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Energetic, economic and environmental benefits of utilizing the ice thermal storage systems for office building applications

B. Rismanchi a,∗, R. Saidur a, H.H. Masjuki a, T.M.I. Mahlia a,b

a Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
b Department of Mechanical Engineering, Syiah Kuala University, Banda Aceh 23111, Indonesia

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A B S T R A C T

In recent decades, around the world, a huge amount of daytime peak power has been shifted to the off-peak hours by using different types of thermal energy storage systems. However, the contribution of these systems in Malaysia is still minor in comparison with their potential. Therefore, the feasibility and potentiality of employing ice thermal storage (ITS) systems for office building cooling applications is studied to investigate their economical and environmental benefits. The air conditioning systems in Malaysia are considered as the major energy consumers in office buildings with around 57% share. The economical analysis of the cost benefits is carried out for a system including chiller and storage system. The installation costs are mainly dominated by the total system capacity; hence the study was conducted for a range of 100–2000 tons of refrigeration (TR) (352–7034 kW) for two storage strategy of full storage and load levelling storage strategy. The results indicate that considering the special off-peak tariff rate of $0.06/kWh for the total system capacities of 500 and 1500 TR (1758 kW and 5275 kW), the annual cost saving varies from $230,000 to $700,000 and from $65,000 to $190,000 for full storage and load levelling storage strategy, respectively. The overall results show that the full storage strategy can reduce the annual costs of the air conditioning system by up to 35% while this reduction is limited to around 8% for a load levelling strategy. The comparison study reveals that for the full storage strategy the payback period varies between 3 and 6 years while the payback period for the load levelling strategy varies between 1 and 3 years. It was concluded that the ITS system can play a vital role in consuming the natural resources in a more efficient, economical and environmentally benign way by changing the electricity consumption pattern to overcome the disparity between energy generation and energy demand.

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1. Introduction

Air conditioning (AC) systems account for between 16 and 50% of electricity consumption in many regions around the world, especially in hot and humid countries near the Equator the electricity consumption might be more [1]. People spend around 90% of their time in buildings while about 40% of primary energy needs are due to buildings [2]. In Malaysia, AC systems are the major energy consumers in office buildings with around 57% share [3]. Unlike other building electricity consumers, cooling is only required for a few hours of the day. Generally, thermal energy storage system includes a low or high temperature medium for later use [4]. The gradual development of cold thermal energy storage (CTES) technology over the past decade has allowed for wide deployment in many countries, and it is now considered as one of the best energy saving approaches for AC systems. Generally, electricity consumption is divided into two operating periods – daytime (peak hours) and night-time (off-peak hours) when electricity is cheaper (and often the ambient temperature is lower). CTES is a technology whereby cold energy is stored in a thermal reservoir during off-peak periods for later use [5,6]. Consequently, the offset in electricity demand is accompanied by an improved system performance [7] and reduced total cost [8]. Many electricity providers have recognized the potential of CTES to change electricity consumption patterns, and now offer special pricing structures as incentives for energy users to deploy CTES systems. CTES systems are widely used in different building applications that are mainly occupied during the working hours, such as office buildings [9], hospitals [10], schools [11,12], churches and mosques [13]. Fig. 1 illustrates the general differences between conventional AC systems and a CTES system. The cold energy can be stored as ice, chilled water or in eutectic salt phase change materials (PCM) [14]. This cold energy is then released during periods of peak demand. Therefore, CTES systems are categorized in three major types: ice thermal storage (ITS), chilled water storage (CWS) and eutectic salt thermal
energy storage systems [15]. Although CTES is a mature technology, considerable potential exists to further optimize its performance.

Malaysia is a country located near the Equator with an area of around 329,733 km². It has a tropical climate with an average temperature that varies from 20 °C to 32 °C and an average rainfall of about 3540 mm per annum [16]. Like any other developing country, Malaysia has experienced rapid economic growth in the past decade. In the last 50 years the statistical data [16,17] show that residential electricity consumption has increased dramatically in that the number of AC systems used increased from 13,251 units in 1970 to 253,399 in 1991. Furthermore, it is predicted that the number will reach around 1.5 million by the year 2020 [18,19]. The total energy consumption of AC systems has increased from 1237 GWh in 1999 to around 2277 GWh in 2009 and it is predicted to reach to around 3055 GWh in 2015 [20].

Several investigations and case studies about CTES technology and strategies are available in the literature [21]. Hasnain [22] presented a comprehensive review of different CTES technologies, indicating their advantages and disadvantages over conventional AC systems. Among the available CTES systems the most successful type in common use around the world is the ITS system. The ITS system generally falls into five categories: ice slurry, ice harvesting, internal melt ice-on-coil, external melt ice-on-coil and encapsulated ITS systems [15]. The CWS system is the second most popular technology, especially when space is not an important parameter. Sebza and Rubini [23] investigated the benefits of employing CWS systems in the Kuwaiti climate. They found that a CWS system can decrease the peak load by up to 100%, and reduce the required chiller size by up to 33%.

Campaocca et al. [24] investigated the economical impact of using an ITS system in residential buildings in Italy based on the double-tariff electricity contracts. They have used the Monte Carlo method to estimate the daily cooling required of the residential buildings. They found that the available off-peak tariff rate ($0.101/kWh) is not low enough to encourage the customers to shift their energy consumption to the off-peak hours. Habeebullah [13] performed an economic evaluation to investigate the feasibility of employing an ITS system for the Grand Holy Mosque of Mekkah, the results of his work show that with the current subsidized electricity rate of $0.07/kWh there is no gain through introducing an ITS system neither for full nor for partial storage strategy. Boonma and Namprakai [25] presented a method for determining the optimal capacity of a CWS tank for a building in the University of Technology, North Bangkok. They found that a combination of two chiller units (450 TR) operating continuously with a TES tank (9413 TR and 5175 m³ volume) can reduce the required chiller size by 66%, and reduce peak demand by around 31%.

The use of a CTES system in building applications can decrease energy costs and also reduce the total energy consumption. Consequently, this strategy can decrease the environmental impact. This characteristic fulfills the basic criteria of a green technology [26]. Moreover, electricity production and distribution during the night hours, when the ambient temperature and line losses are lowest, is significantly more efficient than during the day. Although the electricity cost savings of CTES systems are likely to be higher than the energy savings, any decrease in energy consumption can assist in conserving fossil fuels and, consequently, decrease emissions of CO₂, SO₂, NOₓ and harmful CFCs [27,28]. The statistical data show that office buildings consume around 21% of the total electricity consumption of the country [3]. Therefore, great potential is available to reduce utility costs as well as energy consumption and carbon emissions in this sector.

The main purpose of the present work is to investigate the energetic, economic and environmental benefits of utilizing the ITS systems on the conventional AC system of office buildings in Malaysia. Based on the authors’ knowledge there is no work on the potential energy and cost savings of employing ITS systems in Malaysia. Therefore, this work is expected to fill this gap.

2. Methodology

The procedure to calculate the cooling load profile, storage tank sizing, economic evaluation and payback period is presented in this section. The daily load profile of a typical building is influenced by many factors such as the building characteristics, number of occupants, occupant’s activity level, the day of the year, and the power consumption rate of different devices operating in the conditioned space.

2.1. Cooling load profile calculation

Calculating the building load profile for a CTES system over a period of 24 h or more has the same importance as the peak hourly load for a non-storage system. The total 24-h system capacity in a non-storage system is simply 24 times the peak hourly load. However, the CTES system must not only meet the peak load, but also be designed in a way that meets the extended load over time. Therefore, an accurate load profile calculation over the complete storage cycle is the most important part of the design process [15]. The selection of design ambient temperature conditions for CTES systems needs the same consideration as a non-storage system. However, in the event that the design load is exceeded, CTES systems have less recovery capacity than non-storage systems. Therefore, designers must be more conservative in their selection of the design temperature. In order to calculate the load profile, an accurate estimation of occupancy schedules, lighting and equipment is also required. All the heat sources within the conditioned
space have to be considered, because even relatively small heat sources can have a significant effect on the integrated daily load.

In a non-storage system, cooling is only required when the building is occupied, therefore, all the unoccupied heat gains (the pull-down load) are generally met during the first operating hours. Although in CTES systems the pull-down load does not have such a significant effect on sizing calculations, it should be considered as part of the weekly load profile. Thermal losses during the charging, storage and discharging processes are another relatively small load that should be considered during calculation. If the storage tank is insulated properly and is not exposed to direct sunlight or other heat sources, the amount of heat loss normally varies between 1 and 5% of the total storage capacity per day, depending on the system characteristics such as tank shape, storage medium and insulation material. In conventional AC systems, the cooling load is described as “kW of refrigeration” or “tons of refrigeration (TR),” while in CTES systems the building load is measured in “kWh” over the entire operating cycle.

2.2. Cooling plant and storage tank sizing

The chiller operating time is divided into two periods of day-time (peak hours) and night-time (off-peak hours). Hence, the total chiller capacity is calculated using Eq. (1) [29].

\[
\text{total kWh} = \text{chiller day kWh} + \text{chiller night kWh}
\]  

(1)

The total “chiller day” capacity is equal to the chiller capacity (kW) multiplied by the daytime working hours. Consequently, the total “chiller night” capacity is equal to the chiller capacity multiplied by the night time (off-peak) operating hours. However, because the chiller capacity during charging is different from its capacity during direct cooling, a derating factor is applied to the chiller capacity to obtain its capacity during the charging process. The derating factor is directly related to the system design and manufacturer’s standards. Generally, it varies between 0.65 and 0.72% for compressor chillers [29]. Hence, the chiller capacity can be calculated as follows:

\[
\text{chiller kWh} = \frac{\text{total kWh}}{\text{day hours} + \text{derating factor} \times \text{night hours}}
\]  

(2)

However, the total building load (kWh) is equal to the storage capacity plus chiller “day capacity”. Therefore, the total storage capacity is equal to the total kWh minus chiller day capacity.

2.3. Economic evaluation

For a system consisting of a chiller and a storage tank, the total annual cost, \(C_{\text{total}}\), is a function of the capital cost for the chillers, \(C_{\text{Ch}}\), capital cost for the storage system, \(C_{\text{St}}\), and the utility costs, \(C_{\text{Util}}\). The utility cost itself is a function of operating time, \(t_{\text{op}}\), total energy consumption, \(E\), and the localized electricity tariff rate, \(e_{\text{tar}}\) ($/kWh) [13].

\[
C_{\text{total}} = f(C_{\text{Ch}}, C_{\text{St}}, C_{\text{Util}})
\]  

(3)

\[
C_{\text{Util}} = f(t_{\text{op}}, E, e_{\text{tar}})
\]  

(4)

To calculate the annual repayment of the chiller and storage system to pay back the investment in a specified time frame, the capital costs must be multiplied by the capital recovery factor (CRF). The CRF is defined as the ratio of a constant annuity to the present value of receiving that annuity for a given length of time [30].

\[
\text{CRF} = \frac{i((1+i)^n - 1)}{1+i^n - 1}
\]  

(5)

where \(i\) is the interest factor and \(n\) is the number of years. Therefore, by substituting Eqs. (5) and (4) into (3) the total annual cost can be expressed as follows:

\[
C_{\text{total}} = \frac{i((1+i)^n - 1)}{1+i^n - 1}[C_{\text{Ch}} + C_{\text{St}}] + \int_{0}^{t_{\text{op}}} e_{\text{tar}} E dt
\]  

(6)

In Eq. (6) the total energy consumption, \(E\), is a function of climate condition, building geometry, occupancy profile, and activity level, etc. In this work, the total energy consumption (building cooling load) is calculated based on the cooling load temperature difference (CLTD) method [31] for every hour of a design day.

2.4. Localized costs for installation and maintenance

The installation cost of a conventional AC system is mainly dominated by the total system capacity. For a conventional AC system design, the total system capacity or the total required building cooling load is equal to the chiller capacity, however, for the cold storage system design the total chiller capacity is highly depended on the storage strategy. Generally, in the Malaysian market, if the total cooling capacities are 1000 TR (3514 kW) and above, a rule of thumb of $370/kW (RM3500/TR) can be adopted, which includes the supply and installation of the chillers, pumps, cooling towers, piping and valve fittings, electrical and control system cost and chemical treatment. For system capacities of less than 1000 TR (3514 kW) the installation costs vary from $470 to $670/kW. The same rule of thumb may also be applied for the installation cost of the ITS systems. If the total cooling capacities are 1000 TR (3514 kW) and above, the installation cost of $700/kW (RM6000/TR) can be adopted, which includes the supply and installation of chillers, pumps, cooling towers, ice tanks, piping and valve fittings, electrical and control system cost, glycol and chemical treatment. As for cooling capacities less than 1000 TR (3514 kW), the price varies from $700 to $1100/kW. Fig. 2 is generated based on the above rule of thumb. A curve fitting study shows that the best relation...
Comparison between normal and special rate structure for medium voltage commercial (C2) [33,34].

<table>
<thead>
<tr>
<th>Descriptions</th>
<th>Normal rate per kW</th>
<th>Special rate per kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak hours</td>
<td>8:00 to 22:00</td>
<td>9:00 to 21:00</td>
</tr>
<tr>
<td>Peak duration</td>
<td>14 h</td>
<td>12 h</td>
</tr>
<tr>
<td>Tariff rate</td>
<td>$0.104 (RM0.312)²</td>
<td>$0.104 (RM0.312)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>During peak hours:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.104 (RM0.312)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>During off-peak hours:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.06 (RM0.182)</td>
</tr>
<tr>
<td>Maximum demand charges</td>
<td>$8.633 (RM25.90)</td>
<td>$12.86 (RM38.60)</td>
</tr>
</tbody>
</table>

* $1 is equal to RM3 [34].

between installation cost and total system capacity can be defined by the power order equation as follows.

Installation cost = a(total system capacity)ᵇ (7)

The annual maintenance costs for ice tanks alone are minimal and can be assumed to be $0.5/kW/year. The annual cost of maintenance for the conventional AC system can be adopted with the rule of thumb of $1.9/kW/year and for the ITS system it is around $2.5/kW/year.

2.5. Payback period

The payback (PB) period is defined as the period of time required for the profit or other benefits of an investment to equal the cost of the investment [30].

PB = Initial cost / uniform annual benefit (8)

For the ITS system, the initial cost includes the supply and installation of the chillers, pumps, cooling towers, piping and valve fittings, electrical and control system cost and chemical treatment. The annual cost saving is the difference between the ongoing costs of a conventional AC system and the ongoing costs of an ITS system working in the same condition.

2.6. Survey data

The ambient temperature records for different cities of Malaysia show that the diurnal temperature varies between 19 °C and 36 °C, whilst relative humidity (RH) varies from 51 to 100% and there are no distinct seasonal variations to this pattern [32]. For estimating the daily cooling load profile inside the conditioned space, both demographical and climate data are considered.

Based on the latest information released by Tenaga Nasional Berhad (TNB) Malaysia, the main Malaysian electricity provider, the peak period for medium voltage commercial use (C2) is from 8:00 to 22:00 (14 peak hours per day). However, to encourage customers to shift their electricity use to off-peak hours, TNB offers special rate structures for those using thermal energy storage systems. Based on the special rates, the peak period is reduced by 2 h (from 9:00 to 21:00), creating 12 peak hours and 12 off-peak hours each day. The electricity tariff rate and the maximum demand charge for the conventional AC system and for the ITS system is presented in Table 1.

A typical office building located in Kuala Lumpur is considered to calculate a sample cooling load profile. The building is assumed to be occupied from 7:00 to 19:00 every day. The building is pre-cooled from 6:00 to 19:00 in order to overcome the pull-down load. It is assumed that inside the conditioned space, the most significant energy consumption comes from the use of computer hardware. The input data used during calculation are presented in Table 2.

3. Results and discussion

In this study, the results of a macroscopic analysis on the energy and economic benefits of using an ITS system for office building applications in Malaysia is presented. First, a normalized cooling load profile for office buildings located in Malaysia has been calculated. The economic evaluation is made based on the calculated load profile for the Malaysian climate. Finally, the potential energy saving is presented.

3.1. Cooling load profile and chiller and storage tank sizing

The building cooling load is calculated based on the CLTD method for every hour of the design and the resultant profile over 24 h is presented in Fig. 3. The results show that the building peak load occurred at 16:00. Hence, for normalizing the profile, the maximum cooling load is considered at hour 16 and the minimum is considered as zero for the unoccupied hours. A conventional AC system rarely works at full load during the entire daily cooling cycle and the peak normally occurs between 14:00 and 16:00. It can be clearly observed from Fig. 3 that full chiller capacity is only required.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description/value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum outside temperature</td>
<td>35.8 °C [32]</td>
</tr>
<tr>
<td>Design room temperature</td>
<td>21 °C</td>
</tr>
<tr>
<td>Wall material</td>
<td>10 cm face brick + tile</td>
</tr>
<tr>
<td>Glass material</td>
<td>Double glass, without shading</td>
</tr>
<tr>
<td>Working days</td>
<td>Monday to Friday</td>
</tr>
<tr>
<td>Working hours</td>
<td>7:00 to 19:00</td>
</tr>
<tr>
<td>Occupant’s activity level</td>
<td>Moderate activity, office work</td>
</tr>
<tr>
<td>Sensible heat of occupants</td>
<td>73.2 W (250 Btu/h)</td>
</tr>
<tr>
<td>Latent heat of occupants</td>
<td>58.5 W (200 Btu/h)</td>
</tr>
<tr>
<td>CFM per person</td>
<td>15 CFM</td>
</tr>
<tr>
<td>Computers power consumption rate</td>
<td>350 W (1195 Btu/h)</td>
</tr>
<tr>
<td>ITS type</td>
<td>Internal ice-on-coil storage system</td>
</tr>
<tr>
<td>Derating factor</td>
<td>70% [35]</td>
</tr>
<tr>
<td>Annual working days</td>
<td>240 days (5 days x 4 weeks x 12 months)</td>
</tr>
</tbody>
</table>
for around 2 h (from 15:00 to 17:00) and less chiller capacity is required during the rest of the day.

By using the cooling load profile, the chiller size for the conventional AC system, full storage and load levelling storage strategy can be calculated. The chiller size for the conventional system is considered as the baseline. The comparison study between the results shows that the chiller size for full storage strategy is around 1.19 times more than the conventional AC system. However, the chiller size for the load levelling strategy is significantly lower than the chiller size for the conventional AC system being around 51% lower. Table 3 shows the chiller sizing results.

The differences between the chiller size and chiller operation hours of the conventional AC system, full storage and load levelling storage strategies can also be observed in Fig. 3. It can be clearly observed that the chiller size for the full storage strategy is considerably more than the chiller size for the conventional system. For the full storage strategy, the chiller only works during the off-peak hours, while for the load levelling strategy the chiller must work on its full capacity for 24 h a day. The chiller size for the design hour is considered as the base line. The results show that the chiller size for the full storage strategy is around 20% more than the required chiller size for the conventional AC system.

Generally, in the Malaysian market, the total system capacities are 1000 TR and above. Hence, by using the above mentioned normalized correlation, the required chiller size for three different system designs has been calculated for the various ranges of system capacities, as presented in Fig. 4. It is assumed that the chiller size increases linearly as the total system capacity of the design day increases.

### 3.2. Economic evaluation

The total installation cost for three different system designs over the range of different system capacities has been calculated based on the above mentioned rule of thumb. The results show that the total installation cost of the full storage strategy is significantly higher than the conventional AC system. However, it is observed that the total installation cost of the load-levelling strategy is in the same range as the conventional AC system. The results are only valid for a new system design and they cannot be expanded for retrofit projects.

The maintenance cost for different system capacities is calculated and the results show that the maintenance cost for the ITS system with full storage strategy is the most expensive one due to its large chiller size. The total electricity cost comprises two main parts – the maximum demand charge and the ongoing charges. The maximum demand charge is calculated based on the maximum required load during the peak period. It was found that the conventional AC system has the highest demand charge due to its large electricity consumption during the peak hours. The demand charge of the load levelling storage strategy is slightly lower than the conventional system. Although the chiller size in the load-levelling strategy is lower than the conventional system, the daily usage of this strategy would raise the demand charge. The demand charge for the full storage strategy is at the lowest possible level owing to the off-peak chiller usage. In this strategy, the only daily electricity usage is for the circulation system and the chillers will not work during the day. The annual ongoing charge is then calculated based on the national electricity tariff structure [33]. The results show that the annual ongoing costs for the conventional AC system and load levelling storage strategy are nearly similar and the prices for full storage strategy are slightly lower. By adding the annual maximum demand cost to the annual ongoing charges the total annual electricity costs of the AC system are calculated and the result is presented in Fig. 5. The results show that the conventional AC system has the highest annual costs and the full storage strategy has the lowest costs.

By deducting the total annual electricity costs of the full storage and load levelling storage strategy from the total annual electricity charges of the conventional AC system, the annual cost saving for each storage strategy can be calculated and the result is presented in Fig. 6.

The payback period can now be calculated according to the annual cost saving level, using Eq. (8). The results show that the PB period of the full storage system varies between 5 and 6 years for system capacities less than 3500 kW and for capacities more than that the PB period is around 3–4 years, as given in Fig. 7. On
the other hand, the PB period for the load-levelling strategy is considerably lower than the full storage strategy and it varies mostly from 1 to 3 years for system capacities of less than 3500 kW and less than 2 years for system capacities of more than that.

3.3. Energy saving

Most of the energy efficient systems reduce the energy consumption but do not change the energy usage pattern. Therefore, for a proper energy saving evaluation of a TES system, both energy used in the building and energy used by the power generator must be considered. Generally, for the CTES system, the site energy saving is highly dependent on the system characteristics and there is no guarantee, however, by shifting the energy consumption to the nights, source energy savings almost always occur.

The energy evaluation has been conducted for the full storage and load levelling strategies to investigate the system characteristics. The results for the full storage strategy show that this system configuration consumes significantly more energy than the conventional AC system, which is mainly due to its considerably larger chiller. Considering the load levelling strategy, although the chiller size is significantly smaller than the conventional system, but the long operating hours will consume significant electricity. Therefore, the results of the present study show that the overall energy consumption of the load levelling strategy is around 4% less than the conventional systems. However, the cumulative energy saving over the year shows that considerable amount of energy can be saved. The cumulative energy saving of the load levelling strategy is presented in Table 4.

3.4. Environmental effect

The obvious reason for using the TES system is to reduce the energy costs. Besides, energy saving, improving indoor air quality and emission reduction are the other important goals that can be achieved with a proper system design. In Malaysia around 60% of daily electricity is generated by natural gas in gas turbine power plants. It is known that the ambient conditions under which a gas turbine operates have a noticeable effect on both the power output and efficiency. On the other hand, the operating load has a direct effect on the fuel consumption and consequently on the emission production level of the primary pollutants of CO₂, CO, and VOCs. Generally, the power diminishes in higher ambient temperatures due to the decrease of air density and air flow mass rate. This would lead to reduce the total efficiency because the compressor requires more power to compress air of higher temperature. Conversely, during the nighttimes when the ambient temperature is lower the power and efficiency will boost up. For a typical gas turbines at inlet ambient temperatures of near 37 °C that occurs normally during the day in Malaysia, power output can drop to as low as 90% compared to the standard condition of sea level and 15 °C [36]. By having the daily temperature range of an average day in Malaysia the annual fuel consumption reduction due to shifting load to the nighttimes can be predicted for the electricity source. The potential of the natural gas to produce CO₂ based on Malaysia data is around 0.53 kg/kWh [37]. By having the annual energy saving on site (in the building) and the annual fuel consumption reduction on source (on the power plant) due to the energy consumption shift, the annual emission reduction potential can be estimated. The result for the site emission reduction of the load levelling strategy is tabulated in Table 5.

It can be observed that the ice thermal energy storage system can noticeably reduce the CO₂ emission production level. It is achievable by reducing the total energy consumption of the
building by changing the electricity consumption pattern to overcome the disparity between energy generation and energy demand times. Based on the authors understanding it is believed that in near future these systems can play a vital role to manage the consumption of the limited natural resources in a more efficient, economical and environmentally benign way.

4. Conclusion

This work investigated the feasibility and potential of employing ITS systems for the cooling application of office buildings in Malaysia along with the economical and environmental benefits of utilizing these systems. This study is mainly conducted due to the vast potential that the country has, the statistical data shows that in Malaysia, AC systems are the major energy consumers in office buildings with around 57% share. However, they are not well promoted in Malaysia and their potentials are not yet well investigated. The main concluding remarks of the present study are summarised as follows:

(a) The installation costs were formulated for the total capacity ranges of 100–2000 TR and the results were implemented for two main storage strategies of full storage and load levelling.

(b) The results based on the calculated load profile and climate conditions show that considering the special off-peak tariff rate of $0.06/kWh, the annual cost saving for full storage strategy varies from $230,000 to $700,000 for full storage and from $65,000 to $190,000 for load levelling strategy for the total system capacities of 500 TR and 1500 TR (1758 kW and 5275 kW), respectively.

(c) The overall results show that the full storage strategy can reduce the annual costs of the air conditioning system by up to 35% while this reduction is limited to around 8% for a load levelling strategy. The literature review reveals that in other countries like USA the reported annual cost savings are more significant, this discrepancy is mainly due to the additional demand charge under the time-of-use energy rate that are charged in Malaysia. However, since the cold thermal energy storage design is highly related to the localized parameters, the comparison between the cost benefit results of this study with other countries may not be a proper way to judge the advantages and disadvantages of these systems.

(d) By comparing the installation, maintenance and electricity costs of the conventional system with the ITS system, it was found that for the full storage strategy it will take between 3 and 6 years for the benefits of the investment to be equal with the investment. For the load levelling strategy this period varies between 1 and 3 years.

(e) The comparison results between the conventional AC system and the ITS system indicate that a proper design could lead to lower energy consumption due to better utilization of the equipment. It shows that the load levelling strategy consumes around 4% less energy than the conventional AC systems.

(f) By having the annual energy saving, the emission reduction potential of utilizing ITS system was estimated based on the potential of the natural gas to produce CO₂ emission. The results show that the annual CO₂ emission reduction for load levelling strategy varies from 3000 to 60,000 ton for the total system capacities of 352 and 7034 kW.

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References


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Table 5

<table>
<thead>
<tr>
<th>System capacity (TR)</th>
<th>System capacity (kW)</th>
<th>Total annual on site CO₂ emission reduction (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>352</td>
<td>3000</td>
</tr>
<tr>
<td>500</td>
<td>1758</td>
<td>15,100</td>
</tr>
<tr>
<td>1000</td>
<td>3517</td>
<td>30,300</td>
</tr>
<tr>
<td>1500</td>
<td>5275</td>
<td>45,500</td>
</tr>
<tr>
<td>2000</td>
<td>7034</td>
<td>60,000</td>
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