# An approach for reducing the air conditioning costs in office buildings in Vietnam

*Van Hung* Tran[1,2,*], *Thanh Nhan* Phan[1,2], and *Momchil* Vassilev[3]

[1]Ho Chi Minh City University of Technology (HCMUT), 268 Ly Thuong Kiet Street, District 10, Ho Chi Minh City, Vietnam
[2]Vietnam National University Ho Chi Minh City, Linh Trung Ward, Thu Duc District, Ho Chi Minh City, Vietnam
[3]Technical University of Sofia, Power Engineering and Power Machines Department, 8 Kliment Ohridski Blvd., 1000 Sofia, Bulgaria

**Abstract.** According to statistics from the Ho Chi Minh Energy Saving Center, the electricity costs of the air conditioning system for office buildings are about 70% of the electricity costs. There are many solutions that have been proposed to reduce the operating costs of the air conditioning systems, this article discusses a method of accumulating cold to reduce the cost of electricity for the air conditioning system of an office building.

## 1 Introduction

Nowadays, the consumption of electricity for an air conditioning system in an office building is one of the most important issues not only for the owners but also for the electricity suppliers. The cooling needs of the building are not constant, and the price of electricity at different times of the day also has a different value. There is a lot of research on saving electricity costs by different methods. One approach to reducing air conditioning costs is to reduce energy consumption by applying the active cooling method [1]. Another approach is the accumulation of cold. The accumulation of cold is used not only to save on electricity costs but is also used for other purposes. According to the research of D. Shlichkov [2], a chilling system with a storage tank, in which the ice freezes on the outer surface of the heat exchange tubes of the evaporator, leads to a significant reduction in electricity costs for air conditioning systems. The combined method between cold accumulators and cryocoolers has been considered by Arkhipov et al [3] in order to increase the life of the cryogenic cooling system. According to R. Sekret et al [4], the cold accumulator is applied by using the latent heat of a phase-change material in a layer of capsules with diameters of 80 mm, 70 mm, and 60 mm, the optimal working conditions according to the study are when using capsules with a diameter of 70 mm and a mass flow rate of 0.084 kg/s. In Vietnam, a study by Nguyen The Bao [5] also mentioned the melting of ice outside the pipes used in the cold storage battery in air conditioning systems.

[*] Corresponding author: tvhung@hcmut.edu.vn

In Vietnam, as in other countries, consumption in the national electricity grid for one day is not stable (Figure 1), so the Vietnamese Electricity Company (EVN) sets three prices to stimulate the reduction of electricity consumption during the main peak periods and to encourage the use of electricity in the low hours.

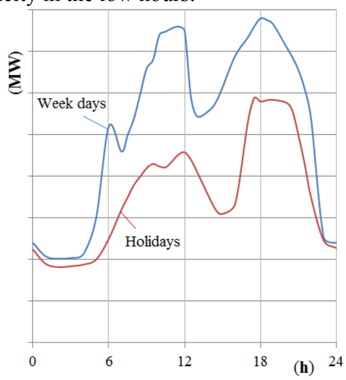


**Fig. 1.** Electricity consumption in weekdays and holidays [6].

According to EVN, the price of electricity at the peak hours is 4,586 VND/kWh (19.80 $cent/kWh), in normal hours the price is 2,666 VND/kWh (11.51 $cent/kWh) and in the low hours the price is 1,662 VND/kWh (7.18 $cent/kWh). The peak hours are during the intervals 10:00 ÷ 12:00 and 17:00 ÷ 20:00. The normal hours are in the intervals 4:00 ÷ 10:00, 12:00 ÷ 17:00 and 20:00 ÷ 22:00. The low hours are in 22:00 ÷ 4:00.

An opportunity for savings arises if at night, when the price of electricity is lowest, the cooling system works and the produced cold accumulates, and in other periods, when the price is higher, this accumulated cold is used to cool a building. The accumulation of cold not only reduces the electricity costs of the air conditioning system but also stabilizes the national electricity grid. Ho Chi Minh City is an economic and commercial centre not only in Vietnam but also in Southeast Asia and is known for its large number of large office buildings. These buildings do not work at night (when the price of electricity is lowest), which is why an office building was chosen as the subject of this study.

## 2 Modelling office building and conditioning system

The pilot building is an office building, located in Ho Chi Minh City. It has 3 basements for parking, 22 floors for offices and total area of 19,800 m$^2$. The mode of operation of the building is only on weekdays, from 7:00 to 17:00.

The air conditioning system is designed according to Vietnamese norms. The designed indoor temperature and relative humidity are $t = 26^oC$, $\varphi = 65\%$.

The cooling load of the building is calculated by the Carrier method, according to which the total heat load is calculated by:

$$Q_o = \sum Q_{ht} + \sum Q_{at} = Q_{11} + Q_{21} + Q_{22} + Q_{23} + Q_{31} + Q_{32} + \\ + Q_{4h} + Q_{4a} + Q_{Nh} + Q_{Na} + Q_{5h} + Q_{5a} \quad , \tag{1}$$

where:

- $\sum Q_{ht}$ : Total sensible heat load of the building, kW;
- $\sum Q_{at}$ : Total latent heat load of the building, kW;
- $Q_{11}$: Heat from solar radiation through the transparent area, kW;
- $Q_{21}$, $Q_{23}$: Heat transfer through the roof and through the floor, kW;

- $Q_{22}$: Heat transfer through the walls, doors and windows, kW;
- $Q_{31}$, $Q_{32}$: Heat from lighting systems and from equipment, kW;
- $Q_{4h}$, $Q_{4a}$: Sensible and latent heat of people, kW;
- $Q_{Nh}$, $Q_{Na}$: Sensible and latent heat of fresh air, kW;
- $Q_{5h}$, $Q_{5a}$: Sensible and latent heat of infiltration air, kW.

The cooling load of the building is $Q_o$ = 3128 kW (894 tons of refrigeration). The air conditioning system is designed with 3 chillers Model RTHD – D2G2G1 (RTHD 300 – 350 Tons – built for Industrial and Commercial Application), with Refrigerant R134a.

## 3 The cold accumulation systems

Currently, there are many cold accumulation technologies and schemes, divided of two groups:

- Sensible cold accumulation storage;
- Latent cold accumulation storage (ice cold storage, eutectic salt cold storage and etc.).

In this study, Christopia's technology was chosen to represent the second group. Cristopia technology offers the accumulation of cold in phase-change materials. The phase change temperature (-33°C → 27°C) can be selected according to the user's needs (Table 1).

**Table 1.** Properties of phase change materials according to Cristopia's technology [7, 8].

| Nodule type | Phase change temperature °C | Latent heat Ql kWh/m$^3$ | Sensible heat solid Qss kWh /°C | Sensible heat liquid Qsl kWh /°C | Heat transfer PCM crystallisation Kvcr kW /°C | Heat transfer PCM fusion Kvfu kW /°C | Nodule weight kg | Toxicity LD50 value in mg/kg **a** | Operating temperature limits °C |
|---|---|---|---|---|---|---|---|---|---|
| SN.33 | - 33 | 44.6 | 0.7 | 1.08 | 1.6 | 2.2 | 724 | 2,600 | |
| SN.29 | - 28.9 | 39.3 | 0.8 | 1.15 | 1.6 | 2.2 | 681 | 1,200 | -40°C |
| SN.26 | - 26.2 | 47.6 | 0.85 | 1.2 | 1.6 | 2.2 | 704 | 1,200 | to |
| SN.21 | - 21.3 | 39.4 | 0.7 | 1.09 | 1.6 | 2.2 | 653 | 1,300 | +60°C |
| SN.18 | - 18.3 | 47.5 | 0.9 | 1.24 | 1.6 | 2.2 | 706 | 2,700 | |
| IN.15 | - 15.4 | 46.4 | 0.7 | 1.12 | 1.6 | 2.2 | 602 | 8,400 | |
| IN.12 | - 11.7 | 47.7 | 0.75 | 1.09 | 1.6 | 2.2 | 620 | 5,000 | -25°C |
| IN.10 | - 10.4 | 49.9 | 0.7 | 1.07 | 1.6 | 2.2 | 617 | 11,000 | |
| IN.06 | - 5.5 | 44.6 | 0.75 | 1.1 | 1.6 | 2.2 | 625 | 18,000 | to |
| IN.03 | - 2.6 | 48.3 | 0.8 | 1.2 | 1.6 | 2.2 | 592 | 58,000 | |
| IC.00 | 0 | 48.4 | 0.7 | 1.1 | 1.6 | 2.2 | 558 | 85,000 | +60°C |
| AC.00 | 0 | 48.4 | 0.7 | 1.1 | 1.15 | 1.85 | 560 | 85,000 | |
| IC.27 | + 27 | 44.5 | 0.86 | 1.04 | 1.6 | 2.2 | 867 | 2,500 | |

### 3.1 Cristopia's technology

With this technology, the phase change material is contained in nodules with structure (Figure 2) as follows:

- A sphere one millimetre thick, obtained by blow moldings of a blend of polyolefins. This material is neutral towards the heat transfer fluids;
- Phase Change Material (PCM) [9]. It could be organic (paraffin and fatty acids for example) or inorganic (hydrated salts), depending on temperature;
- Air pocket for expansion, the effect is a low stress on the nodule shell;
- Plug.

 https://doi.org/10.1051/e3sconf/202132701012

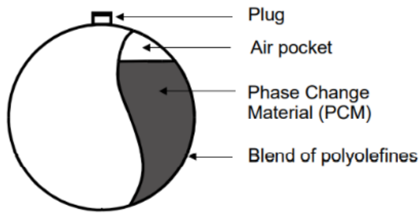


**Fig. 2.** The structure of a nodule.

The cold accumulation tank (STL – *le stockage latent* in French [10], or STorage of Latent heat) is made of steel or concrete and is well thermally insulated. The heat exchange between the spherical nodules and the system is by a liquid, in this case water. The tank can be horizontal or vertical (Figure 3).

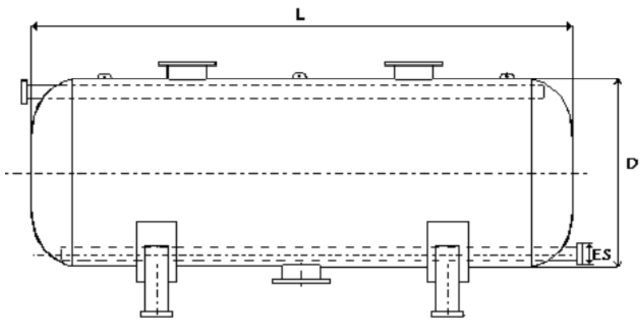


**Fig. 3.** A cold accumulator tank (storage of thermal latent - STL).

### 3.2 Principle of operation of the cold accumulation system

The principle of operation can be represented by five operating modes of the system.

**- STL charging:** At hours when the price of electricity is the lowest and there is no cooling load, the chillers work and the produced cold accumulates as the energy of the phase change (from liquid to solid phase) of the substance in spherical nodules (Figure 4.a).

**- The chillers work for building's cooling needs:** In off-peak hours, the chillers work for air conditioning system and there is no flow through the STL (Figure 4.b).

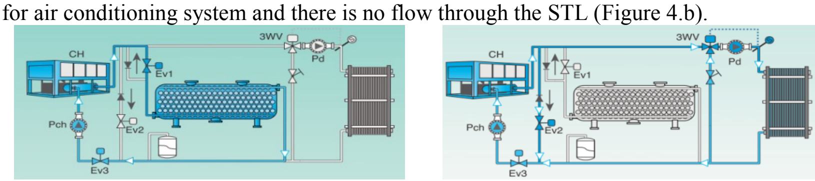


**Fig. 4.** **a**) STL charging; **b**) Chillers work for cooling needs.

**- STL discharging:** At peak hours, when the price of electricity is highest, the chillers do not work and the air conditioning system uses accumulated cold from STL (Figure 5.a).

- **In case of overload of the air conditioning system or some of chillers are damaged:** STL can also be used when the air conditioning system is overloaded or some of chillers are damaged, to share cooling power (Figure 5.b).

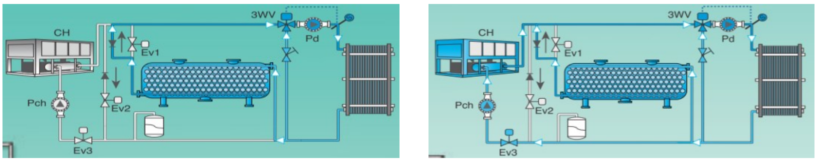


**Fig. 5. a)** STL discharging; **b)** The chillers working and STL discharging.

-**The chillers work for cooling needs and charge the STL** (Figure 6).

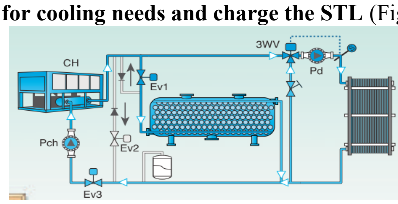


**Fig. 6.** Chillers work for cooling needs and charge the STL.

## 4 Analysis of the options for cold accumulation

Principle of operation: The STL system accumulates a sufficient amount of cold in hours when the price of electricity is the lowest. This accumulated cold will satisfy 100% of the required cold at peak hours and part of the required cold at normal hours.

Three steps to determine electricity costs:

- Step 1: Calculation of the cooling load of the building for each hour according to the Carrier method with the climatic data of Ho Chi Minh City. The climatic data includes the hourly values of temperature, relative humidity and solar radiation on horizontal and 8 vertical surfaces [11]. The temperature and relative humidity could be seen below (Figure 7).

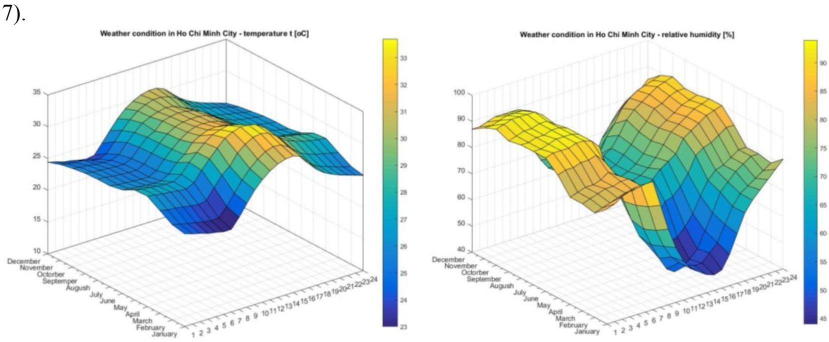


**Fig. 7.** Hourly values of outdoor temperature and relative humidity of Ho Chi Minh City.

- Step 2: Determination of electricity consumption for each hour, by a calculated EER:

$$EER = \frac{Q_0 - N_2 - N_5 - N_6}{N_1 + N_2 + N_3 + N_4 + N_5 + N_6}, \qquad (2)$$

where:

- $Q_0$ - Cooling capacity of chiller, kW;
- $N_1$ - Electric power of chiller, kW;
- $N_2$ - Electric power of the pump for the first circulation circuit, kW;
- $N_3$ - Electric power of the pump for the second circulation circuit, kW;

 https://doi.org/10.1051/e3sconf/202132701012

• $N_4$ - Electric power of the cooling tower fans, kW;
• $N_5$ - Electric power of fans in AHU and FCU, kW;
• $N_6$ - Electric power of fresh air fans, kW.

- Step 3: According to the calculated electricity consumption for each hour of a typical day of the month from January to December, the annual saved electricity costs can be calculated using the following options:

➢ Option 1: The accumulated cold in STL is used only during the peak hours. In other periods, the cooling load is provided by the chiller system.
➢ Option 2÷7: The total consumption of cold at peak hours and 10% to 60% of the cooling demand at normal hours are provided by STL.

The calculation for Option 1 for January is shown below in Table 2, the same calculations are made for each month. Summarizing the results for all months leads to a result for the whole year.

In option 1, the distribution of cooling power for a typical day in January is shown in Figure 8. At peak hours (10:00 ÷ 12:00), when the price is highest, the demand for cooling of the building is satisfied by the accumulated cold in the STL tank. This accumulated cold is produced in the low hours (22:00 ÷ 4:00) when the price is the lowest.

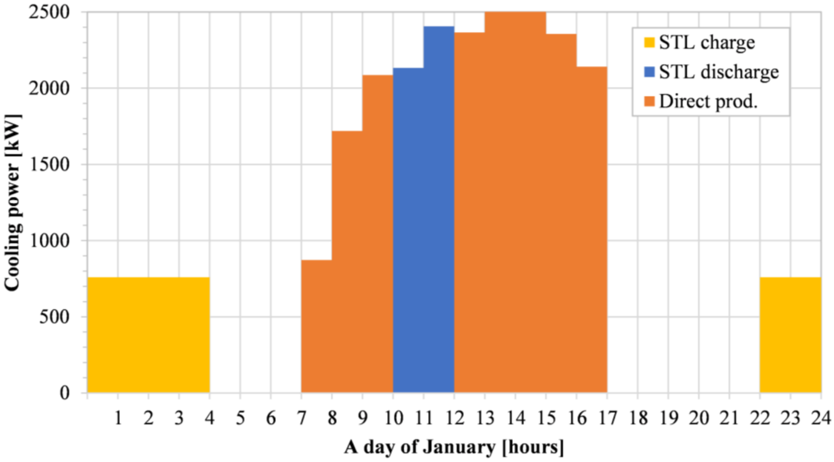


**Fig. 8.** Distribution of the cooling power of January (Option 1).

The saved electricity costs for a typical day of the month are calculated using the electricity costs for systems with and without STL as shown below.

- Calculation of electricity costs for a chilling system without STL:
Based on the hourly climate data, the required cooling capacity for each hour is calculated. Therefore, the electricity consumption and electricity costs of the chilling system for each hour can be calculated.
- Calculation of electricity costs for the chilling system with STL:
The required chiller capacity for each hour, electricity consumption, and electricity costs of the chilling system in normal hours (7:30÷10:00, 12:00÷17:00) are calculated as without STL. Electricity consumption from the chilling system and electricity costs in peak hours are calculated at the lowest price of electricity (Table 2).

The difference between the total amount of daily electricity costs without STL (717.73 USD) and the total amount of electricity costs with STL (571.13 USD) is the savings for one day: 146.60 USD.

**Table 2.** Analysis of a typical day of January in Option 1.

| A day of January (22 workdays) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Time | Without STL | | | With STL | | | |
| | Required cooling capacity (kW) | Hourly electricity consumption of the chiller system, (kWh) | Electricity costs (USD) | Accumulated cold in STL (kWh) | Required cooling capacity (kW) | Hourly electricity consumption of the chiller system (kWh) | Electricity costs (USD) |
| 0h ÷ 1h | | | | 2,270.1 | 756.7 | 193.53 | 13.89 |
| 1h ÷ 2h | | | | 3,026.8 | 756.7 | 193.53 | 13.89 |
| 2h ÷ 3h | | | | 3,783.5 | 756.7 | 193.53 | 13.89 |
| 3h ÷ 4h | | | | 4,540.2 | 756.7 | 193.53 | 13.89 |
| 4h ÷ 5h | | | | 4,540.2 | | | |
| 5h ÷ 6h | | | | 4,540.2 | | | |
| 6h ÷ 7h | | | | 4,540.2 | | | |
| 7h ÷ 8h | 872.2 | 223.07 | 25.68 | 4,540.2 | 872.2 | 223.07 | 25.68 |
| 8h ÷ 9h | 1,719.2 | 439.69 | 50.61 | 4,540.2 | 1,719.2 | 439.69 | 50.61 |
| 9h ÷ 10h | 2,086.0 | 533.50 | 61.41 | 4,540.2 | 2,086.0 | 533.50 | 61.41 |
| 10h ÷ 11h | 2,133.6 | 545.68 | 108.05 | 2,406.6 | | | |
| 11h ÷ 12h | 2,406.6 | 615.50 | 121.88 | | | | |
| 12h ÷ 13h | 2,366.0 | 605.12 | 69.66 | | 2,366.0 | 605.12 | 69.66 |
| 13h ÷ 14h | 2,521.4 | 644.86 | 74.23 | | 2,521.4 | 644.86 | 74.23 |
| 14h ÷ 15h | 2,506.0 | 640.92 | 73.78 | | 2,506.0 | 640.92 | 73.78 |
| 15h ÷ 16h | 2,356.2 | 602.61 | 69.37 | | 2,356.2 | 602.61 | 69.37 |
| 16h ÷ 17h | 2,142.0 | 547.83 | 63.06 | | 2,142.0 | 547.83 | 63.06 |
| 17h ÷ 18h | | | | | | | |
| 18h ÷ 19h | | | | | | | |
| 19h ÷ 20h | | | | | | | |
| 20h ÷ 21h | | | | | | | |
| 21h ÷ 22h | | | | | | | |
| 22h ÷ 23h | | | | 756.7 | 756.7 | 193.53 | 13.89 |
| 23h ÷ 0h | | | | 1,513.4 | 756.7 | 193.53 | 13.89 |
| **Total** | **-** | **5,398.78** | **717.73** | **-** | **-** | **5,398.78** | **571.14** |

Based on the saved electricity costs for a typical day of January and the number of working days per month, the saved electricity costs for one month are calculated. The same calculations are made for other months. Summarizing the results for all months, the saved electricity costs for the whole year are calculated.

To calculate the effectiveness of each option, it is necessary to calculate the investment. Based on the summary of the accumulated cold (kWh) each month for the option, the volume of the STL tank is calculated from the data in Table 1 (kWh/$m^3$). So the investment for the option is also calculated. The result of option 1 is shown in Table 3.

**Table 3.** Analysis of option 1.

| | Low hours | Normal hours | Peak hours | Total for year |
|---|---|---|---|---|
| Price of electricity ($cent/kWh) | 7.18 | 11.51 | 19.8 | |
| 1. Air conditioning system without STL | | | | |
| Power consumption of chiller system (kWh) | 0 | 1,033,973 | 283,327 | 1,317,300 |
| Electricity costs (USD) | 0 | 119,023 | 56,103 | 175,126 |
| 2. Air conditioning system with STL | | | | |
| Power consumption of chiller system (kWh) | 283,327 | 1,033,973 | 0 | 1,317,300 |
| Electricity costs (USD) | 20,332 | 119,023 | 0 | 139,355 |
| 3. Result | | | | |
| Annual saved electricity costs (USD/year) | 35,771 | | | |
| Investment costs for STL system (USD) | 96,058 | | | |
| Payback time (year) | 2.7 | | | |

Options 2 to 7 explore the greater potential for cold accumulation. This inevitably leads to larger investments, which must be assessed through technical and economic analysis.

Figure 9 shows the distribution of cooling power in January for option 4 when the total cold consumption at peak hours and 30% of the cold consumption at normal hours are used by STL. Compared to option 1, the accumulated cold (kWh) is larger, so the volume of STL is larger and therefore the investment is also larger.

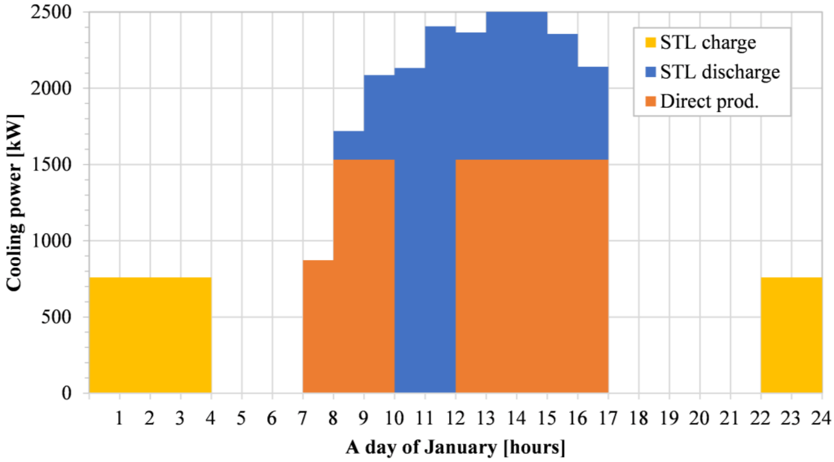


**Fig. 9.** Distribution of the cooling power of January (Option 4, peak hours + 30% normal hours).

Technical and economic analysis was made for all seven considered options. Nominal interest rate (8% for Vietnam) and inflation (3% last year) are taken into account. The economic life for all options is 15 years. The results of the analysis are shown in Table 4.

**Table 4.** Summary results for all options (calculated using the software *ENSI Economy*).

**Printed from the ENSI® Economy Software**

Project: **Summary results**

**All Measures**

Real interest rate: 4,9 %

| Measures | *) | Investment [USD] | Net savings [USD/Year] | Lifetime [Year] | PB [Year] | PO [Year] | IRR [%] | NPV [USD] | NPVQ |
|---|---|---|---|---|---|---|---|---|---|
| Peak hours only | | 96.058 | 35.771 | 15 | 2,7 | 3,0 | 37 | 278.914 | 2,90 |
| Peak hours +10% of normal hours | | 131.113 | 44.742 | 15 | 2,9 | 3,2 | 34 | 337.898 | 2,58 |
| Peak hours +20% of normal hours | | 166.168 | 44.559 | 15 | 3,7 | 4,2 | 26 | 300.925 | 1,81 |
| Peak hours +30% of normal hours | | 201.224 | 49.047 | 15 | 4,1 | 4,7 | 23 | 312.915 | 1,56 |
| Peak hours +40% of normal hours | | 236.279 | 53.500 | 15 | 4,4 | 5,1 | 21 | 324.539 | 1,37 |
| Peak hours +50% of normal hours | | 271.334 | 57.952 | 15 | 4,7 | 5,4 | 20 | 336.152 | 1,24 |
| Peak hours +60% of normal hours | | 306.390 | 62.405 | 15 | 4,9 | 5,7 | 19 | 347.775 | 1,14 |

PB = Payback, PO = Pay-off, IRR = Internal Rate of Return, NPV = Net Present Value, NPVQ = Net Present Value Quotient

The analysis shows that option 1 has the best: Pay-off, Internal rate of return and Net present value quotient. Another advantage of this option is the lowest space required to install facilities.

## 5 Conclusion

The use of a cold storage system can reduce the electricity costs of air conditioning systems for office buildings in Ho Chi Minh City. With the option to accumulate cold only at peak hours (Option 1), the annual savings are $ 35,771, while the investment costs are $ 96,058 and the Pay-off period is 3.0 years. The Pay-off period for other options is from 3.2 to 5.7 years. The pilot building works only 5 days/week, from 7:00 to 17:00 (working hours include only 1 peak period/day) and for buildings with more working days/week, as well as including the second peak period (17:00 ÷ 19:00), the Pay-off period will be even less.

We would like to thank Ho Chi Minh City University of Technology (HCMUT), VNU-HCM for the support of time and facilities for this study.

## References

1. M. Zlateva. *Proceedings of the XXI Scientific Conference with International Participation FPEPM 2016 (in Bulgarian)*, **1**, pp. 199 – 204, (2016).
2. D. Shlychkov. *E3S Web of Conferences,* **135**, 03071, ITESE-2019, (2019).
3. V. T. Arkhipov, V. F. Getmanets, A. Ya. Levin, R. S. Mikhalchenko, H. Stears. *Cryocoolers*, **10**, pp. 689-696, (1999).
4. R. Sekret, P. Starzec. Energies, **14**(9):2703, (2021).
5. T. B. Nguyen, H. A. Truong. Sci. Tech. Dev. J., **10**, No.02, (2007).
6. Tran Thanh Ky, Nhà máy nhiệt điện, Trường ĐH Bách Khoa TPHCM, (1998).
7. *Technical manual*. Cristopia Energy Systems, (2000).
8. Cristopia Energy Systems. Thermal energy storage. https://www.ciat.uk.com/wp-content/uploads/2017/02/cristopia-brochure.pdf, (2017).
9. A. Amer, V. Lebedev. Int. J. Sci. Eng. Res., **9**(5), (2018).
10. I. Dincer, M. A. Rosen. *Thermal energy storage: systems and applications - 2$^{nd}$ ed.*, Wiley, (2011).
11. Vietnam Building code, Natural Physical and Climatic data for construction QCXDVN 02: 2015/BXD, (2015).