# MAXIMIZATION THE LATENT HEAT STORAGE UNIT (LHSU) ENERGY SAVING USING SIMULATED ANNEALING ALGORITHM

**ANDRZEJ DRWIEGA[1], QAYS ADNAN ALI[2], MAREK DUDEK[1], NIHAD RAOUF MAAROOF[3], LAYTH MOHAMMED ABDALI[4], BORIS A. YAKIMOVICH[5]**

[1]KOMAG Institute of Mining Technology, Gliwice, Poland

[2]Department of Fuel and Energy Techniques Engineering, Technical Engineering College/Kirkuk, Northern Technical University, Kirkuk, Iraq

[3]Department of Dormitories, Presidency of the University of Kirkuk, Kirkuk University, Kirkuk, Iraq

[4]University of Kufa, Presidency University of Kufa Najaf, Iraq

[5]Sevastopol State University, Institute of Nuclear Energy and Industry, Sevastopol, Crimea

**DOI: 10.17973/MMSJ.2023_06_2023025**

**e-mail to corresponding author: mdudek@komag.eu**

An integration between latent heat storage unit (LHSU) and an air cooler was studied to reduce the space cooling energy consumption in telecommunications base stations (TBSS). A mathematical model was developed to address the heat transfer processes within energy storage modules and air cooler. Furthermore, a solid works simulation was used to simulate the real system virtually. A simulated annealing algorithm (SA) was utilized to maximize annual energy savings ratio which was considered a performance criterion for the proposed system. The calculations included comparisons the relative errors of air and temperature difference between the optimized using simulated annealing algorithm and tested (virtual) results which were calculated for both operation modes energy charging and energy discharging. The obtained results illustrated a remarkable improvement both relative errors and annual energy savings ratio for the study case.

**KEYWORDS**

Annealing algorithm, latent heat storage unit, thermal energy, phase change material

## 1 INTRODUCTION

### *1.1. Energy and Telecommunication*

Nowadays, there are advanced progress in applying computing technologies [Liu 2021, Abd Ali 2019, Vologdin 2019, Zidan 2017, Zidan 2019, Kuric 2019, Kushinov 2019] that have significant progress in artificial intelligence. The energy consumption in telecommunication industry has increased rapidly worldwide. For instance, data center energy consumption increased by about 36% between 2005 and 2010 in the US [Zidan 2019a, Abdel-Aty 2020, Chebaxsarov 2019]. A backbone of the infrastructure for telecommunication system is a telecommunications base station (TBS) which consists of set of equipment including heat generating equipment and electronic. The main task of these stations is addressing a telecommunications traffic between mobile phones and network subsystems [Alsharif 2015, Sun 2014]. The rising attention involves innovative and dependable services in the field of telecommunication has caused an increase in the number of TBSS used globally. Furthermore, the function of TBS requires 24-hour operation daily throughout year to ensure high level of reliability and quality of service [Ayang 2016]. Normally, the huge expansion in the infrastructure of TBSs needs to larger consumption of energy, about 3% of the global consumption of electrical energy for information and communication technologies [Humar 2011]. Alive example for this issue is presented by China, the annual electric consumption of telecommunications is about 20 billion kWh. The share of TBSs is about one third of the entire energy, cooling systems consumes 30-50% of entire consumption [Wang 2018].

### *1.2. Thermal Energy Storage (TES) Systems*

Based on the forgoing, using energy savings technologies for cooling space in TBSs is essential for handling the higher thermal density and power. These technologies are based on renewable energy, a coupling thermal energy storage (TES) system with renewable energy technologies performs a matching between the supply and demand as well as saving energy [Romani 2019, Abd Ali 2021, Rimar 2022]. TES systems can be categorized according to technology used for storing thermal: sensible heat, latent heat, sorption and chemical reactions heat [Kuvshimov 2021]. Sufficient solutions can be presented by TES in many fields include waste heat recovery, building energy conservation [Pomianowski 2013] and solar thermal energy air conditioning [Abd Ali 2019]. Thus, TES technologies have a large impact on the energy management [Abd Ali 2019], latent heat storage technology is based on a concept of phase change materials (PCMs) from solid to liquid and vice versa, solving the mismatching problem between energy demand and supply in addition to storage of thermal energy are attributable to this process of changing [Wu 2019, Diao 2019]. Latent heat storage technology used in cooling and heating applications widely. [Takeda 2004] developed a ventilation system containing PCMs; the offered system achieved a noticeable reduction of ventilation load. [Romani 2019] Proposed a cooling system based on a combination of PCMs and heat pipes as an alternative to traditional air conditioning. This combination provided reduction of the need for compressor-driven air conditioning. [Sun 2014a] proposed a technology based on a combination between PCM within latent heat storage unit (LHSU) and natural cold source for reliable cooling space in telecommunications base stations (TBSs) in China. The obtained results of the energy efficiency ratio and the adjusted energy efficiency ratio were used to evaluate the proposed technology. [Yantong 2015] proposed LHSU which was developed in [Abd Ali 2019, Kurpiel 2020], the developed a genetic algorithm [GA] was used to find optimal PCM melting temperature, fan flow rate, and pump flow rate [Cubonova 2019]. The results showed an annual energy savings ratios (ESRs) and relative errors were improved noticeably. This paper studies a performance of the integrated LHSU which was proposed in [Sun 2014]. A mathematical model was developed and handled using Simulated annealing algorithm (SA) [Pechac 2016] to find optimal working conditions including the PCM melting temperature, the fan flow rate and pump flow rate. Maximization of annual saving energy ratio was used as criteria to evaluate the performance of system. The authors [Tlach 2017] use a similar method of performance measurement for industrial automation in engineering. A solid works simulation provided a virtual experimental environment to simulate the real model sufficiently.

## 2 DESCRIPTION OF TBS AND LHSU

The operation parameters of the TBS proposed in [Turpenny 2021] consider the indoor air temperature between 18 and 28, upper limit is 30, and the relative humidity should be within range (40%-70%). The four external walls had been constructed of a 240-mm thick brick layer coated with a10-mm thick cement layer on both outside and inside. The door of station had been made of wood with dimensions 0.9 m x 2 m and a ceiling height of 3.5 m. The average overall heat transfer coefficient of the walls is 1.122 W/m²/. TBS is supplied by 24 batteries with a voltage of 2 V and a total capacity of 1000 Ah. The thermal power generated by the electronic equipment is 2052 W. The entire description of TBS is shown in Fig 1.

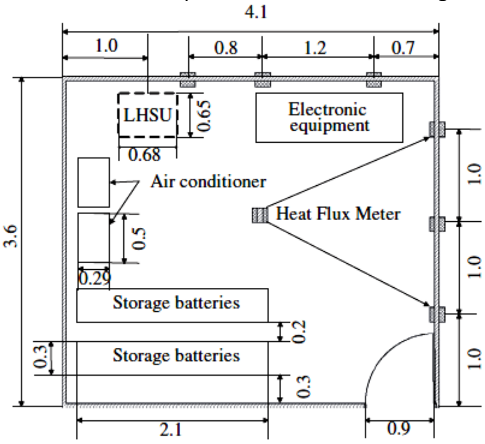


Figure 1. Conventional telecommunications base station (TBS)

The LHSU proposed in [Yatong 2015] has a cooling capacity of 3 kW for an indoor temperature of 28. The dimensions of LHSU are 68 cm x 65 cm x 168 cm (W x D x H). Components of the LHSU are shown in Fig. 2 including two energy storage modules (ESMs), one blower fan, one pump, and one air cooler.

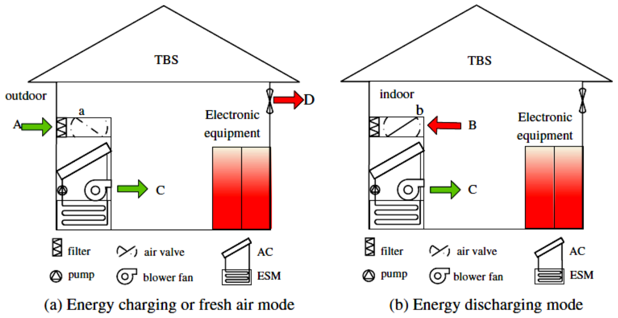


Figure 2. Schematic diagram of the latent heat storage unit (LHSU) inside a TBS

Dimensions of each ESM are 68 cm x 30 cm x 30 cm (W x D x H) shown in Fig. 3. It is worth mentioning that external surface of the ESM was insulated with a 10-mm thick rubber foam.

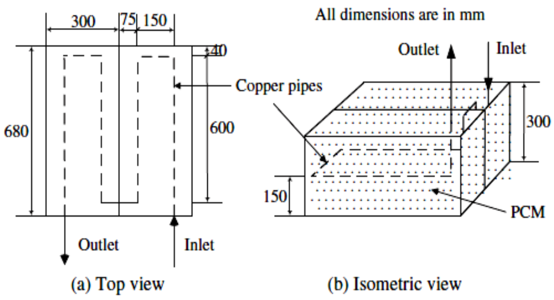


Figure 3. Energy storage module (ESM)

The wall thickness of copper pipes which connect the AC and the ESM forming a closed water loop is 0.35 mm [Wiecek 2019]. The outer diameter of the pipes was 9.52 mm and it`s length is about 3 m. The thermal properties of the PCM used in the LHSU including range of transition temperatures (°C), latent heat of fusion (kJ/kg), heat conductivity (W/m/°C), specific heat (kJ/kg°C) density (kg/m³) are shown in.

## 3 OPERATION MODES

### 3.1 Energy Charging Mode

LHSU is switched to this mode when the temperature of the outdoor air is between 0°C and the PCM melting temperature. Power consumption and flow rate of pump are 50 W, 0.4 m³/h respectively, whereas power consumption and flow rate of fan are 400 W, 2000 m³/h respectively. The electricity consumption of LHSU under this mode was calculated by

$$I_{ec} = \int \left(P_p + P_f\right) d\, \frac{Q_{cl}}{Q_{aw}} \tau_{ec} \times 10^{-3} \qquad (1)$$

where: $Q_{cl}$ is the space cooling load of the TBS and the $P_p$ and $P_f$ are the power of the pump and the fan. $\tau_{ec}$ is the energy charging mode operation time, $Q_{aw}$ is the heat transfer rate between the incoming air and the water in the AC as well as the heat transfer rate between the water and the PCM in the ESM during this mode were calculated using Eqs. (3).

### 3.2 Fresh Air Mode

LHSU is switched to fresh air mode when the temperature of outdoor air is between the PCM melting temperature and 25°C whereas power consumption and flow rate of fan are 400 W, 2000 m³/h respectively. The electricity consumption of LHSU under this mode was determined by

$$I_{fa} = \int P_f d\tau_{fa} \times 10^{-3} \qquad (2)$$

where: $\tau_{fa}$ is the fresh air mode operation time.

### 3.3 Energy Discharging Mode

Under this mode the temperature of outdoor air is over 25°C and Power and flow rate of pump are 50 W, 0.4 m³/h respectively, whereas power and flow rate of fan are 400 W, 2000 m³/h respectively. The electricity consumption of LHSU was evaluated by

$$I_{ed} = \int \left(P_p + P_f\right) d\, \tau_{ed} \times 10^{-3} \qquad (3)$$

where: $\tau_{ed}$ is energy discharging mode operation time. It is worth mentioning under energy discharging mode similar behavior of heat transfers under energy charging mode is happened. However, the process is in opposite direction.

## 4 ENERGY SAVING BASED ON PCM

The core of latent heat storage technology is a phase change material (PCM); this change is from solid to liquid and vice versa. The mechanism of the phase change includes two operation modes. One is carried out when outdoor temperature is lower than indoor temperature (during night-time). The cool air enters storage unit and carries away heat from liquid PCM to solidify it (charging mode). The process goes on until the outdoor temperature is lower than the melting/solidification temperature of PCM. Whereas another mode would be active when the indoor temperature is higher than the comfort boundary (during day-time), hot air enters the PCM storage unit then PCM absorbs (stores) heat from the air. Thus, PCM would be converted from solid to liquid phase. Consequently, the air temperature would be lowered to comfort limit and the cold storage during charging mode is conveyed to the space (discharging mode) [Du 2018, Waqas 2013]. That leads to a significant conclusion, the PCM has played a direct role in reduction of the electrical load due to decrease the electricity consumption of air conditioning system during day-time. In other words, PCM is an active way of shifting daytime electrical loads to night – time with a low cooling load [Du 2018, Farid 2018]. Based on the foregoing, the latent heat storage technology has great benefit economically and it contributes in the stability of electrical power grid [Sun 2014, Quresi 2011].

## 5 THEORETICAL FORMULATION

### 5.1 Optimization Background

Optimization algorithms are providing computerized methods to solve numerous complex problems, thus decision makers save large amount of time and money. The main task of these algorithms is obtaining optimal or near to optimal solution. Metaheuristic optimization overcomes a difficult issue involves dealing with many synchronizing different natures of decision variables, especially with wide range of applications in diverse fields such as medicine, agriculture, economics, computer, and engineering. The crucial aspect of metaheuristic algorithms is addressing the complex structure of practical problem and obtaining accurate solution. Thus, using these algorithms facilitates problems as much as possible to the decision makers [Akyol 2017, Ada Ali 2020, Pechac 2017, Saga 2011 and 2019, Krenicky 2022]. Simulated annealing (SA) is one of high performance. Metaheuristic algorithms, this technique had been based on physical phenomena involves heating and cooling metal slowly (annealing) [Fera 2013, Pechac 2016, Pechac 2017]. The procedure of Simulated annealing (SA) starts from new random point at each iteration. A calculation of distance between new and current point with a scale a probability distribution depending on the current temperature [Wang 2016, Cheboxarov 2019a, Sun 2015].

### 5.2 Case Study and Results

The Simulated annealing algorithm (SA) was carried out to evaluate LHSU performance, high qualities of this technique mentioned previously lead to reliable and precise results. SA was utilized to obtain maximum energy savings ratio (ESR) of the LHSU taking into consideration the PCM melting temperature, the fan flow rate and pump flow rate. Fig. 4 offers flow chart of energy savings ratio optimization process for different working conditions.

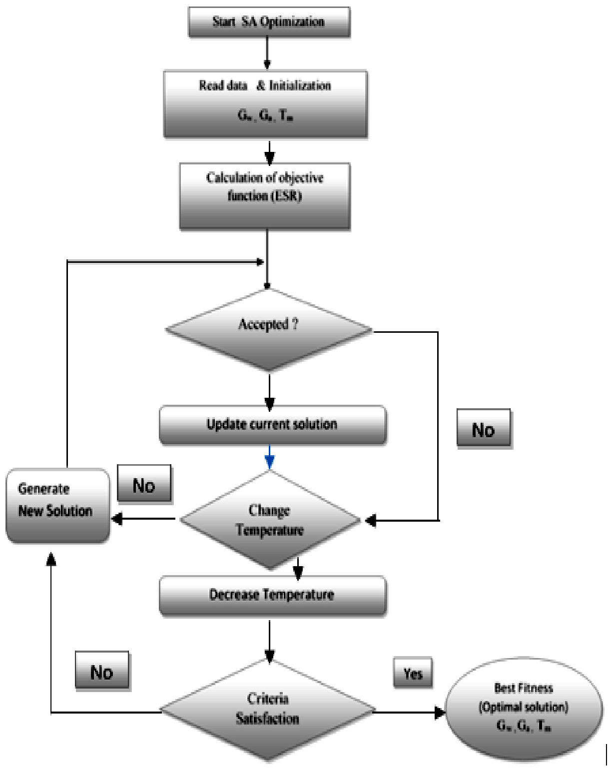


**Figure 4.** Flow chart of energy savings rate optimization process for different operational conditions using SA

The objective function which addressed in SA was annual energy savings ratio, which was described as the rate of energy savings achieved by using LHSU to the energy consumption of the conventional air conditioner. It considered the fan flow rate, pump flow rate, and PCM melting temperature. The annual energy savings ratio (ESR) was calculated by:

$$\mathrm{ESR} = \frac{I_{con} - (I_{ec} + I_{fa} + I_{ed})}{I_{con}} \times 100\% \quad (4)$$

where: $I_{con}$ is energy consumption of the conventional air conditioner.

The case study which was proposed in this paper involved evaluation of the ESR of TBS in four Chinese cities located in diverse climate areas. Table 1 presents electricity consumption of the conventional air conditioners for TBSS in the four cities. All required data involve annual mean temperature, temperature difference between day and night, besides all essential data which were stated in followed in the proposed study.

**Table 1.** Electricity consumption of the conventional air conditioners for TBSS in the four cities [Cheboxarov 2019]

| Location | Enclosure type | Air conditioner | |
|---|---|---|---|
| | | Cooling Capacity (KW) | Quantity |
| **Shenyang** | Brick and cement | 7.5 | 1 |
| **Zhengzhou** | Brick and cement | 5 | 2 |
| **Changsha** | Light steel structure | 7.5 | 2 |
| **Kumming** | Brick and cement | 12 | 1 |

## 6 DISCUSSION

Fig. 5 showed comparisons between the calculated results using SA and simulated (tested) results which were obtained using solid works simulation. In addition to the calculated results which were obtained using genetic algorithm (GA) in [Yantong 2015, Pechac 2017] as well as those were in [Sun 2014].

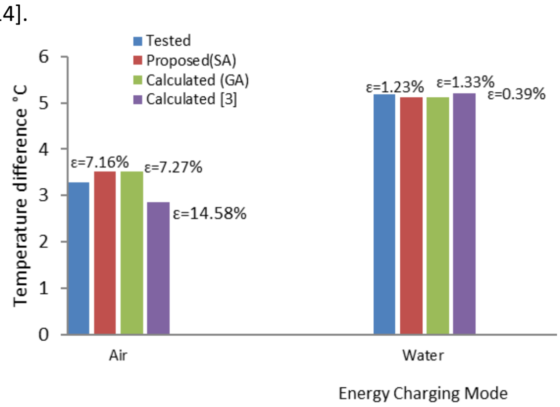


**Figure 5.** Comparisons between calculated and tested temperature differences and relative error

Comparisons demonstrated a noticeable improvement in terms of the relative error which was calculated using (SA). The relative error of temperature difference was calculated by:

$$\varepsilon = \frac{|\text{expriemental value} - \text{caculated value}|}{\text{expriemental value}} \times 100\% \quad (5)$$

Table 2 shows the results which were obtained using simulated annealing algorithm for the four cities. The settings of operation conditions before optimization were 20°C, 2000 $m^3/h$ and 0.4 $m^3/h$ for the PCM melting temperature, fan flow rate and pump flow rate respectively.

Obviously, from Table 2 there was a noticeable improvement in terms of annual energy savings ratios of the LHSU in four cities. The percentage of improvement was 6.6%, 4.58%, 3.52% and 3.87% for Shenyang, Zhengzhou, Changsha, and Kunming respectively. Furthermore, there was distinct variations for the operation conditions. Thus, this proposed model illustrated that the (SA) was a sufficient tool to characterize precisely the optimal settings of operation conditions for the proposed system.

**Table 2.** Optimization results of LHSU using simulated annealing algorithm

| Locations | Working conditions after optimization | | | ESR (%) | |
|---|---|---|---|---|---|
| | Fan flow rate ($m^3$/h) | Pump flow rate ($m^3$/h) | Melting temperature (ºC) | Before optimization | After optimization |
| **Shenyang** | 1875.43 | 0.95 | 5.03 | 53.45 | 56.98 |
| **Zhengzhou** | 1764.27 | 0.87 | 4.28 | 54.55 | 57.05 |
| **Changsha** | 1931.77 | 0.95 | 3.91 | 55.09 | 57.03 |
| **Kunming** | 1336.14 | 0.58 | 4.05 | 54.76 | 56.83 |

## CONCLUSION

This work was an attempt to study a performance of the combination of latent heat storage unit with energy storage modules and an air cooler which was examined to lessen the space cooling energy. The evaluation of the proposed system depended on the annual energy savings ratio as a study tool. The main conclusions can be stated as below:

1. The ability of Simulated annealing algorithm in dealing with many synchronizing parameters (melting temperature, pump flow rates and fan flow rates) and offering optimal solutions. Thus, for the proposed case study annual energy savings ratios and relative errors had been improved clearly.
2. Acceptable success of solid works simulation environment in addressing the experimental model of the proposed problem. that leads to increase the reliability of virtual environments for handling more complex problems.
3. The latent heat storage technology can play an important role in the allocation of energy resources for large scale applications. As well as electricity consumption, thus it has a remarkable impact on electric power providers and consumers.
4. As future work, the latent heat storage technology can be a considerable constraint in all economic cost functions in electricity sector.

The use of holographic interferometry for study heat transfer appears to be an interesting idea in future research [Abdali 2022, Shuravin 2022, Pivarciova 2019 and 2022].

| Abbreviations | Nomenclature |
|---|---|
| AC | Air cooler |
| ESM | Energy storage module |
| HFM | Heat flux meter |
| LHSU | Latent heat storage unit |
| PCMs | Phase change materials |
| TBS | Telecommunications base station |
| ESR | Energy savings ratio |
| GA | Genetic algorithm |
| SA | Simulated annealing |
| C | Specific heat (kj/kg°C) |
| d | Diameter (mm) |
| $G_a$ | Volumetric air flow rate ($m^3$/h) |
| $G_w$ | Volumetric water flow rate ($m^3$/h) |
| I | Electricity consumption (KWh) |
| L | Length (mm) |
| T | Temperature (°C) |
| ΔT | Temperature difference (°C) |
| $T_m$ | Melting temperature (°C) |

**Subscripts**

| | |
|---|---|
| a | Air |
| ac | Air cooler |
| aw | Between air and water |
| cl | Cooling load |
| cp | Copper pipe |
| ec | Energy charging mode |
| ed | Energy discharging mode |
| ext | Exterior space |
| f | Fan |
| fa | Fresh air mode |
| int | Interior space |
| p | Pump |

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**CONTACTS:**

**Andrzej Drwiega, Marek Dudek**
KOMAG Institute of Mining Technology,
Pszczynska 27, 44-101 Gliwice, Poland

**Qays Adnan Ali**
Department of Fuel and Energy Techniques Engineering, Technical Engineering College Kirkuk,
Northern Technical University, 36001 Kirkuk, Iraq

**Nihad Raouf Maaroof**
Presidency of the University of Kirkuk,
Kirkuk University, Kirkuk, 36001, Iraq

**Layth Mohammed Abdali**
University of Kufa, Presidency University of Kufa Najaf,
54001, Iraq

**Boris A. Yakimovich**
Sevastopol State University,
Institute of Nuclear Energy and Industry,
Sevastopol, 299015, Crimea