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BUILDINGS DESIGN INTEGRATION WITH GEOTHERMAL ENERGY SYSTEM TECHNOLOGIES AND AIR CONDITIONING APPLICATIONS

تكامل تصميم المباني مع تقنيات وتطبيقات تكييف الهواء باستخدام الطاقة الحرارية فى باطن الارض

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ABSTRACT

Nowadays, global warming and thermal islands in modern cities are spending much energy on heating and cooling spaces. Geothermal energy is a sustainable technique for space air-conditioning. Therefore, the (GSHPs) are increasingly interested in their expressive capability to lessen fossil fuel depletion and accordingly; decrease greenhouse emissions. Meanwhile, geothermal energy could be employed either direct utilization or electricity generation, which depends on the enthalpy resources chemistry and temperature. Recently, direct utilization has varied significantly, and there are several methods available for temperatures typically ranging from 4°C up to 80°C. (Lund J.W., 2012) This paper poses a comprehensive literature review of heat pump technologies by utilizing the ground source for cooling and heating applications to achieve human thermal comfort. Subsequently, propose the influence factors of the scheme components that would undoubtedly reflect on the optimal design of the building. As a result, achieve precisely an integrated building.

KEYWORDS

Ground Source Heat Pumps; Applications; Building design Integration.

الملخص

فى الوقت الحالى يتسبب الإحتباس الحراري والجزر الحرارية في المدن الحديثة فى إنفاق الكثير من الطاقة لتدفئة وتبريد الفراغات فى المبانى. الطاقة الحرارية الأرضية تعتبر من التقنيات المستدامة فى تبريد وتدفئة الفراغات. لذلك تحظى باهتمام متزايد لقدرتها على تقليل إستهلاك الوقود الأحفورى و بالتالى تقليل الإنبعاثات المسببة للإحتباس الحرارى. و فى غضون ذلك يمكن استخدام الطاقة الحرارية الأرضية فى توليد الكهرباء و لأغراض التبريد و التدفئة و اعتمادا على درجة حرارة المصدر. مؤخرا الإستخدام المباشر للطاقة الحرارية الأرضية تنوعت أنظمته للإستفادة من درجات الحرارة التى تتراوح من ٤ الى ٨٠ درجة سيليزيوس. يبدأ البحث باستعراض تطبيقات الطاقة الحرارية الأرضية لأغراض التبريد والتدفئة فى المبانى لتحقيق الراحة الحرارية. ثم يبدأ البحث بمناقشة مكونات النظام واستعراض تاثيرها على تصميم المبنى من خلال إفتراض العوامل والتى لابد من توافرها فى المبنى وذلك لتحقيق مبنى متكامل تصميميا لمتطلبات استخدام الطاقة الحرارية الأرضية.

الكلمات المفتاحية

الطاقة الحرارية الأرضية- التطبيقات- التصميم المتكامل للمبنى

1. Introduction

The built environment uses about 40% of our overall energy requirements. As a result, environmental problems and fossil fuel depletion have occurred. Accordingly, the challenge exists between conserving energy and indoor air quality. In the architectural design of buildings, the key challenge is achieving indoor thermal comfort by reducing energy consumption in buildings. Therefore, applications of environmentally mechanical ventilation systems in buildings are urgently necessary. That could indeed remove cooling and heating needs with the integrated design process. To maintain the indoor environment satisfactory, use the available energy resources at the site along with the purchased energy for active cooling systems. Hence, the total possible lessen of using non-renewable energy will accordingly reduce the building's carbon footprint, which will consider a significant impact on the human thermal comfort of buildings. One of the approaches to addressing this is to minimize fossil fuel consumption by using modern renewable energy resources. Consequently, there is a vital need to develop new technologies that can utilize these green renewable energies to improve energy efficiency. (Furundzic et al, 2012)

Utilization of the (GSHP) typically considers the ground as a heat injection or rejection basin to condition space, also, provides domestic hot water. The temperature of the underground sufficiently provides more temperatures for heating and lower temperatures for cooling and, underground temperature variations are lower than the ambient air temperatures. Consequently, the developed GSHP technology provides more effective energy for space air-conditioning than the traditional systems of air conditioning (A/C). (Yang H, et al., 2010; Ioan S., Calin S., 2016) To date, systems of GSHP are efficiently utilized in domestic and commercial buildings widely. The whole installed bulk for the direct application of geothermal worldwide has projected to be 70,329 MW. By the end of 2014, the total installed had a noticeable increase of 45.0 percent over World Geothermal Congress (WGC) in 2010 and the annual compound rate was rising 7.7 percent. (John W. Lund and Tony L. Boyd, 2015)

Nomenclature:

GSHP	Ground Source Heat Pumps
GWHP	Ground Water Heat Pumps
GCHP	Ground Coupling Heat Pumps
SWHP	Surface Water Heat Pump
A/C	Air Condition
HVAC	Heating, Ventilation, and Air Conditions

1.1 Problem Statement

Due to the massive scale of consuming energy in buildings, the use of renewable energy is considered a challenge to face. Simultaneously, geothermal energy is an important form of utilization in the renewable energy system. Therefore, the efficient employment of geothermal energy can mitigate the debilitation of traditional energy sources. Additionally, the system requirements are absent through the building design process.

1.2 Research Hypothesis

In the light of the buildings confront the challenge of achieving life properly qualifies of buildings' with preventing the negative impact on the environment. Therefore, there is a concern to introduce the geothermal air conditioning system as a sustainable and alternative service by specific requirements.

1.3 Purpose

This research aims to propose through the design process, a more complete integrated geothermal energy system for cooling and heating needs in the building. Then consider the space requirements of the system without negative effects on the building function efficiency.

1.4 Methodology

The adopted approach is analyzing the geothermal energy cooling and heating systems and their characteristics. Meanwhile, analyzing the effect of the system components and subsequently, determine the effect on the architectural design process. Therefore, this study is limited to the application of geothermal power as new renewable energy to the building spaces through the building design phase.

1. Geothermal Utilization Technology

The effective utilization of geothermal fluid is categorized into two classes; indirect use and direct use depend on fluid temperature and enthalpy. (Nshimyumuremyi E., 2014) low and medium temperature is suitable for direct applications while the excessive temperature is more proper for electricity generation. Operating shallow geothermal heat exchangers considers the greatest effective method of the direct utilization of heating and cooling needs in buildings. Hence, electricity is the only source of energy to operate the energy distribution part (pumps and fans) of the system. The air-conditioning geothermal system is classified into a firstly ground heat pump system, secondly the SWHP system, and thirdly the underground heat pump system.

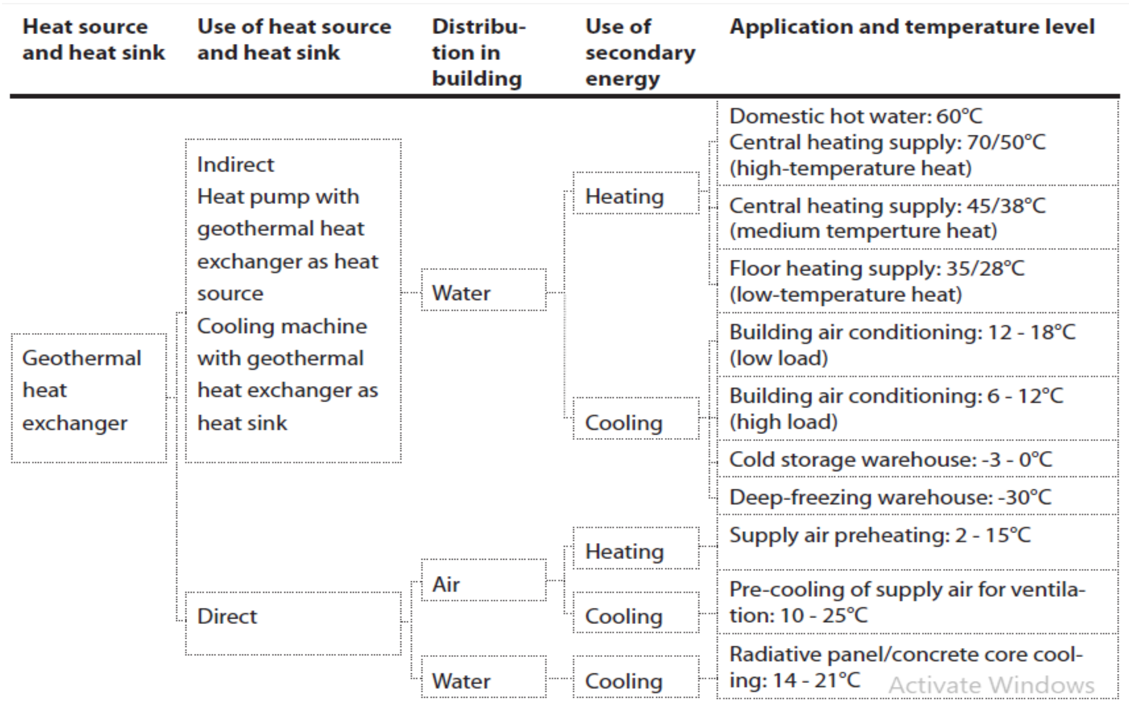


Figure 1, Applications of geothermal energy use. (Eicher U., 2014)

2.1- Systems of Ground Source Heat Pumps

The ground heat pump provides hot water for domestics besides heating and cooling spaces. An environmentally safe heat conversation liquid circulates through a continuous loop installed beneath the ground frost line according to the region regulations. the heat conversation liquid transfers the heat as of the ground in winter and discharges heat to the ground in summer. The loops material is usually the high-density polyethylene (HDPE) in a vertical, horizontal, or oblique manner. Soil temperatures beneath the surface are additional constant year-round than outside the ambient air temperatures.

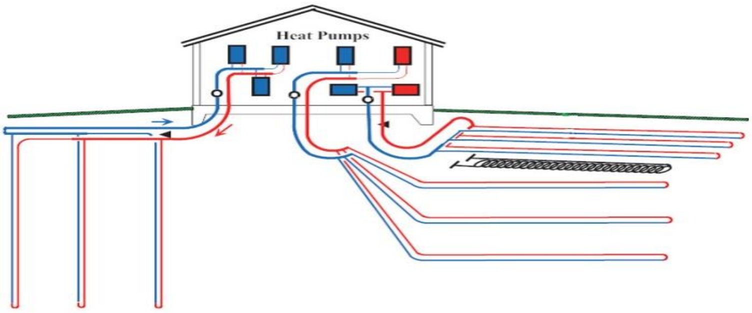


Figure 2- Ground-Coupled Heat Pumps with Three variant options of Closed-Loops (Source: Kavanagh S, Rafferty K, 2014)

2.2- Surface Heat Pump System

Exceptionally, that system utilizes the surface water bodies like seawater or biological water sources, rivers, lakes, and ponds as the heat source of heat pump units. Mainly the system suites buildings are in sites where a sufficient surface water body available besides the building. Meanwhile, the water bodies employ as a heat sink/source for the buildings. Also, SWHPs could be either closed-loop systems like GCHPs or open-loop systems like GWHPs.

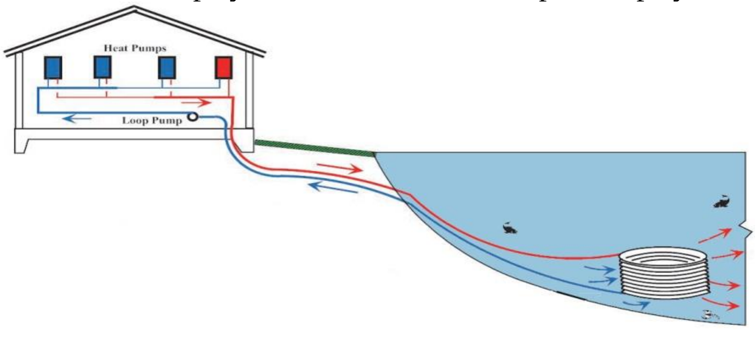


Figure 3- Surface-Water Heat Pump with a Locked-Ring Lake Coil Option. (Source: Kavanagh S, Rafferty K, 2014)

2.3- System of Underground Water Heat Pump

Underground WHP system could use water well or two wells. The water well system name is Standing Well System that the groundwater extracted from and dumped in the same well as given away in figure (5). The system operates two wells known as pump and rejection system, which pump the extracted groundwater from one well and rejected to another (PRS), as given away in figure (6). (Yao Y. & Olson G., 2018), (Egg J, et al, 2013) However, the utilization method of the system categorized into direct use system and indirect uses system as indicated in Figure 7.

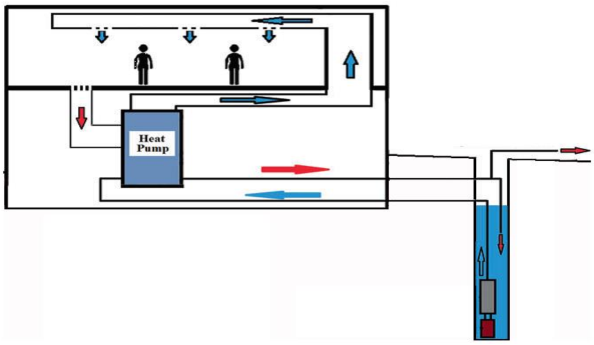


Figure 5- Standing well system. (Source: Yao Y. & Olson G., 2018 & modified by Author, 2020)

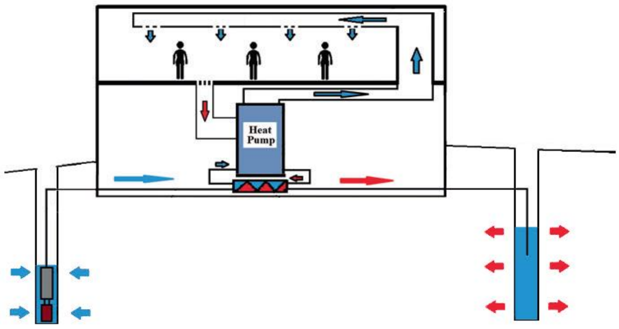


Figure 6- Pump and Rejection system. (Source: Yao Y. & Olson G., 2018 & modified by Author, 2020)

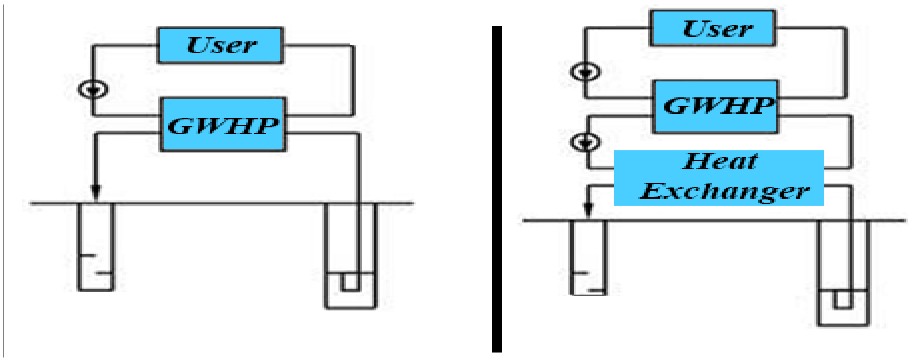
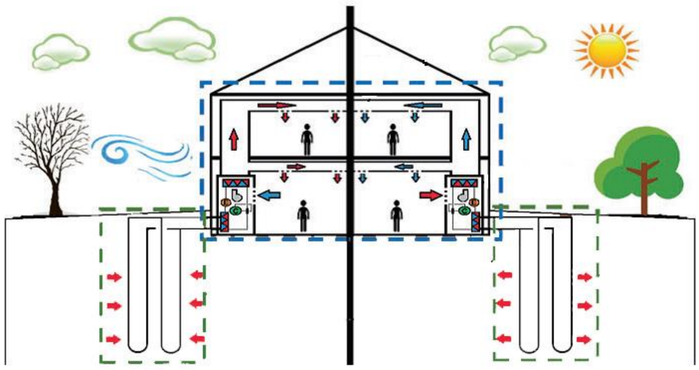


Figure 7- Direct & Indirect ways of GWHP Utilization (source: Wei S., 2018 & Modified by Author, 2020)

2. Geothermal Heat Pump System Component

Precisely, the GSHP system typically includes heat pump units outdoor and indoors. On-site the ground loops relate to the indoor distribution equipment, like heat exchangers (Water – to- air, water-to-refrigerant, water-to-water, etc.) as given away in Fig.8. Therefore, the principal components of the GSHP besides the energy source are - (1) the ground Connection subsystem to transfer the energy to (2) the indoor heat pump subsystem and (3) the indoor distribution energy subsystem.



Outdoor Distribution system   Indoor Distribution system

Figure 8- Typical GSHP system components.
(Source: Yao Y. & Olson G., 2018 and modified by Author, 2020)

3.1- Ground Connections

The ground connections system links the indoor heat pump in the building to transfer the extracted heat from and to the underground. In general, these types of systems are open or closed loops. The open system utilizes the groundwater or the surface water as a heat carrier in loops then directly or indirectly transports the local groundwater or surface water to the heat exchanger. Whereas, the closed system circulates a heat carrier medium (water or antifreeze) through an embedded loop of pipes (vertical, horizontal, or diagonal arrangement). Subsequently, the heat transfers from the ground, groundwater basins, or any other reservoirs to the indoor heat pump and vice versa, as given away in figure 9.

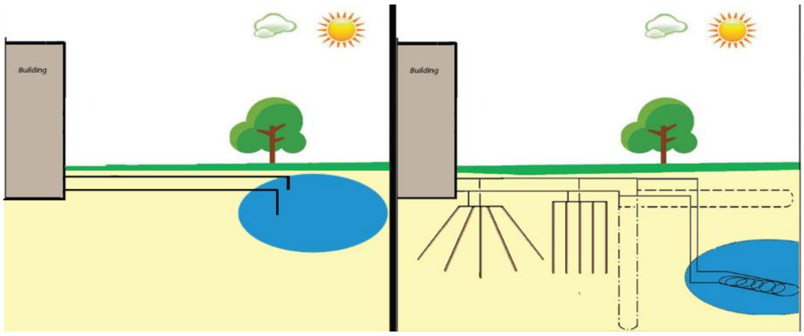


Figure 9- open (left) and closed (right) loops of GSHP systems. (Source: Author, 2020)

3.2- The Indoor Heat Exchanger Subsystem

The indoor heat exchanger unit in addition to the distribution subsystem is the typically indoor part of the GSHP system. The first part of the indoor system is the heat exchanger, which is the main component to exchange heat between two mediums air, antifreeze, or water. Also, the typically employed heat exchanger in the GSHP system inside buildings is either water-to-water or water-to-air heat pump units where could be conveniently located in cabinets, ceiling plenums, or mechanical rooms on the basement floor as indicated in figure 10.

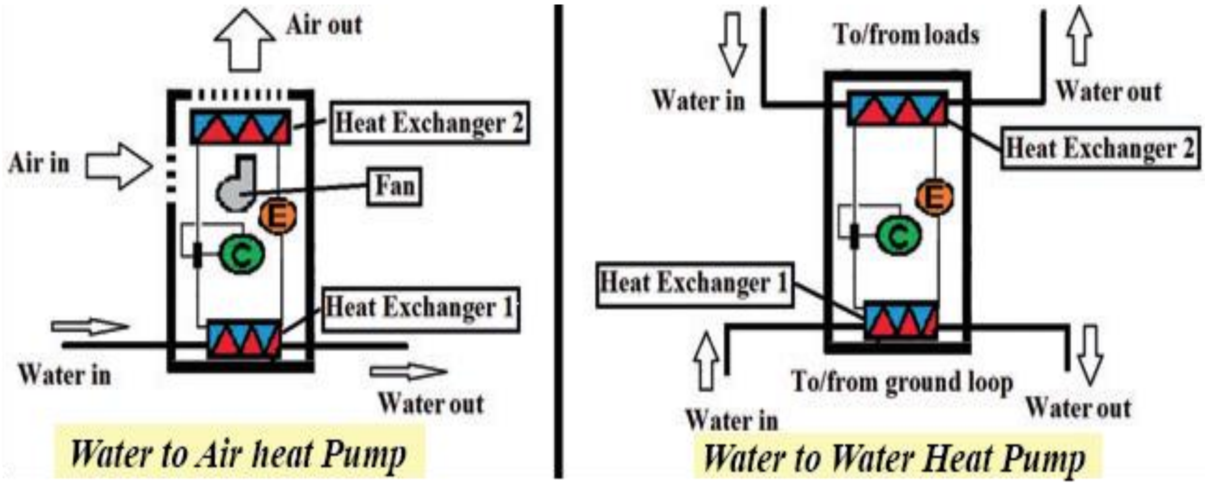
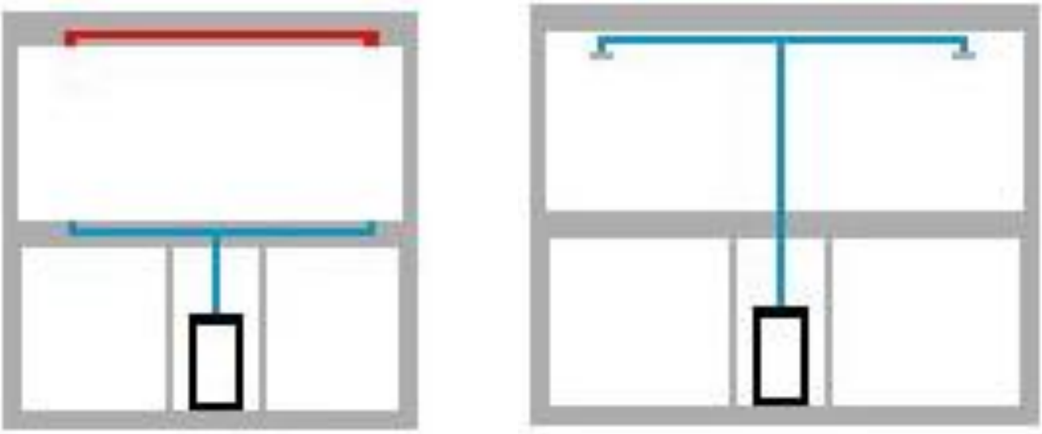


Figure 10: Types of heat exchangers.
(Source: Yao Y. & Olson G., 2018)

3.3- Distribution Subsystem

The distribution subsystem connects the indoor energy source and delivery devices. The cooled or heated water or air in the heat exchanger circulates in pipes or ducts to the delivery devices to air condition spaces. Air distribution trees have a huge mass; accordingly, have enormous visual impacts unless they harbored above ceilings, below floors, or within vertical shafts as given away in figure 11. Meanwhile, Water distribution trees consume much less space (a given volume of water carries vastly more heat than the same volume of air dose at the same temperature). Besides, the water distribution tree is integrated easily within structural members like structural columns. (Walter T., Alison G., 2015)



A-Air ducts B- water pipes

*Figure 11- Distribution trees. **A**-Air delivery and **B** water delivery. (Source: Walter T., Alison G., 2015)*

4. INTEGRATED DESIGN OF GEOTHERMAL ENERGY SYSTEM IN BUILDINGS

Building integration with renewable energy is a process, which combines architectural and geothermal energy systems. Analyze the effect of the renewable system at the beginning of the construction process and then assess their specifications, as given away in Table 1.

Table1. Impact of the geothermal utilization system on the architectural design

Renewable energy source & technology	Influencing factors	Integration in design
Geothermal energy (GSHPs)	Geological characteristics	Site layout
	Indoor heat exchanger Mechanical room location and size	Architectural design layout & Interior design
	Distribution tree and delivery devices	

According to the influencing factors of geothermal energy technology, there is a need to consider the system requirements in the architectural design process. The architectural design stage of renewable energy building includes two essential parts: site planning and building design.

Additionally, meeting the functional architectural design requirements' is necessary to meet the geothermal energy requirements.

4.1. Site Layout Planning

Site layout planning requires software to simulate accurately the building spacing, height, and orientation, to determine accurately the building footprint and location. Then propose the best position of the building to lessen heat gain and loss. The thermal characteristics of the geologic pattern perform an enormous role in the GSHP application succession. The thermal characteristics include ground temperature and the ground source thermal conductivity, which relies on the geographic locations, the ground source type, and depth. Therefore, typically on-site tests are utilized to precisely measure the properties of the energy source specifically for large commercial projects despite smaller projects like residential projects.

Consequently, on-site tests or traditional methods are to obtain the geological properties of the site and site location in the city or the country. Besides, the ground loop configurations are defined horizontally or vertically depending on the on-site position, project sizes, and heating or cooling loads. In contrast to other ground systems, for example, horizontal ground loops involve large land areas. Thus, in urban commercial buildings, the horizontal ground-coupled heat pump is barely used except for the horizontally deep bored pipes. (Yao Y. & Olson G., 2018) Besides, the outdoor environment influences horizontal ground loops as the pipes are near to the ground surface. However, the straight-up closed rings are useful where the area site is limited. The surface heat pump is used, where an adequately large body of water is adjacent to the building. However, the lake depth should never drop below 2.5 m with a sufficient area. (Grondzik W., Kwok A, 2015)

4.2. Architectural Design Layout

Providing space for HVAC equipment, distribution, and maintenance will severely affect system performance and longevity. HVAC systems demands could have a fundamental reflection on space planning, ceiling heights, besides other interior design issues. The indoor portion of the system consists of the thermal source plant for cooling and heating, the distribution subsystem, and the delivery devices in each zone. Therefore, the coordination between mechanical and architectural designs at the beginning of the building design is necessary.

4.2.1. Integration with Building Spaces

The thermal source plant represents a connection between the buildings outdoor and indoor. Therefore, the GSHP requires mechanical room for heat exchanger, the ground loops installations, and distribution subsystems and often locates in a basement or on a roof. Moreover, GSHP typically occupies in retrofits, where small mechanical systems are vastly desirable alike schools where site areas are abundance or historic structures. (Grondzik W., Kwok A, 2015) Distribution components typically connect source components to deliver air or water as a distribution medium. Thus, the distribution component in the case of water distribution medium is pump and pipes instead of air handling units and ducts in the air distribution medium system.

(AHU) in common is a packaged component found in both air and air-water systems. According to the project needs, the AHU will typically include a filter (to purify the air and protect the fan and coils), a fan (to circulate air through the system), and a cooling coil (when cooling is required and the cooling by water or air medium). Heating coils for a variety of system types are often usually included with AHUs. Hence, the Mechanical room for the AHU needs fresh air from outside, so direct access by louvers or shafts is necessary.

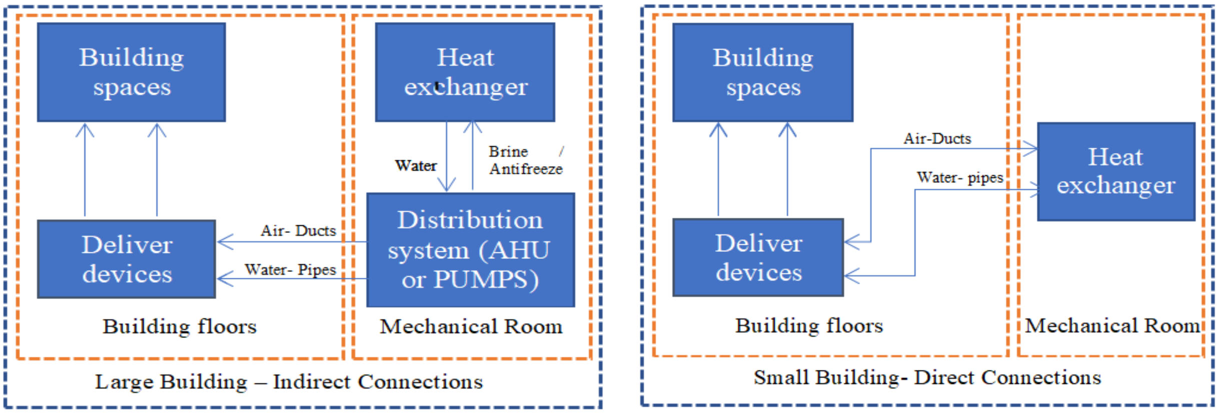


Figure 12- the interior part of the GSHP system with indirect or direct connections in buildings. (Source: Author, 2020)

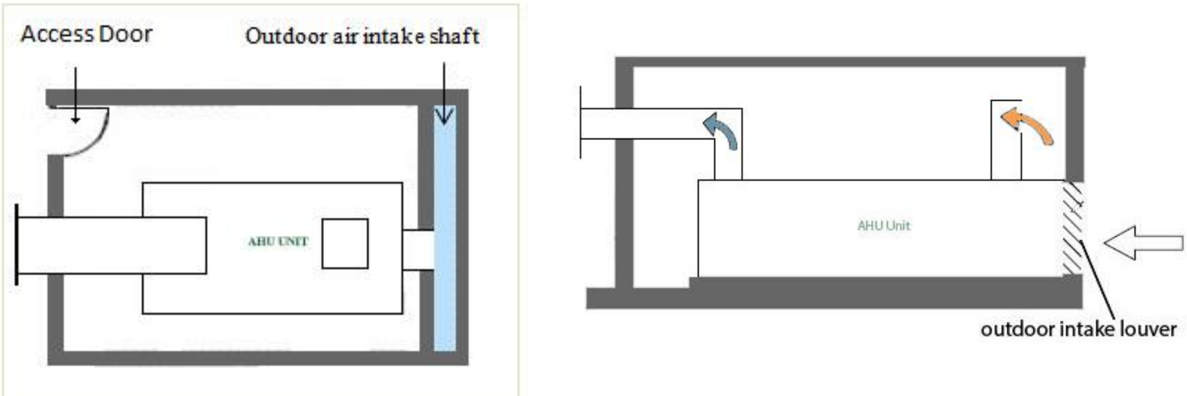


Figure 13- Typical plan & section of the mechanical room for AHU with shaft or louver. (Source: Author,2020)

4.2.2. Integration with Building Floor and Ceiling

Delivering air or water to spaces by using distribution trees enters any space by both horizontal and vertical methods. Therefore, necessary coordination is required with the lighting, ceiling design, and other interior design elements. Distribution trees are like a tree in nature have root as the same as the machines of air / water heating and cooling. The tree's stalk typically considers the dominant duct or pipe from the mechanical equipment to the served zone. The branches of the tree are like the system ducts or pipes that drive to spaces individually. Leaves represent the delivery devices that supply the served space with conditioned air/water.

Distribution trees circulate horizontally and vertically as well. Vertical distribution affects the space renting flexibility unless using vertical shafts to raise the ducts. Meanwhile, horizontal distribution affects the ceiling depth and the floor-to-floor height as given away in Figures 14 and 15. Hence, using raised floors with 0.6 by 0.6 m modules to run small ducts. Binggeli Croky (2003) stated that to accommodate the floor – to – floor air conditioning satisfactory, the proper height should be at least 2.7 m.

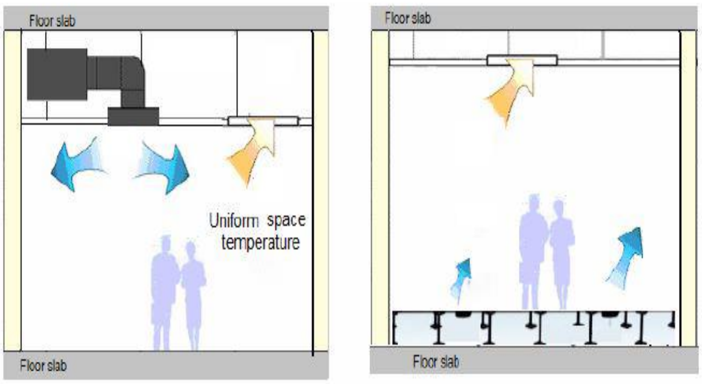


Figure 14- Distribution trees Underfloor and Overhead system (Source: CED,2015)

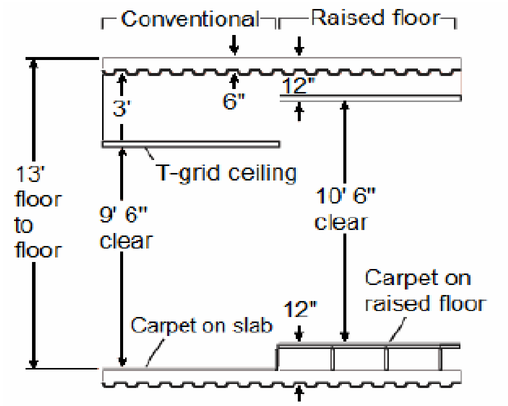


figure 15 –Required depth for the overhead and the underfloor system
(Source: CED, 2015 & ASHREA,2001)

On the other hand, delivering water conditioned to spaces has more specific restrictions than air. The heating or cooling water devices in an HVAC system include chilled beams, hydronic radiant panels. Chilled beams are a manufactured device hinged to the ceiling, where cozy air growths and cooled by the chilled beam; once it has cooled sufficiently, the air sprays back to the ground, where the round starts through as figure 16. Meanwhile, hydronic radiant panels embedded in the floor or ceiling, their performance genuinely affected by the building insulations as given away in figure 17. (*Grondzik W., Kwok A, 2015*)

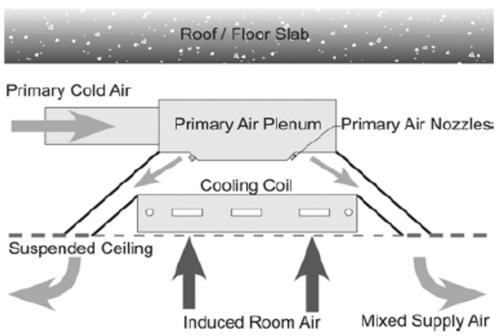


Figure 16- Chilled beam cooled water delivery device
(Source: Grondzik W., Kwok A, 2015)

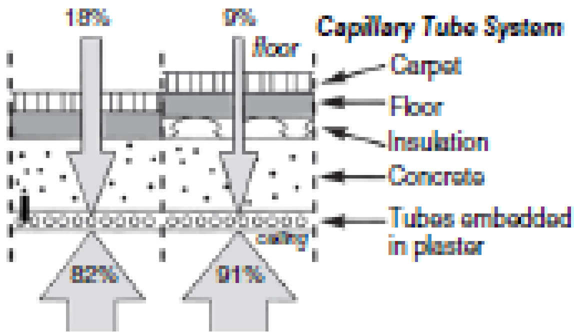


Figure 17- Hydronic Radiant panel.
(Source: Grondzik W., Kwok A, 2015)

The AHU equipment room area should be suitable for the equipment size, maneuvering space for service, maintenance, and replacement purposes. Therefore, building designers should provide clear circulation aisles and sufficient access to all equipment for service and preservation purposes. Besides, the arrangement should take into consideration the subsequent removal and replacement of equipment. Also, an important decision is whether to group or separate the HVAC source equipment and the HVAC distribution (AHU). Hence, the suitable space area for AHU is determined by the proper equipment dimensional size according to the necessary operational capacity of the supplied air-conditioned per second (L/S) as made known in table 2.

Table 2-Recommended mechanical and Electrical room dimensions for AHU variant size. (Source: Grondzik W., Kwok A, 2015)

Air Handling Unit Capacity	Approximate Overall Dimension of Supply Air Equipment (m)					Recommended Room Dimensions (m)				
L/s Range	Width	×	Height	×	Length	Width	×	Height	×	Length
470–849	1.4		0.8		4.5	3.8		2.7		5.7
850–1415	1.5		1.1		4.9	4.2		2.7		6.1
1416–1887	2.1		1.3		4.9	5.3		2.7		6.1
1888–2831	2.3		1.3		5.1	5.5		2.7		6.3
2832–3303	2.4		1.4		5.6	5.6		2.9		6.8
3304–4247	2.4		1.5		5.7	5.8		3.0		6.9
4248–5662	3.0		1.7		6.4	7.0		3.4		7.6
5663–7550	3.1		1.8		6.7	7.2		3.8		7.9
7551–8966	3.2		2.0		7.2	7.3		4.0		8.5
8967–10,381	3.6		2.2		7.6	8.1		4.6		8.8
10,381–12,741	3.6		2.6		7.9	8.2		4.9		9.1
12,742–15,100	4.0		3.0		8.5	8.8		5.5		9.7

As given away in table 2 the minimum height of the room is 2.7m and 2.4 m extra in width for maintenance and 1.2 m in length to ease replacement. About 4% to 6% of a building floor gross area should be available at each floor for the air-handling unit in case of a separated. (Joseph B. Wujek, 2010) The mechanical room area approximates 5% to 10% of the building gross area. (Binggeli Croky, 2003)

5. GEOTHERMAL ENERGY IN EGYPT

Fossil fuels resources of Egypt are limited including oil, natural gas…etc. Therefore, Egypt has to invest in the renewable energy sector to cover the growing energy demand because of the population growth. Egypt has set a target to achieve 20% of the generated electricity from the renewable energy mix by 2020. (RCREEE, 2019) (Lashin A, 2020) the government signed memorandum. However, up to date, Egypt has a little number of buildings utilize the heat pump for cooling and heating where could be found in Ayun Mousa spring-Sinai for swimming pools, German culture center (Goethe institute) at the 17th of Hussien Wasef street in Dokki-Giza, Egypt etc.

5.1 German Culture Center (Goethe Institute) in Dokki, Giza.

The Goethe-Institute is a non-profit German cultural association with 159 institutes worldwide, offering the study of the German language abroad. (Goethe,2020) The Building Location is close to under groundwater basins formed from the Nile river. Therefore, the German culture center branch at the 17th of Hussien Wasef street, Dokki, Giza is utilizing the pump and rejection system technique to achieve cooling and heating for the building.

Figure 18- The Northern façade of the Goethe Institute, Dokki, Giza. (Source: Bit-Design Architecture Office, 2020)

Figure 19- Building form creates shaded patio to the Class Rooms. (Source: Bit-Design Architecture Office, 2020)

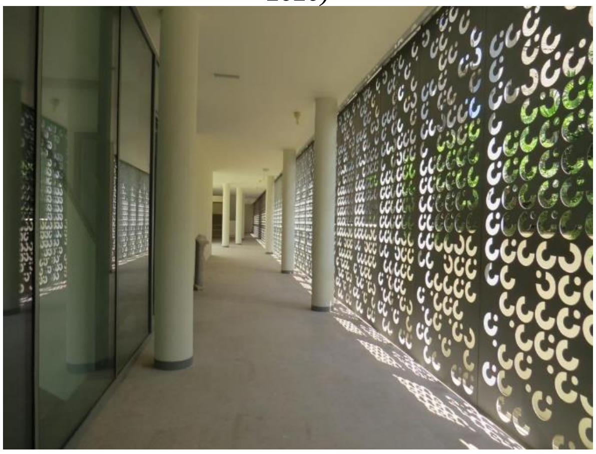


Figure 20- The Southern Façade shows the Architectural solution to decrease the building Heat Gain. (Source: Bit-Design Architecture Office, 2020)

Figure 21- Green Walls in the patio to prevent Heat Islands from creating. (Source: Bit-Design Architecture Office, 2020)

5.2. The Mechanical Room

The system utilizes three water wells of 19 °C temperature one for supplying water and the others for the rejection. The underwater flows into a water-to-water heat exchanger (1) where is located in the basement to absorb heat from the circulated water. Consequently, the circulated water gains heat from the refrigerant in the water-to-refrigerant Heat Exchanger (2). The underwater returns to the rejection well and in the other hand the cooled refrigerant will cool the air of the space in the AHU, and then cooled air will flows through the distribution Duct system to reach the building spaces as shown in figures 22 & 23. (Bit-Design Architecture Office, 2020) The central mechanical room area is 174.43 m² which represents an 5% from the building gross area.

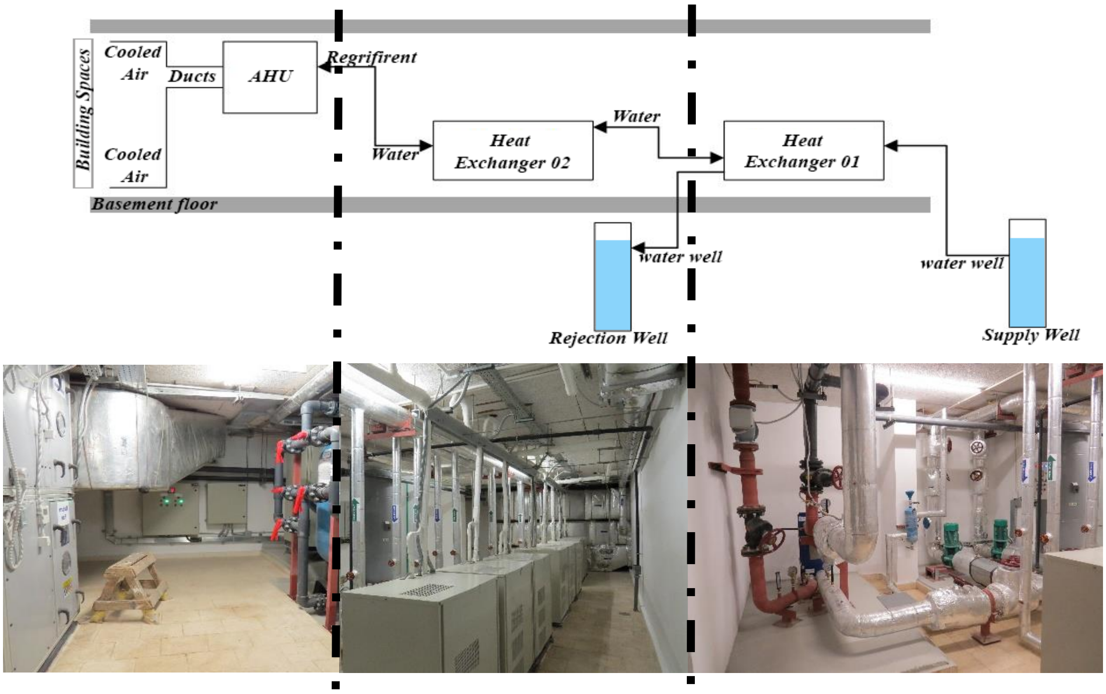
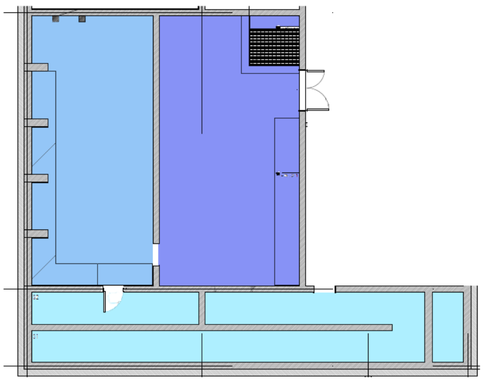


Figure 22-Typical diagram of Pump and Rejection technique and the used in The Goethe Institute Dokki , Giza. (Source: Bit-Design Architecture Office, 2020)



Heat Exchanger 1 & 2 Room *AHU Room* *AHU Outdoor Fresh Air Intake & Exhausted Air*

Figure 23: The Central Mechanical Room Spaces in The Basement of The Goethe Institute, Dokki, Giza. (Source: Bit-Design Architecture Office, 2020)

6. CONCLUSION

This paper presents the effective integration of design building with the proper utilization of the GSHP. Firstly, introduce geothermal energy for air conditioning including the system components and applications. Secondly, tentatively propose the influencing factors affect the building design. The integration between the building and the geothermal energy system necessities in the building provides new design considerations. Therefore, that should reflect on architectural design. Therefore, the unified renewable energy system through the design process could undoubtedly increase the energy efficiency in buildings. However, more researches are needed in future to present the potential of the direct utilization of the geothermal energy in buildings in Egypt.

REFERENCE

Books:

Egg J, Cunniff G, Orio CD, (2013), Modern geothermal HVAC – engineering and control applications. Mc-Hill Edu., Printed in the USA

Walter T. Grondzik, Alison G. Kwok, (2015), Mechanical and Electrical Equipment for Buildings. Published by John Wiley & Sons, Inc., Hoboken, New Jersey

Yu Y., Olson G. (2018) Ground Source Heat Pump Systems. In: Wang R., Zhai X. (eds) Handbook of Energy Systems in Green Buildings. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-49088-4_3-1

Binggeli Corky, (2003): Building Systems for Interior Designers. Published by John Wiley & Sons, Inc., Hoboken, New Jersey Published simultaneously in Canada

ASHRAE, (2001). ASHRAE Handbook of Fundamentals, A. Soc. Hea., Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, Chapter 32.

Kavanagh S, Rafferty K, (2014). Geothermal heating and cooling: design of the GSHP, 2014.ASHRAE, ATLANTA

Joseph B. Wujek, (2010). Mechanical and electrical systems in architecture, engineering, and construction. Pearson Prentice Hall, New Jersey, fifth edition.

Journals:

Lund J.W., (2012). Geothermal Resources Worldwide, Direct Heat Utilization of. In: Meyers R.A. (eds) Encyclopedia of Sustainability Science and Technology. Springer, New York, NY. https://doi.org/10.1007/978-1-4419-0851-3_305

Furundzic, A.K.; Kosoric, V.; Golic, K., (2012). Potential for reduction of CO2 emissions by the integration of solar water heating systems on student dormitories through building refurbishment. Sustain. Cities Soc. 2012, 2, 50–62.

Yang H, Cui P, Fang Z. (2018). Vertical-borehole ground-couplet heat pumps: a review of models and systems. Appl Energy 2010; 87:16–27.

Ioan Sarbu and Calin Sebarchievici, (2016). Using Ground-Source Heat Pump Systems for Heating/ Cooling of Buildings.

Bose JE, Smith MD, Spitler JD. Advances in the GSHP - an international overview. In: Proceedings of the 7th International Conference on Energy Agency Heat Pump, Beijing, China; 2002. pp. 313–324.

John W. Lund and Tonya L. Boyd, (2015). Direct Utilization of Geothermal Energy 2015 Worldwide Review, World Geothermal Congress 2015 Melbourne, Australia, 19-25 April 2015.

Esdras Nshimyumuremyi, 2014, M.S. Thesis Preliminary Feasibility Analysis on the Direct Use of Geothermal Energy in Rwanda: Case Study Gisenyi Hot Spring.

Eicker Ursula, (2014). Energy Efficient Buildings with Solar and Geothermal Resources.

Wei Shule, Renewable Energy Technologies Applied in Architecture and Its Innovative Research, 2018. IOP Conference Series: Earth and Environmental Science: 186 012007.

CED,(2015): HVAC Systems Noise Control retrieved from https://www.cedengineering.com/userfiles/HVAC%20Systems%20Noise%20Control.pdf

RCREEE (Regional Centre for Renewable Energy and Energy Efficiency): Egypt Country Profile of Energy. Retrieved from: https://www.rcreee.org/content/egypt.

Lashin A, (2020). Review of the Geothermal Resources of Egypt: 2015-2020, Proceedings World Geothermal Congress 2020, Reykjavik, Iceland, April 26 – May 2, 2020

Goethe, (2020) retrieved from https://www.goethe.de/ins/eg/ar/index.html

Bit-Design Architecture Office, (2020) Consulting Office.