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Experimental Study Of A Peripherally Integrated Air/Soil Heat Exchanger Around An Underground Water Tank In Arid And Semi-Arid Regions

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Jury:

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Étude expérimentale d'un échangeur air/sol intégré périphériquement à une bâche de stockage de l'eau dans les régions arides et semi-arides

Jury :

Pr.	Adel Benchabane	Pr	Université de Biskra	Président
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Dedication

To my hero, my support, my strength

to you, my dear dad.

To my soul, my life, my trust

to you, my dear mom.

To the light and roses of my life, my candles

to you, Samiha, Yassmine, Mouataz Billah, and Ahmed.

To those who have illuminated my path and left a mark on my life

thank you.

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Nomenclature

Symbol	Designation	Unit
Cp	Heat capacity	$J.kg^{-1} .K^{-1}$
Cp_{air}	calorific capacity of the air	$J.kg^{-1}.k^{-1}$
$D_{inner -tube}$	Inside diameter of buried exchanger pipe	m
h_{conv}	convection coefficient of air	$w.m^{-2}. k^{-1}$
L	length of exchanger	m
m	Mass flow rate	$kg.s^{-1}$
R	External radius of buried tube	m
r	Internal radius of buried tube	m
R_{conv}	Thermal resistance convection between air and tube	$m^2.k.w^{-1}$
R_{soil}	Radius of the adiabatic soil layer	m^2.k.w-1
R_{tub}	Thermal resistance of buried tube	m^2.k.w-1
t	time	h
t_0	the day that has maximum temperature in the year	days
$T_{air-inlet}$	Air temperature at the inlet	C°
$T_{air-outlet}$	Air temperature at the outlet	C°
T_{amb}	Ambient temperature	C°
T_{max}	maximum temperatures	C°
T_{min}	minimum temperature	C°
T_{soil}	Soil temperature	C°
U	Total thermal conductance between air and soil	$w.m^{-2}.k^{-1}$
V_{air}	Velocity of the air inside the exchanger	$m.s^{-1}$
Z	the depth of burial from the surface of the air/soil heat exchanger	m

Dimensionless Number

Nu	Nusselt number
Pr	Prandtl number

Re	Reynold number	

Abbreviations

ACHP	Air Cooled Heat Pump
ASHP	Air Standalone Heat Pump
ACC	Air-Cooled Condenser
CFC	Chlorofluorocarbon
DBGHE	Deep borehole Ground Heat Exchanger
EAHE	Earth Air Heat Exchanger
EAM	Exchanger Abdelhafid Moummi
GHE	Ground Heat Exchanger
GSHP	Ground Source Heat Pump
HVAC	Heating Ventilation Air Conditioning
HAGHE	Horizontal Air-Ground Heat Exchanger
PCM	Phase Change Material
PGHE	Pile Ground Heat Exchanger
VBGHE	Vertical Borehole Ground Heat Exchanger
WCHE	Water-Cooled Heat Exchanger

Greek letters

α	the thermal diffusivity	$m^2. days^{-1}$
λ_{air}	Thermal conductivity of air	$w.m^{-1}. k^{-1}$
λ_{soil}	Thermal conductivity of soil	$w.m^{-1}. k^{-1}$
λ_{tub}	Thermal conductivity of the buried tube	$w.m^{-1}. k^{-1}$
μ_{air}	Dynamic viscosity of the air	$kg.m^{-1} .s^{-1}$
ρ	Density	$kg.m^{-3}$

General Introduction

“*We are the first generation to feel the impact of climate change and the last generation that can do something about it” (Barack Obama)*

General Introduction

Thermal comfort contributes to overall satisfaction, well-being, and performance,[1] as it presents the condition of someone who expresses well-being when considering the thermal environment in an inhabited zone.[2] It is described in general as the condition of someone who expresses well-being. The level of thermal comfort is one of the most essential aspects that engineers take into consideration when developing various designs. However, this level of thermal comfort is typically reached by employing a significant quantity of electrical energy.

The United Nations General Assembly (UN-GA) established a set of 17 interconnected global goals, in 2015[3]. These goals, which are collectively referred to as the Sustainable Development Goals (SDGs), are intended to be completed by the year 2030 and serve as a "blueprint to build a better and more sustainable future for all". Because of this, engineers have been looking into alternative methods of achieving thermal comfort through the use of renewable energies, with a particular emphasis on the ecological paradigm. The objectives of energy policies are aligned, and they promote distributed energy resources and energy efficiency. Thus, the use of renewable energy for power generation, primarily wind, solar, and geothermal “underground” energy, has increased significantly in recent years, in conjunction with efforts to develop a low-carbon society and mitigate climate change. The primary objective is to generate the most energy feasible while incurring the fewest possible expenses, using the least amount of space, and exerting the fewest possible efforts[4].

The potential of the Earth's geothermal “underground” resources is immense when compared to their current use and humanity's prospective energy demands. In recent years, geothermal sustainability has been discussed in the literature, in part because the term "sustainable" has become quite trendy[5]. Consequently, researchers have paid great attention to underground energy because it enables them to exploit its energy at the lowest cost, especially on ground-based heat exchangers in desert areas, including Hamdane et Moummi [6], who were interested in a study of systematic prediction of the outlet temperature of an air/soil exchanger in arid and semi-arid regions for different types of soil.

The growing demand for energy efficiency and the limited availability of space in various applications present a significant challenge. In this work, we aim to investigate and identify innovative solutions and technologies that can achieve high energy density and efficiency within minimal spatial constraints. Through a review and a bibliographic study, this research aims to answer the fundamental question: How can we obtain great energy from the smallest space??

Both numerical and experimental research have been conducted. A study was undertaken to examine the impact of integrating the underground water tank. The exchanger (EAM) realized by Professor Abdelhafid Moummi in the city of Lichana, Biskra, Algeria. A numerical model was created to calculate the outlet temperature of the heat exchanger. Experimentally, an underground water tank was built and surrounded by a heat exchanger consisting of PVC pipes distributed to varying depths from 1.2 to 2.4 meters and wrapped externally around the water tank, with a length of 27 meters. The major advantage of this design lies in its small installation surface, and the possibility of application in most buildings, which should considerably reduce electricity consumption, benefiting both citizens and the government. Our study will focus on the compromised effect of obtaining thermal comfort in the residential sector to design future bioclimatic buildings with low energy consumption.

This study is structured around four chapters:

- The first chapter includes the fundamental principles of buried air/ground heat exchangers as well as a brief review of some relevant previous research on the subject.
- The second chapter presents a detailed description of the experimental setup, including the location chosen, the measuring instruments used as well as the approach followed during the taking of the measurements.
- The third chapter is devoted to the development of a calculation code using three analytical models, which were adapted to our configuration, to simulate the thermal behavior of the exchanger for different operating conditions.
- The last chapter is dedicated to an analysis and interpretation of the results obtained both by the experimental device and by the numerical model.
- Finally, a general conclusion, which summarizes the objective of the work, the methodology followed for its implementation with the main results obtained.

Chapter I:

Bibliographic study and general information on the principle of Earth/air heat exchangers.

I.1 Introduction

In response to growing concerns about carbon dioxide emissions and global warming, the exploration of renewable energy development and utilization has emerged as a strategy to mitigate the environmental impact of space heating and cooling. This chapter provides a comprehensive review of developments and advancements in three types of Ground Heat Exchangers (GHE): Vertical Borehole GHE (VBGHE), Pile GHE (PGHE), and Deep Borehole GHE (DBGHE), which are currently prevalent in larger Ground Source Heat Pump (GSHP) systems. The first section focuses on analytical models proposed to analyze the heat transfer process of VBGHE under various geological conditions, including homogeneous or heterogeneous ground, with or without groundwater advection. The review encompasses numerical and short-time step models, along with measures to enhance the thermal performance of GHE. The second part offers a summary of research advances in PGHE, covering heat transfer models, the influence of geometric structure, operational modes, pile spacing, use of phase change material (PCM), and thermal properties of PCM, as well as thermo-mechanical considerations.

I.2 Generality

I.2.1 Arid and semi-arid regions

An arid region is characterized by a level of precipitation well below the minimum required to support most types of vegetation and ecosystems. Aridity is often quantified using aridity indices, such as the relation between potential evapotranspiration and precipitation. Arid regions generally have limited vegetation cover, high evaporation rates, and minimal surface water availability.

A semi-arid region represents a climatic zone intermediate between arid and humid regions, characterized by levels of precipitation that are moderate, insufficient to maintain extensive vegetation, but not as severely restricted as in arid environments. Semi-arid climates often exhibit rainfall variability, with distinct wet and dry seasons. Table I.1 below summarizes the main differences between arid and semi-arid regions.

Ma et al [7], highlight the pervasive impact of drought on various regions across the globe throughout the 21st century. This phenomenon is projected to intensify due to the predicted consequences of global warming, manifesting as increasingly extreme climatic events such as heat waves and droughts in the coming decades.

Table I-1: Characteristics of Arid vs. Semi-Arid Regions[8]

Feature	Arid Region	Semi-Arid Region
Precipitation	< 250 mm/year	250-500 mm/year
PET	High	High
Aridity index	< 0.2	0.2-0.5
Vegetation	Sparse, drought-adapted	Grasslands, shrubs, some trees
Agriculture	Limited, often reliant on irrigation	Possible with careful water management

Figure I.1 visually depicts the global distribution of climatic zones, highlighting the extensive presence of arid regions. Notably, over 41% of Earth's land surface falls within this classification, exemplified by Algeria where aridity encompasses more than 80% of its territory. Despite these dry conditions, these climatic zones are surprisingly populated, housing over a third of the global population[9].

The prevalence of extreme heat waves has rendered arid regions particularly challenging for human habitation. This dire circumstance is anticipated to escalate due to the ongoing impacts of climate change and the shifting weather patterns attributable to human activities[10].

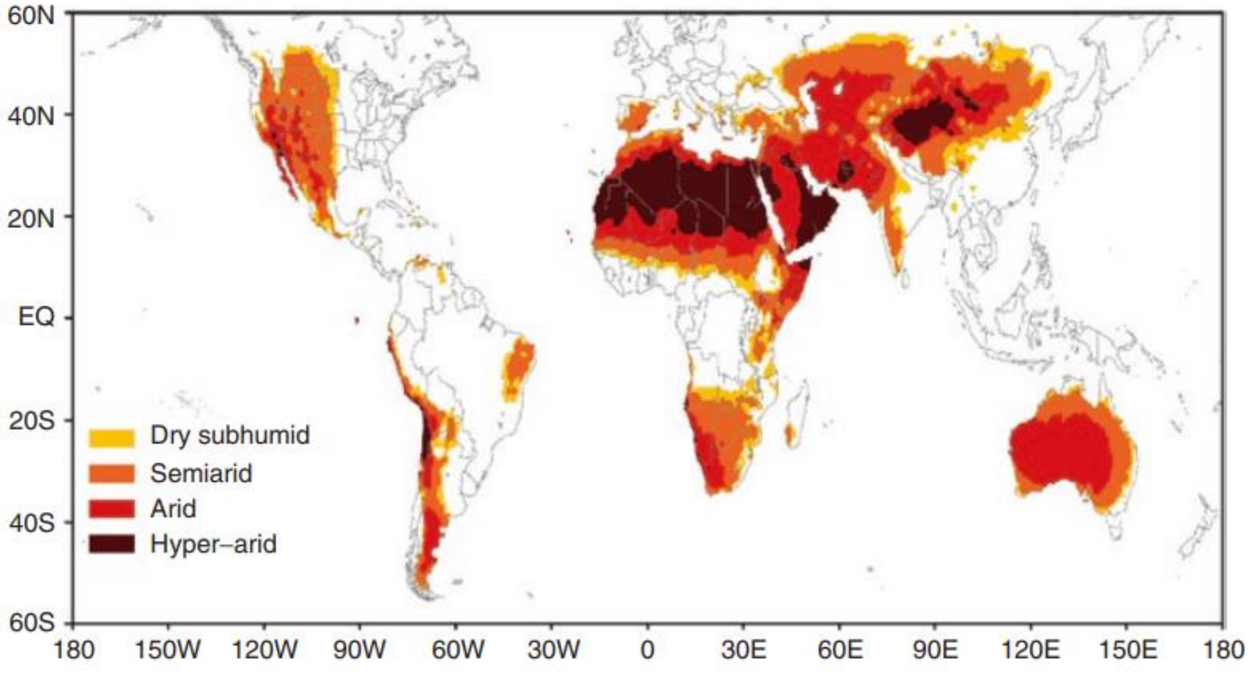

Figure I.1 Map of the global distribution of climatic zones[10].

I.2.2 Types of energy: geothermal energy

You've provided a great overview of the three main types of geothermal energy based on their temperature ranges and applications. Let's dive deeper into each type to understand their nuances.

I.2.2.1 High-energy geothermal energy

High-Energy Geothermal Energy (80°C - 300°C):

Electricity Generation: This "hot rock" resource is the workhorse of geothermal power production. Flash and Binary cycle power plants utilize steam or hot water to drive turbines and generate electricity. Examples include The Geysers in California and Hellisheidi Power Station in Iceland.

Industrial Processes: High temperatures make this suitable for various industrial applications like paper production, food processing, and mineral extraction.

Advantages: Highly efficient electricity generation, reliable baseload power, and minimal land use compared to fossil fuel plants.

Disadvantages: Limited geographically to areas with active volcanic zones or tectonic plate boundaries, high upfront drilling and infrastructure costs, and potential for hydrogen sulfide[11].

I.2.2.2 Low-energy geothermal energy

Low-Energy Geothermal Energy (30°C - 100°C):

District Heating: This "warm water" resource is ideal for heating homes and buildings in entire communities through networks of underground pipes. Examples include Reykjavik in Iceland and Budapest in Hungary.

Greenhouse Heating: Provides a constant and sustainable heat source for growing fruits, vegetables, and flowers year-round, especially in colder climates.

Aquaculture: Warms fish farms, promoting faster growth and higher yields.

Advantages: More widely available than high-energy resources, lower development costs, and environmentally friendly heating alternative.

Disadvantages: Lower energy output compared to high-energy resources, requires extensive piping infrastructure for district heating, and potential challenges in maintaining optimal water temperature for specific applications[12].

I.2.2.3 Very low-energy geothermal

Very Low-Energy Geothermal Energy (10°C - 30°C):

Geothermal Heat Pumps: This "ground source" resource leverages the Earth's constant underground temperature to provide efficient heating and cooling for individual buildings. Heat pumps transfer heat from the ground in winter and vice versa in summer.

Advantages: Highly efficient and cost-effective heating and cooling system, reduces reliance on traditional fossil fuel-based systems, and environmentally friendly[13].

Disadvantages: Requires installation of geothermal heat pumps, initial investment might be higher than conventional systems, and heating/cooling capacity might be limited in extreme weather conditions[14].

I.3 Geothermal resources in Algeria

Algeria has several hot water sources with temperatures varying between 20°C and 98°C. In the north, there are around 200 thermal sources, with temperatures ranging from 22°C to 90°C, and in the Sahara sedimentary basin there are huge reservoirs of hot water varying from 50°C to 56°C. There are also high-temperature sources, with temperatures of up to 118°C at Ain Ouelmen and 119°C at Biskra.

As we can see, the geothermal potential in our country is very high, to exploit and develop it. In southern Algeria, there are several sources at depths varying in depth from 80 meters in the El Meni'a region to 1,500 meters at Touggourt, with temperatures ranging from 40 to 60°C, offering great potential for heating greenhouse heating[12].

I.4 EAHE systems

I.4.1 EAHE system significance

The EAHE system is a passive system that shares many of the same specifications as passive systems. It is an environmentally friendly alternative to conventional air-conditioning systems, which contribute to ozone depletion and global warming due to chlorofluorocarbons (CFCs). The energy consumption of the EAHE system is negligible compared with that of conventional air-conditioning systems. The design of the EAHE system is straightforward, as will be shown in the next component. Unlike many passive systems, the ground can be used as a heat source. This is signified by an undisturbed temperature at certain depths throughout the year. This undisturbed temperature is generally lower than the ambient air temperature in summer and higher than the ambient temperature in winter, making the EAHE system effective for pre-cooling habitats in hot periods (summer) and pre-heating them in cold periods (winter)[9].

I.4.2 EAHE system designs

The EAHE system can be designed in two different types: Individual design or integrated design.

I.4.2.1 EAHE system individual designs

This part presents a comprehensive review of the latest developments and advances in three types of geothermal heat exchanger (GHE), including Vertical borehole GHE (VBGHE), Pile GHE (PGHE), and Deep borehole GHE (DBGHE) that are currently popular in large GSHP systems. The analytical models suggested to analyze the VBGHE heat transfer process under various geological conditions are summarized. On the other side, a summary of research advances in PGHE is provided, which includes the heat transfer models of PGHE, the effects of geometric structure, operation modes, pile spacing, use of phase change material (PCM), thermal properties of PCM, thermo-mechanical behavior and/or thermal performance of PGHE. The effects of groundwater flow direction and velocity on PGHE are also summarized briefly[15].

Ground source heat pumps (GSHPs) offer considerable potential for energy conservation in residential and commercial buildings, contributing to CO_2 emission reduction and air pollution prevention [2]. A typical GSHP system comprises a ground heat exchanger (GHE), heat pump units, and a terminal system within the building. Geothermal energy utilization in this context is primarily indirect, relying heavily on the performance of the GHE. This review focuses on four prevalent GHE designs: horizontal GHEs, vertical borehole GHEs (VBGHEs), pile GHEs (PGHEs), and deep borehole heat exchangers (DBGHEs), illustrated in Figure.I.2**.** Due to its inherent requirement for expansive land area, the horizontal GHE is excluded from further discussion in this paper. Table.I.2. provides a comparative analysis of the advantages and disadvantages associated with these four representative GHE types.

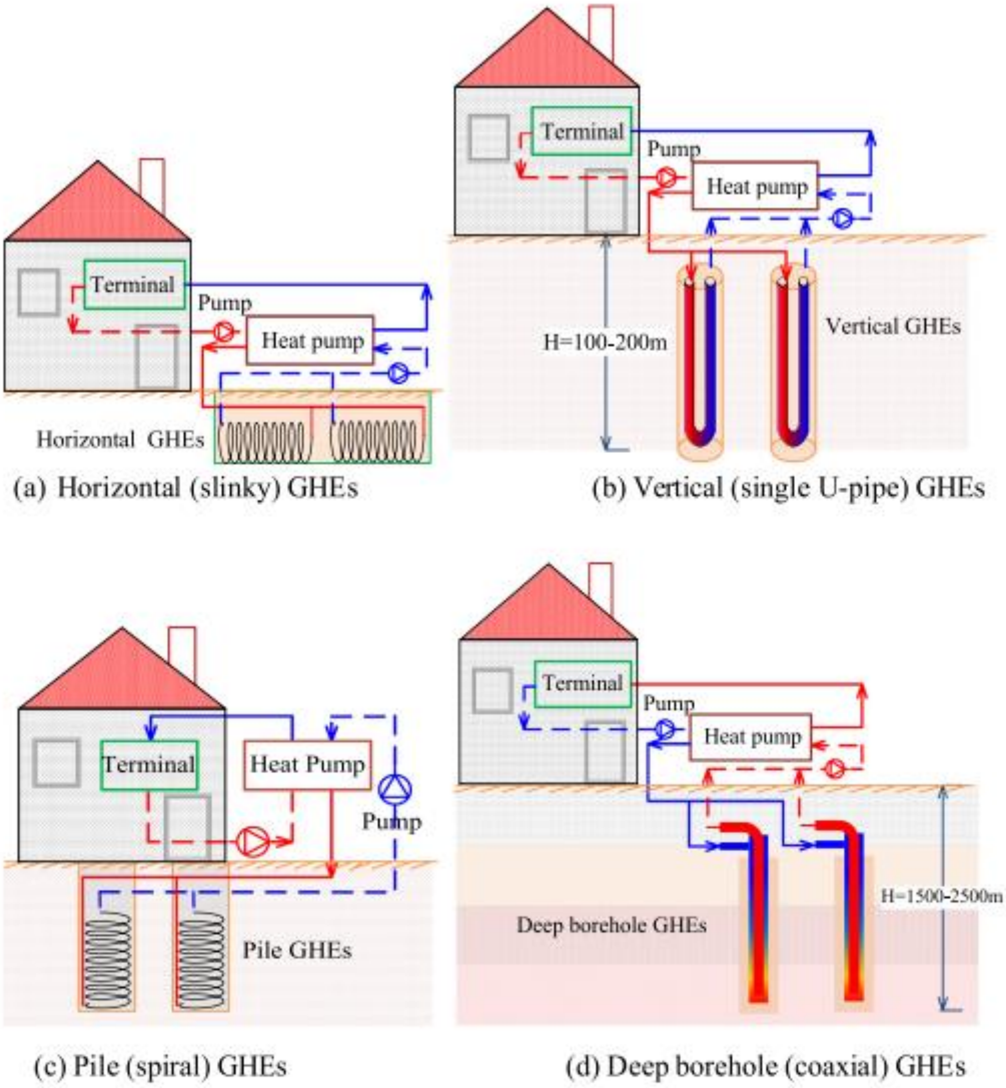

Figure I.2 The main schematics of four typical GHEs[15].

Table I-2: A summary of the advantages and disadvantages of four typical GHEs[15].

	DBGHE	**Advantages**	**Disadvantages**	**Applicable situations**
Horizontal GHE	U-shaped pipe, serpentine pipe and Slinky, etc	Provide heating and cooling; lower construction cost of ditching compared to drilling cost of VBGHEs	Heat transfer efficiency is affected by external climate; high pipe consumption; large occupied land area	Suitable for single-family homes and some occasions requiring or suitable for large excavation.
VBGHE	Single U-pipe or double U-pipes	Provide heating and cooling; stable working performance; less occupied land area.	Drilling cost is affected by geological conditions; heat transfer performance is affected by borehole spacing and annual cooling and heating load.	Suitable for the buildings with well-balanced heating and cooling loads.
PGHE	W-shaped pipe, single or multiple U-pipes and spiral pipe, etc	Provide heating and cooling; lower construction cost and smaller land area; higher heat transfer rate per pile meter compared to VBGHEs.	After long-term operation, temperature change may affect the mechanical properties of pile foundation.	Suitable for projects where land is in short supply or drilling is not suitable
DBGHE	coaxial pipes or U-bend pipe	Stable heat source; larger heat extraction capacity compared to VBGHEs; higher energy efficiency and smaller occupied land area for drilling.	Only for space heating, cannot provide the cooling; the drilling is difficult and the initial investment is high.	Suitable for heating-dominated buildings in cold regions.

I.4.2.2 EAHE system integrated designs

EAHE can be integrated into several systems to improve their performance, the integrated systems being either a conventional air conditioner or a passive cooling/heating system, as shown in Figure.I.3. and Figure. I.4.

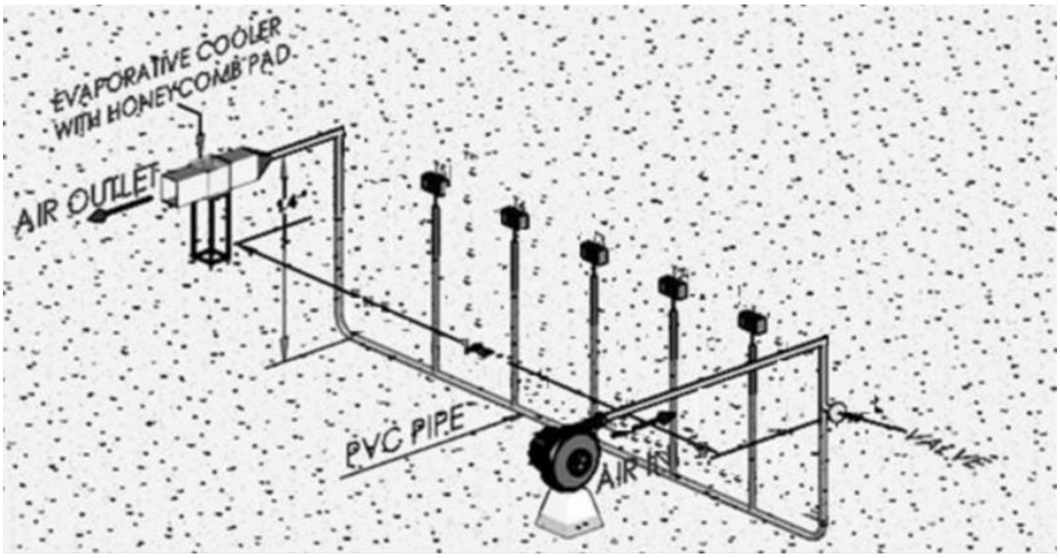

Figure I.3 An integrated EATHE-evaporative cooling system is put up experimentally[16].

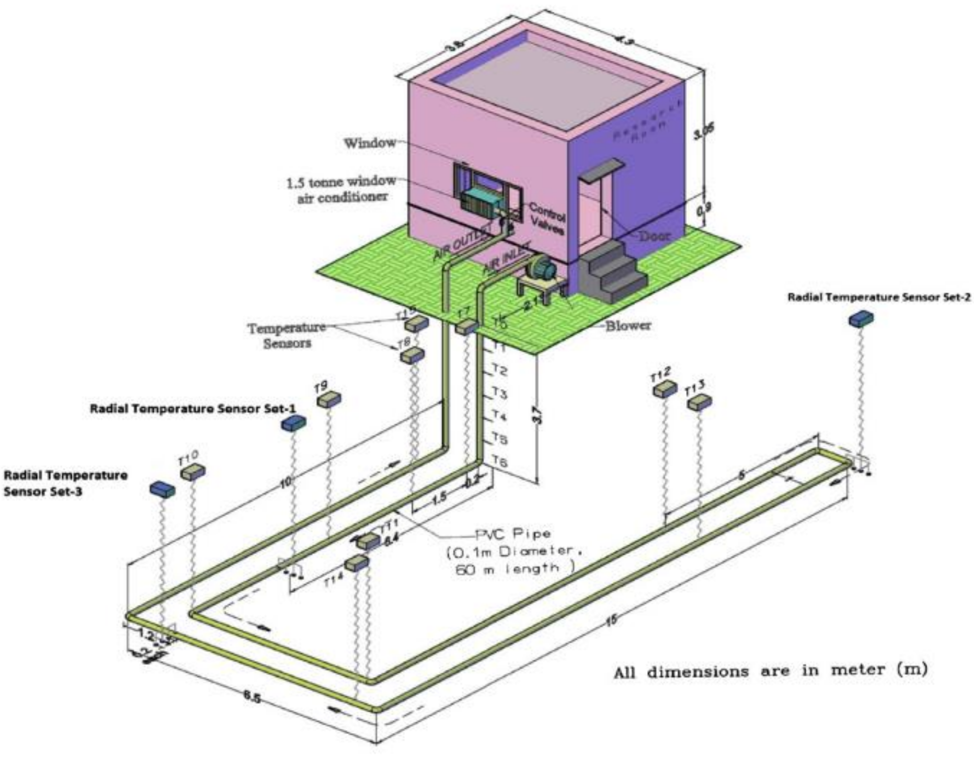

Figure I.4 EAHE integrated with a vintage air conditioner system[17].

I.5 Bibliographic studies

EAHE, or Earth-Air Heat Exchanger, is a highly sustainable system that efficiently provides both heating and cooling. It harnesses the temperature difference between the earth's subsurface at a specific depth and the surrounding air temperature throughout the year. Multiple experimental and computational investigations have examined the impact of operational conditions on the thermal performance of the EAHE (1-8). In their study, Bansal et al. conducted experiments to investigate the impact of operation duration in continuous mode on pipes of varying lengths[18].

The researchers discovered that the efficiency of the EAHE is mostly influenced by the time of operation. In a recent study, Belloufi et al. conducted experiments to analyze the thermal efficiency of Earth-to-Air Heat Exchangers (EAHE) in the Biskra region. The study focused on how the duration of EAHE operation affects its performance.[19].

Measurements were conducted continuously for a duration of 71 hours throughout the summer season. The results indicated that the continuous operating mode had no significant impact on the outlet air temperature, even in the presence of lengthy pipe lengths (53m). Consequently, the EAHE performances were consistent throughout the test period. Rouag et al[20]introduced a novel transient semi-analytical model, known as the RBM model, for analyzing the soil radius around the EAHE pipe. This model considers factors such as the duration of operation, soil thermal diffusivity, and inlet circumstances.

Recently, reported experimental results have focused on validating the universality of the RBM model. The aforementioned generalization has led to the development of a novel model, referred to as the GRBM model, which aims to forecast the transient temperature distributions of the air as it passes through the EAHE pipe under continuous cooling conditions[21].

Benhammou and Draoui[22]conducted numerical research which proved that the thermal performance of EAHE is mostly affected by changes in the period of operation, pipe diameter, and air velocity.

According to the data, almost 70% of the overall heat transmission took place within the first twenty meters. In addition, Mehdid et al[23]. provided experimental data indicating a 30% decrease in energy efficiency and a 43% decline in performance coefficient.

Hamdane and Moummi[6]studied the systematic prediction of outlet air temperature within a PVC air/soil heat exchanger buried at a depth of 0.3 meters. Designed to cool air in summer and heat it in winter for arid and semi-arid regions, the system's dynamic and thermal behavior is governed by three mathematical models: Ambient temperature model: Accurately simulates changes in surrounding air temperature. Soil temperature model: Predicts fluctuations in soil temperature based on various environmental factors. Outlet air temperature model: Estimates the temperature of air exiting the buried exchanger. Utilizing MATLAB 9.0, a dedicated calculation code was developed to simulate the evolution of outlet air temperature over time, taking into account both external and soil temperature variations.

Sakhriet all[24] have an experiment about the Earth-to-Air Heat Exchanger (EAHE) utilized for heating and cooling in arid regions, specifically in Bechar, Southwest Algeria. This study investigates the efficiency of an EAHE without external devices. The 66m PVC pipe, buried at 1.5m depth in an agricultural zone with a subsoil temperature of 28°C, showed a 19% increase in relative humidity (RH) during humidification and a 27% decrease in RH during dehumidification. The daily working regime involves 62.5% dehumidification (00 h to 09 h and 18 h to 23 h) and 37.5% humidification (10 h to 17 h), indicating the EAHE's potential for enhancing building hygrometry in arid regions.

Numerous studies have demonstrated the enhanced effectiveness and utility of EAHE systems when combined with other passive or active systems. Notably, passive systems offer low energy consumption by utilizing natural forces like wind and solar radiation, while active systems, despite higher energy demands, can provide more robust performance. This part specifically focuses on leveraging EAHEs to reduce the thermal load and power consumption of active systems like air conditioning. Additionally, coupling with passive systems like solar chimneys and wind towers can deliver pre-conditioned air and ventilation with minimal energy input. Table I.2 provides an overview of different hybrid EAHE configurations, which will be further discussed in subsequent sections**.**

Baglivo et al[25]proposes a novel concept for the Mediterranean climate: coupling an air-cooled heat pump (ACHP) with a horizontal air-ground heat exchanger (HAGHE) system. During summer, pre-cooled air from the HAGHE is supplied to the ACHP condenser, enhancing its efficiency and potentially reducing energy consumption. Conversely, in winter, pre-heated air from the HAGHE is directed to the ACHP evaporator, improving its heating performance. The authors report an annual energy savings potential of approximately 1115 kWh compared to standalone ACHP operation, highlighting the potential benefits of this hybrid system for the Mediterranean climate.

Do et all[26]investigated the energy saving potential of an Earth-Air Heat Exchanger (EAHE) system for building cooling in a hot and humid Texas climate. They achieved this by implementing an EAHE coupled air-source heat pump (ASHP) system, as depicted in Figure.I.5. Through their analysis, they observed annual cooling energy savings of up to 13.8% compared to a standalone ASHP system. This finding highlights the potential of EAHE technology to significantly reduce energy consumption for cooling in similar climatic conditions.

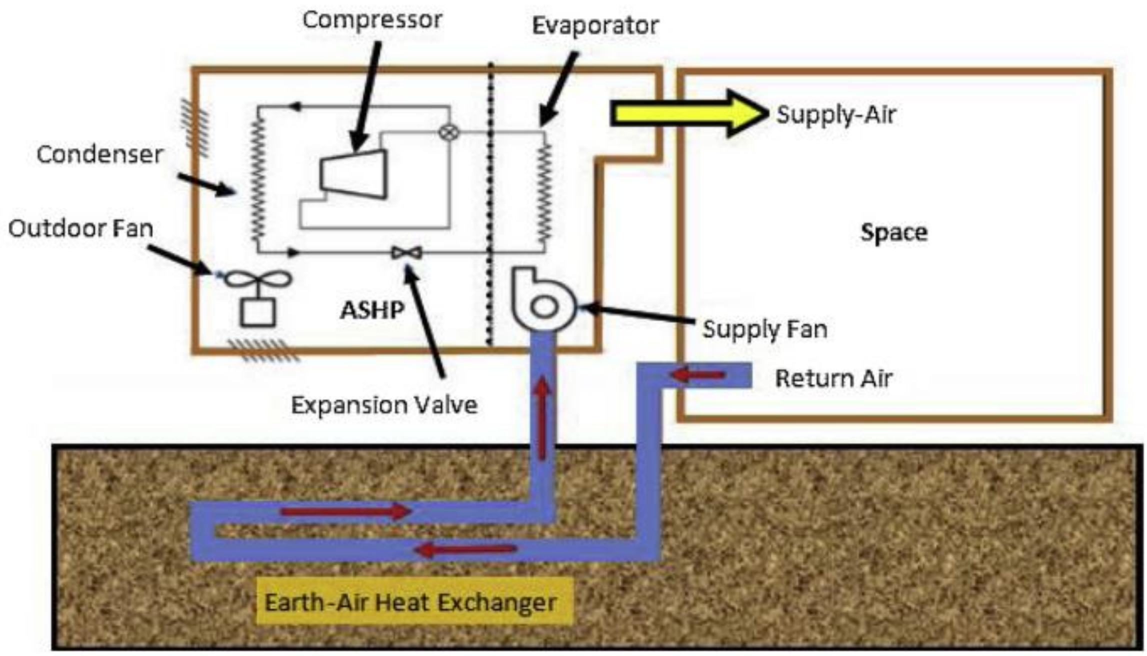

Figure I.5 Schematic diagram of EAHE integrated with ASHP unit[26].

Li et al [27] exploited the feasibility of combining an EAHE with an AHU for preheating fresh air in severe cold regions and concluded that this hybrid system significantly increased air temperature. The analysis revealed a temperature rise of 26.1 °C, with the EAHE contributing 14°C and the AHU providing the remaining 12.1 °C. This combined preheating effect eliminated the need for an auxiliary heating system, demonstrating the system's potential for reducing energy consumption and maintaining thermal comfort in harsh winter climates.

Zapałowicz et Opiela [28] studied a novel hybrid air-conditioning system for buildings, as illustrated in Figure.I.6. The system integrates a conventional air conditioner with a ground-air heat exchanger (GAHE) and a solar photovoltaic (PV) unit. Ambient air is first pre-cooled by the GAHE, enhancing its thermal exchange efficiency. A portion of this pre-cooled air then flows through a dedicated channel behind the PV modules and the building wall. This air circulation serves two purposes: reducing the temperature of the PV modules, thereby improving their electrical efficiency, and directly cooling the building wall (particularly the south-facing side), minimizing heat gain into the building envelope. The remaining pre-cooled air is then supplied to the air conditioner, significantly reducing the cooling load and contributing to overall energy savings.

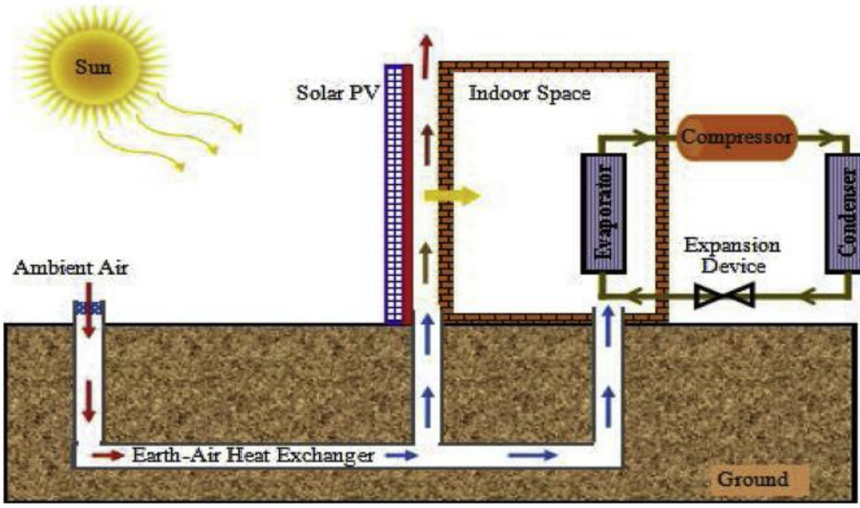

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Figure I.6 . Schematic diagram of EAHE integrated with SPV and AC unit[28]

Rodrigues and Gillott[29] investigated the synergistic effect of coupling an Earth-Air Heat Exchanger (EAHE) with phase change material (PCM), as depicted in Figure.I.7. The analysis revealed a remarkable improvement in cooling effectiveness of up to 47% compared to a conventional AC system, attributed to the combined action of PCM and EAHE. This finding highlights the potential of this hybrid system to significantly reduce energy consumption and enhance thermal comfort in buildings.

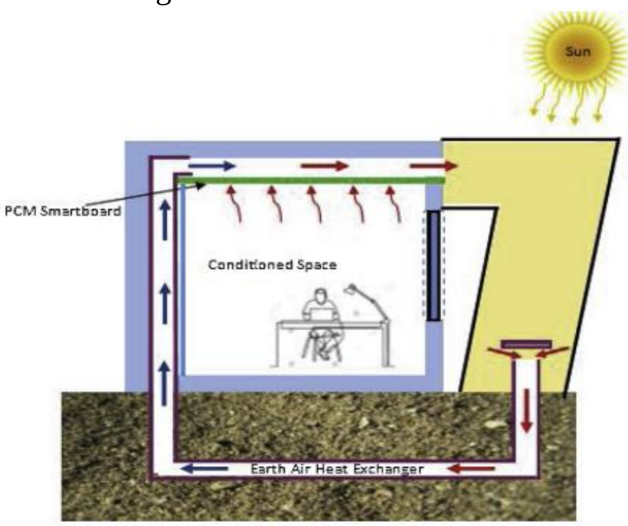

Figure I.7 EAHE connected to the PCM system[29]

Jakhar et al [30]investigated the efficacy of connecting a water-cooled heat exchanger (WCHE) in series with an Earth-Air Heat Exchanger (EAHE) for summer air cooling. It was observed that both the simple and hybrid EAHE systems achieved significant air temperature reductions. The simple EAHE system yielded an average air temperature drop of 11.0°C, while the hybrid EAHE system demonstrated an even greater reduction of 16.27°C. These findings highlight the potential of this combined approach to efficiently cool air during the summer season.

Agrawal et al[31] aimed to compare the summer and winter performance of EAHE systems installed in dry and wet soil conditions within the semi-arid climate of Ajmer, India. Two identical experimental setups were established, with a water trickling system implemented in the wet setup to maintain higher soil moisture content. The analysis revealed a significant reduction in the required pipe length for the EAHE system within the wet soil environment. This finding suggests that utilizing naturally moist soil or implementing moisture control mechanisms can optimize performance and potentially reduce construction costs of EAHE systems in similar climatic conditions.

I.6 Conclusion

The Earth-to-Air Heat Exchanger (EAHE) system serves as an efficient and dependable passive technique for providing heating and cooling effects in various settings, including living spaces, agricultural houses, and industrial applications. While the EAHE system offers advantages for both heating and cooling in diverse climates, its limitation in humid conditions requires the use of an additional dehumidifier to regulate humidity. Furthermore, when the EAHE system falls short in providing adequate cooling during summer, an extra cooling device is integrated for sufficient cooling. Similarly, in winter, the air is pre-heated through the EAHE system and can be further heated using an electric or gas heater if needed.

EAHE systems have found successful applications in heating and cooling buildings and greenhouses worldwide. The literature review underscores that the efficiency and effectiveness of EAHE systems can be significantly enhanced by integrating them with other active/passive systems, such as solar chimneys, evaporative coolers, HVAC systems, wind catchers, solar air heaters, and building thermal mass. Additionally, EAHE systems prove to be a viable choice for industrial purposes, such as pre-cooling air for air-cooled condensers (ACC) and air compressors.

Chapter II :

Experimental Study

II.1 Introduction

Earth/air heat exchangers offer a passive approach to preheat (in winter) and precool (in summer) outdoor air (ventilation or process) by exchanging thermal energy to and from the surrounding earth. Several factors influence the efficiency of this exchange process. These factors encompass soil characteristics such as type, moisture content, and compaction; surface cover properties; dimensions of the earth tubes (including diameter, thickness, and length), as well as the material and arrangement of the tubes; airflow velocity.

This chapter serves as a gateway to understanding the precise methodologies and methods used in implementing this innovative experiment, which is to integrate a heat exchanger (earth/air) with an underground water tank. Starting from the installation of the system until exporting the results of the experiment, through systematic exploration of experimental design, setup, and instrumentation, we seek to ensure the reliability and validity of our research findings. Where this chapter provides a detailed description of the experimental system, including the setup, materials, and equipment used. In addition, it explains the procedures followed during the experiment.

II.2 Description of Experimental System

II.2.1 Description of the location of the heat exchanger

In this study, this innovative earth/air heat exchanger was installed and monitored within a contemporary single-family dwelling located in Lichana, Algeria (Figure II.1). Lichana is situated approximately 35 kilometres southeast of Biskra and exhibits a semi-arid climatic regime [32], making it a suitable exemplar for research in such environments. The implemented heat exchanger is positioned near a vacant plot designated for cultivating diverse plant species[24], potentially influencing the surrounding microclimate (Figure II.2). The figure indicates the heat exchanger's location with the letter "T".

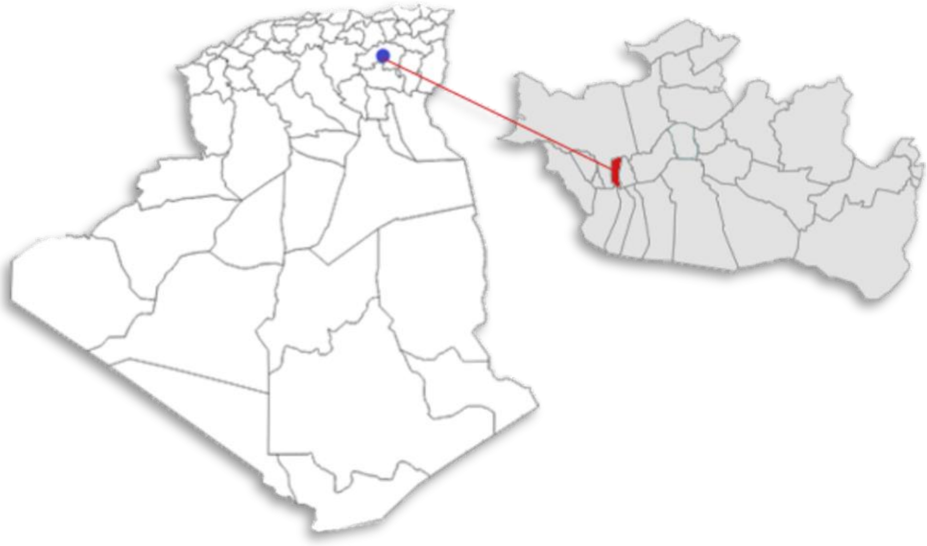

Figure II.1 Location of the city of Lishana, Biskra, Algeria.

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Figure II.2 location of the Earth/Air Heat Exchanger inside the house.

II.2.2 Description of Underground Water Tank

We designed an underground water tank in a cubic shape with precise dimensions, offering a depth of 2.4 m. To maintain stiffness during water filling, The structural strength of the tank was reinforced through the use of 15 cm of reinforced concrete, followed by an additional 15 cm of meticulously laid bricks to reinforce the strength and structure of the tank. To ensure good thermal conductivity between the surrounding soil and the buried ground air exchanger, a layer of 5 cm of gypsum soil was introduced between the brick wall and the exchanger duct. The role of the water reservoir is to provide an additional source of heat in winter and coolness in summer, Which contributes to maintaining a relatively constant temperature at low depths [33].

II.2.3 Connections and Pipework

The geothermal air/soil exchanger comprises a network of high-pressure PVC tubes, each with an external diameter of 110 mm. It is the best diameter for the purpose[34]. This sophisticated system consists of eight horizontal tube segments seamlessly integrated peripherally around the underground water tank, as depicted in Figure.II.3. The length of the exchanger tubes reached 27m due to the lack of space because at least there must be a distance of 0.3 m between each two tubes to avoid the effect between them, which is reflected in the performance of the exchanger[35]. These tubes, which are strategically inclined at a 10 % angle, enable efficient thermal exchange processes[36]. The reason for the tilt of the pipe is to ensure that condensation water drains out effectively from inside the pipe. Compact in design, the exchanger maximizes surface area contact with the surrounding soil, enhancing heat transfer efficiency. We position the initial horizontal segment at a depth of 1.2 m below the surface, gradually descending to a final depth of 2.4 m for the final segment, this depth was chosen based on previous studies proving that small depths negatively affect the effectiveness of the exchanger[37]. This meticulously planned configuration optimizes the use of subsurface thermal gradients[38], thereby improving the efficacy of geothermal heat exchange operations within the experimental framework.

Figure II.3 PVC tubes mounted horizontally on the faces of the ground walls constituting the water tank.

II.2.4 Details of Device Setup

We meticulously installed a total of six PT 100-type temperature sensors to comprehensively evaluate the thermal efficacy of the air/soil heat exchanger. We strategically positioned these sensors to monitor temperatures at critical points, including the outside ambient environment, the air's entrance and exit from the exchanger, the subterranean water tank, and two distinct soil depths of 1.2 and 2.4m. This arrangement allowed for a detailed thermal profile across the system's various components.

Moreover, an air pump at the entrance facilitates the air flow through the exchanger in the setup. The air pump can precisely control the amount of air it pumps into the system, ensuring optimal airflow rates for efficient thermal exchange.

Additionally, to avoid any potential interference with the thermal exchange process, we integrated a dedicated system for draining condensate water from inside the pipes.

Temperature data acquisition was conducted in real-time using an NI-LabVIEW Signal Express system[39], illustrated in Figure.II.7. This system interfaced with the sensors through an NI Compact DAQ-9188 Ethernet Chassis, which boasts eight slots to accommodate the array of sensor inputs, as shown in Figure.II.8. This configuration ensured the precise and continuous monitoring of temperature variations[40], vital for assessing the heat exchanger's operational performance under varying environmental conditions.

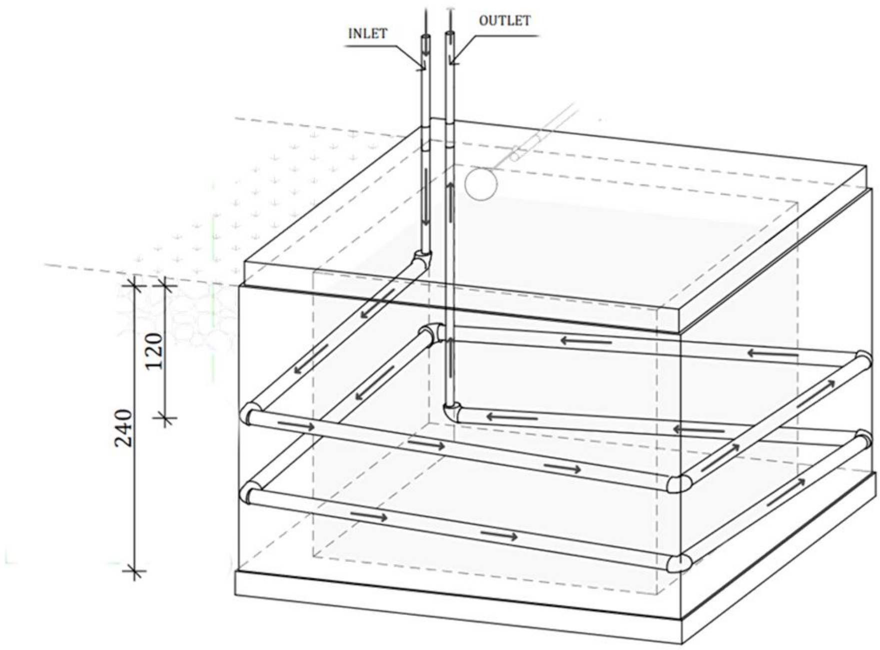

Figure II.4 Experimental EAHE device.

II.3 Materials and Equipment

II.3.1 List of Materials

High-Pressure PVC Tubes: Utilized to construct the air/soil heat exchanger to withstand operational pressures and environmental conditions.

PT 100 Temperature Sensors (6): Employed for precise temperature measurement at various points within the experimental setup, including the air inlet and outlet, ambient environment, water tank, and soil depths.

NI-LabVIEW Signal Express Data Acquisition System: Used for real-time data collection and analysis of temperature measurements from the PT 100 sensors.

NI Compact DAQ-9188 Ethernet Chassis: Integrated to interface with the temperature sensors, facilitating data transmission to the NI-LabVIEW system.

Air Pump: Installed at the entrance of the air/soil exchanger to regulate airflow rates and facilitate efficient thermal exchange processes.

Condensate Drainage System: Integrated within the pipework to remove condensation water and prevent interference with the heat exchange process.

Reinforced Cement, brick, and Gypsum Soil: Utilized for the construction of the underground water tank, ensuring structural integrity and stability.

II.3.2 Description of Each Material and Equipment

High-Pressure PVC Tubes: We selected these tubes for their durability and ability to withstand high pressures and environmental conditions[41]. They were utilized in the construction of the air/soil heat exchanger to facilitate the exchange of thermal energy between the air and soil, as shown in the figure.II.5.

Figure II.5 PVC pipes.

PT 100 Temperature Sensors (6): These temperature sensors are renowned for their high accuracy and stability[42]. As shown in Figure II.6, we strategically placed them at key points within the experimental setup to measure temperatures accurately, including the air inlet and outlet, ambient environment, water tank, and soil depths.

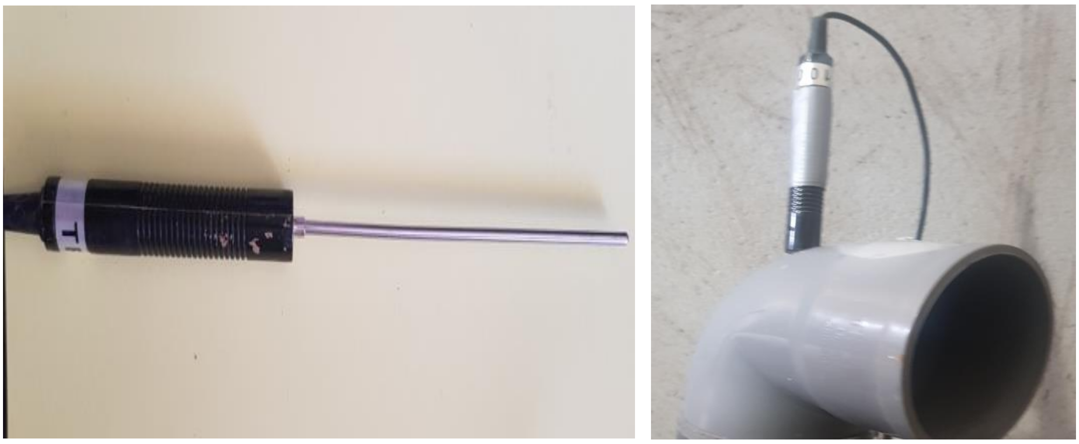

Figure II.6 PT 100 Type Temperature Sensors

NI-LabVIEW Signal Express Data Acquisition System: This data acquisition system is a powerful tool for real-time data collection and analysis[39]. It was employed to capture temperature measurements from the PT 100 sensors, providing valuable insights into the thermal dynamics of the experimental setup, as outlined in Figure.II.7.

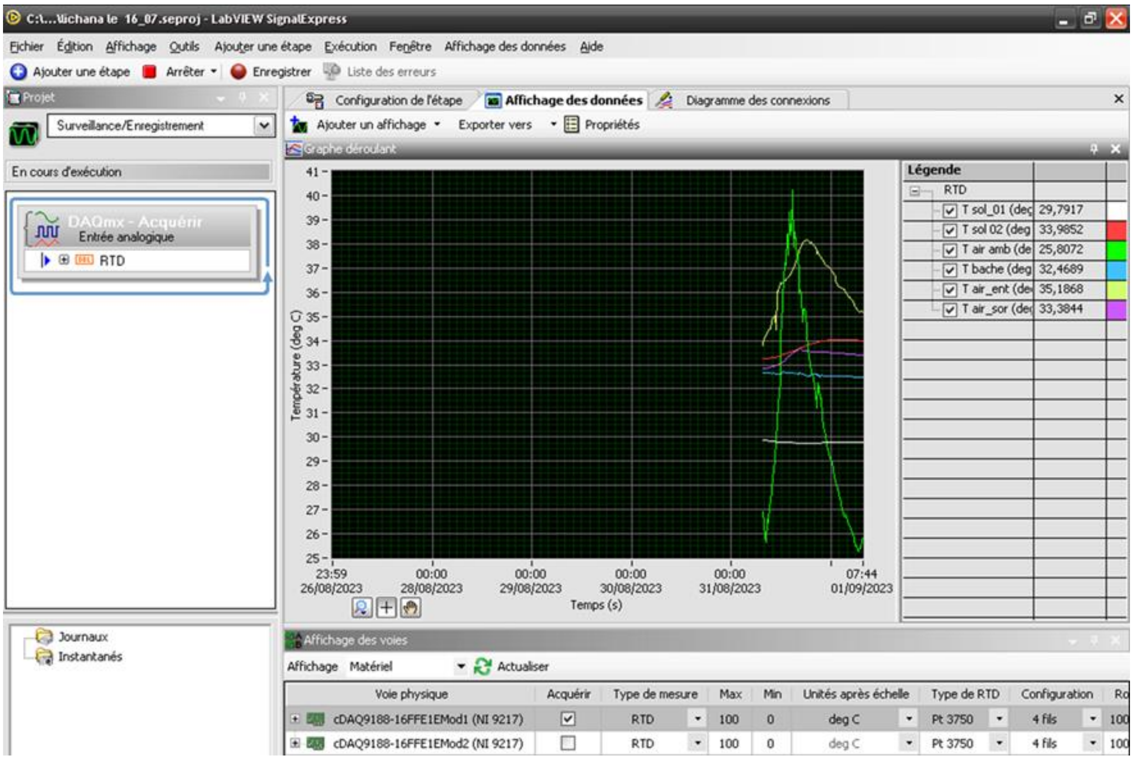

Figure II.7 Interface for temperature measurements via a NI-Labview Signal Express acquisition.

NI Compact DAQ-9188 Ethernet Chassis: This Ethernet chassis serves as the interface between the temperature sensors and the NI-LabVIEW system. It facilitates seamless data transmission, allowing for efficient monitoring and analysis of temperature variations [40], as represented in Figure.II.8.

Figure II.8 NI Compact DAQ-9188 Ethernet 8-Slot chassis with 02 modules which supports 04-wire PT-100 Type temperature sensors.

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Air Pump (TD 800): The air pump was installed at the entrance of the air/soil exchanger to regulate airflow rates. It plays a crucial role in optimizing thermal exchange efficiency by controlling the volume and velocity of air passing through the exchanger[6].

Figure II.9 Air Pump (TD 800).

Condensate Drainage System: The condensate drainage system was integrated within the pipework to effectively manage condensation water and mitigate any potential disruptions to the heat exchange process. Ensuring the seamless operation of the exchanger, this system is designed with careful consideration, featuring pipes constructed with a precisely engineered slope of 10%. This strategic inclination facilitates the efficient flow of condensation water, directing it toward the drainage system for proper disposal. By expeditiously eliminating excess moisture buildup, this sophisticated drainage infrastructure contributes to the optimal functionality of the experimental setup, upholding operational integrity and facilitating consistent performance[43], as shown in Figure.II.10.

Figure II.10 Condensate drainage system.

Voltage Regulator: This device is used to regulate the volumetric flow rate injected by the air pump and to control the airflow rate injected by the air pump for precise regulation of thermal exchange processes. By adjusting the voltage supplied to the air pump, it ensures consistent and controlled airflow, allowing for optimal thermal exchange efficiency in the experimental setup.

Figure II.11 Voltage Regulator.

Propeller Anemometer: The propeller anemometer Figure II.12 is utilized for measuring airflow velocity within the experimental setup. It plays a crucial role in ensuring the optimal operation of the air/soil heat exchanger by providing accurate and real-time data on airflow rates. This information is essential for monitoring and optimizing thermal exchange processes.

Figure II.12 Propeller Anemometer.

Differential Manometer: This device is employed for measuring pressure differentials within the system between the ends of the inlet and outlet exchanger respectively, which will make it possible to estimate the pressure losses for different operating regimes as presented in FigureII.13. The data provided by the differential manometer aids in fine-tuning the experimental setup for efficient heat transfer.

Figure II.13 Differential Manometer.

Wattmeter: The wattmeter is used to measure electrical power consumption within the experimental setup. It provides insights into energy usage and efficiency by accurately measuring the power consumed by the air pump. This information is available to estimate the energy levels of the installation and to evaluate the performance coefficient of the installation for different functional conditions.

Figure II.14 Wattmeter.

Computers: Computers were used to control the data acquisition system, monitor experimental parameters, and analyze collected data. They provided the computational power necessary for real-time data processing and analysis.

Safety Gear: Personal protective equipment (PPE) including gloves, safety goggles, and protective clothing were worn during construction and maintenance tasks to ensure the safety of personnel involved in the experiment.

II.3.3 Arrangement of Experimental Setup

The air/soil heat exchanger was positioned horizontally on the ground surface, with the high-pressure PVC tubes arranged in a parallel configuration to maximize surface contact with the surrounding soil to increase the conduction. The tubes were evenly spaced and securely anchored to the ground to prevent movement during operation.

At the entrance of the exchanger, the air pump was installed to regulate airflow rates and ensure uniform distribution of air across the tube surfaces. The pump was connected to the high-pressure PVC tubes via rigid piping, allowing for precise control over the volume and velocity of air passing through the exchanger.

Temperature sensors (PT 100 type) were strategically placed at key points within the experimental setup, including the air inlet and outlet, ambient environment, water tank, and soil depths. These sensors were securely mounted in place to ensure accurate temperature measurements throughout the experiment.

The condensate drainage system was integrated within the pipework to remove any excess moisture buildup and prevent interference with the heat exchange process. Drainage pipes were routed to a designated collection point away from the experimental area to maintain a dry and controlled environment.

Additionally, computers equipped with data acquisition software were stationed nearby to monitor experimental parameters and collect real-time temperature data from the sensors. This setup allowed for continuous monitoring and analysis of thermal dynamics within the experimental system.

Overall, the arrangement of the experimental setup was designed to optimize thermal exchange efficiency while ensuring reliable data collection and precise control over experimental conditions.

II.4 Experimental Procedures

II.4.1 Basic Steps for Experiment Execution

Setup Preparation: Ensure all components of the experimental setup, including the air/soil heat exchanger, water tank, temperature sensors, and data acquisition system, are properly assembled and positioned according to the experimental design.

Calibration of Equipment: Calibrate temperature sensors and verify the proper functioning of the data acquisition system to ensure accurate measurement and recording of temperature data throughout the experiment.

Water Tank Preparation: Fill the underground water tank with the desired volume of water, maintaining a consistent water level and ensuring proper sealing to prevent leakage during operation.

Startup Procedure: Activate the air pump at the entrance of the air/soil exchanger to initiate airflow through the high-pressure PVC tubes. Monitor airflow rates and adjust as necessary to achieve the desired thermal exchange conditions.

Temperature Monitoring: Begin real-time temperature monitoring using the data acquisition system. Record temperature readings at various points within the experimental setup, including the air inlet and outlet, ambient environment, water tank, and soil depths.

Data Collection: Continuously collect temperature data throughout the experiment, ensuring data integrity and accuracy. Monitor temperature trends and variations to assess the thermal performance of the experimental system.

Experimental Run: Experiment with the predetermined duration, maintaining consistent operating conditions and closely monitoring system parameters. Note any anomalies or deviations from expected behavior for further analysis.

Shutdown Procedure: Upon completion of the experiment, deactivate the air pump and stop temperature monitoring.

Data Analysis: Analyze collected temperature data to evaluate thermal dynamics and assess the effectiveness of the experimental setup in facilitating heat exchange between the air and soil mediums. Interpret results and draw conclusions based on experimental findings.

II.4.2 Time and Duration Measurements

This section details the time intervals and duration measurements used in the experimental procedures to ensure accurate data collection and analysis.

Experimental Run Schedule: The experiment is conducted twice a month, starting at the beginning and middle of each month. The initial experiment commenced on 07-31 and continued until the end of the school year.

Time Interval for Data Collection: Temperature measurements are taken in real-time at regular intervals, with data recorded and displayed every 15 minutes throughout the experiment duration.

Total Experiment Duration: Each experimental run spans the entire duration from the start date to the end date, capturing temperature data continuously over the specified period.

Time Synchronization: Time synchronization between different components of the experimental setup is ensured to maintain temporal coherence in the dataset. Timestamps are applied to all recorded temperature data to facilitate accurate analysis and correlation with experimental conditions.

Duration of Control Parameters: The experiment maintains consistent control parameters, such as airflow rate, throughout each run to ensure reproducibility and consistency in experimental conditions.

Recording of Time-Stamped Data: Temperature values recorded by the thermocouples are exported to an Excel file at the end of each experimental run. The temperature data is organized into columns based on time intervals for further analysis and interpretation.

Analysis of Time-Dependent Variables: Temperature profiles and heat transfer rates are analyzed over the duration of each experimental run to identify trends and patterns in the temporal evolution of these variables. The recorded temperature data provides valuable insights into the thermal dynamics of the experimental setup and its performance under varying conditions.

II.4.3 List of Measurements Used

This section provides an overview of the measurements taken during the experiment to quantify various variables and parameters relevant to the study.

Air Temperature: Measurements of the air temperature at the inlet and outlet of the geothermal heat exchanger duct to assess changes in air temperature throughout the experimental setup.

Soil Temperature: Measurements of soil temperature at consistent depths, typically at 1.2 and 2.4 m, to evaluate the thermal characteristics of the soil surrounding the heat exchanger.

Water Temperature: Measurements of water temperature in the water tank to track changes over time and assess its role in heat exchange processes.

Ambient Temperature: Measurements of the ambient temperature outside the experimental setup to account for external influences on temperature variations within the system.

Airflow Rate: Measurements of the volume flow of air through the geothermal exchanger conduit to quantify the rate of air movement and its impact on the efficiency of heat exchange, on the other hand this parameter makes it possible to evaluate several performance parameters at different operating conditions.

Time: Time measurements to track the duration of the experiment and synchronize data collection with specific time intervals for analysis.

II.5 Conclusion:

In this investigation, we carried out an experimental study on the thermal behavior of a new prototype of an air/ground geothermal exchanger integrated peripherally into an underground water storage tank.

We were interested in evaluating the cooling performance in summer and warming in winter provided by this innovative device, in arid and semi-arid regions where thermal comfort conditions are practically unfavorable.

The experimental protocol consists of a network of several high-pressure PVC tubes, PT 100 temperature sensors, and a sophisticated data acquisition system. The different constituent elements are carefully interconnected to ensure reliable collection and analysis of experimental readings, for different operating conditions with airflow maintained constant during the course of the experiments.

During the experiments, temperature readings at different measurement points are carried out, in particular, the temperature of the air at the inlet and outlet of the buried exchanger, of the ground, and the temperature of the water in the underground reservoir, as well as the ambient temperature. Real-time data collection and analysis provided valuable information on the thermal behavior of the installation, which will allow us to evaluate the thermal performance under different environmental operating conditions.

Chapter III:

Methodology And Validation

III.1 Introduction

In the search for sustainable and energy-efficient solutions, the use of ground-air heat exchangers has emerged as a promising method. These systems take advantage of stable ground temperatures to regulate ambient air, providing a viable alternative to traditional heating and cooling methods. However, the effectiveness of these systems begins at 3 m and requires a minimum length of 35 m, making their installation challenging in urban areas and narrow spaces, as previously discussed in the first chapter. Consequently, we introduced the concept of installing this heat exchanger to fully utilize the tank's internal energy. We implemented the innovative idea of integrating an earth/air heat exchanger with an underground water tank. The length of the exchanger reached 27 m at a depth ranging from 1.2 to 2.4 m, as described precisely in the previous chapter. In this chapter, we will perform a numerical simulation using MATLAB 2017a to illustrate the effect of integrating the exchanger with a groundwater reservoir.

III.2 Validation Methodology

III.2.1 Overview of Validation Methodology

In this section, we present the methodology we used to validate the numerical model from MATLAB 2017a and compare them with the experimental results we will present in the next chapter. Validation is essential to ensuring the accuracy and reliability of the numerical model. The following organizational chart shows the method used to verify the validity of the results.

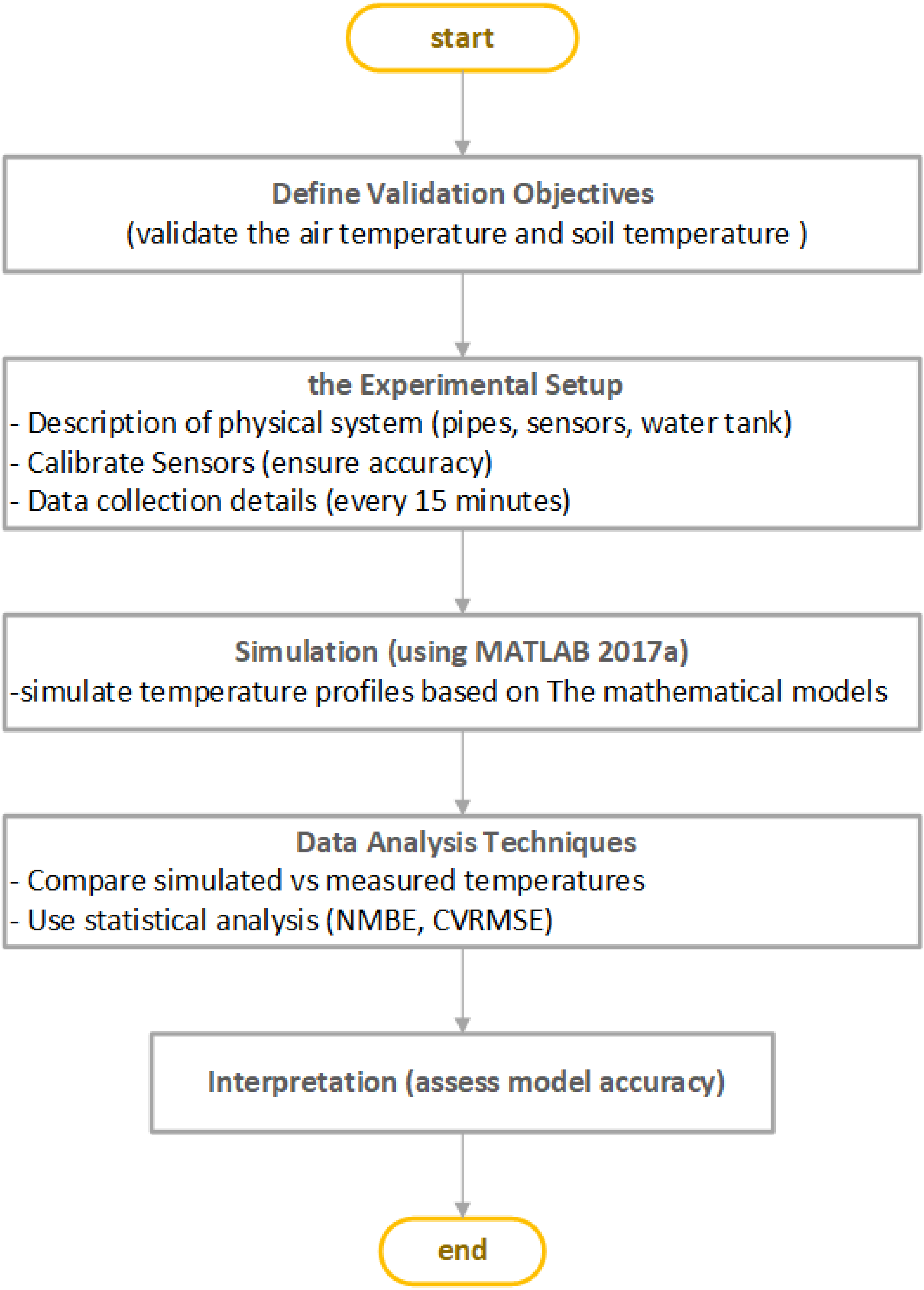

Figure III.1 Organizational chart of Validation Methodology

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III.2.1.1 Validation Objectives

The primary goals of the validation process are to evaluate the accuracy and predictive capabilities of the numerical model. In particular, we want to make sure that the model gives accurate values for the air and soil temperature at different depths. This way, we can compare the exchanger output correctly between the numerical and the experiment.

III.2.1.2 Experimental setup

The experimental setup integrates an earth/air heat exchanger system peripherally with an underground water tank. It consists of pipes with a diameter of 110 mm and a length of 27 meters. Additionally, there is an air pump located at the entrance. We have installed temperature sensors at two different depths: 1.2 and 2.4 meters, at the inlet and outlet of the heat exchanger and at the water tank. We measure all of the temperatures to better understand the tank's impact on the heat exchanger. We collect data every 15 minutes to capture temperature changes under various operating conditions. The previous chapter provided a detailed description of the system along with illustrative pictures.

III.2.1.3 Data analysis techniques

The data analysis compares the simulated temperatures produced by MATLAB 2017a's code with experimental temperature measurements. We will use statistical analysis, including normalized mean bias error (NMBE) and the coefficient of variation of the root mean square error (CVRMSE), to determine the accuracy of the simulation model. To ensure accurate data analysis in the upcoming chapter, identify the key factors that influence temperature forecasts and validate the results.

III.2.1.4 Validation Protocol

1. Calibration of Sensors: Temperature sensors are calibrated before data collection begins to ensure accuracy and consistency.
2. Data Collection: collection begins to ensure accuracy and consistency. We use calibrated sensors to record ambient air, soil, and outlet temperatures every 15 minutes, as detailed in the experiment description from the previous chapter.
3. Simulation: We use MATLAB 2017a to simulate temperature profiles, which are based on mathematical models detailed later in this chapter.

4. Analysis: We perform statistical analysis and calculate NMBE and CVRMSE to determine the level of agreement between the simulated and measured temperatures.
5. Interpretation: The next chapter interprets the results to assess the simulation model's accuracy and reliability in predicting temperature changes within the integrated ground/air heat exchanger system.

III.2.2 The program used

Numerical computing and data visualization are basic uses of a high-level programming language and interactive environment. MATLAB stands for "Matrix LABoratory", reflecting its original focus on matrix calculations, although it has since expanded to include many other types of numerical and symbolic calculations. MATLAB provides a comprehensive set of tools for algorithm development, data analysis, modeling, and simulation, as well as application development. MATLAB includes built-in functions for various fields, such as linear algebra, statistics, optimization, signal processing, image processing, and more. In addition, MATLAB supports the creation of graphical user interfaces (GUIs) for building interactive applications.[44]We specifically used MATLAB 2017a, a release from the first quarter of 2017. Each version of MATLAB typically introduces new features, improvements, and bug fixes aimed at improving the usability, performance, and capabilities of the program.

III.2.3 Model Assumptions

In this section, we delineate the key assumptions underpinning the mathematical models employed for simulating temperature profiles within the integrated ground/air heat exchanger system. Model assumptions play a critical role in simplifying the complexity of real-world systems and facilitating tractable numerical simulations.

Homogeneity of Soil Properties

We assume the soil to exhibit homogeneous properties throughout the simulation domain, including thermal conductivity, density, and specific heat capacity. This simplifying assumption enables the use of one-dimensional heat transfer models and facilitates the calculation of temperature profiles within the soil.

One-dimensional heat transfer

Heat transfer within the soil is predominantly one-dimensional, occurring primarily through conduction. This assumption allows for the formulation of simplified heat conduction equations, neglecting lateral heat transfer effects.

Adiabatic boundary conditions

We assume the heat exchanger system to be adiabatic, with negligible heat exchange with the surrounding environment, except for the soil. This assumption implies that heat transfer between the heat exchanger and the surrounding air is negligible, simplifying the calculation of heat transfer rates and temperature profiles.

Negligible Thermal Storage Effects

We assume that the thermal storage effects within the soil and heat exchanger components are negligible over the simulation period. This assumption allows for the application of instantaneous heat transfer models, neglecting transient effects associated with thermal inertia.

III.3 Theoretical Study

III.3.1 Model of Ambient Air Temperature

To track how the air temperature changes at the outlet of a buried earth-air heat exchanger throughout an entire day, it's crucial to understand the daily variations in ambient temperature. In our case, this ambient temperature serves as the input for the geothermal exchanger, and the thermal performance of the system significantly relies on this continuously fluctuating parameter.

The outdoor ambient temperature, often referred to as the outside dry temperature, is influenced by various factors. These include incident solar radiation at the location, the duration of daylight, the latitude and altitude of the area, local weather conditions, wind patterns, proximity to bodies of water like seas and lakes, as well as the presence of mountains and vegetation.

To simulate the outdoor ambient temperature throughout the day, a predictive model was employed. This model relies primarily on data such as the minimum temperature (T_{min}) and maximum temperature (T_{max}), typically derived from extensive experimental surveys conducted over several years by meteorological stations at a specific geographic location.

In this work, a semi-empirical model published by F. Chabane et al[45]. has been used. This model enables the observation of ambient temperature variations, determining hourly values numerically based on the minimum and maximum values of the ambient temperature, as provided by measurement stations on the web[45].

We took the result of the maximum and minimum ambient temperature In the Biskra region of this curve.

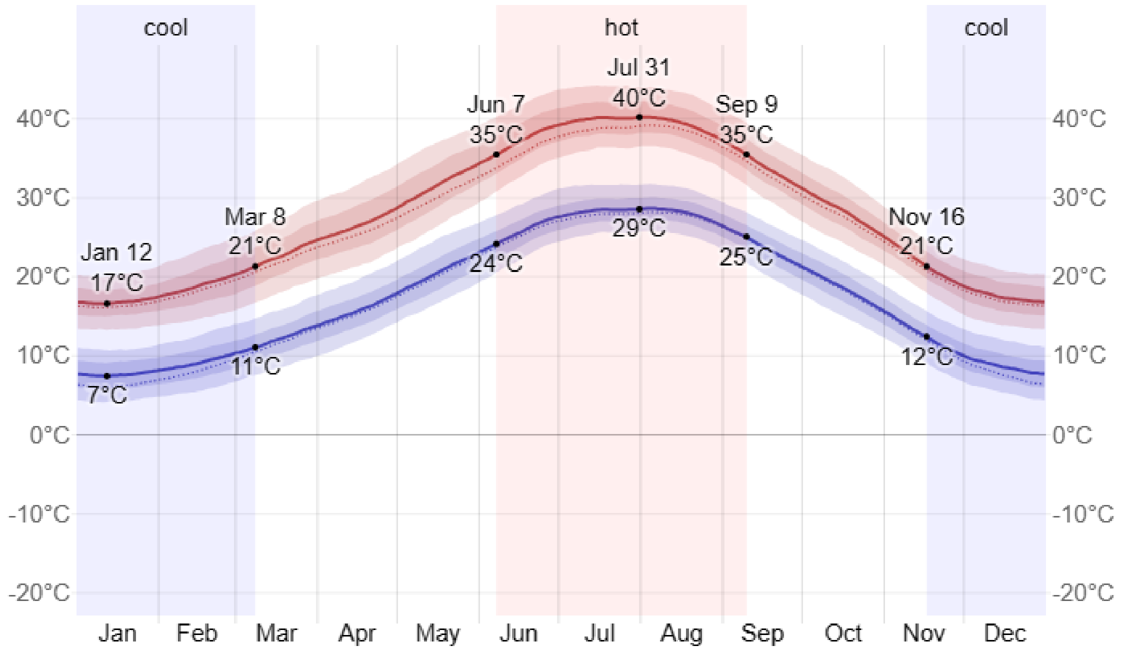

Figure III.2 Evolution of maximum and minimum ambient temperature in Biskra.

The ambient temperature is given by this equation [45]:

$$T_{air-amb}(t) = T_2 + T_1 \cos\left(\frac{(14-t)\pi}{12}\right) \quad \text{(III.1)}$$

With

$$T_1 = \frac{T_{\max} - T_{\min}}{2} \quad \text{(III.2)}$$

$$T_2 = \frac{T_{\max} + T_{\min}}{2} \quad \text{(III.3)}$$

T_{max} and T_{min}: respectively, represent the maximum and minimum temperature [°C] during the day.

t: time(h)

III.3.2 Model of Soil Temperature

Assessing the viability of utilizing surface geothermal energy through buried air-to-soil exchanger technology necessitates understanding the year-round fluctuations in soil temperature at various depths. These variations are derived through a straightforward model, considering soil properties and ambient temperatures. The temporal changes in outdoor ambient temperature are also modeled over time (day), described by a semi-empirical relationship as mentioned in the preceding paragraph.

The soil temperature model employed in this study assumes that heat transfer within the soil is one-dimensional, predominantly occurring through conduction, and treats the soil as a homogeneous medium. The governing equation for the temperature variation in the soil is expressed as follows[46]:

$$T_{soil}(z,t) = T_2 + T_1 . e^{-z\sqrt{\frac{\pi}{365a}}} \left[\cos\left(\frac{2.\pi}{365}(t-t_0) - \frac{z}{2}\sqrt{\frac{365}{\pi.a}} \right) \right] \quad \text{(III.4)}$$

With

t_0: the day that has a maximum temperature in the year [days].

Z: the depth of burial from the surface of the air/soil heat exchanger [m].

α: the thermal diffusivity [m^2. $days^{-1}$].

A soil exhibits three primary parameters that directly impact the thermal performance of the buried air/soil heat exchanger. These parameters include the evolution of the temperature of the injected air, as well as the thermal conductivity, density, and specific heat capacity of the soil.

III.3.3 Model of Outlet Air Temperature

The basic thermal balance through a section of length dx of the exchanger tube shows how the temperature changed at the exit of the air that was moved inside the buried air/soil exchanger. Integration from input to output gives the expression of the theoretical air temperature at a certain distance travelled by the fluid, which is described by the following mathematical model[47].

$$T_{air-outlet}(L) = T_{soil} + (T_{air-inlet} - T_{soil}).e^{\frac{-U}{m \cdot Cp_{air}}L} \quad \text{(III.5)}$$

With

$T_{air-inlet}$: Corresponds to the outside ambient temperature.

Cp_{air}: calorific capacity of the air [$J.kg^{-1}.k^{-1}$].

U: Total thermal conductance between air and soil [$w.m^{-2}.k^{-1}$], is given by :

$$U = \frac{1}{R_{soil} + R_{tub} + R_{conv}} \quad \text{(III.6)}$$

With R_{soil}: Thermal resistance between tube and soil [m.k.w^{-1}], expressed by:

$$R_{soil} = \frac{1}{2 \cdot \lambda_{soil} \cdot \pi} \ln\left(\frac{r}{R}\right) \qquad \text{(III.7)}$$

R_{tub}: Thermal resistance of buried tube [m.k.w^{-1}] calculated with the rule next:

$$R_{tub} = \frac{1}{2 \cdot \lambda_{tub} \cdot \pi} \ln\left(\frac{R}{r}\right) \qquad \text{(III.8)}$$

R_{conv}: Thermal resistance convection between air and tube [m.k.w^{-1}], is expressed by this equation:

$$R_{conv} = \frac{1}{2 \cdot h_{conv} \cdot \pi \cdot r} \qquad \text{(III.9)}$$

With

r: Internal radius of the buried tube [m].

R: External radius of the buried tube [m].

R_{soil}: Radius of the adiabatic soil layer [m].

λ_{tub}: Thermal conductivity of the buried tube [w.m^{-1}. k^{-1}].

λ_{soil}: Thermal conductivity of soil [w.m^{-1}. k^{-1}].

h_{conv}: convection coefficient of air [w.m^{-2}. k^{-1}], is calculated from the Nusselt number, for a turbulent flow within a circular duct cross-section, expressed by:

$$h_{conv} = \frac{Nu \cdot \lambda_{air}}{2 \cdot r} \qquad \text{(III.10)}$$

Where the number of Nusselt is given by the following relation[47] :

$$Nu = 0.026 \cdot \mathrm{Re}^{0.8}\, \mathrm{Pr}^{0.33} \qquad \text{(III.11)}$$

With

Re: Reynolds number is expressed by:

$$\mathrm{Re} = \frac{\rho_{air} V_{air} D_{inner-tube}}{\mu_{air}} \qquad \text{(III.12)}$$

Pr : Prandtl number :

$$Pr = \frac{\mu_{air} Cp_{air}}{\lambda_{air}} \quad \text{(III.13)}$$

With

V_{air}: Velocity of the air inside the exchanger [$m.s^{-1}$].

$D_{inner\text{-}tube}$: Inside diameter of buried exchanger pipe [m] .

μ_{air}: Dynamic viscosity of the air [$kg.m^{-1}.s^{-1}$].

λ_{air}: Thermal conductivity of the air [$w.m^{-1}.k^{-1}$].

III.4 Validation Protocol

III.4.1 Validation of Outlet Temperature

created a MATLAB code to calculate the outlet temperature of the heat exchanger using the mathematical expressions mentioned previously in this chapter. The first code calculates the outlet temperature of the heat exchanger in the absence of an underground water tank. Since there is no mathematical expression for the exchanger located at varying depths, by cutting the exchanger channel into three equal sections, we assume that each section was installed at a fixed average depth, ranging between 1.2 and 2.4 m, which are the distances at which the ground heat exchanger was installed. We also created a hotter code to calculate the exchanger outlet, but this time, the entire exchanger is located at a fixed depth of 2.4 m. These illustrative diagrams explain how each works separately:

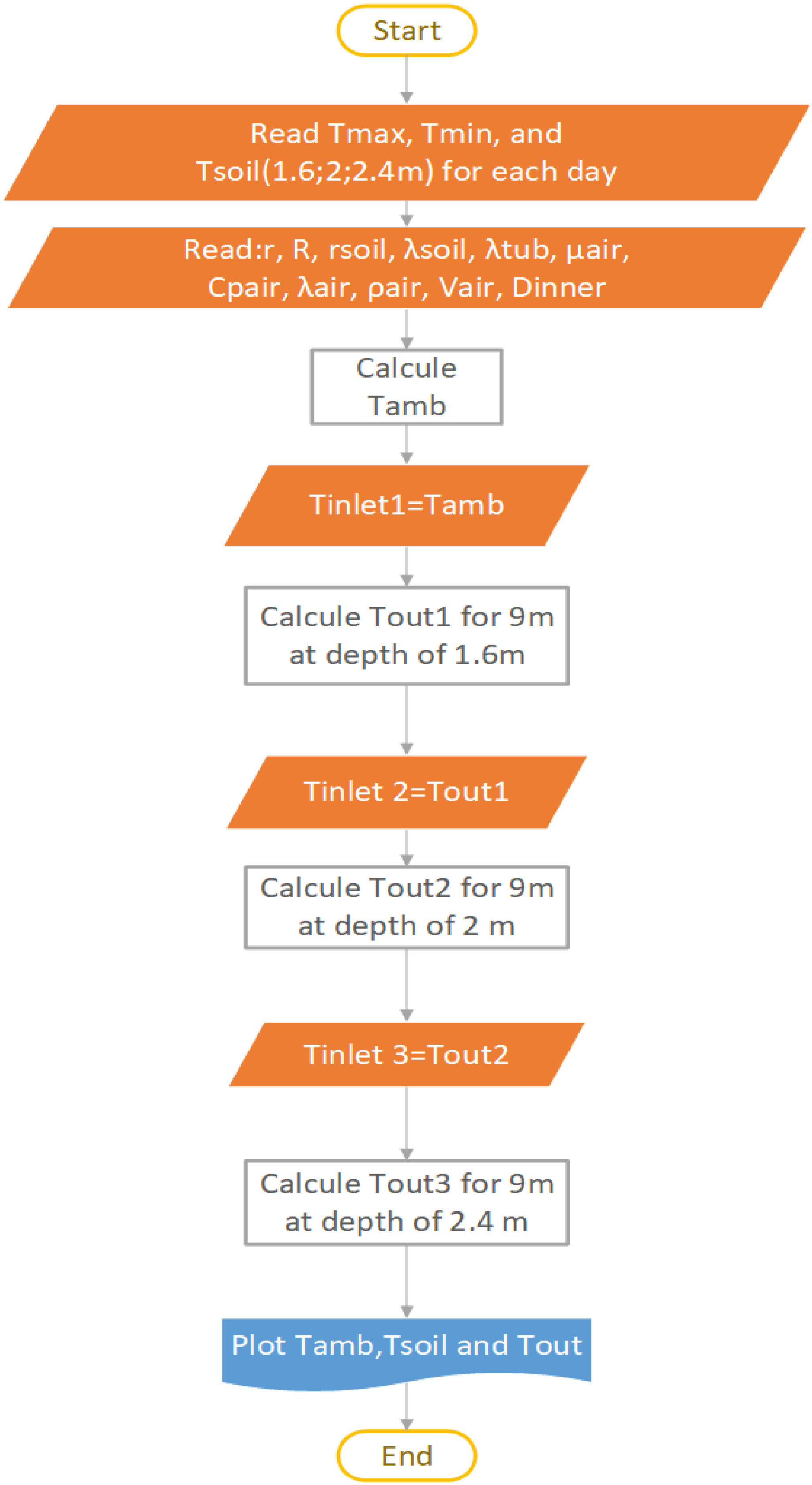

Figure III.3 Organizational chart for the Outlet temperature with variable depth

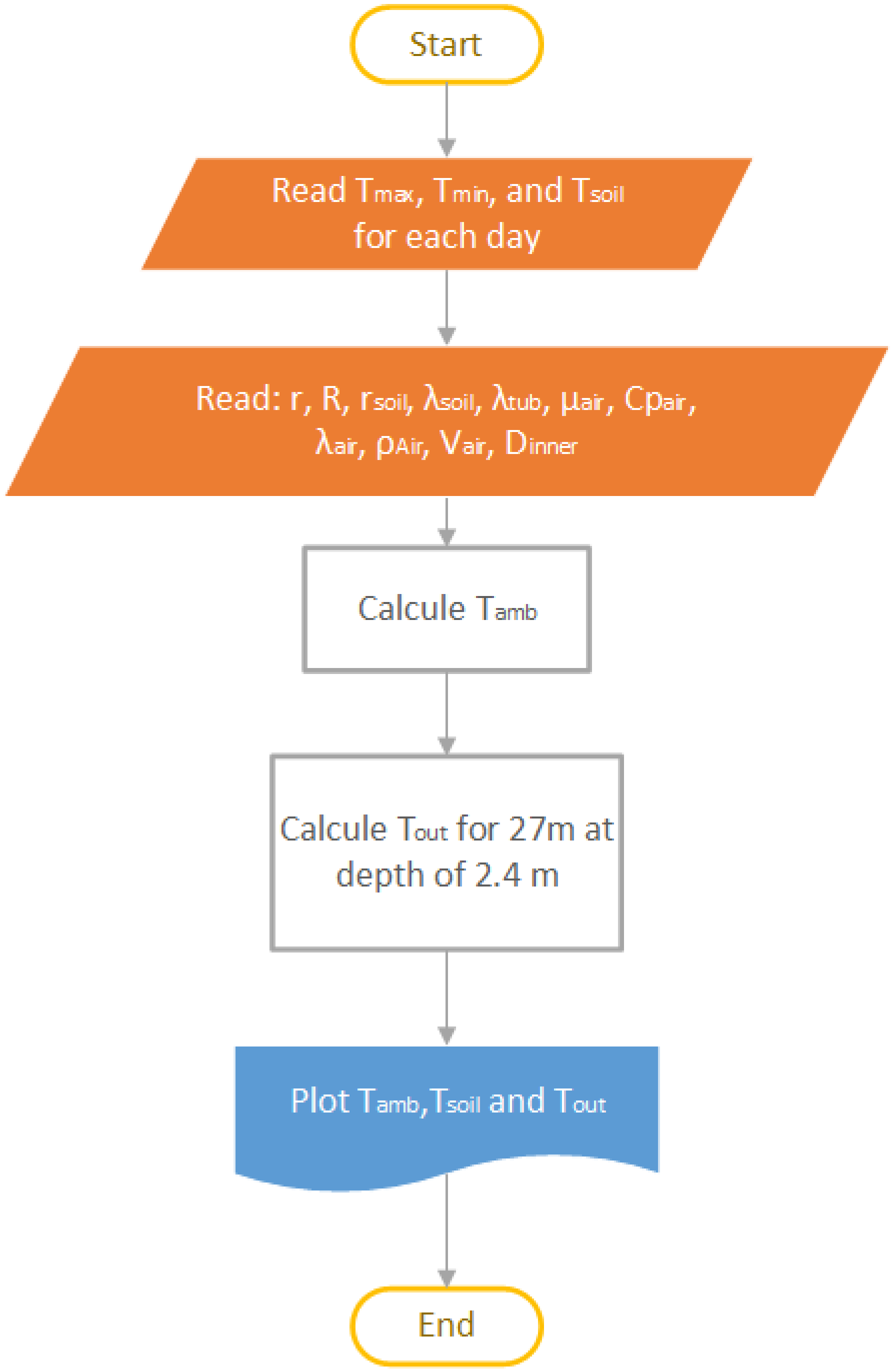

Figure III.4 Organizational chart for the Outlet temperature at a constant depth of 2.4 m

III.4.2 Validation of Ambient Temperature

Our air temperature is considered one of the most important factors affecting the process and is characterized by its wide range of changes throughout the day. We have used the expressions mentioned in the previous paragraphs of this chapter and have explained the code as follows.

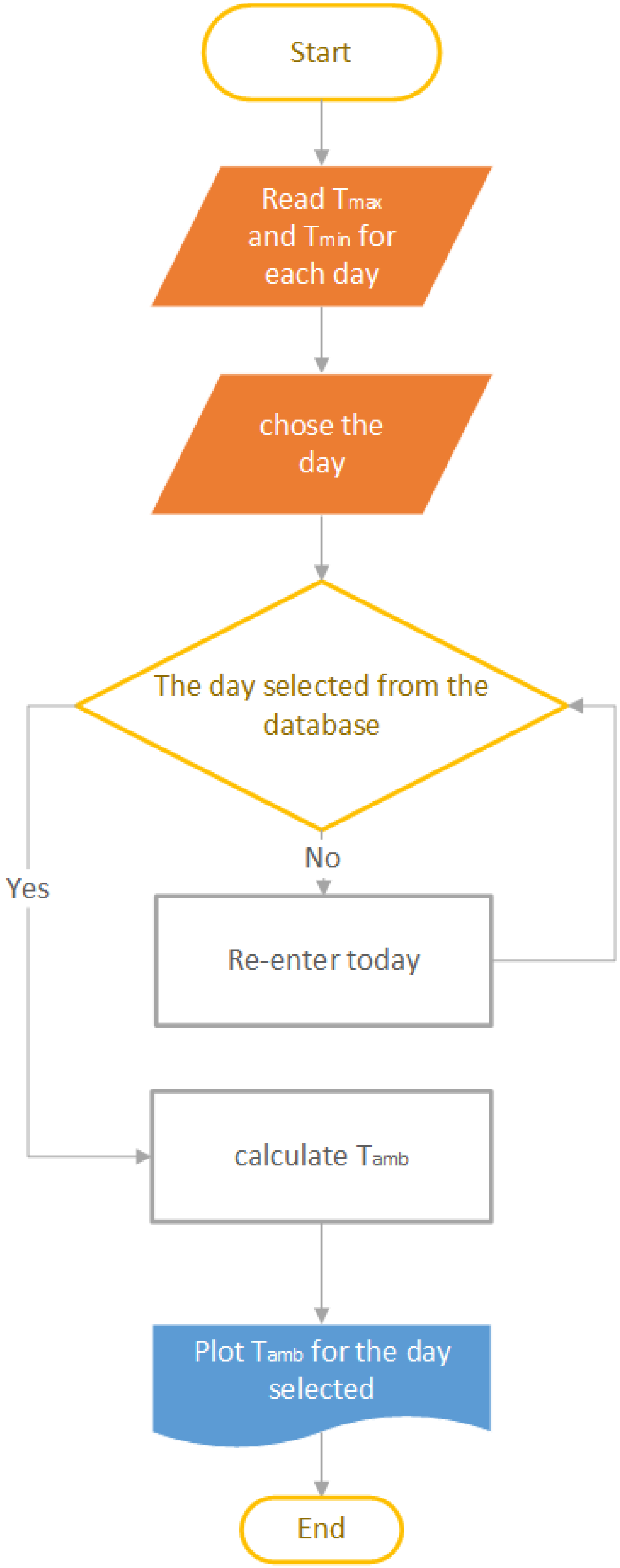

Figure III.5 Organizational chart for Ambient temperature

III.4.3 Validation of Soil Temperature

Weather factors, especially in the depths near the surface, affect the soil's temperature, which makes the earth/air heat exchange effective. We used the previously mentioned mathematical expressions in MATLAB codes, the first of which presents a graphic curve for temperature change. The soil is at varying depths throughout the year, and in the second code, we incorporate the day and depth to determine the ground's temperature, as shown in the following organizational chart respectively:

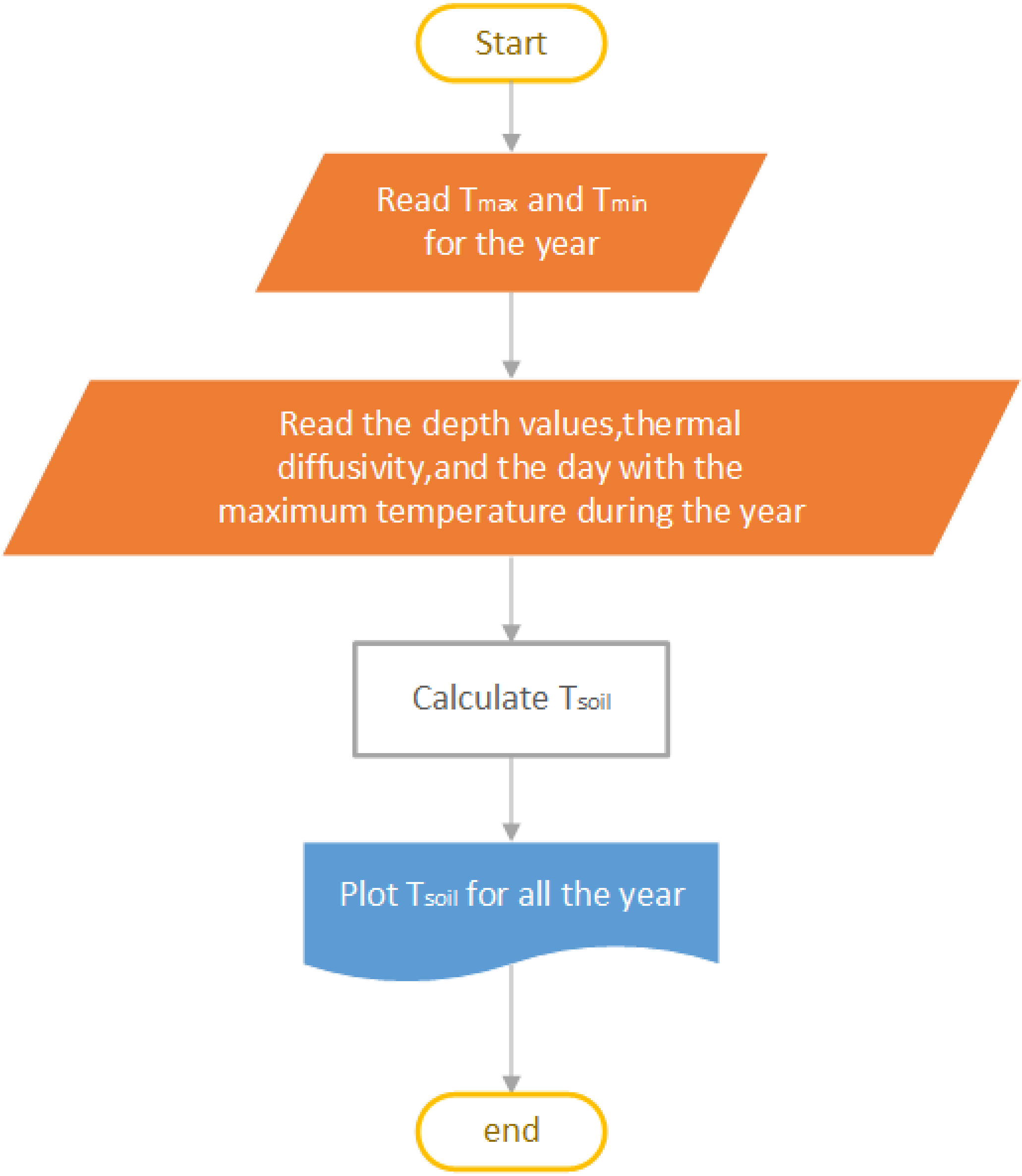

Figure III.6 Organizational chart for the soil temperature (plotted throughout the entire year).

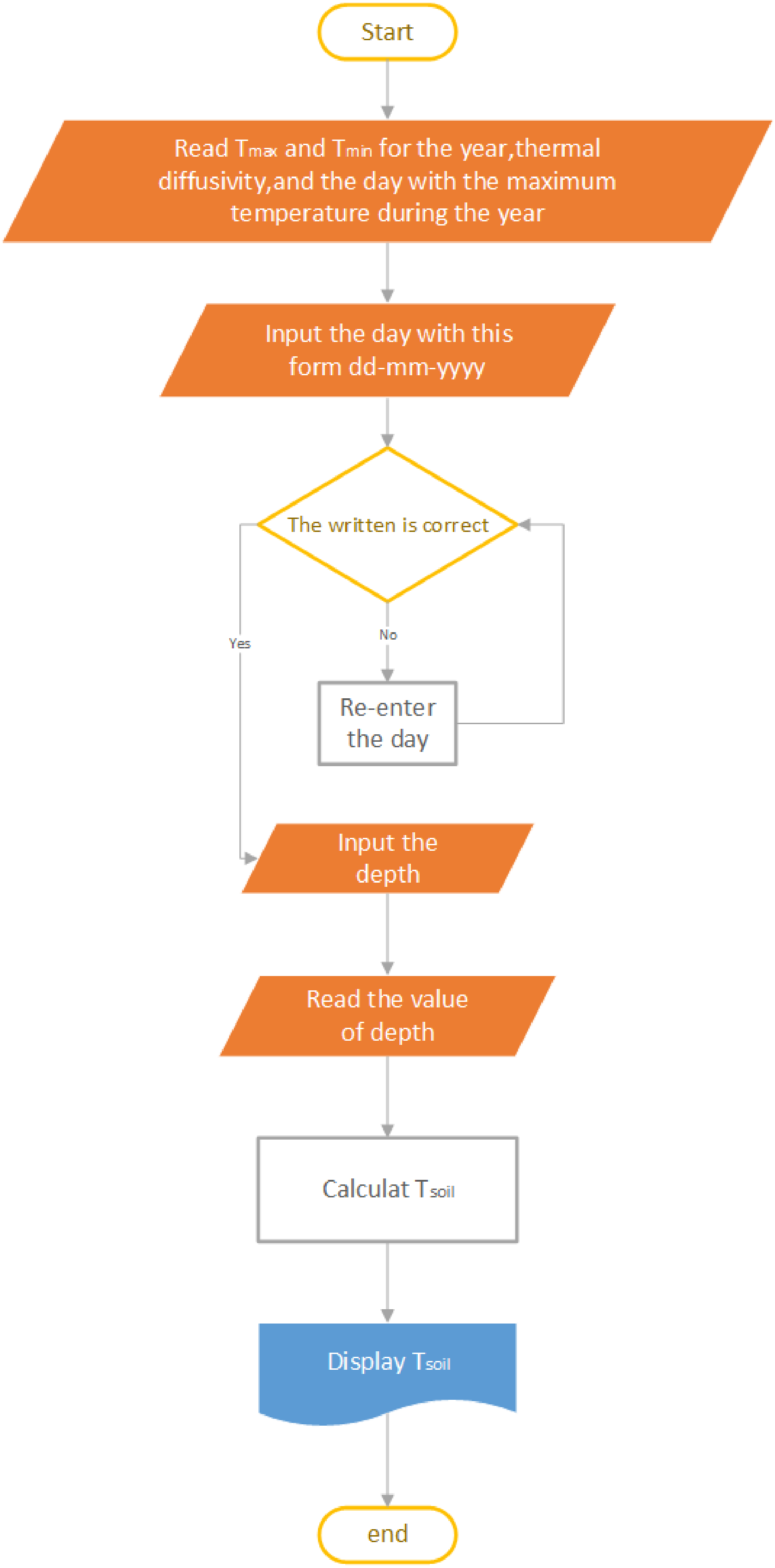

Figure III.7 Organizational chart for the soil temperature (for a specific day).

III.5 Conclusions

In this chapter, we embarked on a meticulous journey to validate the simulation results obtained from MATLAB 2017a, aiming to corroborate them with the forthcoming experimental findings. We carefully checked our numerical model's accuracy and ability to predict using a well-thought-out validation protocol. This made sure that it could accurately show how the integrated ground/air heat exchanger system changed over time. We also created and used mathematical models to simulate the temperatures that are important for a buried earth-air heat exchanger system. MATLAB 2017a served as the software platform for these simulations. The chapter has outlined the equations used to model the ambient air temperature, considering its daily variations. Next, the chapter presented a soil temperature model that took into account heat transfer and the influence of ambient temperatures. Finally, the description of a model for the exchanger's outlet air temperature took into account factors like air flow rate, soil properties, and thermal resistances. We also included organigrams to visually represent the calculation methods within the MATLAB codes. These simulations demonstrate the potential for mathematical models to analyze and possibly optimize the performance of these buried earth-air heat exchangers.

Chapter IV:

Result and Discussion

IV.1 Introduction

After determining the characteristics of an earth/air heat exchanger integrated peripherally with an underground water tank through the description of the experimental device (Chapter II) and numerical modeling (Chapter III), we will try to present through this chapter the experimental results as well as those obtained by numerical simulations. Later in this chapter, we will validate the numerical results with the experimental results. Next, we will show how different thermal, physical, and geometric factors influence the thermal behavior of this innovative heat exchanger. Finally, we will discuss how the integration of the exchanger into an underground water tank enhances its thermal performance. To do this, we will carefully compare the experimental results with the numerical results to get a full picture. This analysis will not only validate the mathematical model's accuracy but also unveil the influence of design parameters on the system's performance. We will, on the other hand, try to explain the origin of the differences observed between the experimental and numerical results, through a regular analysis, which will subsequently allow us to give a valuable complement of information and open the way to future perspectives in this area of research.

IV.2 Validation

The validation models used in this work are the Coefficient of Variation of the Root Mean Square Error (CVRMSE and Normalized Mean Bias Error (NMBE) [48].

The Coefficient of Variation of the Root Mean Square Error (CVRMSE)

CVRMSE is a statistical measure used to assess the accuracy of a predictive model, particularly in the context of comparing the model's predictive performance relative to the magnitude of the actual data values. CVRMSE is expressed as a percentage and provides a normalized measure of the root mean square error (RMSE) by relating it to the mean of the observed data values. This allows for a better understanding of the model's predictive error about the scale of the data. [49]

The CVRMSE is given by the following equation:

$$CVRMSE = \frac{RMSE}{\overline{Y}} \times 100 \tag{IV.1}$$

Where

- RMSE: the Root Mean Square Error, which measures the average magnitude of the prediction errors.
- $\overline{Y}$: the mean of the observed data values.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(T_{amb-sim} - T_{amb-\exp})^2}{n}} \tag{IV.2}$$

- $T_{amb-sim}$: Ambient air temperature generated by the simulation.
- $T_{amb-exp}$: Ambient air temperature resulting from the experiment.
- n: Number of iterations

Normalized Mean Bias Error (NMBE)

The Normalized Mean Bias Error (NMBE) is a statistical measure used to evaluate the accuracy of a predictive model by quantifying the average bias in the model's predictions relative to the actual values. NMBE is expressed as a percentage, providing a normalized measure of the mean bias error (MBE) by relating it to the mean of the observed data values. This helps in understanding whether the model systematically overestimates or underestimates the observed values [49].

The NMBE is given by the following equation:

$$NMBE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{T_{amb-\exp} - T_{amb-sim}}{T_{amb-\exp}}\right) \times 100\% \tag{IV.3}$$

$T_{amb-sim}$: Ambient air temperature generated by the simulation.

$T_{amb-exp}$: Ambient air temperature resulting from the experiment.

n: Number of iterations

- **Positive NMBE:** Indicates that, on average, the model overestimates the observed values.
- **Negative NMBE:** Indicates that, on average, the model underestimates the observed values.
- **NMBE Close to Zero:** Suggests that the model predictions are, on average, very close to the observed values, indicating little to no systematic bias.

IV.3 Ambient air temperature

To calculate the ambient air temperature using the equation (III.1) in the mathematical model mentioned in the previous chapter, we need the maximum and minimum ambient air temperatures recorded during the day, which can be viewed from weather websites[50].

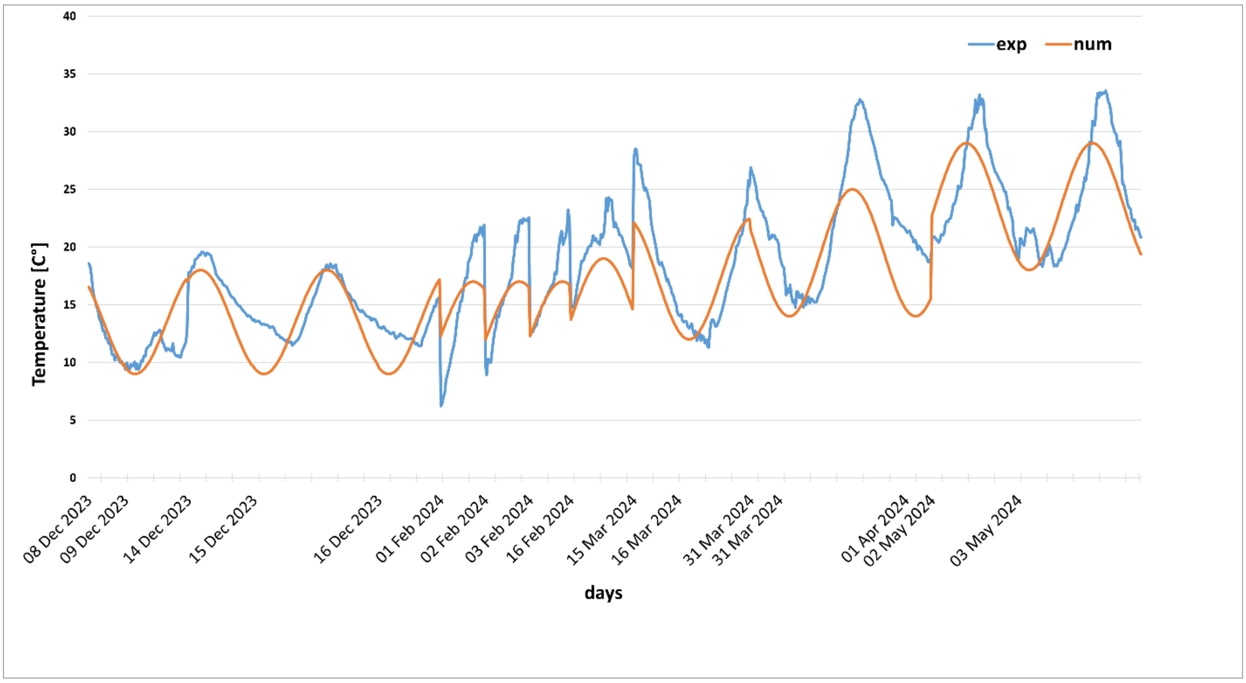

Figure IV.1 Ambient air temperature changes for both experiment and numerical.

The comparison between the profiles of the temperatures obtained by the numerical model and the experiment shows that the distribution of ambient temperature is similar and periodic. Figure (IV.1) shows a small error between the temperature rise and fall trends, which proves that the proposed numerical model effectively predicts the overall dynamics of ambient air temperature fluctuations with the change of seasons. This aligns with our understanding of typical seasonal variations in ambient air temperature.

For more precision, we calculate the NMBE and CVRMSE to verify the accuracy of our results as shown in table (IV.1).

Table IV-1: Ambient air temperature validation results.

	NMBE	*CVRMSE*
T_{amb}	-7.33%	1.9304

From Table (IV.1) the NMBE of -7.33% indicates a systematic underestimation by the model, with an average discrepancy of 7.33% compared to the actual values. Here, the RMSE of 1.93 reflects the average magnitude of the errors, regardless of direction (overestimation or underestimation).

This indicates that the mathematical model provides a good approximation for experimental work. The model's limitations in capturing the full spectrum of factors influencing the actual values could be the cause of this underestimation. Potential factors not accounted for by the model might include:

- Since there is no mathematical model that expresses this type of exchanger, we divided it into three parts at varying depths to study the full model, which we discussed in detail in the previous chapter.
- Weather Fluctuations: Unforeseen weather changes can deviate from the model's assumptions.
- Ambient Air Humidity: Humidity directly affects the rate of heat transfer through the air, influencing how quickly temperature rises or falls.
- Wind Speed: Wind speed influences heat exchange through convection, with higher wind speeds promoting faster temperature changes.
- Proximity to Green Areas and Lakes: Bodies of water and vegetation can moderate temperature fluctuations, creating microclimates with less extreme variations.
- Solar Radiation: Solar radiation directly impacts air temperature, with variations in sunlight intensity throughout the day and year affecting heating and cooling rates.
- Random Events: The model might not account for stochastic events like sudden rainfall.

IV.4 Soil temperature

To calculate soil temperature using equation (III.4) in the mathematical model discussed in the previous chapter, we need the maximum temperature during the year and the thermal characteristics of the soil are presented in the next Table (IV.2)[47].

The maximum temperature during the year is:

T_{max}= 40 C° on 31th July at 213 days[50].

Table IV-2: Thermal characteristics of Gypsum soil

	ρ_{soil} [kg/m^3]	λ_{soil} [W/m.K]	Cp_{soil} [J/kg.K]	α [m^2 /days]
Gypsum soil	2050	0,52	1840	0,0119

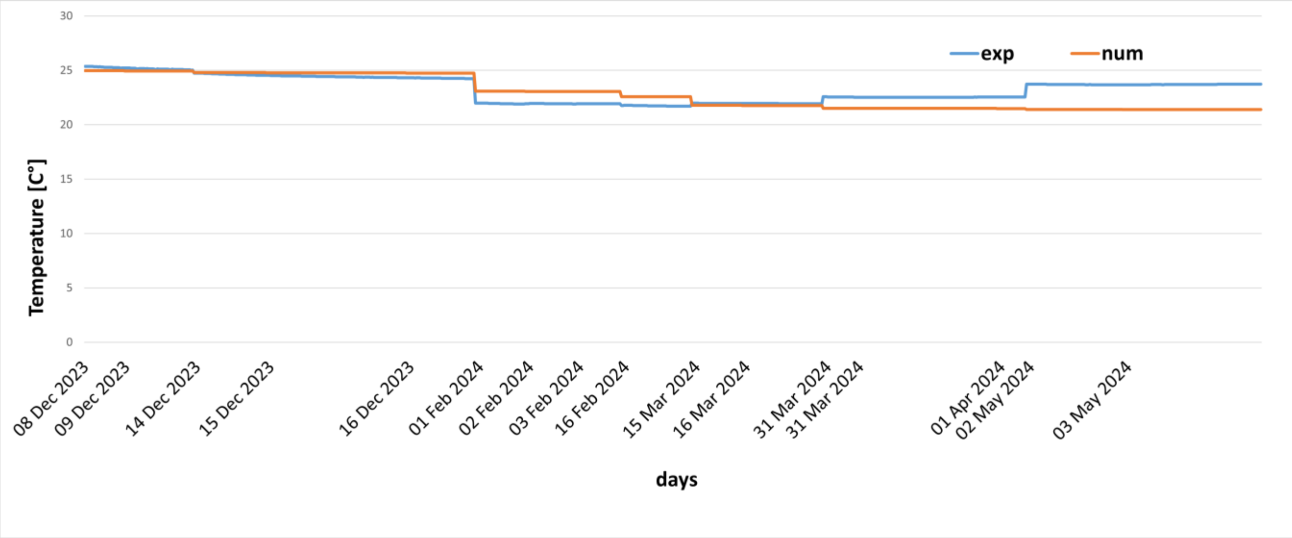

Figure IV.2 Soil temperature changes for both experimental and numerical.

The comparison between the temperature profiles resulting from the numerical model and experiment indicates that the curves follow a similar, periodic course. Figure (IV.2) indicates that the numerical model effectively captures the general trends of soil temperature variations. The slight differences observed can be attributed to the assumptions underlying the mathematical model mentioned in the previous chapter, which include:

- Homogeneity of soil properties
- One-dimensional heat transfer
- Adiabatic boundary conditions
- Negligible thermal storage effects

Figure IV.3 shows the difference in ground temperature resulting from numerical simulations at varying depths. External factors such as weather conditions, sunlight, and plants affect the soil temperature at small depths[34]. This is what prompted us to add an underground tank to the exchanger to reduce the temperature change.

- For more precision, we calculate the NMBE and CVRMSE to verify the accuracy of our results, as shown in Table (IV.3).

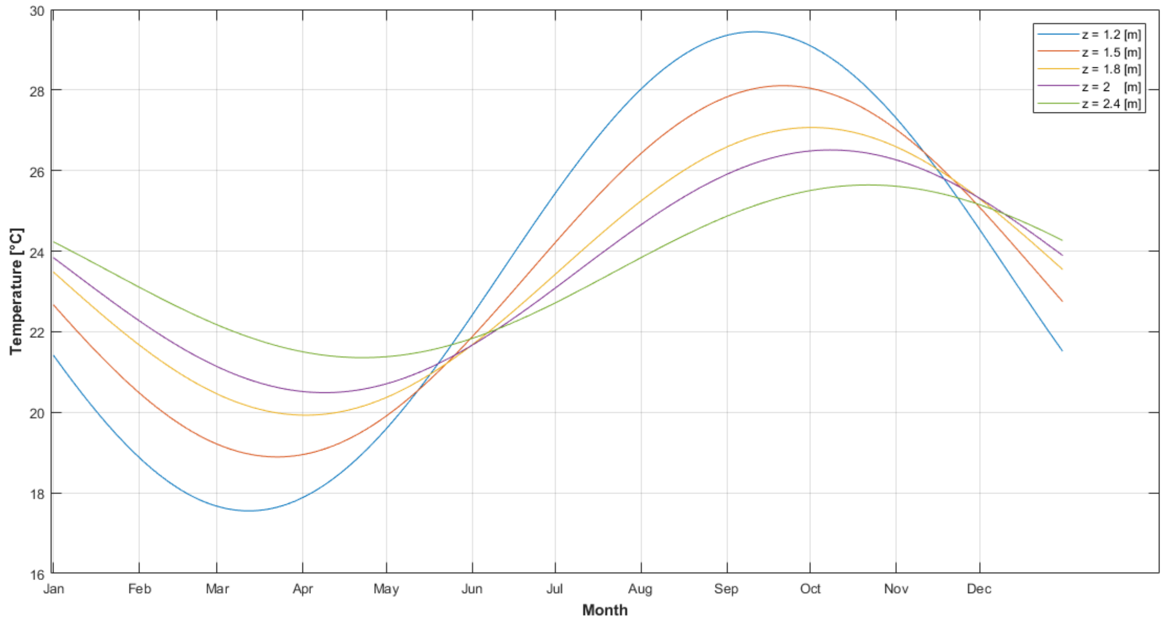

Figure IV.3 Soil Temperature Changes from Numerical Simulations at Varying Depths

Table IV-3: Soil temperature validation results.

	NMBE	*CVRMSE*
T_{soil}	-1.82%	0.504

From Table (IV.3), the NMBE of -1.82% indicates a slight underestimation by the model, with an average NMNE of 1.82%. The CVRMSE of 0.504% reflects the high accuracy of the model in predicting soil temperature variations.

IV.5 Outlet temperature

To demonstrate the effectiveness of this innovative soil/air heat exchanger, we analyzed the air temperature changes at the outlet. From December to May, we measured the outlet temperature to evaluate the efficiency and Coefficient of Performance (COP), and to identify the optimal airflow rate for the exchanger. This data provides insights into the exchanger's performance under different seasonal conditions.

The results of outlet temperature changes are shown in Figure (IV.4).

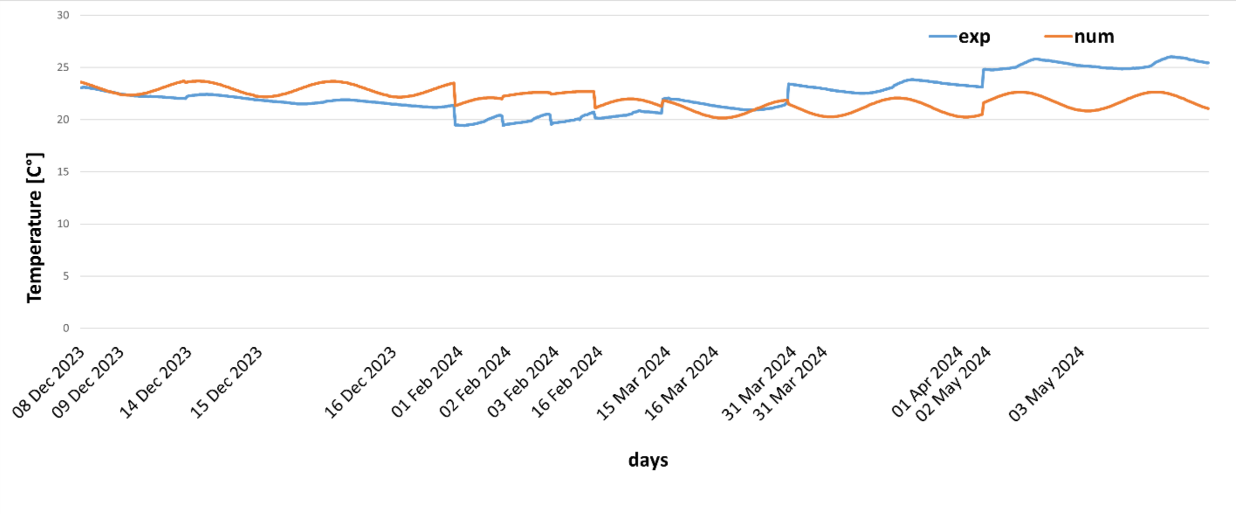

Figure IV.4 Outlet Temperature Changes for Both Experimental and Numerical.

The comparison between the outlet temperature profiles obtained by the numerical model and the experiment reveals that the distribution of outlet temperatures is similar and periodic. Figure IV.4 shows that the results are close to each other. The temperature rises and fall trends demonstrate the efficiency of the proposed numerical model in predicting the overall dynamics of outlet temperature fluctuations with seasonal changes. This aligns with our understanding of typical seasonal variations in ambient air temperature.

To clarify and analyze the results, we present the results obtained from both the experimental side and the numerical model.

Figure (IV.5) shows that on December 15, although the ambient air temperature was low, the outlet air temperature remained relatively stable, closely approaching ground temperature. Here, the ability of the exchanger to heat the place appears, despite the low temperatures outside. The comparison between Figures (IV.5) and (IV.6) shows that the numerical model closely matches the experimental results at all measured temperatures, with slight differences attributable to model assumptions.

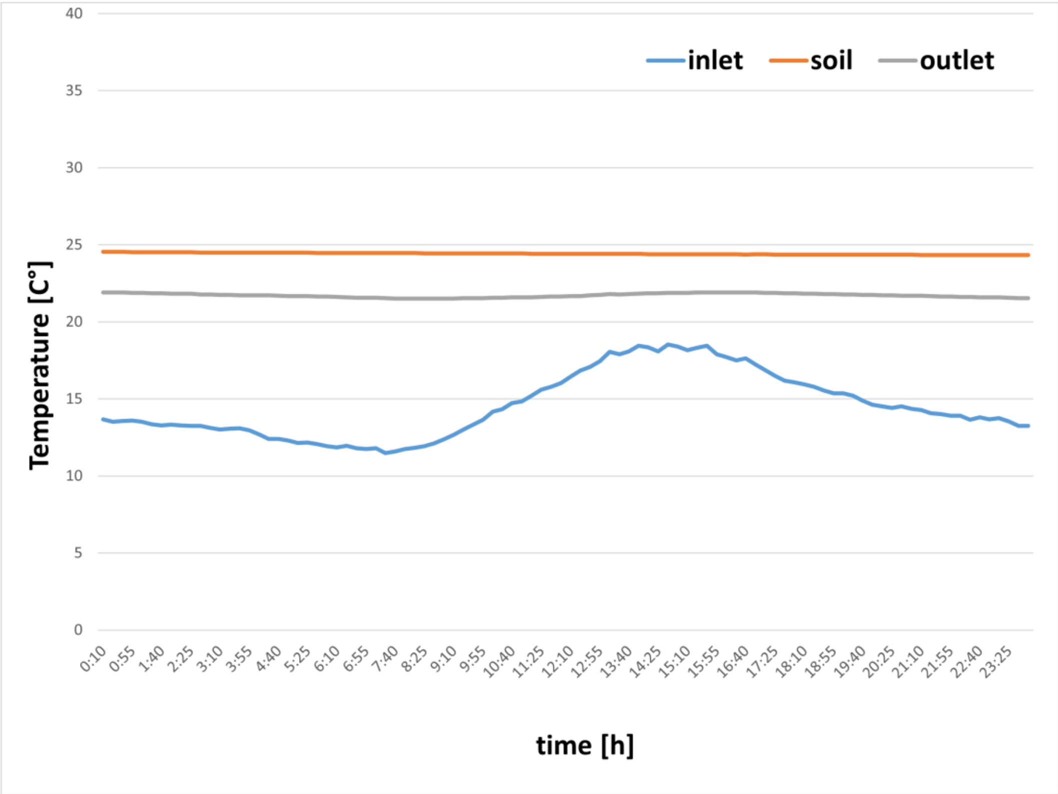

Figure IV.5 Experimental Temperatures Changes on December 15th .

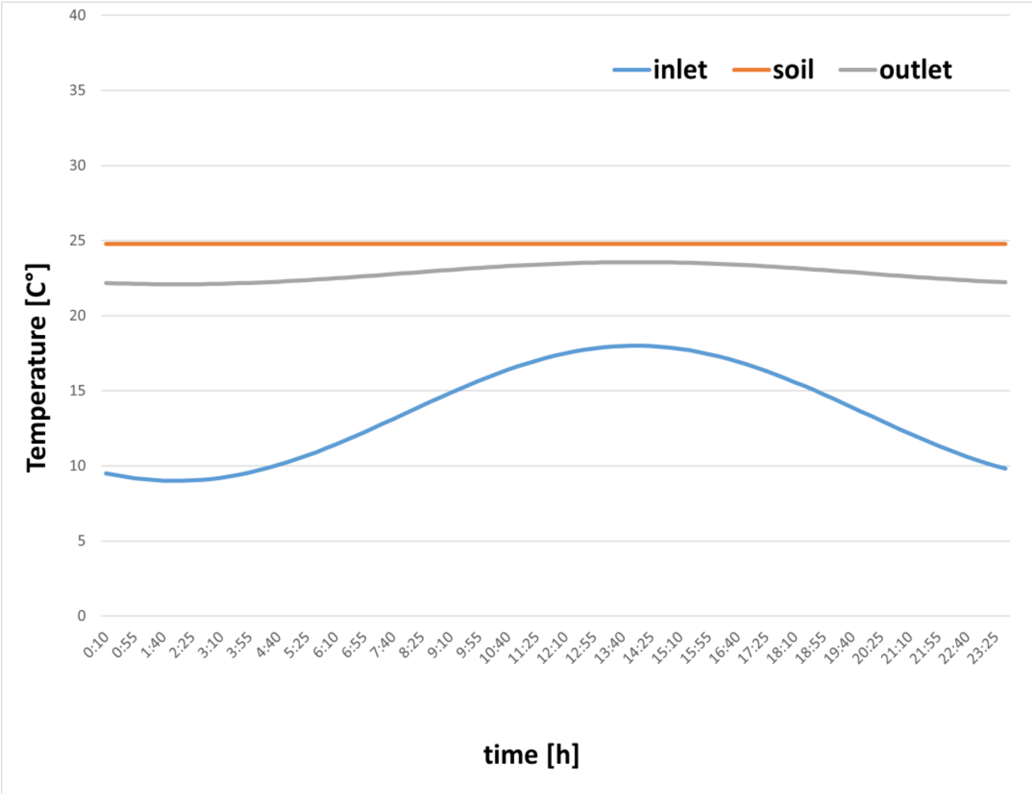

Figure IV.6 Numerical Temperatures Changes on December 15th.

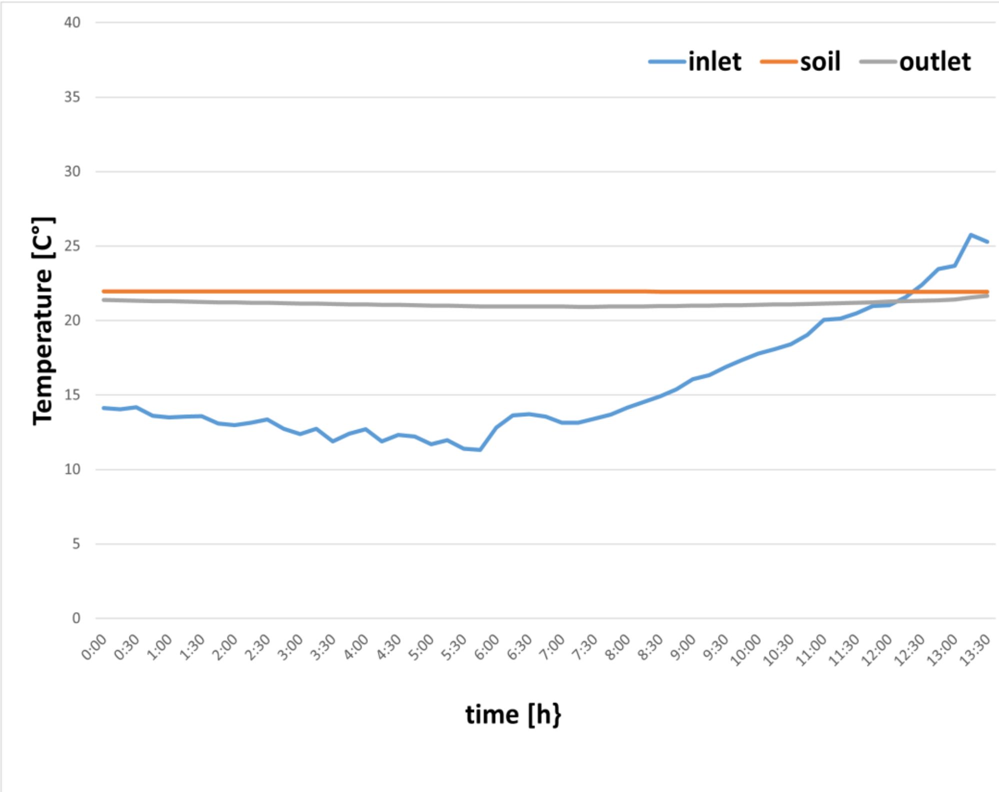

Figure IV.7 Experimental Temperatures Changes on March 16th .

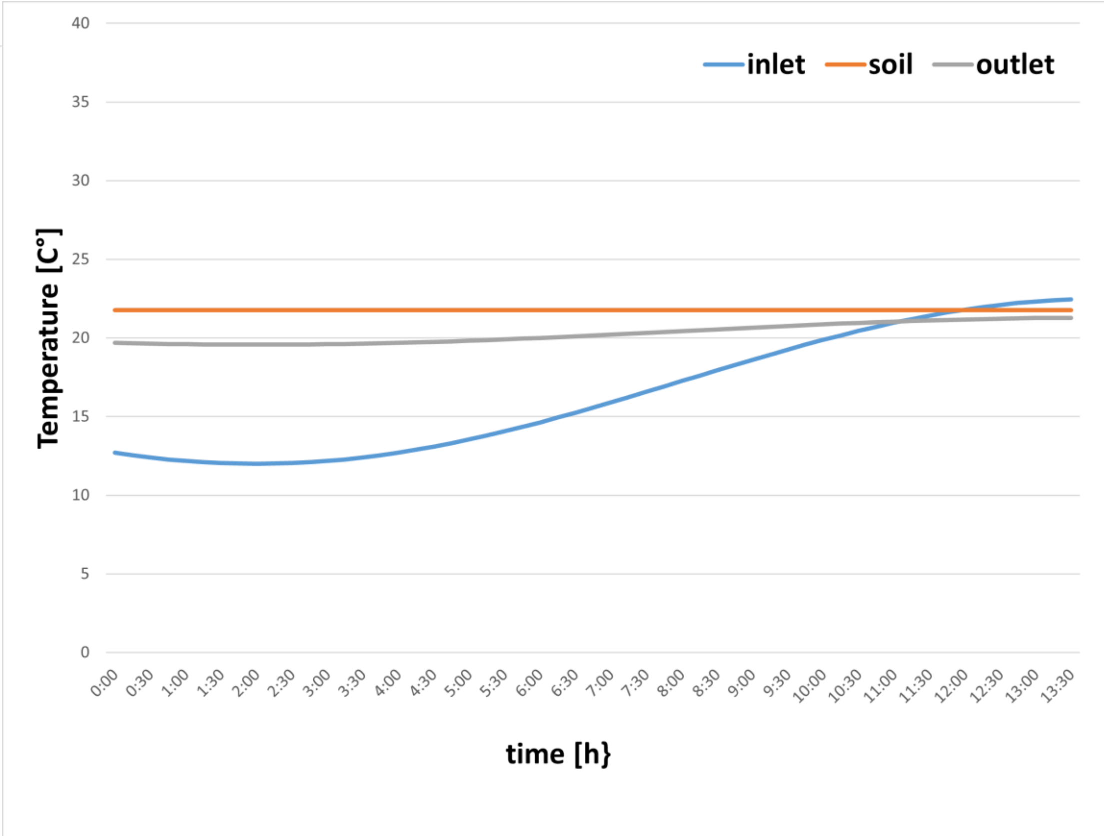

Figure IV.8 Numerical Temperatures Changes on March 16th.

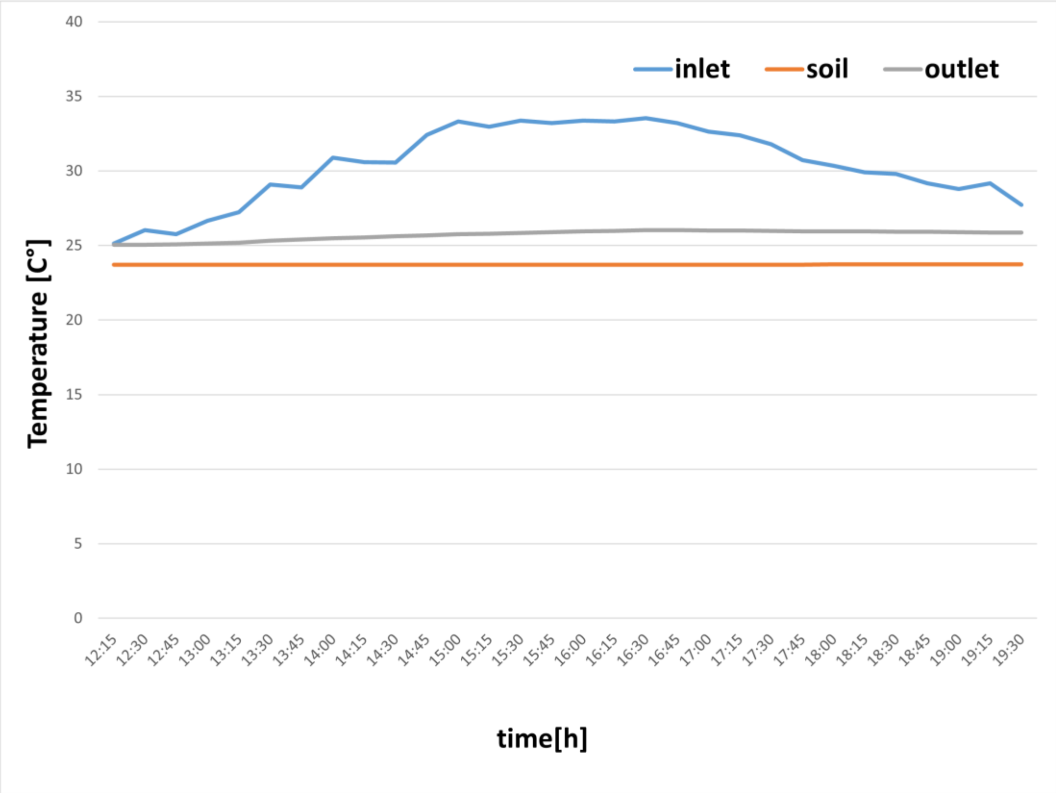

Figure IV.9 Experimental Temperatures Changes on May 03th .

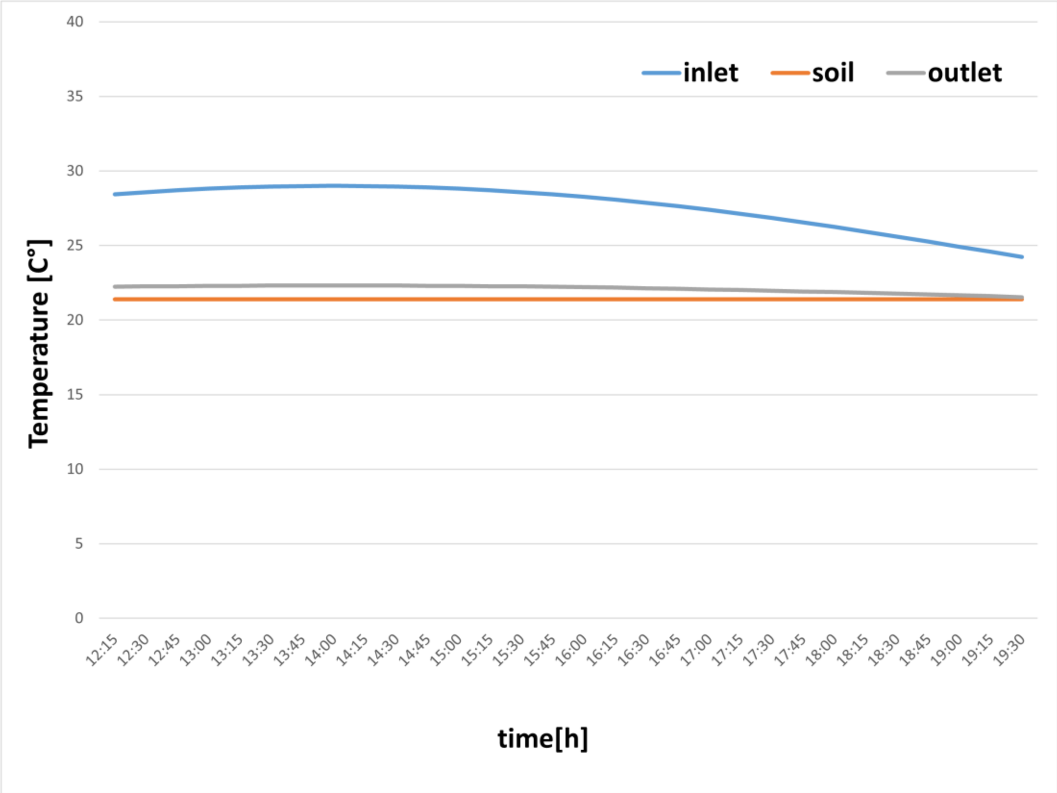

Figure IV.10 Numerical Temperatures Changes on May 03th.

To analyze the thermal performance of the buried heat exchanger in cooling mode, an experiment was carried out in continuous operating mode during the month of May 2024.

The experimental results are shown in Figure IV.9, where we notice that although it was hot outside, the air leaving the exchanger device was cool, proving to provide acceptable cooling. Comparing Figures IV.9 and IV.10, we see that the numerical model agrees fairly well with the experimental results for the entire range of temperatures tested, with the presence of some small differences attributed to the model's assumptions.

IV.6 Effect of Underground Water Tank

By integrating the underground water tank with the heat exchanger, we aim to reduce the change in ground temperature due to external factors.

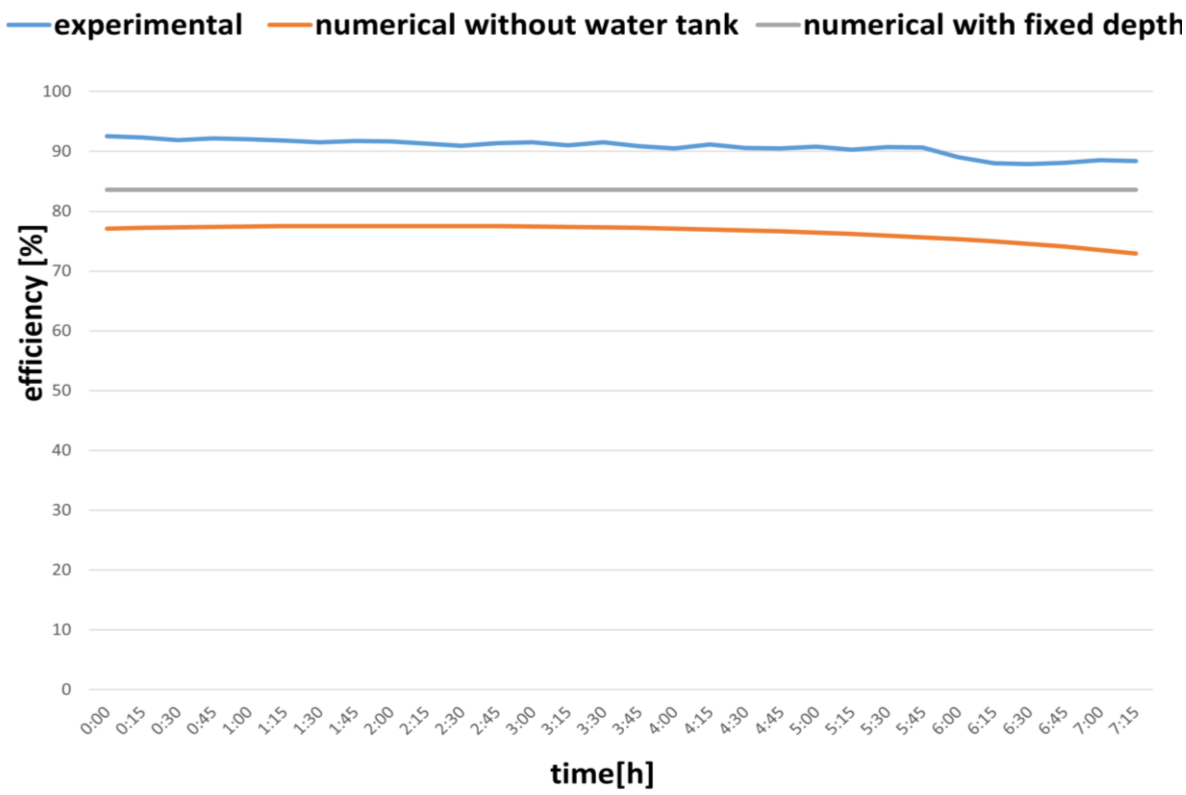

Figure IV.11 Efficiency Changes on March 16th - Experimental vs. Numerical (Without Underground Water Tank vs. With Fixed Depth).

We chose to analyze March because it is an optimal period to study the effect of integrating an underground water tank, as it does not represent extremely high or low temperatures. Figure (IV.9) shows experimental Temperature changes on March 16th, showing that the outlet temperature is very close to the ground temperature, despite changes in the ambient air temperature. Figure (IV.10) highlights the impact of using an underground water tank on the system's thermal performance. The heat exchanger integrated peripherally with an underground water tank is more effective, with an average efficiency of 91%, which shows higher efficiency compared to previous work done in the same month [1]. In comparison, the numerical models without a water tank show an average effectiveness of 77%. The exchanger with a fixed depth of 2.4 m exhibits greater stability throughout the experiment, with an average effectiveness of 83%. Figure (IV.12), which presents the COP in the experimental setup, underscores the effectiveness of the integrated underground water tank, highlighting the importance of thermal mass and consistent conditions for optimal heat exchanger efficiency.

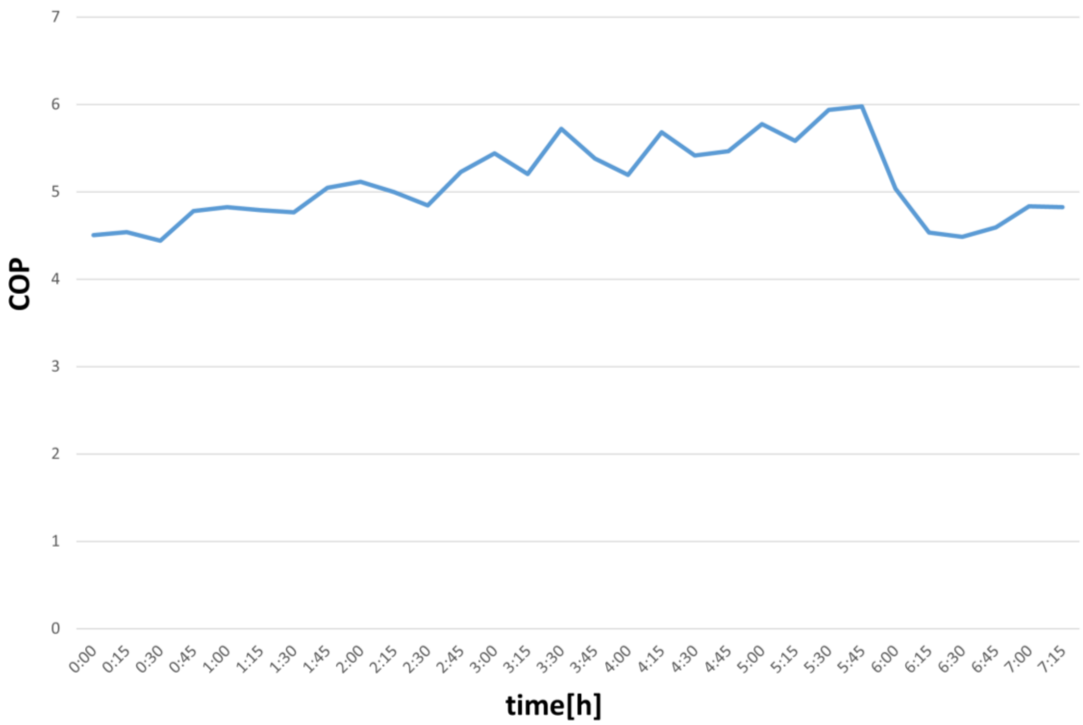

Figure IV.12 Experimental COP analysis on March 16th.

IV.7 Effect of airflow

To clarify the effect of airflow inside the heat exchanger, we conducted a numerical study, and the results are shown in the following figure.

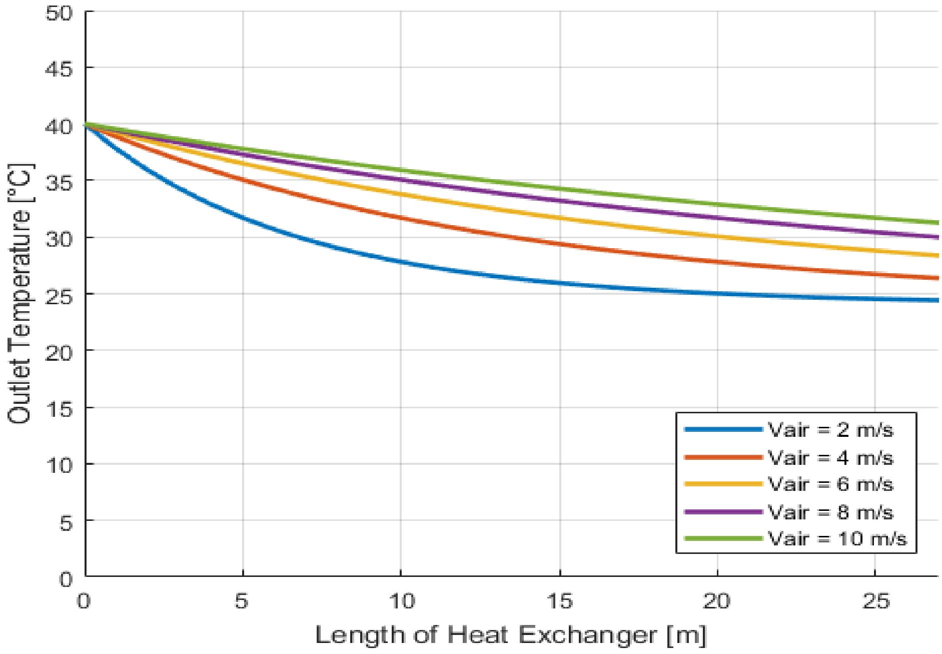

Figure IV.13 Impact of Air Velocity on Heat Exchanger Outlet Temperature.

Figure (IV.12) shows the variations in the outlet temperatures of the buried exchanger at different air flow rates. The results indicate that low injected airflow velocities result in outlet temperatures closer to the ground temperature. The stay of the air with the walls of the exchanger is long enough to achieve efficient heat transfer. Generally, it is at higher speeds that heat transfer is improved by inducing increased turbulent flow and contact with the internal surfaces of the exchanger. However, thanks to the serpentine-shaped design of our underground exchanger, sufficient turbulence is generated even at lower speeds, facilitating efficient heat transfer.

IV.8 conclusion

Through the analysis of experimental results, we tried to demonstrate the significant impact of the integration of an underground water tank with a buried earth/air heat exchanger on the efficiency and thermal performance of the system. Experimental and numerical results show notable improvements in efficiency, or the experimental setup exhibits higher efficiency than the numerical model.

The major interest in integrating an air/soil exchanger with a water tank is to improve the mass and thermal stability, which is why the experimental device has an average efficiency of 91%, which is higher than the 77% obtained by numerical models without a water tank. The coefficient of performance (COP) analysis also supports the idea that the experimental setup is better, showing that it can maintain higher COP values even when external conditions change. These results highlight the importance of incorporating additional thermal mass for optimal heat exchanger efficiency and offer valuable insights for advancing sustainable heating and cooling technologies.

General conclusion

General conclusion

Renewable energy sources are becoming more significant in the effort to decrease power usage and pollution caused by fossil fuels. Harnessing the energy stored in the Earth's subsurface at small depths is regarded as one of the most promising and sustainable sources of energy. This energy may be utilized to provide cooling for residences during the summer and heating during the winter, resulting in thermal comfort without the need for substantial power usage.

In this work, we are interested in the integration of a peripheral air/soil heat exchanger with an underground water reservoir. A detailed description of the experimental protocol was started in the second chapter, then followed by a numerical simulation based on three analytical models, a calculation code was written in MATLAB to understand and analyze the impact of the main parameters influencing the thermal behavior and the efficiency of the buried air/soil exchanger, integrated with an underground water tank.

The research focuses on the capacity to produce significant amounts of energy throughout a small area. Heat exchangers usually require large areas and depths greater than 3 meters since they are greatly affected by the climate, which in turn affects the temperature of the earth at small depths. An underground water tank is essential in this context. It functions as a sustainable internal energy source for the system, ensuring a consistently stable ground temperature at small depths.

Analysis of experimental results demonstrated the significant impact of integrating an underground water tank with a buried ground-to-air heat exchanger on the system's efficiency and thermal performance.

- Experimental and numerical results showed substantial gains in terms of efficiency. The experimental setup showed higher efficiency compared to the numerical model using analytical relationships of the heat exchanger without groundwater tank impact.
- This innovative heat exchanger has proven to be very effective in heating mode during the winter period (month of December) and cooling in the summer period (month of May), because it makes it possible to maintain lower air outlet temperatures. Close to comfort levels, despite climatic changes in the external environment.
- The integration of the underground water tank significantly improved the thermal performance and stability of the system. The experimental setup with a water tank achieved an average efficiency of 91%, exceeding the 77% efficiency obtained with the numerical simulation without a water tank.

- Analysis of the evolution of the coefficient of performance (COP) shows that values between 4.5 and 6 can be achieved throughout the entire period of continuous operation, making it possible to maintain high COP values despite fluctuations external parameters.
- A numerical study of airflow proved that reducing air velocity led to outlet temperatures closer to ground temperature. This was explained by the increase in contact time between the air and the walls of the exchanger.
- The coil design of the exchanger promotes sufficient turbulence even at low airflow rates, facilitating efficient heat transfer.

Through the experimental results obtained, it is important to underline the considerable impact of integrating an additional thermal mass to improve the thermal performance and the efficiency of the air/ground heat exchanger. These benefits provide valuable information to improve the thermal performance and efficiency of sustainable, energy-efficient heating and cooling technology.

Abstract

The objective of this work is to evaluate the thermal performance of an innovative geothermal air/soil (EAM) heat exchanger peripherally integrated with a water storage tank in the city of Lichana, Biskra, Algeria, realized by Professor Abdelhafid Moummi. This new concept uses the water reservoir as an additional mass, adding to the thermal inertia of the ground. We also created a numerical model using MATLAB to study the effect of the reservoir on the exchanger. The experimental results show temperature differences of around 13°C between the ambient air inlet temperature and that at the exchanger outlet, with an efficiency observed over the course of a day of 91%, and an average COP coefficient of performance 5.5. This study shows that the heat exchanger combined with an underground water tank system partially meets the needs for cooling in summer and heating in winter in the building sector.

Keywords: air/soil heat exchanger, water tank, cooling, heating, building, regions arid and semi-arid

Résumé

L'objectif de ce travail est d'évaluer les performances thermiques d'un échangeur de chaleur air/sol (EAM) géothermique innovant intégré périphériquement avec une bâche de stockage d'eau. Dans la ville de Lichana, Biskra, Algérie, réalisé par le professeur Abdelhafid Moummi. Nous avons également créé un modèle numérique sous MATLAB pour étudier l'effet du réservoir sur l'échangeur. Ce nouveau concept utilise le réservoir d'eau comme une masse supplémentaire s'ajoutant à l'inertie thermique du sol. Les résultats expérimentaux montrent des écarts de températures de l'ordre de 13 °C entre la température d'entrée ambiante de l'air et celle à la sortie de l'échangeur, avec une efficacité observée au cours d'une journée de 91 % et un coefficient de performance COP moyen de 5,5. Cette étude montre que l'échangeur de chaleur combiné avec un système de réservoir d'eau souterrain répond partiellement aux besoins de rafraîchissement en été et de réchauffement en hivers dans le secteur du bâtiment.

Mot-clés : échangeur de chaleur air/sol, bâche d'eau, rafraichissement, réchauffement, bâtiment, régions arides et semi-arides.

ملخص

الهدف من هذا العمل هو تقييم الأداء الحراري لمبادل حراري مبتكر هواء/تراب (EAM) يعمل بالطاقة الحرارية الأرضية تم تركيبه جانبيا على محيط خزان للمياه في مدينة ليشـــانا، بســـكرة، الجزائر، من انجاز البروفيســـور عبد الحفيظ مومي. أسـتخدم هذا المفهوم الجديد لخزان المياه ككتلة إضـــافية مدعمة إلى القصـــور الحراري للأرض. وقمنا كذلك بإنجاز نموذج رقمي باســـتخدام MATLAB من اجل دراســـة تأثير الخزان على المبادل. أظهرت النتائج التجريبية فرق في درجات الحرارة تصل حوالي 13 درجة مئوية بين درجة حرارة مدخل الهواء الخارجي ودرجة حرارة مخرج المبادل، مع ملاحظة كفاءة على مدار اليوم تبلغ 91% ومتوسـط معامل أداء COP يبلغ 5.5. من خلال النتائج بينت هذه الدراسـة أن دمج المبادل الحراري جانبيا مع خزان المياه تحت الأرض يلبي جزئيا احتياجات التبريد في الصيف والتدفئة في الشتاء في المباني.

كلمات مفتاحية: مبادل حراري هواء/تراب، خزان مياه، تبريد، تدفئة، البناء، المناطق الجافة وشبه الجافة.

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Annexes

Annex A

المعهد الوطني الجزائري للملكية الصناعية

INSTITUT NATIONAL ALGÉRIEN DE LA PROPRIÉTÉ INDUSTRIELLE

inapi

الجمهورية الجزائرية الديمقراطية الشعبية

RÉPUBLIQUE ALGÉRIENNE DÉMOCRATIQUE ET POPULAIRE

R2-FO-03
E1

Nature de la demande de protection *

Brevet d'invention ☑ Extension de la demande internationale selon le PCT ☐ Certificat d'addition ☐

[71] - DEPOSANT[S] : *Nom, Prénom, [dénomination], et Adresse complète*

Universite de Biskra, Laboratoire de Genie Mecanique, LGM, B.P. 145, RP 07000, Biskra, Algeria.

Nationalité du ou des déposants ALGERIENNE

[72] - INVENTEUR[S] : *Nom, Prénom, Adresse*

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[54] - TITRE DE L'INVENTION :

Échangeur air/sol intégré périphériquement à une bâche de stockage d'eau destiné au rafraîchissement et réchauffement de l'air dans les habitations

[30] – REVENDICATION DE PRIORITE (S)

[31] - N°[s] de dépôt	[32] - date[s] :	[33] - pays d'origine	Nature de la demande

Numéro de dépôt	Date de dépôt	Heure

N° de la demande internationale et date internationale de dépôt

Visa

Annex B

الملتقى العربي الثاني

Certificate of Appreciation

ARCME

الملتقى العربي الثاني للميكانيكا والهندسة

Second Arab Conference on Mechanics & Engineering

We undersigned do hereby proudly present this certificate of attendance to recognition of an outstanding attendance record to ***Okba Boucherit***

In technical Oral Presentation, recognition and appreciation of research contributions to ARCME'23: ARab Conference on Mechanics & Engineering held on 10th, 11th and 12th of December 2023 in University of Biskra, Algeria.

Title: ***Experimental Study Of A Peripherally Integrated Heat Exchanger Around An Underground Water Tank In Arid And Semi-Arid Regions.***

Co-Authors: ***Safieddine Ounis, Abdelhafid Moummi.***

Conference Chair
Dr. Kamel Aoues

University of Biskra-Algeria
ARCME'23

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