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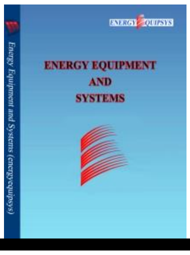

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Optimizaion of cold thermal energy storage systems with commissioning and storage time approach by using intelligent algorithms

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ABSTRACT

The application of cold thermal energy storage systems (CTES) is to reduce power consumption in air conditioning systems. For the optimization, the objective functions are considered as exergy efficiency and total annual cost owing to CO_2 *emissions from the CTES systems. Multi-objective optimization methods are used by MOPSO and SEAP2. The findings achieved from multi-objective optimization indicated a difference in the optimal amounts of design points compared to single-objective optimization, the first objective function (i.e., exergy efficiency), and the second objective function (i.e., total annual costs). In addition, the results of revising this model represent that because of the use of CTES, there is a reduction of electricity consumption in the system. Also, because of transferring cooling load from peak hours to low consumption and reducing power consumption, the system saw a reduction in operating costs compared to a traditional air conditioning system. Finally, the results show that the payback period for a CTES system in partial storage mode is 3.43 years and for a full storage mode is near 3.88 years. Moreover, due to further reduction of operating charges in full storage mode, the total stored cost of this system is more than the partial storage type. It should be noted that the use of the CTES system decreases the production of* CO_2*, which reduces environmental pollution. Finally, the PCMs used in the construction industry are introduced and compared with each other in terms of exergy efficiencies.*

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1. Introduction

Using energy storage systems at buildings is an economical approach. So, by using energy storage systems, instead of using fossil fuels, a great potential of energy sources can be obtained. This will ultimately decrease fossil fuel consumption and CO_2 emissions. A steady increase in electricity consumption annually, especially in air conditioning, leads to complete power outages in different parts of the world (especially in developing countries). That's why energy storage systems are a proper solution to solve this problem. In addition to being the best technical methods,

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they are also economical [1]. There are different methods of energy storage. Some of these methods aren't widely used. Perhaps the most important point is that they are not economical, although the most important aspect is their efficiency. Thermal energy storage systems can be used to balance energy consumption during peak and off-peak hours. Usually, the cooling features of these systems have received more attention. Thermal energy storage systems are divided into two main groups, latent and overt heat. In latent mode, heat transfer occurs by phase change. The operation of these systems is such that energy is saved during off-peak hours (when the cost of electricity is inexpensive) and at peak hours (when the cost of electricity is more expensive) this energy is discharged for numerous applications [2]. By increasing power consumption and decreasing fossil fuels resources, the applications of thermal energy storage systems (heating or cooling) are increasing; particularly in tropical regions. These systems are used periodically and intermittently, producing ice during off-peak hours (for example, after midnight) and by a mechanism during the hot hours of the day to meet the cooling (or heating) needs of the building to increase the capacity [3], [4]. Dincer [17]studied techniques and applications of introducing, evaluating, and employing thermal energy storage systems, in addition to the economical, thermal conservation, and environmental characteristics of these systems.

Habeebullah [5] conducted an economic study of using TES in the Holy Mosque (Saudi Arabia). The total required cooling load during the day was 342/172 kWh, while 289,175 kWh was provided by the TES systems. The results represented that based on the electricity price equaled to 0.07 US$/kWh for days (peak consumption) and 0.016 US$/kWh for nights (low consumption) compared to the system without TES with an economic profit equaled to 595.4 US$ per day. The payback period was 10 years, while its economical profit reached 40.7611 US$ per day. Chen et al. [6] studied and modeled a CTES system and analyzed the amount of saved ice in the CTES along with the heat transfer rate and charge cycle systems. They used a compression refrigeration system with a refrigerant (R22) to produce ice at CTES. Bi et al. [7] Studied the dissipative exergy and entropy generated in a CTES system. In that research, they considered exergy loss as an objective function that should be minimized in a CTES system. Sanaye and Shirazi [8] modeled and analyzed an ITES system by exergy loss They considered that the exergy loss would be an objective function. In this study, with the help of a genetic algorithm, they obtained the maximum exergy efficiency. Also, in 2012, they [9] modeled and analyzed an ITES system in full storage mode. In that study, they used two objective functions; total cost rate and exergy efficiency. Sanaye et al. [10] compared the 4E analysis of an ITES system for an office building in both full-load and part-load modes. Their results indicated that an ITES system with a partial load mode has a shorter payback period as well as higher exergy efficiency.

Using exergy as a powerful parameter can help to analyze the system and its combination with economic and environmental parameters will assist to perform the optimization process perfectly [11]. Dhahad et al. [12] introduced an original multi-generation power and cooling configuration including a solid oxide fuel cell, absorption, and ejector refrigeration cycles. To evaluate the expediency of the proposed system, it was assessed from energy, exergy, and exergoeconomic points. Based on the results, the energy and exergy productivities, and product cost rates were 55.46%, 47.29%, and 106.7$/GJ, each. Behzadi et al. [13] studied a new solar-powered integrated energy cycle with a thermoelectric generator to deliver cooling and hydrogen. The energy combination was accomplished by evaluating a thermoelectric generator as an alternative for the condenser of the double effect absorption cooling system. Ameri et al. [14] performed energy and exergy studies of a combined cycle power plant. The aim of this research was to examine the influence of surroundings temperature changes on the exergy loss of the heat recovery steam generator. The outcomes displayed that the exergy losses had a minimum point at 19 ^{o}C that was the intentional temperature. Kizilkan et al. [15] performed a thermodynamic evaluation of a borehole thermal energy storage system. The outcomes of the exergy study indicated that the boilers were the major contributor to exergy destruction, followed by the condenser and evaporator. Ahmadi et al. [16] made complete exergy, exergoeconomic and environmental impact examination and optimization of several combined cycle power plants. The obtained results indicated that the main exergy destructions took place in the combustion chamber.

According to provided literature, the study of optimal modeling of cold thermal energy storage systems with commissioning and storage time approach (storage tank and phase change materials) using intelligent algorithms is a novel work and has not been studied yet. This study investigates and analyzes 4E (energy, exergy, economics, and environment) for multi-objective optimization of an A/C system in full storage and partial storage modes. In this regard, a CTES system consisting charging cycle, discharging cycle with an energy storage tank has been modeled and analyzed. Then multi-objective optimization using a genetic algorithm has been used to find the best design values in both full storage and partial storage modes. Objective functions are considered as overall cost rates (including initial capital costs, maintenance costs, operating costs, and compulsory CO_2 production charges which should be minimized) and exergy efficiency (which should be maximized).

2. Theoretical modeling

2.1 CTES Systems

The merits of cooling storage systems over conventional air conditioning systems consist of 1. Compared to the conventional building cooling systems, the capacity of refrigeration equipment is reduced. 2. In TES systems, the chiller operates at 100% of its capacity throughout its operation period. 3. TES systems shift the electrical charge from refrigeration to midnight, and the ambient temperature is usually lower at night than during the day. 4. Reduction in the size of contained components such as chillers, pipes, ducts, etc. 5. Installing CTES systems in the cooling cycle of buildings causes a decrease in chiller capacity and consequently reduces the amount of refrigerant charge.

2.2 TES Systems Function

Energy storage systems (especially the cooling type) are divided into three modes based on their operations to provide consumption needs: full load storage, partial load storage, and demand limited load storage. Full load storage: in this type of operation, the system starts charging TES (heating or cooling) during off-peak hours, and the TES system is responsible for meeting all demands during peak hours. This type of operation minimizes the cost of cooling the building by shifting the total energy consumption from peak to non-peak hours. The full load storage will have more storage capacity than other functions. By full operation, 80 - 90% of power consumption demand during peak hours is reduced compared to conventional systems that do not use TES. Partial load storage: In partial operation (partial storage), the size of the chiller is smaller than conventional systems which do not use TES and operate continuously for 24 hours. Because the chiller operates continuously over time, compared to full performance and limited demand, the size of the storage tank is smaller. Partial storage systems reduce electricity consumption by about 40 - 60 percent during peak hours. Demands limiting load storage: in this type, the chiller works 24 hours a day, but during peak hours, the load on the chiller is relatively reduced.

2.3 Load Leveling

The load-leveling system is such that in case of low consumption, the system works with its nominal load, and during the peak consumption of the system, it works with only 25% of the nominal load. Both of them decrease the VCR system (in this type VCR is smaller than full load and larger than partial load) and reduce operating costs (operating costs are less than full load and the load is partial).

2.4 Demand Limiting System

The optimal state of the system should be defined in terms of how much of the load is stored in the tank at low consumption time and how much at peak consumption. To do this, the coefficient α is defined as below:

$$\alpha = \frac{\dot{Q}_{c,on-peak}}{\dot{Q}_{c,\ off-peak}} \quad (1)$$

In the above relation, the coefficient α is the ratio of the cooling load provided by the VCR system in the peak consumption mode to the low consumption mode. So, the value of α is zero for the full load system, 1 for the partial load system, and 0.25 for the load-leveling system. Therefore, the interval α is between zero and 1 (0 <α <1). So finding the optimum is a major challenge for energy storage systems producers.

2.5 How to Store

Energy storage systems save their cooling energy in storage tanks. Energy storage tanks in CTES systems include chilled water, ice, phase change materials (PCMs), and hydrated salts. Among CTES systems, thermal energy storage systems in ice (ITES) are much more common because of their lower cost and also using smaller storage tanks, and the simplicity of their operating system. But these systems have a big capacity.

3. Research Method

3.1 General Relations of Required Heat Transfer

The relationships used to model this cycle, including air cooling and storage tank, are as follows. We first examine the properties of fluid flow: Reynolds, Prandtl, and Nusselt flow are obtained from the following equations:

$$Re_{di} = \frac{4in_{\omega}}{10ud_i\mu_1} \quad (2)$$

$$NU_i = 0.Re_{di}^{0.625}\left(\frac{A_t}{A_b}\right)^{-0.375} Pr_i^{0.333} \quad (3)$$

$$Pr_{\omega} = 11.255exp\left[-0.020IT\right] \quad (4)$$

Now we investigate some of the physical properties of a fluid (water).

$$C_{P\omega} = 3\times10^{-9}T^4 - 8\times10^{-7}T^3 + 3\times10^{-5}T^2 - 0.003\times T + 4.2177 \quad (5)$$

$$k_{\omega} = -10^{-5}T^2 + 0.0022T + 0.5536 \quad (6)$$

$$c_h = c_{max} = \dot{m}_h c_h \quad (7)$$

$$\mu_{\omega} = 3\times10^{-11}T^4 - 9\times10^{-9}T^3 + 10^{-6}T^2 - 6\times10^{-5}T + 0.0018 \quad (8)$$

Now we investigate the transferred energy:

$$\Delta T_{LMTD} = \frac{(T_{a2} - T_{\omega1}) - (T_{a1} - T_{a2})}{ln\left(\frac{T_{a2} - T_{\omega1}}{T_{a1} - T_{a2}}\right)} \quad (9)$$

$$u = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o} + R''f_i} \quad (10)$$

$$\dot{Q}_{AC} = \dot{m}_a c_{pa}(T_{a1} - T_{a2}) \quad (11)$$

The total heat level in the converter is as follows

$$A_{AC} = \frac{\dot{Q}_{AC}}{u(\Delta T_{LMTD})AC} \quad (12)$$

The constant penetration rate is assumed to be $R'' = 0.00001$. But we can get mass Debi by the below relation:

$$\dot{m}_{\omega} = \frac{\dot{m}C_{pa}(T_{a1} - T_{a2})}{C_{p\omega}(T_{\omega2} - T_{\omega1})} \quad (13)$$

The air mass rate is calculated based on the clear cooling load of the building.

3.2 Energy and exergy analyses

Energy and exergy analyses are performed for both charging and discharging cycles for load leveling and demand limiting conditions. To simplify ITES system operation, the following assumptions were considered:

- Heat losses in the expansion valve and pressure drop within the pipes were taken to be negligible.
- It was assumed that all cooling capacity produced by the ITES system was stored in the (water/ice) storage tank.
- The state of the refrigerant exiting from the evaporator and condenser was assumed to be at saturated vapor and saturated liquid states, respectively.
- The ice storage tank temperature distribution was assumed to be uniform.

It should be noted that the acquired results for the POM-DL condition $(0 < \alpha < 1)$ were different from those for POM-LL $(\alpha = 1)$ due to the difference in the cooling capacity of VCR systems and storage tanks in these two conditions.

The exergy efficiency for the whole ITES system was also expressed as follows:

$$\Psi_{tot} = \frac{\dot{E}_{out}}{\dot{E}_{in}} = 1-\left(\frac{\dot{E}_{D,tot}}{\dot{W}_{fan,AHU}+\dot{W}_{pump,dc}+\dot{W}_{cond}+\dot{W}_{pump,cT}+\dot{W}_{fan,cT}}\right) \quad (14)$$

3.3 Economic Analysis

In all, the total cost rate for an ITES system consists of the capital cost and initial capital for the production of the ITES system, maintenance costs, operational costs, as well as the penalty costs of producing carbon dioxide in the environment, which can calculate total costs as below:

$$\text{Total cos trate} = \dot{Z}_{\text{inv+main}} + \dot{Z}_{\text{op}} + \dot{Z}_{CO_2,\text{penalty}} \quad (15)$$

3.4 Environmental analysis

As was previously stated, one of the advantages of CTES systems is their ability to reduce detrimental emissions during shifting electricity consumption from on-peak hours to off-peak hours. It should also be mentioned that the emission level of these systems depended on their technology, year of manufacture, equipment age, operating load (partial load), type and quality of fuel used, the performance of the pollution filtering equipment, etc. [18]. The penalty cost of CO_2 emissions was estimated by the amount of annual CO_2 production and the pollutant emission cost ($\psi_{em.}$) [10].

$$C = m_{CO_2} \times \psi_{em.}\left[\frac{\$}{kW}\right] \quad (16)$$

3.5 Objective functions and Design Parameters

In this study, the objective function in the form of exergy efficiency in full storage mode and partial storage is considered. It is obvious that for the whole ITES system, the first objective function, which relates to exergy efficiency, should be maximized, and the second objective function, which is related to costs, should be minimized. The decision variables (selection parameters) in an ITES model are selected as follows: 1- Store cold inlet temperature to the tank $T_{in,st}$ 2- Coldwater outlet temperature from a storage tank $T_{out,st}$ 3- Storage tank temperature (temperature distribution inside the tank is supposed to be stable) T_{st} 5- Refrigerant saturation temperature from the operator T_{EV} -5 condenser temperature T_{cond}. A list of all design variables for full storage mode and partial storage mode as well as their correct range is provided in Table (1).

In this study, three methods of genetic algorithm optimization, MOPSO, and SEAP2 are used to optimize objective functions and in the end, these results are compared with each other.

4. Results and discussion

In this research, the ITES system in full storage and partial storage mode is modeled for the same system (A/C), the schematic of this modeling for full storage and partial storage mode is presented in Figs. (1) and (2).

Table 1. Design variables of an ITES system in full and partial storage mode and their precise ranges

Variables	Explanations and Reasons
$3 < T_{in,ST} < 5$	Nominal data for a compression refrigeration system
$11 < T_{out,ST} < 13$	Nominal data for a compression refrigeration system
$-10 < T_{ST} < 0$	Nominal data for a compression refrigeration system
$-30 < T_{EV} < 0$	Minimum and maximum refrigerant saturation temperature in the evaporator for a wide range of those functions and systems
$(T_{wb,out}) + 5 < T_{cond} < 60$	Minimum and maximum refrigerant saturation temperature in the condenser for a wide range of functions
$T_{EV} < T_{ST}$	The necessary condition for establishing heat transfer between the evaporator and the storage tank
$T_{FD,Glycol} < T_{ST}$	The allowable temperature limit for a mixture of water and glycol in the discharge mode

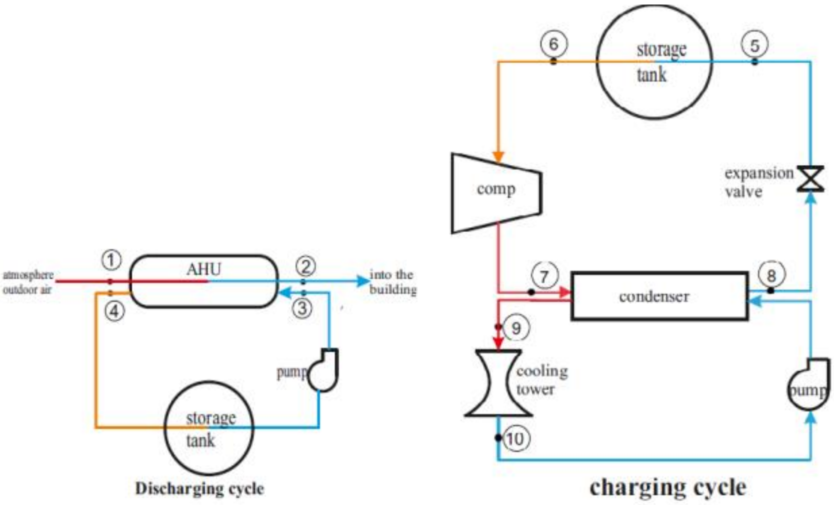

Fig. 1. Modeling an ITES system at full load

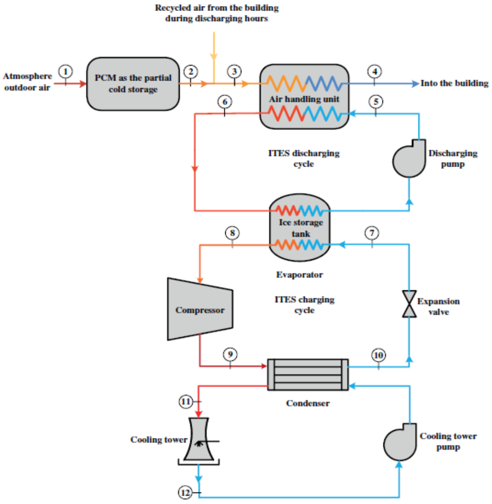

Fig. 2. Modeling an ITES system at partial load

In the charge cycle (vapor refrigeration system), R134a refrigerant is used as the active fluid and in the discharge cycle, the glycol water mixture is used as the active fluid.

4.1 CaseStudy

The represented model and optimization technique mentioned in the first stage report for the optimal design of an ITES system has been studied in an office building in Bushehr. This building is used during office hours between 7 am and 7 pm (Fig. 3).

Table (2) shows a good approximation of the energy stored in the storage tank in full storage mode and partial storage for the charge and discharge cycle. As it can be seen, the required load of the building in low consumption time is zero. In the case of the partial load, a maximum of ten percent of the required load is supplied by PCM and the other 90 percent is supplied by an energy storage tank that saves its required energy at low consumption hours. The used refrigerant in the compression refrigeration system used in the modeling is considered R-134a and its properties are extracted from commercial software.

Thermodynamic resistance (R_{th}) storage tank is considered ($1980\, m^2 kwh^{-1}$) in both full storage and partial storage modes [19]. The optimum temperature for the comfort of the building staff is considered as a temperature efficiency of 19< T< 22 and the relative humidity of the air in which the person does not feel hard is considered as a humidity range between 45% to 55% [20]. Environmental pressure has also been considered once due to the coastal city of Bushehr in Iran. The price of household electricity consumption is estimated at 0.09 US$ per kilowatt during peak consumption and at 0.060 US$ per kilowatt during off-peak hours [9], [21].

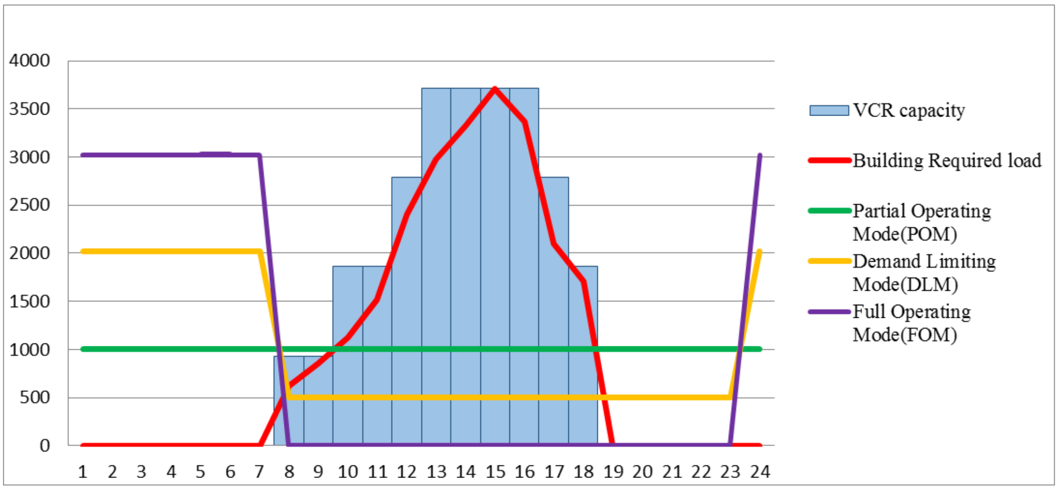

Fig. 3. Nominal load required by the building at different hours of the day, the load generated by electric chiller system (traditional air conditioning), and load generated by the full load storage system

Table 2. The required cooling load of the building and the capacity of the chiller in the ITES system in full and partial storage modes

Hours of day	Required load of building		Chiller capacity and the amount stored in the tank at full load		Chiller capacity in a traditional air conditioning system	
	Full storage	Partial storage	Full storage	Partial storage	Full storage	Partial storage
1	0	0	1579	1421	0	0
2	0	0	1579	1421	0	0
3	0	0	1579	1421	0	0
4	0	0	1579	1421	0	0
5	0	0	1579	1421	0	0
6	0	0	1579	1421	0	0
7	0	0	1579	1421	0	0
8	330	330	0	0	495	495
9	445	445	0	0	495	495
10	598	598	0	0	990	990
11	810	810	0	0	990	990
12	1280	1280	0	0	1485	1485
13	1640	1640	0	0	1980	1980
14	1836	1836	0	0	1980	1980
15	1980	1980	0	0	1980	1980
16	1805	1805	0	0	1980	1980
17	1140	1140	0	0	1980	1980
18	910	910	0	0	90	90
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	1579	1421	0	0

The material used in PCM is manganese nitrate hexahydrate $Mn(\mathrm{NO_3})-6H_2O$ which has a very close temperature to human thermodynamic comfort temperature. PCM, as a partial load supplier, provides between 0 to 10 percent of the required cooling load ($0<\alpha<0.1$). Also for calculating CRF, the annual interest rate, the approximate lifetime of a system and the maintenance factor are 15% and 15 years, and 1.06 of the total initial investment costs have been considered [22]. The income from scrapping (ΔZ_{SV}) is considered into 10% of the total costs of initial investment for each 3 full storage system, partial storage and traditional air conditioning [9], [21].

4.2 Model Verification

The basic parameters of the model which we presented in this report and its value are matched with the similar values presented in the reference [23]. In this comparison, the difference is less than 1.25% (as shown in Table (3)). This difference is acceptable.

4.3 Optimization Assumption

In this part, the range of design parameters in which the optimization is performed using the GA is indicated in Table 4.

Table 4 Design variables of an ITES system in full storage and partial storage mode and their correct range

4.4 Method Selection to Check the Optimal Point in Full Storage and Partial Storage Mode

In this report, after dimensioning the objective functions, two common methods for selecting the optimal point, including the LINMAP method and the TOPSIS method, are examined and evaluated. In LINMAP, the optimal solution for the Pareto-Front chart is the point that has the smallest specific distance from the ideal point (the ideal point is the point at which both objective functions reach their maximum value without considering each other's interactions). This point has been selected as the best optimization point [8], [24]. But in the TOPSIS method, the non-ideal point (the point at which each of the objective functions has its minimum value, without considering the interactions with each other) is also defined [25], [26]. The results in table 5 demonstrate that both selection methods for determining the optimal point achieve the exergy efficiency in a range of almost the same, but the total cost in the partial storage mode between the two selection methods of LINMAP and TOPSIS are different nearly about 11 Thousand dollars. Also, the total cost in full save mode differs by nearly $ 8,000 between the two methods of selecting LINMAP and TOPSIS but reduces the return by 0.5 percent. And we use this method of partial storage so we use this method for both full and partial storage modes.

Table 3. Comparison of the design parameters modeled in this report and the values reported in the reference [23]

Inlets	reported	outlets	reported	Model results
T_{EV} (^oC)	-20	$\dot{m}_r$	2.0	0.201
T_{cond} (^oC)	40	$\dot{w}_{comp}$	9	9.1043
$\dot{Q}_{EV}$ (kw)	9/29	COP	2.87	2.8593

Table 4. Comparison of the design parameters modeled in this report and the values reported in the reference [23]

Variables	Reasons and results
$5<T_{in,ST}<7$	Nominal data for a compression refrigeration system
$11<T_{out,ST}<13$	Nominal data for a compression refrigeration system
$-10<T_{ST}<0$	Nominal data for a compression refrigeration system
$-30<T_{EV}<0$	Minimum and maximum refrigerant saturation temperature in the evaporator for a wide range of those functions and systems
$(T_{wb,out})+5<T_{cond}<60$	Minimum and maximum refrigerant saturation temperature in the condenser for a wide range of functions
$0<T_{in,ST}<0.1$	Due to spatial constraints
$T_{EV}<T_{ST}$	The necessary condition for establishing heat transfer between the evaporator and the storage tank
$T_{FD,Glycol}<T_{ST}$	The allowable temperature limit for a mixture of water and glycol in the discharge mode

The optimal numerical values by using the selected LINMAP method in full save mode and partial save mode for design variables in single-objective and multi-objective mode are presented in Table (6).

4.5 Dimensioning the Results

Since the exergy efficiency (percentage) and also the annual cost rate ($/year) have different units, so for a clearer and more accurate choice, it is necessary to first dimension both objective functions and then use the selected points using the LINMAP method. Figures 4 and 5 show the Pareto-front diagrams while the objective functions by Euclidian nondimensionalization for full and partial load modes.

Table 5. Optimal mode value for exergy efficiency and annual total cost for two TOPSIS-LINMAP selection methods for full storage modes

Target function	LINMAP decision-making method	TOPSIS decision–making method
Exergy efficiency in full storage mode	37.31	37/94
Exergy efficiency in partial storage mode	39.12	39.63
Total cost in partial storage mode	$1.242\times10^{5}$$	$1.253\times10^{5}$$
Total cost in full storage mode	$1.1045\times10^{5}$$	$1.1047\times10^{5}$$

Table 6. Optimal value of system design parameters for all three optimization methods in partial and complete storage mode

Design parameters	Single objective(objective function 1)		Single-objective(objective function 2)		Multi-purpose (Objective Function 1 and 2)	
$T_{in,sT}$ (^oC)	3.86	3.31	4.93	4.83	4.49	4.19
$T_{out,sT}$ (^oC)	12.71	11.75	11.02	10.85	11.75	11.85
T_{ST} (^oC)	-4.12	-4.85	-2.19	-3.06	-2.86	-3.96
T_{EV} (^oC)	-6.18	-6.72	-4.15	-4.71	-5.08	-5.32
T_{cond} (^oC)	37.83	36.57	40.18	39.23	38.54	37.58

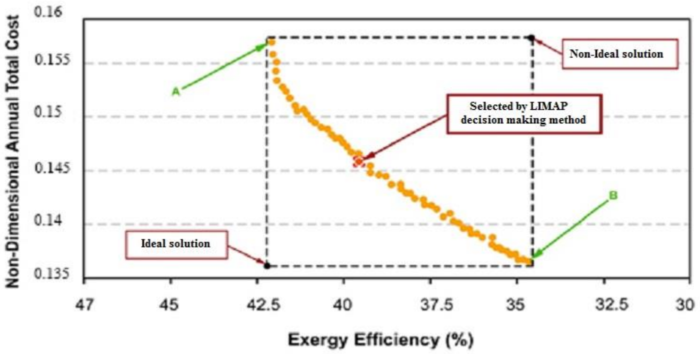

Fig. 4. Pareto-Front diagram of the objective function in a dimensionless mode for partial load mode

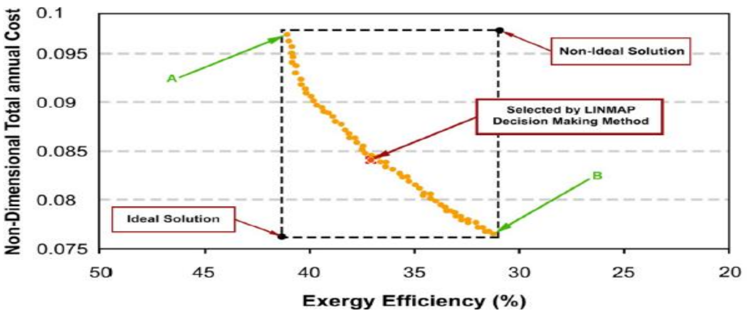

Fig. 5. Pareto-Front diagram of the objective function in a dimensionless model for full load mode

The optimum values of exergy efficiency in the partial storage mode for the optimal objective function 1, objective function 2, and multi-objective mode are 33.11%, 41.93%, and 39.12%, respectively. Also, the optimal value of exergy efficiency in full storage mode for optimal objective function 1, objective function 2 and multi-objective mode is 31.12%, 41.18%, and 37.31%, respectively. Figure (6) represents a comparison between the amount of exergy wasted in different components of the system for full load and partial load. It's apparent from the obtained results that, DLM (Decentralized Linearized Alternating) has lower values in comparison with the POM (Partition-based optimization model) for all components. The reason for this matter is related to the calculation procedures for each algorithm. DLM is based on several centralized while the POM is employed partitions of the optimization problem into sub-problems by expressing supplementary simulated constraints for each sub-problem and applying different community detection algorithms. In this case, the obtained results for the dissipation exergy in two systems of full load and part load for the selected point by LINMAP have been differed by POM and DLM.

Also from an economic point of view, the optimal design point for partial and complete storage mode in single-objective mode, as well as multi-objective mode, is shown in Table (7). As shown in the table, the total cost of an ITES system for objective 1 is the highest, and for objective 2 it is the lowest, and in multi-object, it is an optimal limit between the two.

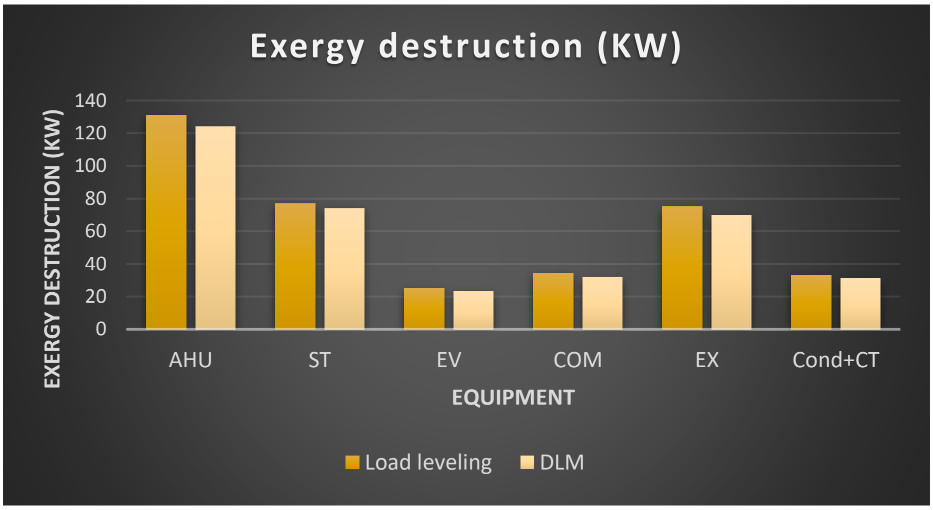

Fig. 6. Comparison between exergy destruction of various ITES equipment at the optimum selected points for DLM $(\alpha = 0.25)$ and POM $(\alpha = 1)$

Table 7. Cost of different components for partial and complete storage mode by three different optimization methods

Different components cost	**Single objective 1**		**Single objective 2**		**Multi-objective**	
	Partial storage	**Full storage**	**Partial storage**	**Full storage**	**Partial storage**	**Full storage**
AHU	0.2505	0.2505	0.2092	0.2292	0.2144	0.2344
Storage tank	0.2152	0.2683	0.1945	0.2105	0.1982	٠,٢٢٤٢
Operator	0.1231	0.1793	0.1025	0.0880	0.1077	.٠0.1138
Discharge pump	0.0410	0.0590	0.0208	0.0189	0.0229	0.0330
Cooling tower pump	0.0385	0.0505	0.0212	0.0220	0.0244	0.0349
co_2 compensation	0.1905	0.1310	0.1643	0.1040	0.1699	0.1186
Condenser and cooling tower	0.2856	0.2908	0.1910	0.2530	0.2153	0.2705
Heat exchanger	0.0007869	0.0007539	0.0003423	0.0007410	0.0004471	0.0007421
Compressor	0.3008	0.3730	0.2493	0.2310	0.2610	0.2980
Total annual cost	$1.377\times10^5$$	$1.283\times10^5$$	$1.152\times10^5$$	$1.051\times10^5$$	$1.242\times10^5$$	$1.104\times10^5$$

4.6 Changes in Operating Costs in Full and partial storage mode

The power consumption in full storage and partial storage compared to a conventional compression refrigeration system is shown in Fig. (7). Both partial and full load modes reduce operating costs by transferring system operating hours to low consumption hours. On the other hand, in partial load mode, ten percent $(\alpha = 0.1)$ of the required load is provided by PCM, so in this case, the cost is also reduced. On the other hand, because in the traditional ventilation system, 25% of the load can be reduced and increased at each stage, so part of the load is wasted because it is more than the required capacity of the building, but in the case of ITES, because the AHU system is used so this waste does not exist and reduces operating costs.

4.7 Calculating the Payback Period in Full and Partial Storage Mode

Figure (7) shows that the power consumption for an ITES system (full storage and partial storage) is lower compared to a similar system to traditional air conditioning. This difference is because the amount of cooling produced in traditional air conditioning mode is much higher than in ITES mode. The amount of cooling load produced in traditional air conditioning is more than the required consumption. However, ITES systems (full storage and partial storage) generate exactly the required cooling load (by controlling the amount of cold water pumped), which means that the overall operating costs of an ITES system are lower than those of a traditional air conditioning system. Another reason for the reduction in cost in the ITES system (full storage and partial storage) is less productive when using ITES. The third reason for the reduction in operating costs in the ITES mode compared to the traditional system is the transfer of electricity consumption time from peak consumption (when electricity prices are more expensive 0.09 kW/h) to low consumption hours (when electricity prices are cheaper (0.06 kW/h). But the main reason for using an ITES system is to transfer peak hours to low hours. This means reducing overall costs by storing production-generated cooling during off-peak hours when costs are lower ($ 0.06 per kilowatt) and using them at peak consumption when electricity costs are higher (0.09 US$ per kilowatt). We consume electricity. The results are given in Table (8).

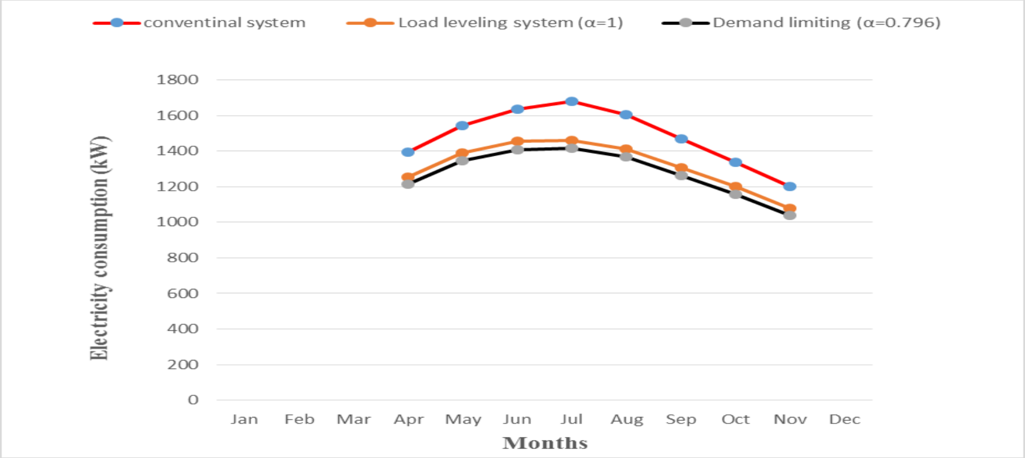

Fig. 7. Comparison of power consumption between a system (A / C) in full storage mode and partial storage mode and traditional air conditioning mode

Table 8. Reduction percentage in operating costs due to the use of ITES compared to traditional air conditioning

System type	Reduction percentage in operating costs due to changes in peak hours
Partial storage	%35.94
Full storage	%29.36

At the end of the payback period, due to the additional costs of the subsidiaries for an ITES system replaced by a traditional air conditioning system, it is approximately 3.43 years for a partial storage system and approximately 3.88 years for a complete storage system. This is because the partial storage system uses a much smaller energy storage tank and a smaller compression refrigeration system than the full storage mode, which reduces overall costs and shorter payback periods in the partial storage mode.

4.8 Comparing Results for Different PSMs

One of the goals of this report is to compare the types of materials with phase change capability (PCM) with each other to achieve a consistent pattern for the use of PCM materials. PCMs are generally divided into two general categories, organic and inorganic. Because organic PCMs are much more expensive than non-organic PCMs, they are less commonly used in construction applications that require large volumes of PCMs. Only PCMs suitable for construction use have melting temperatures in the range of 18 to 29 ° C. In this report, we have compared PCMs according to the night temperature of Bushehr. Table (9) shows the following PCMs with a melting temperature range of 18 to 29 ° C and compared with each other in this report. Also, assuming that the price of all PCMs is equal, they are compared in terms of exergy efficiency.

The results show that manganese nitrate hexahydrate has the best exergy efficiency. Inorganic PCMs cost far less than organic and salt hydrates. Therefore, it is obvious that various sources have mentioned manganese nitrate, hexahydrate, and calcium chloride hexahydrate as two common PCMs in the construction discussion.

Table 9. PCM types and their melting temperature range between 18 to 29 ° C and comparison of exergy efficiencies for different PCMs by MOPSO and SEAP2 optimization algorithms

PCM name	**Exergy efficiency obtained by SEAP2**	**Exergy efficiency obtained by MOPSO**	**Melting temperature** $(^{\circ}C)$	**Hidden heat** $\frac{kJ}{kg}$
$KF-4H_2O$ Potassium Fluoride Tetrahydrate	34.06	34.23	18.5	231
$Mn(NO_3)_2-6H_2O$ Manganese Nitrate Hexahydrate	38.88	39.12	28.7	125.9
$CaCl_2-6H_2O$ Calcium Chloride Hexahydrate	37.92	38.27	29	190.8
$CH_3(CH_2)_{16}COO(CH_2)_3CH_3$ Butyl stearate	34.16	34.18	19	140
$CH_3(CH_2)_{11}OH$ 1-dodecanol	37.76	37.94	26	200
$CH_3(CH_2)_8COOH$ Capric-lauric acid	37.45	36.89	21	186
Cyprylic acid	31.22	31.27	18	148.18
Lactic acid	35.72	35.95	26	184
Potassium fluoride tetrahydrate	31.96	32.18	18.5	231
Calcium chloride hexahydrate	34.55	34.72	27.4	161
Lithium nitrate trihydrate	35.23	35.7	29	286
Paraffin blend(n=16-18)	33.10	33.57	20	152

5. Conclusion

This study investigated and analyzed 4E (energy, exergy, economics, and environment) for multi-objective optimization of an A/C system in full storage and partial storage modes. In this regard, a CTES system consisting charging cycle, discharging cycle with an energy storage tank has been modeled and analyzed. Then multi-objective optimization using a genetic algorithm has been used to find the best design values in both full storage and partial storage modes. Objective functions were considered as overall cost rates (including initial capital costs, maintenance costs, operating costs, and compulsory CO_2 production charges which should be minimized) and exergy efficiency (which should be maximized). The main results :of this research are as follow

- The maximum exergy efficiencies for the multi-objective function in full reserve mode and the partial reserve mode were 37.31% and 39.12%, respectively.
- The minimum total cost rates for the multi-objective function in full reserve mod and partial reserve mode were 1.1045×10^5 US$ and 1.152×10^5 US$, each
- The assessments of the model of this study showed that due to the use of ITES by 11.83% in partial storage mode and 10.23% in full storage mode, we have a reduction in electricity consumption.
- Due to the transfer of cooling load from peak hours to low consumption and reduced 35.12% power consumption in partial storage and 29.36% in full storage mode have a reduction in operating costs compared to a traditional air conditioning system. This reduction in costs compared to a conventional air conditioning system compensates for the additional costs of adding ITES to an A/C system.
- In the end, the results showed that the payback period for an ITES system in partial storage mode is 3.43 years and for a full storage system is close to 3.88 years, but due to further reduction of operating costs in full storage mode, the amount
- The total stored cost of this system after the useful life of the set (15 years) is more than the partial storage mode. As a result, it is up to the consumer to decide whether to opt for a shorter return on investment or to save more after 15 years.

Finally, it should be noted that the use of the ITES system reduces CO_2 production, which reduces environmental pollution. The results also show that manganese nitrate hexahydrate has the highest exergy efficiency.

In this original research paper, we have investigated a wide range of PCMs. The lacks of access to all economic, technical, and environmental information of other types of PCMs were a major obstacle to developing this research to other aspects. More researches on some other specific types such as paraffin wax, polyethylene glycol (PEG), Hygroscopic materials, Heptadecanone, Cyanamide, etc. with applicable additives can be conducted. Moreover, for the proposed cycle, using advanced exergy analysis for further investigations can specify exogenous, endogenous, avoidable, and unavoidable exergy destruction rates for all involved components.

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