Experimental investigation on AC unit integrated with sensible heat storage (SHS)

N A Aziz¹, N A M Amin¹, M S A Majid¹, A Hussin², S Zhubir¹
¹ School of Mechatronic Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia
² ILP Kepala Batas, Jln Tun Hamdan Sheikh Tahir, 13200 Penaga, Penang, Malaysia
nasrulamri.mohdamin@unimap.edu.my

Abstract. The growth in population and economy has increases the energy demand and raises the concerns over the sustainable energy source. Towards the sustainable development, energy efficiency in buildings has become a prime objective. In this paper, the integration of thermal energy storage was studied. This paper presents an experimental investigation on the performance of an air conditioning unit integrated with sensible heat storage (SHS) system. The results were compared to the conventional AC systems in the terms of average electricity usage, indoor temperature and the relative humidity inside the experimented room (cabin container). Results show that the integration of water tank as an SHS reduces the electricity usage by 5%, while the integration of well-insulated water tank saves up to 8% of the electricity consumption.

1. Introduction
Buildings account for approximately 40% of the worldwide energy demand [1]. The usage of air conditioning system in buildings primarily, has increases load on power used, thus increasing energy consumptions and therefore cause of high electricity tariff. Energy efficiency improvements in buildings is therefore vital to reduce the global energy demand towards sustainable development. These issues which was also amplified by a strong demand for uninterrupted supply has encouraged significant development in renewable energy technologies. Thermal Energy Storage (TES) system is one of the technologies which have attracted profound interest from researchers for their use in eliminating environmental problems and to increase the efficiency of energy consumption in general [2].

Thermal energy storage is defined as the temporary holding of thermal energy in the form of hot or cold substances for later utilisation. TES system has an enormous potential to make the function of thermal energy equipment more effective and to facilitate large-scale energy substitutions. They are highly valuable from an economic perspective. It is an advanced energy technology that has recently attracted increasing interest for thermal applications such as space and water heating, cooling and air-conditioning. It appears to be the most appropriate method for reducing the mismatch between the supply and demand of energy [3].

Over the last decades, numerous research were conducted to improve the energy efficiency in buildings by the integration of TES system [4–5]. PCM thermal storage system was acknowledged as most favourable storage system prior this objective. The integration of PCM thermal storage system into air distribution system for peak shaving purpose was studied [4]. PCMs mixtures of paraffin waxes with the heat of fusion around 90 KJ/kg was chosen as thermal storage medium. From this study, the authors
conclude that the integration of TES systems could maintain a constant room temperature without any cold source operation at a certain time.

On the other hand, the possibility of peak shaving control with the incorporation of PCM thermal storage to the ceiling boards was examined [6]. The thermal capacity of PCM ceiling board was measured by using a small chamber, approximately 16m² surface area. The PCM ceiling boards was developed by adding the microencapsulated PCM to the commonly used rock wool ceiling board. The mixture of n-paraffins with a melting point of 25 °C was used in this study. During overnight, the cool air from air handling unit (AHU) will flow into the ceiling chamber space and cools the PCM ceiling board and storing cool thermal energy. Whereas, during the peak shaving period, the air from the room returns to the AHU via the ceiling chamber space.

During the peak shaving period, when the thermal load peaks, the air from the room returns to the AHU via the ceiling chamber space. As a result of passing through the cooled-down PCM ceiling board, the warm air returning from the room cools down before returning to the AHU. With such an arrangement air is precooled and the result was that the maximum thermal load using the PCM ceiling board was 85.2% of that using the rock wool ceiling board. The result shows that, the transition rate of the thermal load to the night was 25.1% thus lowering running cost for 91.6% compared to the rock wool ceiling board [6].

In this paper, the effect of TES system integration into the split unit air-conditioning (AC) unit was investigated. In contradict to the previous research that favour the utilisation of latent heat storage (LHS) medium (eg: PCMs), this paper proposes a sensible heat storage (SHS) medium to be retrofitted to the AC suction line, aiming to reduce the energy consumptions simultaneously improving the thermal comfort inside the buildings.

2. Experimental setup
Figure 1 shows the schematic diagram of the constructed thermal storage air-conditioning system. 1 HP split unit air conditioning system was installed in a 20 × 10 × 8.4 feet room (cabin container). Three cooling systems were experimented and studied. The first system is the conventional air conditioning (AC) as shown in Figure 1 (a). While the second system was tested on the same AC unit but it was integrated with the water tank as illustrated in Figure 1 (b). The helical coil in tank thermal storage was constructed from the polyethylene water tank (as shown in Figure 2 (a) with the dimension of 2 feet high and 1 feet diameter. 5 feet length of 3/8 inch diameter copper tube was assembled 2 feet from the outdoor unit by the used of 3-way valve. The helical coil was then submerged inside the polyethylene water tank which was filled with 98% of water at the room temperature. The third system was upgraded from the second system which the polyethylene tank was well insulated to minimise the heat loss to the surroundings. All tests were experimented under the same condition that conducted in a closed room with AC was set at 16 °C and full speed blower. Heat load for the
Figure 1. Schematic diagram of the tested system (a) conventional AC system (b) AC – TES integrated system

Figure 2. (a) SHS tank (b) Retrofitted SHS tank to the suction line

The pilot test was first conducted to observe the trends of the outdoor temperature. The average temperature of 10 days pilot test was recorded as 27.6 °C, with the maximum and minimum daily temperature were 39 °C and 23 °C respectively. For all set of tested experiments, it is very difficult to be performed under exactly same outdoor temperature. Therefore, the outdoor temperature was monitored to be in a small margin with the average outdoor temperature, assuming they are in the same condition. PEL: power and energy logger was employed to record the voltage, current and power consumption for all three systems. Meanwhile, the HOBO data logger was utilised to monitor the indoor temperature and relative humidity of the tested room. For each test, the data were logged in 5 minutes interval for 10 days long. The data were then compiled and analysed.

3. Results and discussion

Figure 3 shows the comparisons of average electricity usage per day for all three tested systems with the average outdoor temperature of 27.5 °C. The voltage usage for 1 HP AC system was recorded in the
range of 230 – 240 V. With the constraints of similar outdoor temperature and voltage, the conventional AC system was recorded to consume the highest electricity amongst three systems. Meanwhile, comparing the integrated AC – SHS system shows higher consumption than the integrated AC – insulated SHS system. The average power consumption for all three systems was calculated as 420.052 W, 395.828 W and 386.532 W for conventional, AC – SHS, and AC – insulated SHS respectively. These results indicated that the integration of SHS tank would reduce the total energy consumption for at least 5% for uninsulated water tank while it saves up to 8% for insulated water tank integration (at the measured point).

![Comparisons of average electricity consumption for AC unit](image)

**Figure 3.** Graph of the comparisons on the electricity consumption

Nevertheless, in order to evaluate the overall performance of all tested systems, the indoor condition of the room must be taken into consideration. Indoor thermal comfort evaluation is an important measure in analysing the overall performance of the system. Providing a better thermal comfort in the building while simultaneously decreasing the power consumption is an important key in designing more efficient cooling system. The term thermal comfort is basically referring to the state of the indoor temperature, which the resident considers as comfortable to stay in. There are many factors affecting the thermal comfort inside the buildings such as air temperature, relative humidity and air speed [6]. In this study, indoor temperature and relative humidity (RH) were monitored and analysed towards this objective. For a country with a tropical climate, suggested indoor temperature and RH are 21 °C – 27 °C and 28% - 80% humidity respectively [7]. It is vital to maintain the RH at a comfortable range, which is high enough to avoid problems associated with dry air but low enough to be comfortable [8].
Figure 4. Graph of the comparisons on average indoor temperature

Table 1 Relative humidity for all tested system

| System               | Max RH | Min RH | Average RH |
|----------------------|--------|--------|------------|
| Conventional AC      | 71.37  | 59.41  | 65.58      |
| AC – SHS             | 73.06  | 59.69  | 66.52      |
| AC – insulated SHS   | 72.05  | 56.39  | 66.48      |

Figure 4 shows the comparisons on the average indoor temperature, while the minimum, maximum and average relative humidity for all systems were tabulated in Table 1. Referring to Figure 4, it can be seen that the indoor temperature for conventional AC system and the AC – SHS integrated system recorded about the same values. Referring to the plotted graph, it shows that the temperature inside the room for AC – integrated system somehow goes higher than the temperature with the use of conventional AC. These data indicated that the integrated of non-insulated water tank does not show a significant impact towards the thermal comfort of the buildings.

Other than that, the graph shows that the average indoor temperature of the tested room is seen to be less fluctuated with the integration of insulated water tank when compared to the other two systems. The mean temperature reduces about 20% in comparisons with the conventional AC. The average indoor temperature for all three systems are 28.07 °C, 27.46 °C and 22.15 °C respectively. Whereas, the values of RH tabulated in Table 1 shows that an average daily RH were 65.58, 66.52 and 66.48 for all three systems respectively. These data conceded the integration of SHS tank does not show too much significant impact on the thermal comfort of the buildings as all these data were in the range of suggested thermal comfort condition [7]. However, it is clearly proven that indoor temperature and RH were improved by the integration of the insulated SHS tank compared to the use of conventional AC and AC-SHS (water tank) integration.

4. Conclusion
The present work mainly constructed and tested the air conditioning unit performance with and without the integration of sensible heat storage (SHS). The power input usage was recorded and compared for all three tested systems. Results show that the integration of water tank to the AC system would reduce the power consumption by 5% while the integration of well-insulated water tank reduces it by almost 8%. From this study, it is clearly proven that the power consumption, indoor temperature and RH were improved by the integration of the insulated SHS tank compared to the use of conventional AC and AC-SHS (water tank) integration.
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