions and indoor conditions within the acceptable range of ASHRAE standard-55. Otherwise, the energy savings goal cannot be achieved. For this research, the PV-TERP system is designed based on the cooling load of the targeted room located at Kuala Lumpur, Malaysia under indoor parameters within the acceptable range of ASHRAE standard-55. This newly designed is recommended to have cooling load within 5% of the target room cooling load to ensure this design is applicable as the target room's cooling system.

The designed PV-TERP can provide up to 4.84 kW of cooling power, which is about a 0.6% percentage difference from the cooling load of targeted room. This indicates that this design is applicable as the target room's cooling system. Besides that, in radiant panel base design, due to the ease of the bolting method, the chosen thickness for the panel base and substrate is 2 mm and 3 mm, respectively. These thicknesses are adequate for supporting the weight of TEMs. Here, the mechanical bending stress analysis result shows that the effect of TEMs' weight on the displacement of the panel base bolting with substrate is very low, which is about 0.02874 mm.

The PV-TERP can be used as an alternative to conventional AC systems for maintaining the indoor thermal comfort since this system consumes less energy than the conventional AC systems. This system also is refrigerant-free and powered by clean energy that can sustain and preserve our environment for a better future.

5. Suggestions

The successful design and implementation of the PV-TERP system necessitate detailed studies of thermal properties and mechanism of this system. Otherwise, this system may have an impact on indoor thermal comfort and its cooling performance may not be fully utilized. Therefore, it is important to develop a thermal analysis for this system via simulation to support the design feasibility, followed by experimental validation. Other than that, the energy simulation of the designed PV-TERP in terms of energy consumption, heat energy waste, and COP also need to be developed. Then, a quantitative comparison with conventional AC system to ensure that PV-TERP system has the potential to replace the conventional AC system towards preserving the environment.

6. Acknowledgement

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