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Study of a Refrigeration System Utilizing Thermal Rejection: Analysis and Optimization

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Dedication

To those who, after Allah, have had a role in through every stage of my journey.

To the soul of my beloved mother, though she is no longer with us, her love remains the compass guiding me in my life. This achievement is the fruit of the values she instilled in me. May Allah grant her the highest rank in Jennah.

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Dedication

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Abstract:

This study proposes an optimization to enhance sustainability and longevity for the water treatment machines used at "Algerienne des eaux" (ADE) El Hdeb in Ouargla. This proposition suggests the replacement of a traditional cooling tower as the water cooling system that wastes 3.84kW of heat energy by a dual heat energy recovery and geothermal system. This setup shows success in achieving the thermal demand for the winter season 611.11W needed for heating at 20℃, meeting the 861.11 W of energy needed for cooling in the summer season at 25℃, and ensuring water is in optimal temperature at lower than 24.5℃ suitable for treatment throughout the year.

Keywords: Heat recovery, Geothermal, Heating, Cooling, TRNSYS simulation.

ملخص:

تقترح هذه الدراسة تحسينا لتعزيز ديمومة و طول عمر آلات معالجة المياه المستخدمة في الشركة الجزائرية للمياه بالحدب بورقلة، هذا الاقتراح عرض استبدال برج تبريد المياه التقليدي كجهازالتبريد تبريد الذي يضيع 3.84 كيلو واط من الطاقة الحرارية بنظام مزدوج يعمل بالحرارة المسترجعة من مياه الانقاب و الطاقة الجيوحرارية. أظهر هذا النظام نجاحا في تلبية كل الاحتياج الحراري طيلة فصل الشتاء البالغ 611.11 واط للتدفئة عند درجة الحرارة 20℃، و تحقيق الاحتياج الحراري طيلة فصل الصيف المقدر ب 861.11 واط للتبريد عند درجة الحرارة 25℃. كما يضمن بقاء المياه عند درجة حرارة مثالية اقل من 24.5℃ مما يجعلها مناسبة للمعالجة طول العام.

الكلمات المفتاحية : استرجاع الحرارة، الجيوحرارية، التدفئة، التبريد، محاكاة TRNSYS.

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Nomenclature:

Clothing factor	Clothing factor	clo
Cp_{fluid}	Specific heat of a fluid	$J/kg\cdot K$
$Cp_{T\,(bef)}$	Lower bound specific heat for interpolation	$J/kg\cdot K$
$Cp_{T\,(aft)}$	Upper bound specific heat for interpolation	$J/kg\cdot K$
d	Density	kg/m^3
k	Conductivity	$W/m\cdot K$
Metabolic rate	Metabolic rate	met
$\dot{m}_{fluid}$	Mass flow rate of a fluid	kg/s
Q_{cond}	Heat energy of the condenser	kW
Q_{evap}	Heat energy of the evaporator	kW
$Q_{rejected}$	Heat energy rejected	kW

ΔT_{fluid}	Difference of temperatures entering and leaving in an area	K
T_{sup}	Upper bound temperature for interpolation	K
T_{inf}	Lower bound temperature for interpolation	K
T_{avg}	average of inlet and outlet temperatures of water	K
Th	Thickness	m
$T_{in\,(water)}$	Temperature of water entering the system from the well	K
$T_{out\,(water)}$	Temperature of water leaving the system	K
UA	Heat exchange coefficient	W/K
W_{comp}	Work done by the compressor	kW

Abbreviations:

ADE	Algeriènne des eaux
BPHE	Blazed plates heat exchanger
FES	Fossil energy sources
GAHE	Ground to air heat exchange
GWHE	Ground to water heat exchange
GHE	Greenhouse emissions
HEX	Heat exchanger
RA	Return air
RE	Renewable energy
RES	Renewable energy sources
RS	Refrigeration systems
TRNBUILD	Transient system building modeling tool
TRNSYS	Transient system simulation tool
VCC	Vapor compressor cycle
WW	Well water

General introduction

As the impacts of climate change became severe in recent years, countries all over the world has come to acknowledge the necessity to transition towards cleaner renewable and more sustainable energy sources.

Algeria among these countries, although still relies heavily on fossil fuels to meet energy demands, it now aims to achieve 27% share of sustainable and renewable energies by 2030. This decision is critical especially after reaching high greenhouse emissions (GHE), estimated at 198.20 million tonnes of $\mathbf{CO_2}$ equivalent in 2024. Consequently, it is a necessity to optimize industrial processes to reduce this waste.[1], [2]

Within this scope, the water sector is no exception especially in the arid climate of Ouargla. In this region, the “Algerienne des eaux” (ADE) faces two problems. The first is managing the energy of geothermal well water coming at high temperatures. Currently this thermal energy is wasted into the atmosphere by a traditional evaporative water cooling tower. The second problem is that the system fails to cool water to the required temperatures for the water treatment machines.

This study proposes a strategic optimization of the current water cooling system by replacing it with a dual circuit heat recovery system. It aims to capture the heat energy from the well water to meet thermal comfort in the facility in winter and use geothermal energy cooling in summer, while providing effective and stable cooling to the well water in order to reach the precise required temperatures to protect the water treatment machines.

This dissertation is organized into three chapters:

- Chapter 1 establishes the global necessity to switch to sustainable energy sources, refrigeration basics, and literature review.
- Chapter 2 presents the case study of the ADE El Hdeb in Ouargla, detailing the water cooling tower limitations. Then it shifts to the building materials of the security room to provide comfort. Finally, it explains the brazed plates heat exchanger (BPHE) used in heating and the ground to air heat exchangers (GAHE) and ground to water heat exchanger (GWHE) in cooling, both utilized in the optimized new system.

- Chapter 3 is dedicated to the simulation of the thermal demands by the security room, potential of geothermal cooling for the region, as well as the performance of the proposed system using TRNSYS software, to ensure comfort is provided and water is cooled suiting the required temperatures for the water treatment machines.

CHAPTER 1:

Generalities and literature review

1.1. Introduction:

The shift toward sustainable energies has become a global necessity to ensure energy stability as well as minimizing greenhouse emissions (GHE). In This scope , this chapter establishes a comprehensive theoretical framework for the study . First, it starts by the energy transition and objectives of Algeria by 2030. Then it highlights the rising GHE within the country. After that, it sheds light on the growth of cooling and refrigeration needs. Next, it provides necessary functioning principles of different types of refrigeration systems. Finally, a review of various studies conducted in this aspect.

1.2. Sustainable development and energy transition in Algeria:

In recent years, there has been a notable global shift in focus towards sustainable energy transition. Algeria among the countries all over the world has come to acknowledge the urgent necessity of transitioning to cleaner and more sustainable energy sources to combat climate change and mitigate the environmental impacts of traditional energy systems. This developing nation, finds itself in a unique position with its rich endowment of renewable energy resources (RES). Recognizing this potential, it has embarked on a transformative journey towards sustainable energy transition, aiming to use its abundant RES while achieving its economic development objectives[1].

1.2.1. The transaction objectives and energy strategy in Algeria for 2030:

Algeria has set a target to achieve a 27% RES penetration in the existing national energy mix by 2030. The national renewable energy (RE) targets are set to be achieved using solar photovoltaic (PV), concentrated solar thermal, cogeneration, biomass, geothermal, and wind. The proposed renewable energy capacities are expected to be accomplished in two phases. The first phase program (2015–2020) focused on the development of 4525 MW capacity build up based on the contributions of different RE technologies. The second phase

Unit : MW	First Phase	Second Phase	TOTAL
	2015-2020	2021-2030	
Photovoltaic (PV)	3 000	10 575	13 575
Wind Energy	1 010	4 000	5 010
CSP	-	2000	2 000
Cogeneration	150	250	400
Biomass	360	640	1 000
Geothermal energy	5	10	15
TOTAL	4 525	17 475	22 000

Figure 1:1 The energy transaction objectives of Algeria by 2030 [1]

(2021–2030) is deducated towards increasing the installed renewable energy capacity, and the improvement of electrical interconnection between the north and Sahara (Adrar). [3]

1.2.2. Greenhouse emissions in Algeria:

Algeria to this day still depends on fossil energy sources (FES), Algeria has high greenhouse emissions (GHE), estimated at 198.20 million tonnes of CO_2 equivalent in 2024 , as shown in figure 1:2.

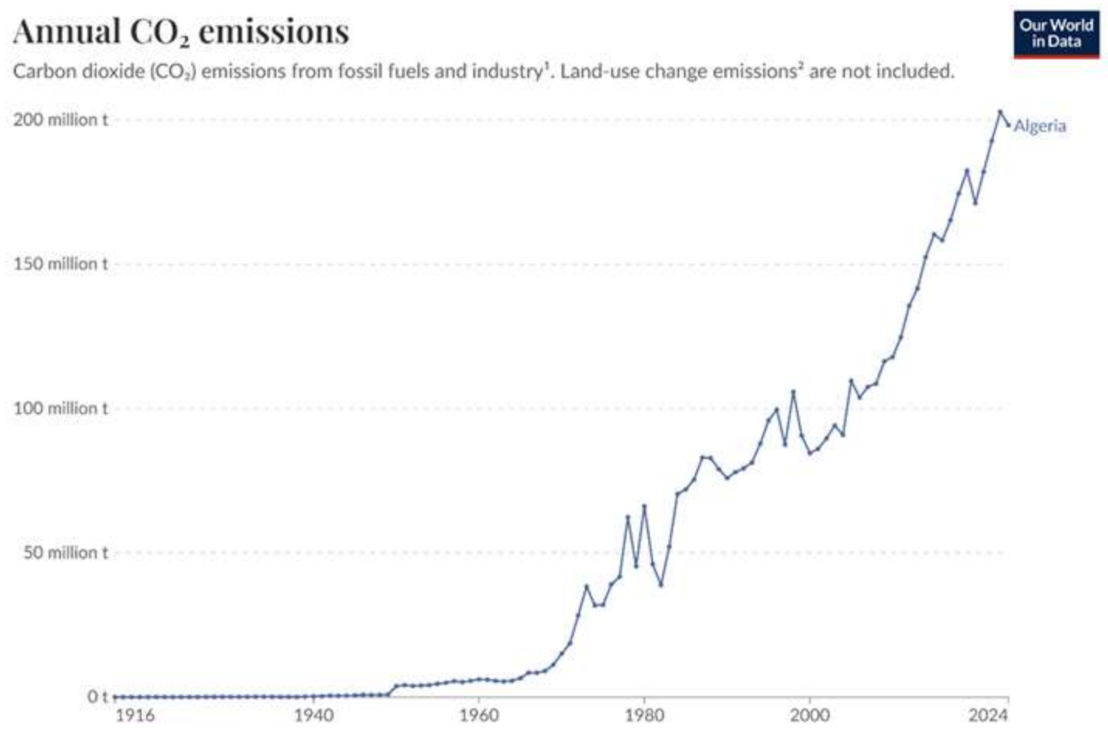


Figure 1:2 Annual CO2 emissions of Algeria 1940-2024 [2]

The developing country has approved the Paris agreement on October 13th 2016, which positioned it within the global effort to reduce the dangerous emissions by between 7% and 22% compared to the business-as-usual scenario. The commitment is realised through exploring RES potential to improve the electricity production, especially solar and wind.[4]

1.3. Growth of cooling and refrigeration needs:

Due to the increase of the GHE, the global warming is still rising which led to the global surface temperature reaching 1,1℃ more in 2011-2020 compared to 1850-1900, and will likely keep augmenting to exceed 1,5℃ during the 21st century [5]. As a consequence of this phenomenon, the demand for refrigeration and cooling systems is growing worldwide to adapt to the higher temperatures. Today, this sector consumes about 20% of the overall electricity used globally, this consumption is expected to more than double by 2050. [6]

1.4. Refrigeration and cooling:

The refrigeration is the operation in which the work is done to transfer heat from a lower temperature region to a higher temperature one. [7]

1.4.1. Refrigeration systems (RS):

1.4.1.1. Definition:

RS are mechanisms that perform the refrigeration process.

1.4.1.2. Types:

We can classify two main types of RS, a type that utilize mechanical energy called mechano-refrigeration systems, and another that uses mainly thermal energy to operate called thermo-refrigeration systems.[8]

Mechano-refrigeration systems:

From this type two other subtypes emerge:

- Liquifiable vapor compression systems
- Utilizing gas cycles systems.

* **Vapor compression cycle (VCC) systems:**

The first description of the VCC for cooling was made by the American Oliver Evans in 1805 who never constructed it as a machine. In 1834, an associate of the previous engineer named Jacob Perkins filed a patent in England for the first VCC device that could cool water and solidify it into ice continuously. This machine was then constructed in 1835. This mechanical device was commercially successful thanks to the efforts of many others, including American inventor Alexander Twining and Australian James Harrison. [9]

The VCC machine as illustrated in figure 1:3 consists of two sides: low pressure and high pressure:

Starting with the low-pressure side the refrigerant enters the evaporator as a mixture of liquid and vapor then leaves as a saturated superheated vapor. In this state, the refrigerant enters the compressor to leave after being compressed with increased pressure and temperature.

Entering the high pressure side, the refrigerant moves to the condenser where it becomes saturated subcooled liquid and heat is rejected. This liquid then goes through a valve where a sudden drop in pressure happens, this drop in pressure results in the reduction of the temperature of the refrigerant turning it into liquid-vapor mixture to re-enter the evaporator once again, the cycle repeats continuously.[10]

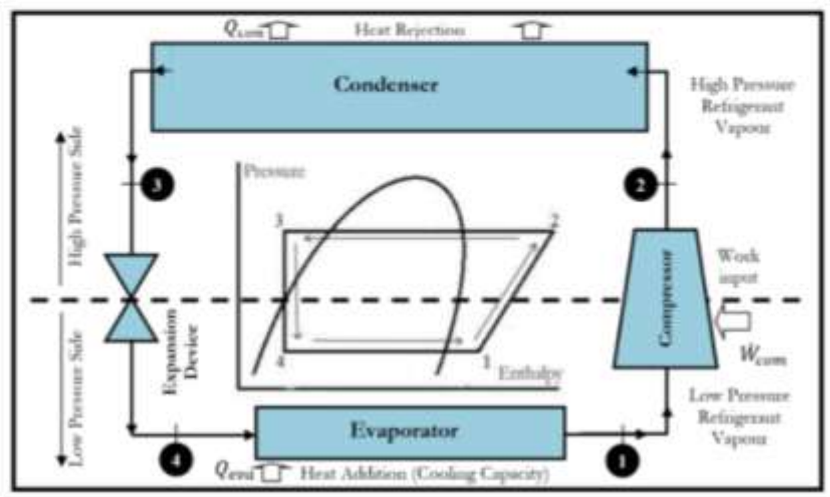


Figure 1:3 machine components and diagram of a VCC [10]

* **Gas cycle refrigeration systems:**

It was the American John Gorrie who patented the earliest machine in 1850-1851 to cool brine to about -7°C , then Alexander Kirk designed a closed cycle air machine inspired by the Pastor Robert Stirling's air engine.

From 1864 onwards, these systems were developed to reach temperatures as low as -13°C thanks to the contribution of many others.

In this type of systems, the working fluid stays in the gaseous state throughout the cycle. The gas temperature increases during compression, then the gas is cooled at high pressure to near ambient temperature. When it expands, the pressure decreases, making the temperature drop resulting in the production of the cooling effect. This makes them the foundation of modern cryogenic cycles used for gas liquefaction and the production of very low temperatures.[8]

Thermo-refrigeration systems:

Among this section there are three more sub-sections:

- Absorption systems
- Adsorption and thermo-chemical systems
- Ejection refrigeration systems.[8]

∗ **Absorption systems:**

The first patent for a continuous absorption cycle machine was made in 1859 by French Ferdinand Carré using Ammonia as the refrigerant and the water as an absorbent. Then in the 1940s, Lithium bromide-water systems were introduced in United States to spread after globally for the use in air-conditioning fields. [8]

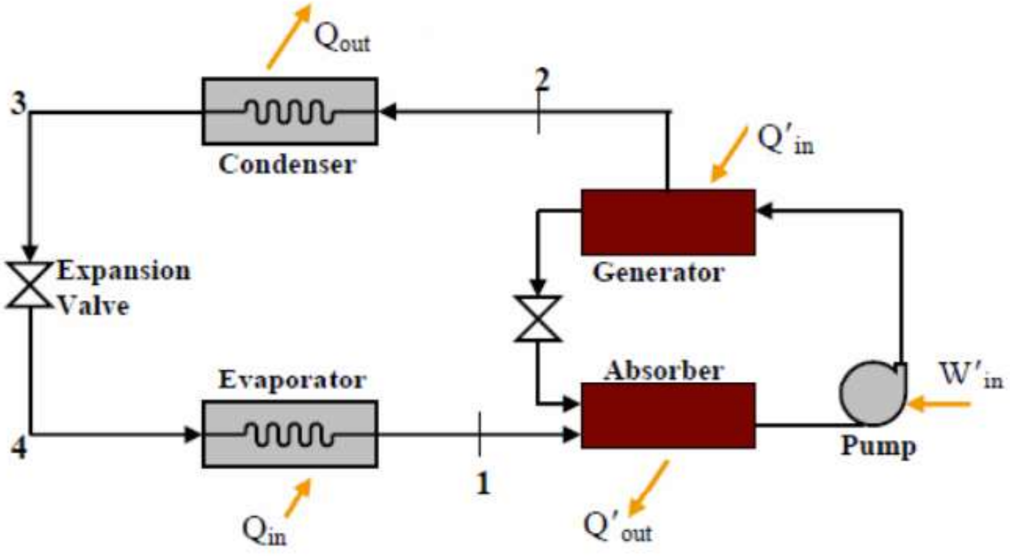


Figure 1:4 Schematic description of an Absorption cycle [8]

In this kind of systems as demonstrated in figure 1:4, starting by the refrigerant entering the evaporator as a low pressure mixture of liquid and vapor (4), where it absorbs heat and vaporizes. This vapor (1) is then absorbed by the absorbent in the absorber, keeping the low pressure. Then the mixture of the absorbent and refrigerant absorbed is pumped to a higher pressure to enter after that into the generator. In this area, heat is supplied to separate the refrigerant from the absorbent. The high-pressure refrigerant vapor (2) then continues to the condenser, where it rejects heat and condenses into a liquid (3). After passing through the expansion valve, pressure decreases to the evaporator level, completing the cycle.

These systems function without a mechanical compressor. Instead, it uses the thermal energy with a small mechanical work needed for the pomp. [11]

* **Adsorption and thermo-chemical systems:**

It was the first half of the 20th century when these machines were developed. They work by the thermal energy generated when a gas is taken up or released by a solid, in the other hand, thermo-chemical systems operate by the formation or the decomposition of chemical compounds with a refrigerant gas. [8]

* **Ejection systems:**

Without any moving mechanical parts, using an ejector to replace the mechanical compressor, these devices rely on the transferring motion from one fluid stream to another to perform the compression process. The first system entering the scene was in 1908 by the French Maurice Leblanc.[8]

The machine’s operation begins with the high pressure vapor leaving the generator being the primary fluid, this vapor then expands in the ejector nozzle. Within this expansion the pressure energy converts to kinetic energy, causing an augmentation in velocity and a sharp drop in pressure at the end of the nozzle area. The low pressure in this area draws in the secondary flowing fluid with a lower pressure, this secondary fluid merges with the high velocity primary fluid flow resulting in an increase in pressure to then enter the condenser. In it, the mixture release heat to the surroundings and condense into liquid to then move to the expansion valve where the pressure decrease before continuing to the evaporator. In the evaporator the refrigerant absorbs heat from the cooling space and evaporates before returning to the ejector, as presented in figure 1:5.[12]

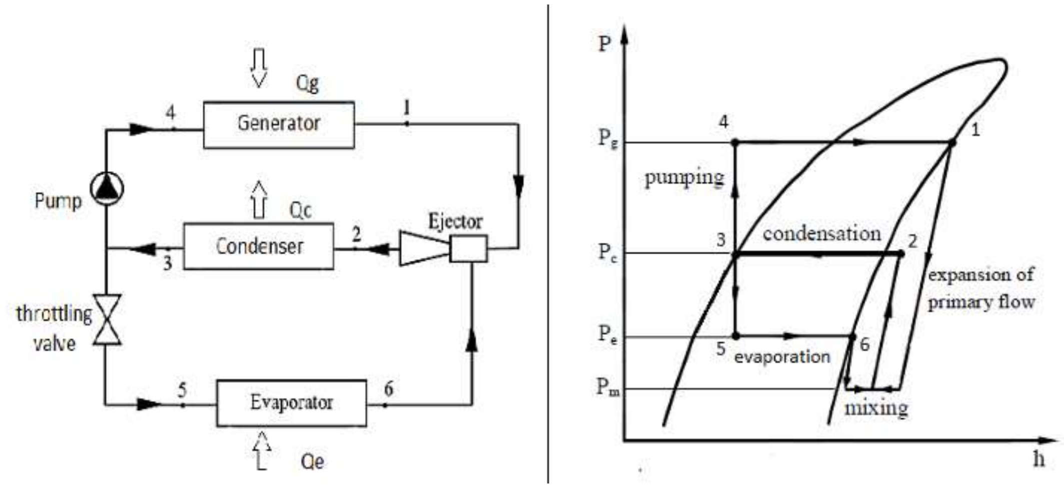


Figure 1:5 Schematic description and cycle of an ejection [12]

As demonstrated in figure 1:6, the ejector consists of three main areas:

- The nozzle: where the primary fluid velocity increase and the pressure drops creating a suction effect that draws in the secondary fluid flow.
- Constant area section: in this section the two fluid flows mix leading to a momentum transfer. A normal shock can happen causing a drop from supersonic to subsonic speed resulting and an augmentation in pressure.
- Diffuser: the mixture flow slows down, leading to a conversion from kinetic energy to pressure, to then exit the ejector at the condenser pressure. [12]

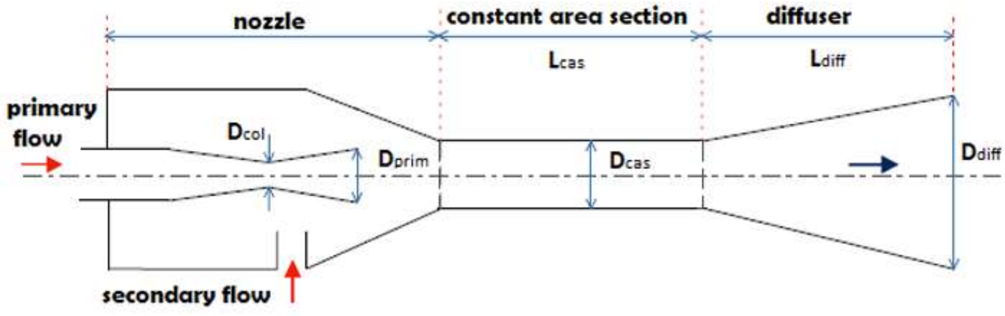


Figure 1:6 Schematic view of an ejector [12]

1.4.2. Thermal energy rejection from refrigeration systems:

Although refrigeration systems are designed to remove heat from a cold space, they produce thermal energy rejected in the form of heat. According to the formula:

$$Q_{rejected} = Q_{cond} = Q_{evap} + W_{comp} \; \dots\dots\dots\dots (1) \quad [13]$$

In cooling systems that operate without mechanical refrigeration components like cooling towers, the rejected heat is given by the formula:

$$Q_{rejected} = \dot{m}_{fluid} \cdot Cp_{fluid} \cdot \Delta T_{fluid} \; \dots\dots\dots\dots (2) \quad [14]$$

Rather than ignoring this heat rejection to turn into wasted energy, it can be captured and reused to fulfill other needs. This use of waste heat is beneficial for the overall energy efficiency, energy cost, and the environment. Making it from waste to a valuable source.

1.5. Renewable energies in cooling and refrigeration systems:

The switch toward the use of renewable energies in cooling and to provide thermal is common globally, for example solar assisted air conditioning are widely adopted due to its reliability and good results. In addition, using earth stable underground soil can be very efficient in meeting thermal demands.

The implementation of renewable sources is very beneficial on people's health's, reduces energy consumption, and decreases GHE. [15]

1.6. Studies made to optimize refrigeration systems:

In the recent years, a growing interest has been growing towards optimizing RS by recovering the rejected thermal energy as well as using renewable energies to fulfil various needs, among the studies regarding these goals are:

- Guemmouli M.C & Gohmes A (2018) used TRNSYS simulation to analyze and evaluate Lithium bromide-water (LiBr-H2O) absorption cooling system in Ouargla. This system utilizes well water at 60℃. They combined this absorption system with solar collectors to meet thermal demand for cooling in summer while reducing electricity consumption and greenhouse emissions.[16]
- Hamzaoui M (2019), by using experimentation with CFD simulation, this study aims to optimize a refrigeration system using low temperature sources (below 90℃) by converting these rejected temperatures into cooling. This rejected heat drives an ejector, letting the system operate at 52℃ generator temperature, and produce 35 kW cooling at 15℃ evaporation, making it a more efficient, ecofriendly cooling, with low energy consumption and cost.[17]
- Beniasadi E & al (2024), proposed a hybrid refrigeration system coupling solar powered adsorption with wind powered evaporative cooling. They developed a digital twin and then confirmed by experimental data. The system achieved a cooling effect of 20 kW and meets a peak thermal demand of almost 74 gJ/month. This system offers a sustainable and entirely free cooling solution for food preservation.[18]

- Derghout Z & al (2024), evaluated the performance and potential of energy saving of a solar powered absoption air conditioning system designed for the climate of Constantine, Algeria. Using simulation, they coupled an (LiBr-H2O) absorption system with solar thermal collectors. This study highlights the summer solar radiation achieving 220 kWh/m^2 that are highly suitable for driving these machines. These machines attended a COP ranging between 0.75 and 0.89, confirming the feasibility of the integration of solar energies into cooling systems.[19]
- Bendermane M & al (2025), optimized a solar adsorption refrigeration system. Utilizing the Dubinin-Astakhov (D-A) model, they simulated the system performance under local solar variations (Algiers, Constantine, Tlemcen, Ghardaia, Tamanrasset) with different working pairs (Activated Carbon/ethanol, Zeolite/Water, Composite/ethanol). Results showcased that Zeolite/water achieved the highest COP of 0.314. this study highlights the importance of choosing best adsorbent material based on climate data, leading to maximum solar cooling potential in Algeria. [20]
- Cui Z & al (2025) developed a waste heat driven cooling system based on absorption cooling for data centers, their triple stage (LiBr-H2O) is designed to operate with ultra-low grade waste heat at 50°C. This design enables 117% increase in in cooling power and reduces mechanical cooling demand by 80.5% in a case study in Guangzhou, China.[21]

1.7. Critical review of the recent studies cited:

The previous studies mentioned highlight the importance of thermal rejection recovery as well as implementations of solar energy into powering refrigeration systems. However, most studies are primarily optimizing absorption and adsorption systems and integration of solar energy, resulting for the cooling towers using ambient air and geothermal energy potential to receive limited attention.

In addition, most studies about waste heat recovery from refrigeration systems focus on the summer cooling potential, leaving winter heating potential largely ignored.

This study analyses a type of these overlooked towers, used in an industrial water treatment facility. In it, these systems are studied, and then replaced with a proposed optimized system that recovers rejected in winter, and utilizes geothermal energy in summer. This system satisfies heating needs in winter and cooling need in summer of a room that belongs to the facility. Additionally, this system also ensures the well water reaches cool temperatures required for the treatment process.

This approach enhances the energy efficiency, sustainability, and the longevity of the treatment machines while in reducing energy waste, and energy consumption.

1.8. Conclusion:

In conclusion, this chapter confirms the urgency of switching to sustainable and renewable energy sources, it structures the theoretical foundation for the study, in addition, the literature review and critique revealed limitations and gaps in studying cooling towers as refrigeration systems, and the use of geothermal energy in cooling. Ultimately, it points the lack of research in using the recovered heat energy for the winter season and geothermal cooling potential for summer in the region.

CHAPTER 2:

Area characterization, modelling, and evaluation of thermal Rejection

2.1. Introduction:

Designing efficient systems requires deep precise analysis of the area climate and structure.in this domain, this chapter focuses on the case study. First, it describes the climate of Ouargla and El Hdeb water station. Then it analyses the current water cooling system and evaluates the heat energy rejected by it. After that, it examines the building materials and their thermodynamic properties used to build the security room as an experimentation zone. Finally, it describes the operation process of both the brazed plate heat exchanger (BPHE) used in winter and ground to air exchangers (GAHE) and ground to water heat exchange systems (GWHE) used for summer. These processes will be used in the new optimized system to replace the current cooling system.

2.2. Study area presentation:

El Hdeb area is located in Ouargla in the southeast of Algeria. The area is known to have a Saharan climate with high temperatures and low rainfall, these conditions have led to limited water sources with ground water being the main source of water distributed to the population.

The production, treatment, management, and distribution of water in Algeria are the role of Algérienne des Eaux (ADE) company. Ouargla's units responsible for the extraction of water from deep wells called as forages. El Hdeb's unit is one of them and is highlighted in figure 2:1 [22]

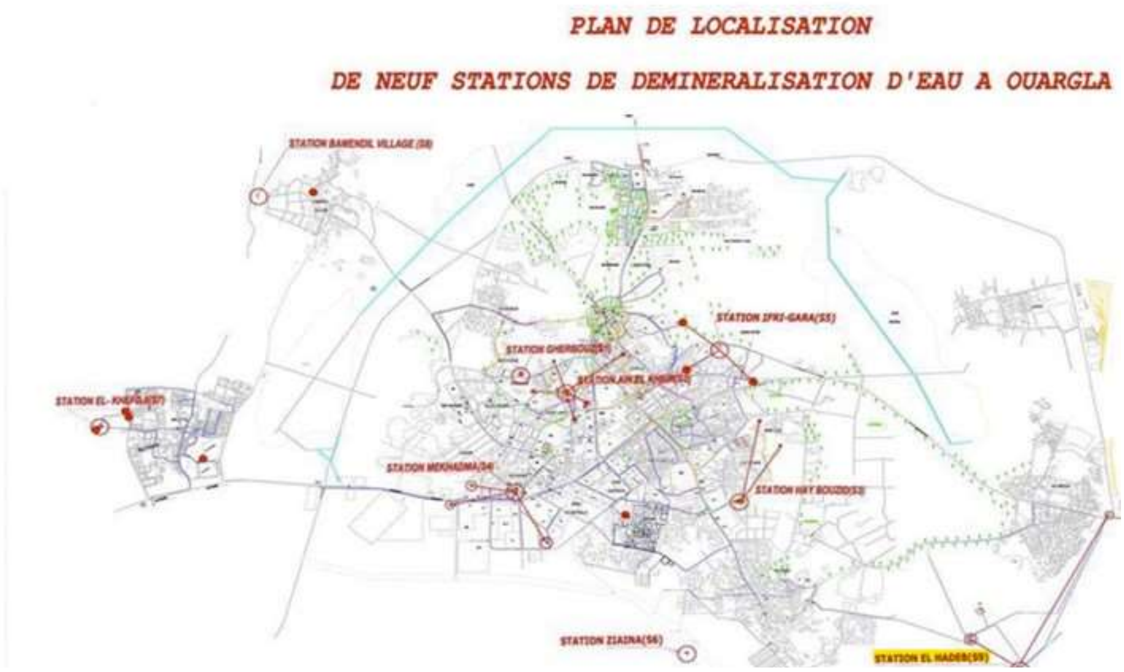


Figure 2:1 Location of the nine water demineralization stations in Ouargla [22]

As shown in figure 2:2, the station has the essential components for water treatment. This includes extraction, pre-treatment, filtration, reverse osmosis, chemical, and pumping units. Adding to that cleaning circuits and storage reservoirs to support this process.

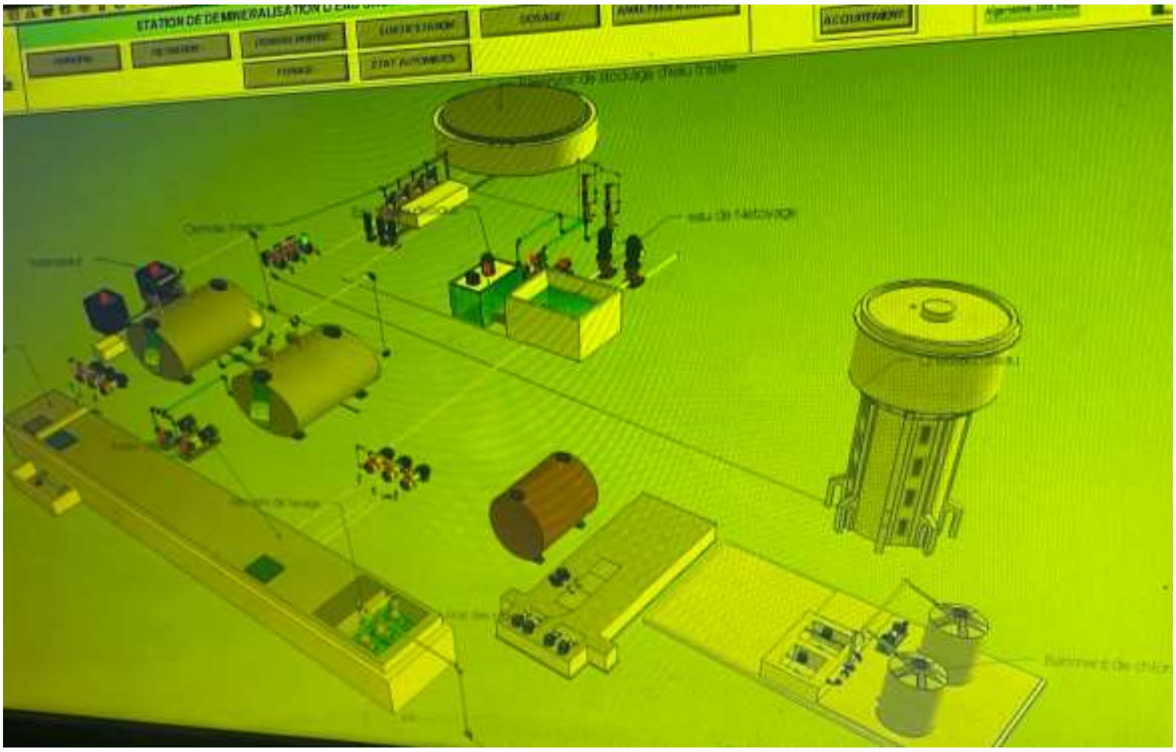


Figure 2:2 A 3D overview of El Hdeb's Water station (ADE).

Due to the depth of forages and geothermal conditions, the water extracted has a relatively high temperature of around 50 °C. This condition makes it unsuitable for direct use in water treatment machines as it may damage them or their functioning and efficiency.

To reduce this high temperature, an evaporative water-cooling tower is used. This system decreases the temperature of the water to around 24.5 °C.

2.3. Description of the cooling system:

In ADE El Hdeb station, the evaporative cooling tower is the type used to dissipate heat from hot water extracted from forages, as described in figure 2:3.

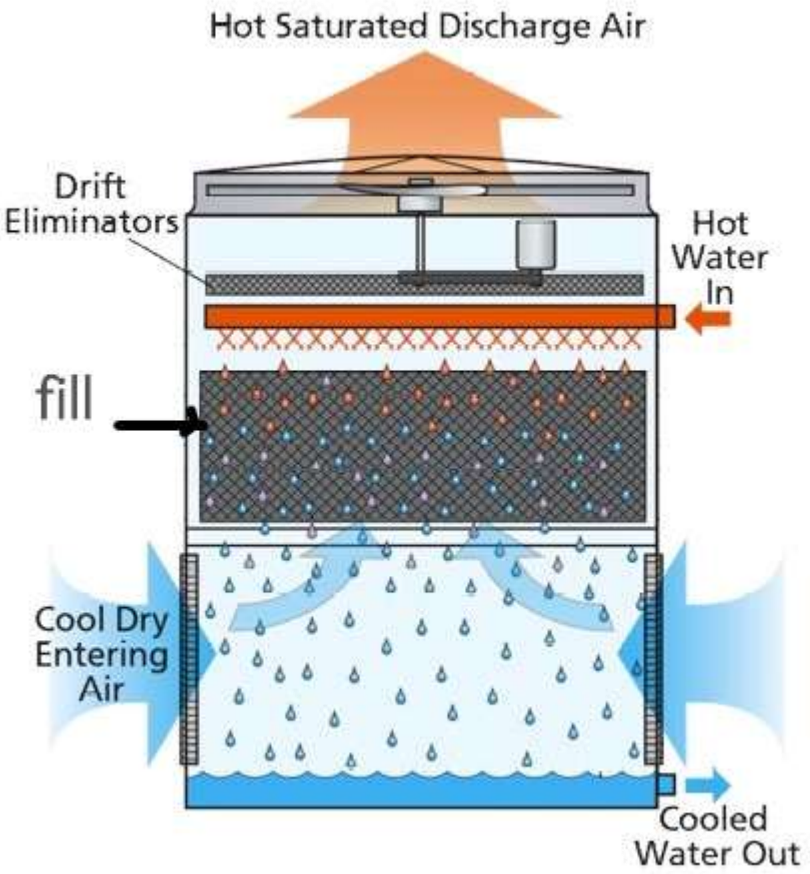


Figure 2:3 Evaporative cooling tower components [23]

An evaporative cooling tower operation process starts by the entering of hot water coming from forages at high temperature to be spread by distribution canals that has small openings called nozzles. These nozzles allow water to flow out evenly over the fill material below it, which increases the surface area of the water by breaking it to droplets. At the same time, air enters from the sides of the tower and moves upwards passing by the droplets causing small portions of it to evaporate absorbing heat from the remaining water and cooling it.

The drift eliminators capture the droplets attached to the air leaving the tower from above with the help of the fan, and the cooled water is collected by a basin at the bottom of the tower.[23]

This type of tower performs well in hot climate and require less fan power compared to other types. The air and water moving in opposite directions elevates the heat transfer make it more efficient for the facility needs. [24]

2.4. The thermal rejection from the cooling system:

In water cooling systems, the thermal energy rejected refers to the heat rejected into the atmosphere at the top of the tower. This form of energy is calculated using the following formula (2):

$$Q = \dot{m}_{water} \cdot Cp_{water} \cdot \Delta T_{water} \quad [14]$$

In our case, the values of the parameters used in this equation are provided from the ADE El Hdeb facility:

- $\dot{m}_{water} = \rho_{\text{water}} \cdot 0.13\ {}^{\text{m}^3}/_{\text{h}} = 1000 \cdot \frac{0.13}{3600}\ {}^{kg}/_{\text{s}}$

$$\dot{m}_{water} = 1000 * 3.61 * 10^{-5}\ {}^{kg}/_{s}$$

- $\text{T}_{\text{in (water)}} = 50\ \text{°C} = 323.15\ \text{K}$
- $\text{T}_{\text{out (water)}} = 24.5\ \text{°C} = 297.65\ \text{K}$
- $\Delta T_{water} = \text{T}_{\text{in (water)}} - \text{T}_{\text{out (water)}} = 323.15 - 297.65$

$$\Delta \text{T}_{\text{water}} = 25.5\ \text{K}$$

- Cp_{water} : this parameter is calculated based on the average temperature of the water. Based on the following table in the table 2:1, we can calculate the specific heat.

Temperature (°C)	Specific Heat (J/g·°C)
37	4.1783
38	4.1784
39	4.1785
40	4.1786
41	4.1787
42	4.1789
43	4.1791
44	4.1792
45	4.1795
46	4.1797
47	4.1799
48	4.1802
49	4.1804
50	4.1807
51	4.1810
52	4.1814
53	4.1817
54	4.1820
55	4.1824
56	4.1828
57	4.1832

Table 2:1 specific heat capacity data for water as a function of temperature [30]

- $\mathrm{T_{avg}} = \frac{\Delta T_{water}}{2} = \frac{50+24.5}{2} = 37.25\ K$

- $\boldsymbol{Cp_{water} \ = \ Cp_{\ T\ (bef)} + \left(Cp_{T\ (aft)} - Cp_{T\ (bef)}\right) \cdot \frac{T_{avg} - T_{(bef)}}{T_{(aft)} - T_{(bef)}}}$

$$\boldsymbol{Cp_{water} \ = 4.1738 + (4.1784 - 4.1783) \cdot \frac{37.25 - 37}{38 - 37}}$$

$$\boldsymbol{Cp_{water} \ = 4.178325 \ \mathrm{J/g} \cdot {}^{\circ}\mathrm{C} = 4178.325 \quad \mathrm{J/kg \cdot K}}$$

- $\boldsymbol{\mathrm{Q} = \ 1000 \cdot 3.61 \cdot 10^{-5} \cdot 4178.325 \cdot 25.5}$

$$\boldsymbol{Q = 3846.3571\ \mathrm{W} = 3.8464\ \mathrm{kW}}$$

In order to minimize the thermal rejection by the tower, a new system is recommended. This system uses a blazed plates heat exchanger (BPHE) to cool water and recover heat energy to satisfy comfort needs in winter. It also uses a ground to air heat exchange system (GAHE) in summer and an underground pipe to make cool water and recover heat and utilize in order to meet thermal comfort in summer.

2.5. Description of the application zone:

In order to evaluate the potential of the system and its behavior, a security room in the station is selected as an application zone. It is selected for the objective of providing comfort for the zone by the new proposed system.

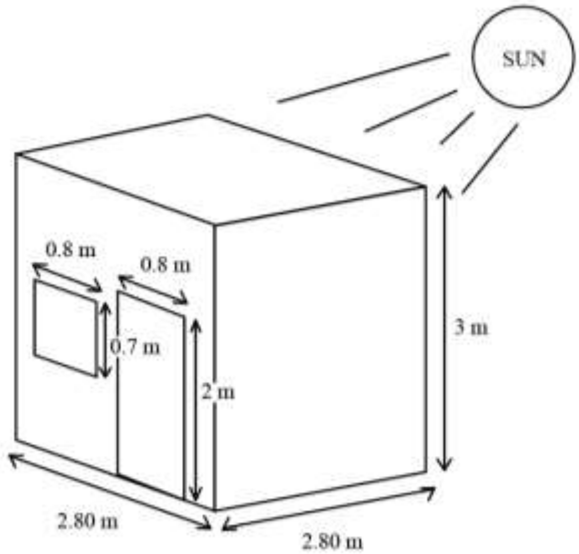


Figure 2:4 schematic representation of the security room

The security room illustrated in figure 2:4, is a structured as follows:

- Four exterior walls have an area of $8.4\ m^2$, they are built with the materials mentioned in the following table which are chosen directly from the TRNSYS library, and are ordered from interior to exterior layers:

material		Thickness (Th) (m)	Specific heat (Cp) $(kJ/kg \cdot K)$	Conductivity (k) $(W/m \cdot K)$	Density (d) (kg/m^3)
1	Interior plaster	0.02	0.8	0.3511	800
2	Hollow brick	0.1	0.794	0.4714	720
3	Air gap	0.05	1.227	0.06	1
4	Hollow brick	0.1	0.794	0.4714	720
5	Exterior render	0.02	1	1.1533	1700

Table 2:2 Thermodynamic properties of the wall's materials

One of the walls is the room's façade, it includes a (0.8 m · 0.7 m) double glazed window, as well as a (0.8 m · 2 m) wooden door with the thermodynamic properties presented in the table 2;3:

material	Thickness (Th) (m)	Specific heat (Cp) $(kJ/kg \cdot K)$	Conductivity (k) $(W/m \cdot K)$	Density (d) (kg/m^3)
Lightweight wood	0.04	1.2	0.1506	500

Table 2:3 Thermodynamic properties of the wood

- The floor is 7.48 m^2 . it is composed with different layers with thermodynamic properties ordered from interior to exterior, and are summarized in table 2:4:

Layer		Thickness (Th) (m)	Specific heat (Cp) $(kJ/kg \cdot K)$	Conductivity (k) $(W/m \cdot K)$	Density (d) (kg/m^3)
1	Ceramic tiles	0.02	0.7	1.7047	2300
2	Cement mortar	0.04	0.84	1.1533	2000
3	Heavy concrete	0.15	0.92	1.755	2300
4	Terra cotta	0.15	0.9	1.1533	1900

Table 2:4 Floor material's thermodynamic properties

- Similar to the floor, the roof is also $7.48\ m^2$. It is structured in distinct layers ordered from interior to exterior, and assembled in table 2:5:

Layer		Thickness (Th) (m)	Specific heat (Cp) $(kJ/kg * K)$	Conductivity (k) $(W/m * K)$	Density (d) (kg/m^3)
1	Plaster board	0.013	0.8	0.3194	790
2	Heavy concrete	0.2	0.92	1.7550	2300
3	Bituminous felt	0.02	1	0.5	1700
4	Outer roof layer	0.09	1.18	0.03	35

Table 2:5 The roof's materials thermodynamic properties

The sun rises from the back of the room, making that area face the east. As a result, the façade faces the west. The other walls are oriented to face the north and south respectively.

2.6. The Brazed plate heat exchanger:

The BPHE as presented in figure 2:5, is a known compact heat exchanger that is widely used around the world. In this type of heat exchangers, a series of rectangular shaped plates are closely arranged and brazed with copper together to form two channels. A hot fluid and a cold fluids flow through these separate channels made through the stacked plates, allowing heat transfer from the hot fluid to the cold one. [25]

Figure 2:5 BPHE in a counterflow configuration. [31]

This type of heat exchangers is chosen due to:

- Its compact design,
- High efficiency in heat transfer,
- It has high shock resistance,
- The ability to function at high temperatures attending to 250°C which equals 523.15 K,
- High durability. [26]

The BPHE captures a part of the heat energy. This recovered energy can be used to fulfill heating demand in winter. It is to be carried by the 25% inhibited propylene glycol water solution as a secondary fluid to the room and will circulate the loop thanks to a pump. This fluid is used for its protecting properties against corrosion, having a freezing point protection at around -10°C, and for being considered as nontoxic. [27]

2.7. Ground to air heat exchange (GAHE) systems for cooling:

These are buried systems of one or more pipes and a fan that moves air inside them. It has two distinctive types closed loop and open loop. Closed loop GAHE systems function by the air flow from inside the building through the pipes to a given depth where it exchanges heat with surrounding soil to then return to the building. In Open loops GAHE systems, the air is extracted from outside the building through the pipes into the building doing the same goal.[28]

Same process can be used to cool water using heat exchange with soil. This type of systems is called ground to water heat exchangers (GWHE).

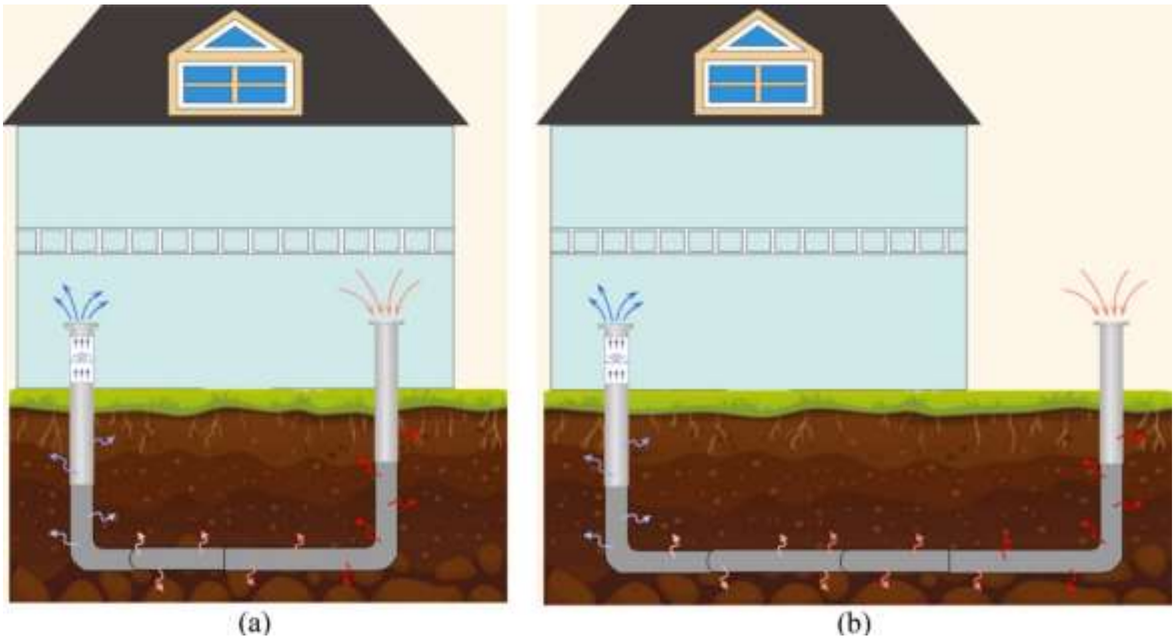


Figure 2:6 Schematic view of GAHE systems types: (a) closed loop, (b) open loop [28]

2.8. Conclusion:

This chapter established the parameters for the modification needed in el Hdeb water treatment station. The current system used wastes almost 3.85 kW into the atmosphere. Then, the security room is analysed to provide data needed for the simulation. Finally, the detailing on the BPHE, GAHE, and GWHE provided information to model about the new system.

CHAPTER 3:

Configuration and simulation results of the optimized system

3.1. Introduction:

Ensuring thermal configuration of the new system requires a transient simulation software to accurately predict its behavior. In this topic, this chapter starts by providing the overview of the TRNSYS software used for this study. Then it focuses on meteorological parameters in Ouargla and the configuration setup of the system highlighting different components and technical details to justify why they were chosen. After that, presents the operational modes across seasons. Finally, it analyses result to evaluate the performance of the optimized system.

3.2. Overview on TRNSYS:

Transient system simulation program is a reference software used by researchers around the world. It is used for detailed analyses of time dependent behavior of any system. Its flexible modular structure enables users to connect components called “types” an extensive library to create complex energy systems.[29]

Calculation values are entered as “inputs”, and the results are referred to as “outputs”. The components are connected via links where the outputs of the type serve as the inputs for the next.

Furthermore, buildings are modeled in a sub-program called TRNBUILD, allowing operators to change dimensions, wall materials, as well as changing the regime types of this specific zone[16].

3.3. TRNBUILD configuration

The guard room and its wall materials are modeled in TRNBUILD with the following parameters:

3.3.1. The internal gains of the room:

The gains of the post guard room were selected realistically in TRNBUILD based on the true values in the station:

- ASHRAE 160W AVII: This value is chosen based on ASHRAE standards describing the one person doing light office work. We assumed an 24/7 presence of the worker to ensure security of the facility.

- Lighting 6W/m^2: This represents the LED lighting installed in the room.
- SIA 2024occ 31office: It is selected to describe the electronic devices such as the computer and landline phone, as well as other electronic devices in the room.

3.3.2. Infiltration:

It is fixed at 1.5 h^{-1} in TRNBUILD which equals $4.1667 \cdot 10^{-4}\ s^{-1}$ because the room is a single zone, its door is frequently open.

3.3.3. Comfort:

The comfort values are based on the normal level of expectation of the European standard to define indoor environment criteria EN16798-1.

3.3.3.1. Comfort in winter:

The Comfort parameters are changed in TRNBUILD as follows:

- Because of the cold weather, temperatures can reach as low as 1℃. It is essential to fix the clothing factor to 1.2 clo.
- The guard duty is considered light work like sitting and writing and rarely standing up to open the door. Because of that, the metabolic rate is fixed at 1.2 met.
- For the external work it is fixed at 0 met.

3.3.3.2. Comfort in summer:

In summer, the clothing factor is the only parameter changed to 0.5 clo in TRNBUILD due to lighter clothing in this season. The other parameters remain constant.

3.3.4. Heating:

It is used with a set temperature of 20℃, and an unlimited sensible heating power.

3.3.5. Cooling:

It is used with a set temperature of 25 ℃, as well as an unlimited sensible cooling power.

3.4. Simulation configurations and results:

According to Figure 3:1, ambient temperature drops to 1℃ in mid-January in the winter season. For the summer season, it reaches to 48℃ in mid-July. These conditions require heating during winter and cooling in summer.

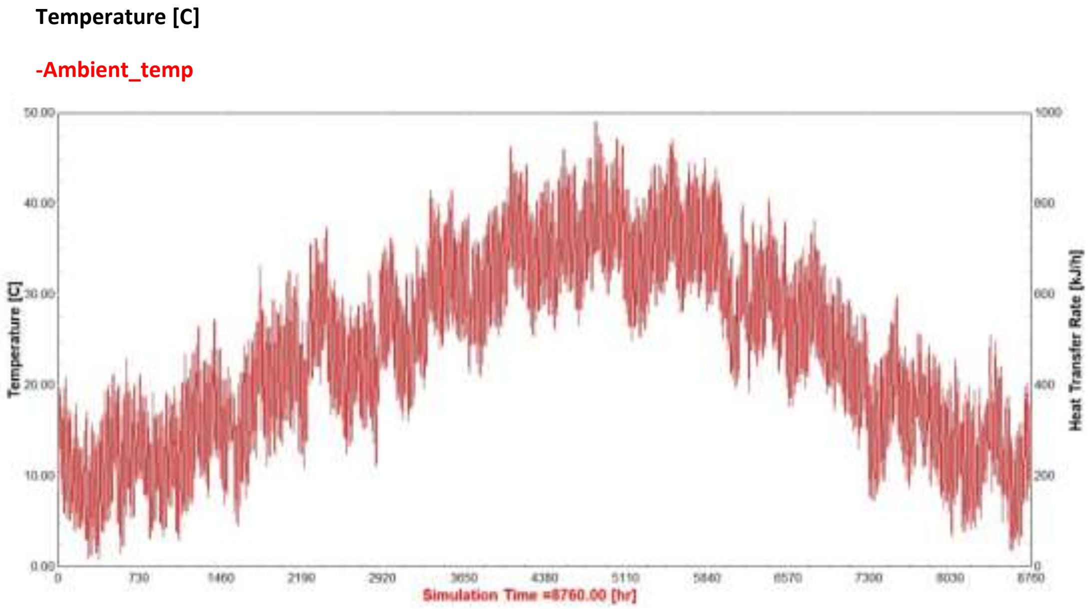


Figure 3:1 ambient temperature variation of Ouargla during one year.

Based on figure 3:2 that presents the soil temperature (℃)variation in relation to the soil depth(m), in the depth that are close to the surface (2m - 4m), soil temperatures change from 18 ℃ to 30 ℃ with seasonal weather variations. In the other hand, as depth increases from 6m to 10m, the soil temperature remains constant at around 23.3 ℃ all year round. This indicates that this land has big potential in cooling water from high temperature values, and 6m depth is the optimal depth to ensure high cooling potential.

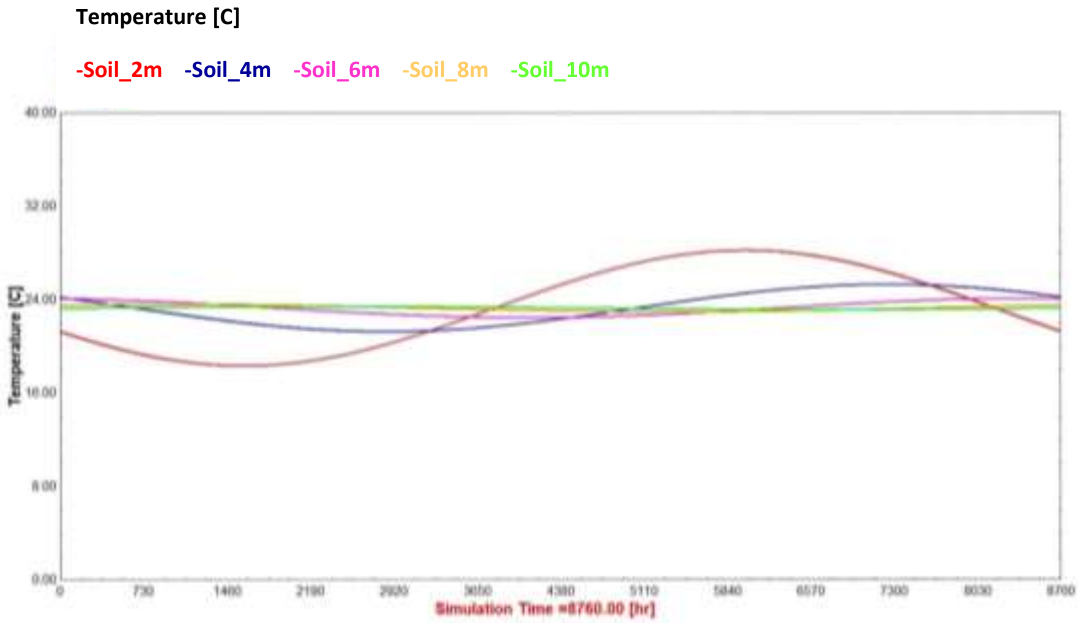


Figure 3:2 Soil temperature of Ouargla in different depths (2m-10m)

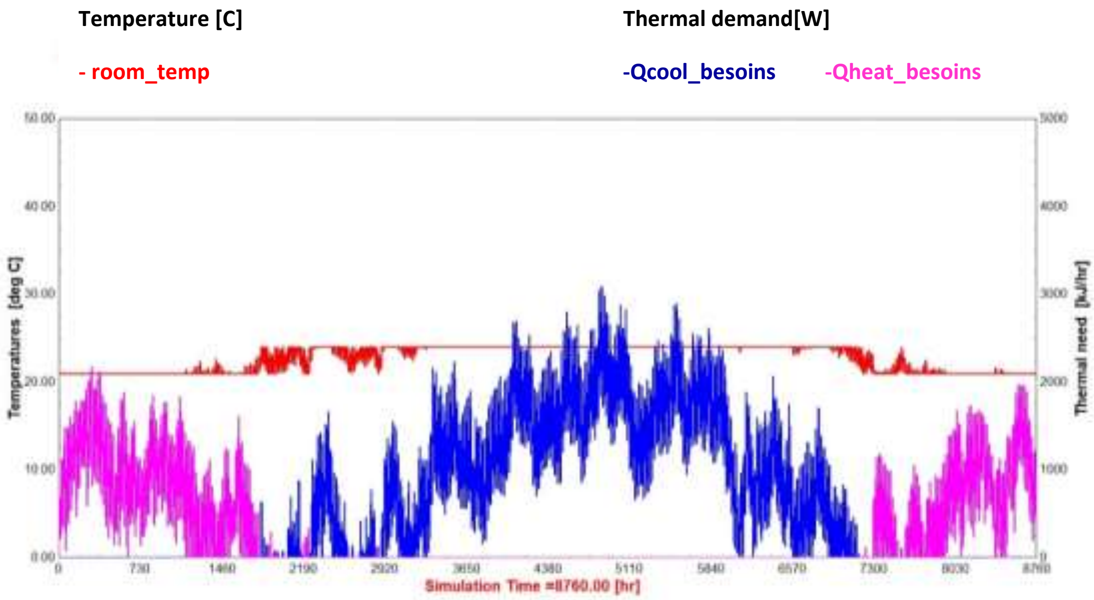


Figure 3:3 Yearly thermal demand of the security room to provide comfort.

Figure 3:3 illustrates significant thermal demands of the security room throughout the year. These demands rise in the winter season and peaks in mid-January at about 2200 kJ/hr which quals to 611.11W to achieve the temperature of comfort at 20℃.In the summer, thermal demands for cooling increase to reach around 3100 kJ/hr in mid-July which equals to 861.11W to get to temperature of comfort at 25℃.

3.4.1. Optimized system modelling:

Table 3:1 presents the components used to model the system as well as the room zone. Each one performs a purpose. Linked together, they simulate the system’s effectiveness to meet the room’s comfort requirements and necessity for the water to be delivered cool to the tanks of before treatment.

Types	Component name	Logo	Technical implementation
56	Multi-zone Building	Type56	This model is used to simulate the thermal behavior of the structure having multiple regime types.
15	Weather data file	Type15	This model reads and interpret Ouargla’s weather data in TMY2 format, in order to calculate the region temperatures, radiation, and seasonal forcing functions.
65d	Online graphical plotter without file	Type65d	This type is utilized to plot results of the simulation for different variables.
158	Vertical tank – no HX	Type158	It is selected to model a vertical tank to store water for the ADE facility.
5b	Counter-flow heat exchanger.	Type5b	Type 5b serves as a BPHE where heat is exchanged between the hot water loop and the heating loop in winter.
114	Single speed pump	Type114	The single speed pump is chosen to circulate the secondary fluid in the heating loop for the room in winter.
14h	Time dependent forcing function	Type14h	This model is implemented to generate well water temperature at 50°C as a forcing function all year long.

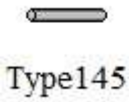
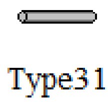
11f	Flow diverter - other fluids		This model is used to manually manage the flow of the well water through different loops based on seasons.
145	Duct		This duct model is used to serve as the duct pipe that air circulates through in a GAHE process.
146	Constant speed fan		It serves as the fan used in GAHE processes to circulate air through the duct pipe.
31	Pipe		This pipe is used to model the transport of the hot water from type143 to the underground depth.
77	Simple ground temperature model		This type is chosen to model soil temperature in order to simulate the geothermal cooling effect of the soil.

Table 3:1 TRNSYS components used in the optimized system.

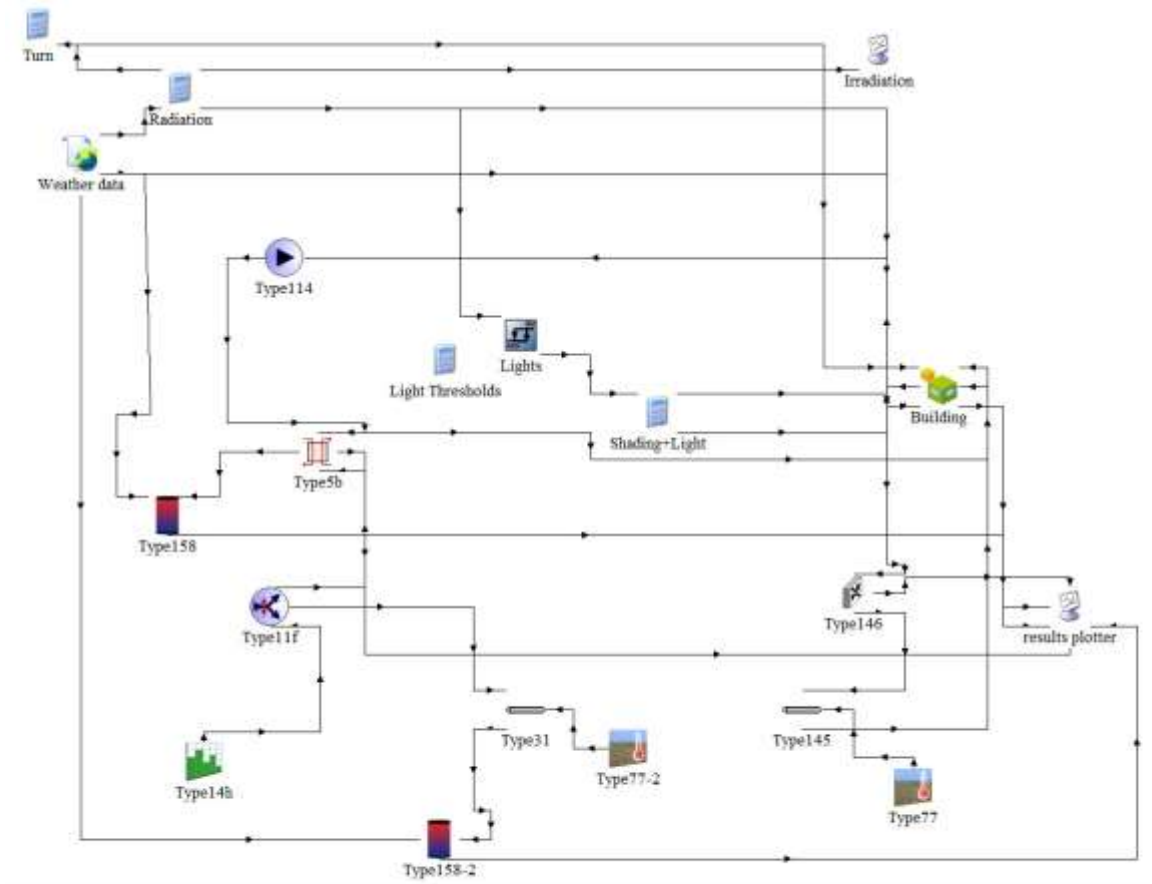


Figure 3:4 The modeling of the new system in TRNSYS.

The system showed in figure 3:4 functions in two modes that are controlled manually using the flow diverter.

- In summer, the flow diverter is fixed on mode 1. In this mode the hot well water comes at 50℃ and with a mass flow rate of 0.0278 kg/s to enter the carrying underground pipe that lengthens 100 m, in 6m depth where the soil is around 23℃. At this stage, water cools by GWHE before entering the tank used for storage before treatment. Through similar process the room is cooled when ambient air goes through the duct pipe to cool via open loop GAHE process and returned to the room.
- In winter, the flow diverter is put on mode 0. In this mode the well water comes at the same temperature at a mass flow rate of 0.0139 kg/s to enter the BPHE. This leads to the heat energy transfer between the hot water as a primary fluid and the cool 25% inhibited propylene glycol water solution as a secondary fluid circulating by a pump at 0.1111 kg/s. The heat transfer ensures water cool to the wanted temperatures before entering the tank that stores water before treatment, in addition,

secondary fluid is heated to enter the room via a coiled pipe helped with ventilation to meet the heating demand in this season.

3.4.1.1. Results of the summer circuit:

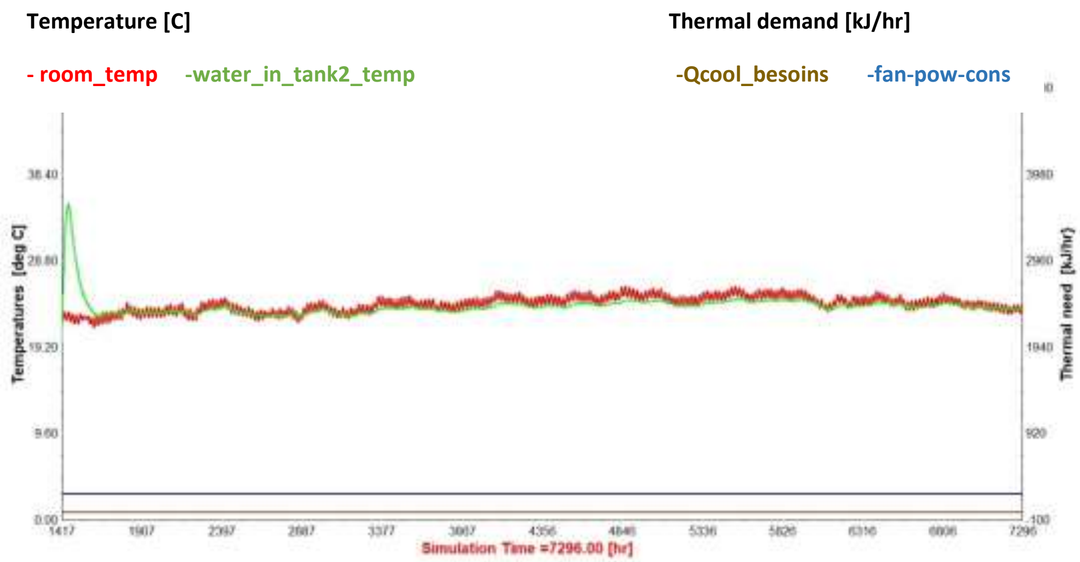


Figure 3:5 Thermal Performance of the summer Circuit (March–October)

As presented in figure 3:5, for the summer season starting in March and ending in in October, the circuit showed a success in:

- Maintaining the room at a cool temperature between 21°C to 25°C.
- Recovering 100% of thermal demand required for cooling for the room for the summer season.
- Cooling water to achieve temperature in tank at 23 to 24.5 °C after peaking at 36.5°C the first 40 hours of works due to start-up conditions of the system.
- Ventilator system consumes 60 W across this season making it a great energy saver, compared by air conditioners power consumption for this region in summer.

3.4.1.2. Results of the winter circuit:

The HEX overall heat exchange coefficient (UA) ranges between 2300-3200 $\mathbf{kJ/h \cdot K}$ equals 638.89- 888.89 W, and an efficiency of 97%.

The pump consumes 2680.7kJ/h which equals to about 0.75 kW.

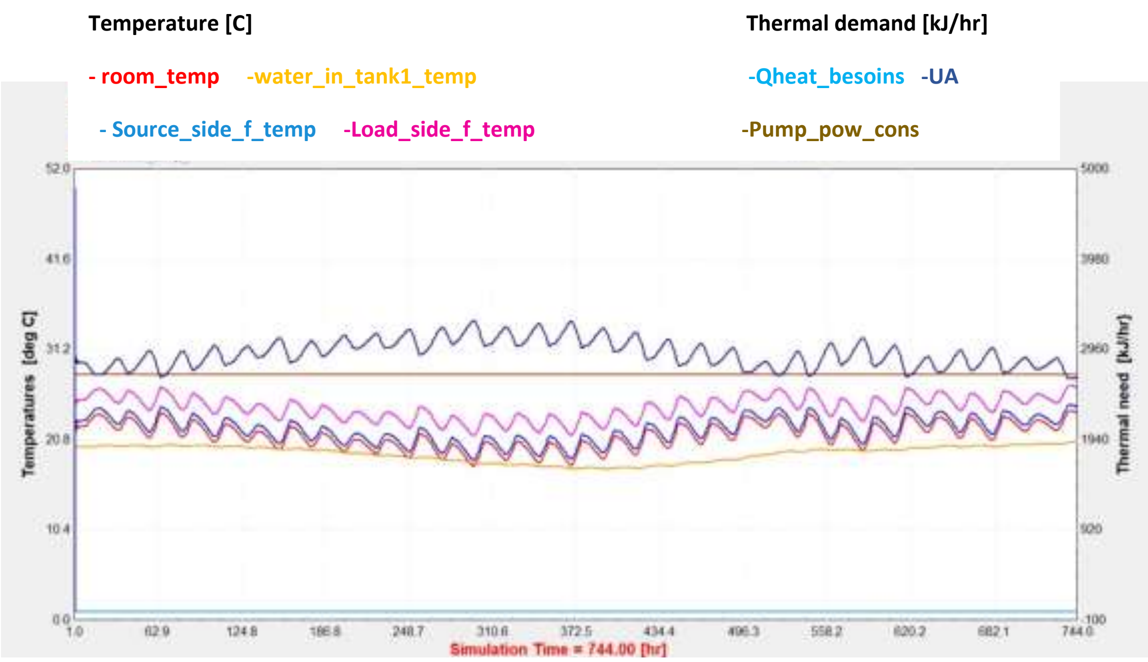


Figure 3:6 Thermal Performance of the winter Circuit

(January – February)

Figure 3:7 HEX efficiency (January- February)

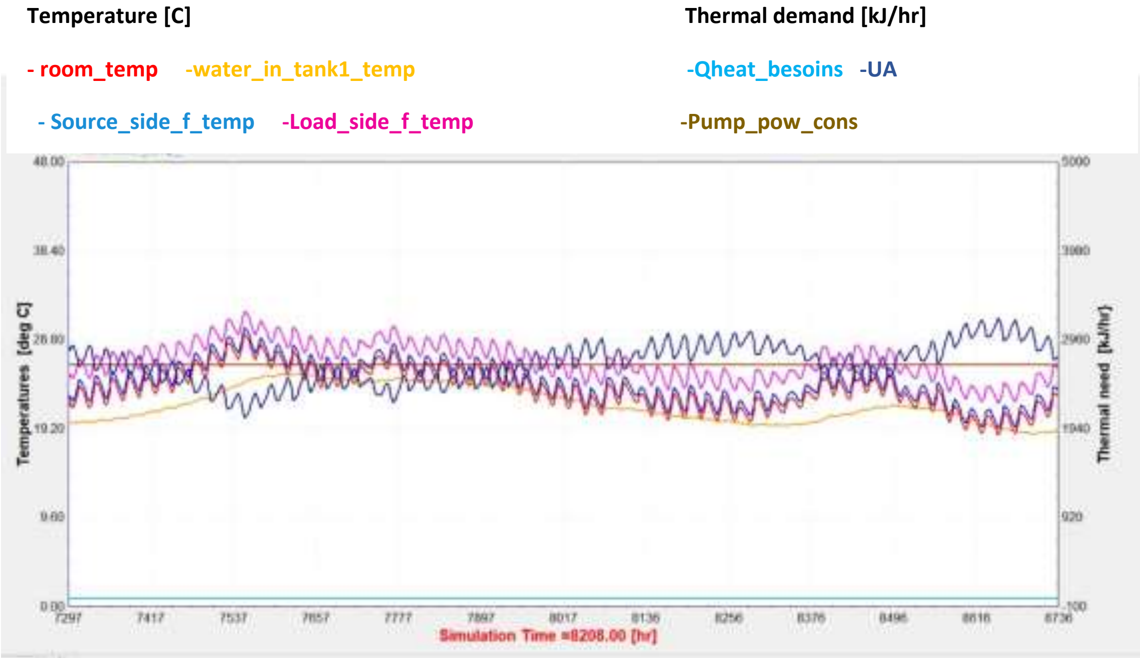


Figure 3:8 Thermal Performance of the winter Circuit (November– December)

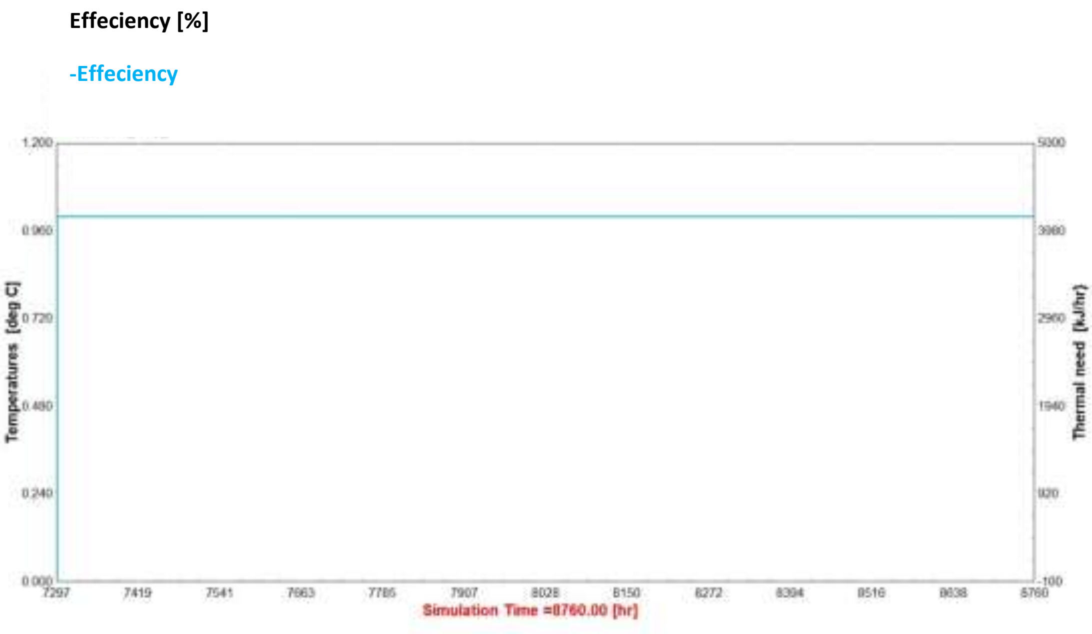


Figure 3:9 HEX efficiency (November-December)

As shown in both figure 3:6 and figure 3:8, in winter season starting from January to end of February and from November to end of December, the winter circuit succeeded in:

- Maintaining the room's temperature from 20℃ to 26℃ making it comfortable during the cold season.
- Recovering 100% of thermal demand required for heating for the room.
- Achieving temperature of water sent to the tank at 24℃ which is suitable for treatment machines for most season.

3.5. Conclusion:

Ultimately, this chapter provided the system's performance. It shows that the chosen components met the need of the ADE El Hdeb facility. The simulation results showcased the system's performance to provide comfort at between 20℃ and 26℃ in winter and 21℃ and 25℃ in summer, recover the heating demands of 612W in winter and cooling demands 861W in summer. In addition, it cools water to precise temperatures between 23℃ and 24. 5℃ optimal for the treatment process. These results confirm the potential of the new system to replace the current water cooling tower and to reduce energy consumption for cooling and heating systems.

General conclusion

This research work focused on the transition from the current water cooling system at ADE el Hdeb facility to an optimized system utilizing heat recovery and geothermal energy. It is a dual circuit system utilizing a BPHE alongside a pump for heating in winter and GAHE alongside GWHE for summer cooling. This system also ensures water is cooled at suitable temperatures via the heat exchange 25% propylene glycol in winter, and by a pipe going underground where soil is cool in summer. This makes water stored for treatment available across all seasons.

The simulation results obtained through TRNSYS showcased the potential of the proposed system in satisfying the thermal demand in heating at 20℃ to 26℃ in winter and cooling at 21℃ to 25℃ for the summer season. In addition, it achieved the precise wanted temperatures for water by heat exchange in the BPHE in winter, and by heat exchange with soil in summer, achieving lower than 24.5 ℃ before the water treatment stage.

Ultimately, this study offers an idea in increasing energy efficiency, the equipment longevity and reliability, and in reducing energy consumption, and energy waste. It aligns with Algeria's goal toward sustainability and renewable energy integration goals.

Recommendations:

- Solar energy integration using photovoltaic (PV) system to power the circulation pump in winter circuit and the ventilator of the GAHE in summer circuit, which transitions the facility towards a Net-Zero energy operation.
- Implementing automated control system with temperature sensors to manage between the seasonal operational modes.
- Improve the room insulation to further reduce energy losses and demands.
- Scaling this model across other Saharan stations, and across other industrial processes.

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