Introduction

1.1 Introduction

Energy is the backbone of all human activities on earth. In recent years, energy demand has increased due to the high-energy consumption in different fields. Growing demand for energy and climate change which is closely related to increased energy consumption on the other hand a major issue worldwide. The existing energy systems including electricity rely heavily on non-renewable sources of energy mainly on fossil fuels such as coal, gas and oil. These are not only unsustainable in the long term but are also thought to be the main cause of global climate change because huge amounts of carbon dioxide and other greenhouse gases are released when they are burned. The energy sector is therefore increasingly seeking alternative sources of energy which will meet the growing demand for energy, provide stability in the long term and have a minimal impact on the environment. Management of energy consumption is also necessary to save energy [1]. The majority of energy production in Sudan depends on fossil fuel which is an un-renewable energy source.

1.2 Problem statement

The geographical climate of Elobied is a continental climate, therefore there is a need for cold during the diurnal and heat through the night. The heat energy accumulation is an ideal solution that can supply heat during the night and cooling during the diurnal.

1.3 Objective

The aim of this research is to investigate the possibility and availability of using heat energy accumulation in to save energy, by applying it in Elobied, mainly in the field of air-conditioning.

1.4 Methodology

This research is a theoretical study, so try to carry the following steps to achieve good results:

- Collect the literature related to the topic.
- Collect the metrological data of Elobied.
- Study the natural changes in Elobied climate and types of heat energy accumulation and select the suitable type for applications.
- Collecting technical data to identify the suitable type of heat energy accumulation method and material, according to availability, adequacy and price.
- Investigate the possibility of using heat energy accumulation for HVAC.
- Calculate and design a prototype suitable to be applied for heat energy accumulation in the local conditions of Elobied.

1.5 Thesis layout

The research consist of five chapters. Chapter one is general introduction, objective, problem statement, methodology and thesis lay-out. Chapter two theoretical background about energy storage and previous study for several project using energy storage in different field. Chapter three, methods of energy storage. Chapter four is a case study of the research. Chapter Five conclusion, recommendations, references and appendices.

Theoretical Background and Previous Study

2.1 Theoretical Background

Nowadays many projects are being developed for optimizing and reducing the financial impact of systems, particularly improving efficiency with less running costs by accumulating and storing the thermal energy that is generated from the power facilities or solar radiation. Using thermal energy storage (TES) opens up potential for reduction of energy consumption, peak heating and cooling loads as well as possibilities for sharing renewable energy to cover the increased energy demand. By using passive storage through increased thermal mass of buildings it is also possible to reduce variations in the indoor temperature, especially excess temperatures during warm periods, which could result in avoiding active cooling in buildings that would otherwise need it.

2.1.1 Energy storage

Energy storage plays an important role in conserving available energy and improving its utilization, since many energy sources are intermittent in nature. Short term storage only a few hours is essential in most applications, and long term storage of a few months may be required in some applications. Solar energy is available only during the day then its application requires an efficient thermal energy storage so that the excess heat collected during sunshine hours may be stored for later use during the night. Also, electrical energy consumption varies significantly during the day and night, especially in extremely cold and hot climate countries where the major part of the variation is due to domestic space heating and air conditioning. Such variation leads to an off peak period, usually after midnight until early morning. Accordingly, power stations have to be designed for capacities sufficient to meet the peak load. Otherwise, very efficient power distribution would be required. Better power generation management can be achieved if some of the peak load could be shifted to the off peak load period [15].

2.1.2 The Importance of Energy Storage

The transition from conventional to environmental friendly and renewable sources of energy is a long term operation, because the available green technologies do not generate enough energy to meet the demand. In addition to technologies development to convert solar, wind, geothermal and similar green sources of energy into electrical, thermal or mechanical energy, there are efforts to develop and improve the existing storage devices and mediums to reduce costs and losses to the minimum and maintain a reliable power supply.

Solar energy can only provide an intermittent energy supply. The magnitude and importance of solar energy as a renewable energy source is obvious. However if solar energy is to become an important energy source, efficient, economical and reliable, solar energy storage devices and methods it developed [15].

2.1.3 Size and duration of storage

It is important to take into consideration the size and the duration of the storage. The size of solar thermal storage for space heating depends on the type of application in function of several parameters: type of material, storage temperature, storage heat losses, cost of the storage medium and container, ambient temperature, collector area. [7].

The costs and the size of the storage vary according to storage duration. Storage duration classify into three groups: short, medium or long term. Short term storage is used to reduce the peak of thermal loads allowing smaller size of the facilities and to take advantage from a cheaper energy fare.

Generally thermal energy is produced and stockpiled during the off-peak periods and released during the peak ones: this kind of storage is called diurnal. Medium and long term storages are used when the delay between the stockpiling and the releasing is within few weeks and several months. An example of this kind of storage is when solar energy is collected and stored during the summer, and it is released during the winter to heat a building.

2.1.5 Thermal energy storage (TES) and HVAC systems

Integrating HVAC systems with TES systems can provide enhanced cooling or heating in various applications e.g., commercial and residential buildings. TES systems are often categorized as heating and cooling TES (CTES). All TES systems incorporate a thermal energy storage material, a container for it and heat exchange equipment. TES storage media are generally chosen according to such parameters as thermal characteristics and capacity, availability, cost, durability and reliability.

2.1.5.1 Heating TES

In heating TES, heating capacity is obtained when available and used subsequently (e.g., seasonal storage systems which collect solar thermal energy during the summer for use in winter), or produced during off-peak hours when energy charges are lower than peak charges for subsequent peak-period use. Such systems usually are designed to provide space heating and/or domestic hot water (DHW). Various types of heating TES systems which can provide these heating loads exist, including sensible and latent types. Some examples of sensible heating TES systems follow [7].

- Concrete TES tanks
- Rock and water/rock TES
- Aquifer TES

These can often be thermally stratified, resulting in improved system efficiencies. Latent TES utilizes a phase change material (PCM) to store thermal energy. Typical PCMs are water, paraffins, eutectic salts and some polymers. Thermochemical TES is receiving increasing interest, via research and feasibility studies, as an alternative type of TES which could increase the compactness of TES.

To better understand this value, it is useful to view it in the context of technical parameters for different types of TES systems. Various types of TES systems for a typical single-family house are compared in terms of storage density, TES volume, and useful life in Table 2.1, where compactness increases as storage density decreases [7].

Table 2.1 **Technical comparison of TES technologies.**[a]

TES type	Energy storage density (GJ/m^3)	Seasonal storage volume for single family house[b] (m^3)	Useful life
Sensible	0.03-0.2 (0.03 for high-temp. oil, 0.1 for low-temp. oil)	120	Long (20 years for high- and low-temp. oil)
Latent (various salts)	0.3-0.5	60	10^2-10^3 cycles
Thermochemical	0.4-3	6	N/A (depends on reactant degradation and side reactions)

2.1.5.2 Cooling TES (CTES)

Cooling TES has systems store cooling capacity. The required cooling capacity is usually produced at night periods and then used in the day. There are two main differences between conventional air conditioning system and cooling TES systems. First, required cooling loads in conventional air conditioning systems are supplied by removing heat with a working fluid (normally air or chilled water or a brine/antifreeze and water solution) while heat is removed in total or part using the storage medium in CTES systems. Second, conventional air conditioning systems operate in peak hours when cooling is required in a building while CTES systems operate during off-peak times when cooling is not required [7].

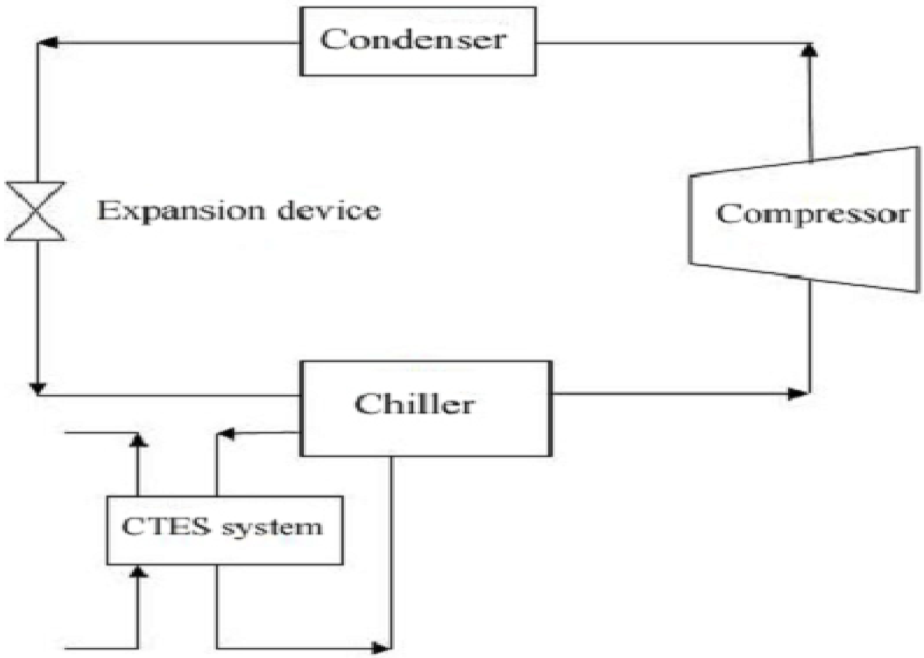

Figure 2.1. Integration of TES in a conventional air conditioning system.

2.2 Previous studies

Many studies have been carried out by various researchers in the field of accumulation of heat energy systems.

Abdelshafi et al [2] investigated the applications of the chilled water and ice cold thermal storage technologies for the air conditioning (AC) systems of the typical office buildings in Saudi Arabia to reduce of the electric energy consumption. The investigations have been carried out on the basis of the calculated load profile and the climatic conditions in July. Partial and full storage strategies are examined for both ice and chilled water storage systems. The investigations reveal that the cold thermal energy storage techniques are effective from both technical and economic perspectives in the reduction of energy consumption in the buildings during peak periods.

Sebzali [2] studied the Assessment of Cool Thermal Storage Strategies in Kuwait to investigate ice and chilled water cool thermal storage technologies and operating strategies for air conditioning. This was motivated by the extreme climatic conditions in Kuwait and the necessity to reduce both, maximum power demand and energy consumption. The strategies were applied for clinic building in Kuwait.

The cooling demand of the clinic building was first estimated using the (ESP-r) building energy simulation program, and chiller, storage tanks, pumps, air handling units for conventional, ice and chilled water storage air conditioning systems were sized and selected by applying operating with load leveling, 50% demand limiting and full storage strategies. For each air conditioning design, the power and energy consumption for the design day condition and over the whole year were calculated and analyzed. Furthermore, the life cycle costs were determined based on the estimated capital, maintenance, operating costs and a financial analysis was carried out. The result was carried out the demonstrate ice and chilled water storage systems reduced the maximum power consumption during the day time when the electricity demand is high and largest reduction in the maximum power achieved full storage strategy.

Abdulgalil et al [4] studied effect of thermal energy storage in energy consumption for air conditioning system in office building in Libya (Tripoli) under the African Mediterranean climate. The office building consists of three floors, each with 1152 m2 of floor area and 3.2 m of height. The Hourly Analysis Program (HAP) was used to estimate the cooling load profile for an office building. The operating strategies (charging and discharging time) were selected at night where outdoor temperature is relatively low for better chiller performance. And the sizes of chiller and storage capacities were calculated. Also the mathematical model was presented to study the performance of external ice during the charging process. Two steps of calculations were carried out to determine heat transfer between water and refrigeration in the storage. The maximum power demand occurs during the peak load 04:00 pm. The lowest power demand during occupied hours of the building occurs in the first and last hours of occupancy (7-8 am and 6-7 pm). And the result of previous study was shown in Table 2.2 below:

Table 1 Chiller and storage capacities sizes and energy consumption for different operating strategies

<table>
<tr><th colspan="2"></th><th>Conventional</th><th>Full storage</th><th colspan="4">Partial storage</th></tr>
<tr><th colspan="2" rowspan="2">Items</th><th rowspan="2">-</th><th rowspan="2">-</th><th rowspan="2">Load leveling</th><th colspan="3">Demand Limiting</th></tr>
<tr><th>55%</th><th>60%</th><th>65%</th></tr>
<tr><td colspan="2">load met by chiller kWh</td><td>4953</td><td>0</td><td>2244</td><td>2724.1</td><td>2971.8</td><td>3219.4</td></tr>
<tr><td colspan="2">Storage capacity kWh</td><td>0</td><td>4953</td><td>3081</td><td>2228</td><td>1981.2</td><td>1733.5</td></tr>
<tr><td colspan="2">Charging hours h</td><td>0</td><td>13</td><td>13</td><td>9</td><td>7.33</td><td>5.9</td></tr>
<tr><td colspan="2">Discharging hours</td><td>11</td><td>11</td><td>11</td><td>11</td><td>11</td><td>11</td></tr>
<tr><td rowspan="2">Chiller capacity kW</td><td>Night</td><td>0</td><td>381</td><td>237</td><td>271</td><td>294.6</td><td>312.4</td></tr>
<tr><td>Day</td><td>484</td><td>0</td><td>204</td><td>247.6</td><td>270.6</td><td>292.6</td></tr>
<tr><td rowspan="2">Power input</td><td>Night</td><td>0</td><td>149.2</td><td>69.2</td><td>83.4</td><td>87.8</td><td>95</td></tr>
<tr><td>Day</td><td>At max load 198</td><td>0</td><td>84.9</td><td>102.2</td><td>107.2</td><td>116.4</td></tr>
<tr><td rowspan="2">COP</td><td>Night</td><td>0</td><td>2.29</td><td>3.29</td><td>3.12</td><td>3.21</td><td>3.15</td></tr>
<tr><td>Day</td><td>2.4</td><td>0</td><td>2.3</td><td>2.18</td><td>2.25</td><td>2.2</td></tr>
<tr><td colspan="2">Energy consumption kWh</td><td>2059.9</td><td>1939.6</td><td>1833.5</td><td>1874.8</td><td>1823</td><td>1843</td></tr>
</table>

Condensing temperature: 50°C during day, 40°C during night. Evaporating temperature: -4.5°C during day& night.

Liu et al [5] compared the field performance of TES systems with the conventional systems. The field data for several TES sites have been analyzed by using a 'mean-day' and 'peak-day' approach. Energy usage, direct power costs of ice, chilled water, and eutectic salt systems have been compared to that of conventional systems and have concluded that the TES systems is better than other systems.

Hasnain et al [6] discussed the means of reducing the peak electrical demand in large Saudi office buildings by using CTES. It was observed that the incorporation of a partial ice storage system in office buildings in the city of Riyadh (KSA) can reduce the peak time electrical power demand and the peak time cooling load in the range of 10% to 20% and 30% to 40%, respectively.

Habeebullah [18] investigated the economic feasibility of retrofitting an ice thermal energy storage (ITES) system for unique AC plant of the Grand Holly Mosque of Mecca in Saudi Arabia in full storage and partial storage scenarios. In his study, the operational and the capital investment costs were considered as objective function and finally minimized. The results showed that applying the full storage strategy is more reasonable to reduce the electricity consumption.

Methods of energy storage

3.1 Introduction

Energy storage (ES) has recently been developed to a point where it can have a significant impact on modern technology. In particular, ES is critically important to the success of any intermittent energy source in meeting demand. ES systems can contribute significantly to meeting society's needs for more efficient, environmentally benign energy use in building heating and cooling, aerospace power and utility applications. The use of ES systems often results in such significant benefits as:

- Reduce energy costs
- Reduce energy consumption
- Improve indoor air quality
- Increase flexibility of operation
- Reduce initial and maintenance costs
- Reduce equipment size
- More efficient and effective utilization of equipment
- Conservation of fossil fuels (by facilitating more efficient energy use)
- Reduce pollutant emissions (e.g., CO_2 and chlorofluorocarbons (CFCs)) [8].

3.2 Different methods for energy storage

Energy storage is storing energy during the time when excess energy is available in order to be used later. In other words, energy storage is used to correct the mismatch between the time of energy supply and energy demand.

3.2.1 Mechanical Energy Storage:

Mechanical energy may be stored as the kinetic energy of linear or rotational motion, as the potential energy in an elevated object there are three main mechanical storage types in this section:

3.2.1.1 Hydro-storage (Pumped Storage)

Hydro-storage is a simple ES method. At night, when energy demand is low, pumps deliver water upward from the river Figure 3.1. The water is pumped through a pipe to a reservoir. During the day, when energy demand is high, the reservoir releases water, allowing it to flow downhill. The flowing water turns the turbine to generate electricity. The pump that delivers the water upward from the river can be powered by solar energy during the day. At night, when there is no solar energy, the stored water turns the turbine to generate electricity [8].

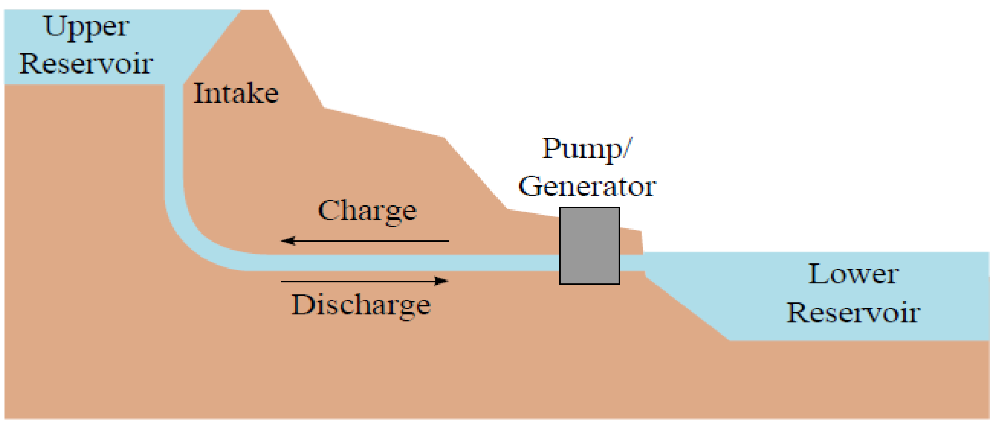

Figure 3.1. Pumped storage

***Advantages:**

- Mature technology, capable of storing huge amounts of energy
- High overall efficiency (around 70-80 percent)
- Fast response times
- Inexpensive way to store energy
- Few potential sites
- Huge environmental impacts

***Disadvantages**

Due to the design requirements of pumped hydro energy storage PHES facility, its dependence on specific geological formations since the two large reservoirs must be with a sufficient amount of hydraulic head between them. However, these geological formations normally exist in remote locations such as mountains, where construction is difficult and the power grid is not present.

3.2.1.2 Compressed Air energy Storage (CAES)

In a compressed-air ES system, air is compressed during off-peak hours and stored in large underground reservoirs, which may be naturally occurring caverns, salt domes, abandoned mine shafts, depleted gas and oil fields, or man-made caverns. During peak hours, the air is released to drive a gas turbine generator. The technique used by such a system to compress air to store energy is relatively straight or ward. In a conventional gas turbine, high-pressure hot gas is supplied, and about two-thirds of the gross power output is used to drive the compressor.

In practice, two general categories of compressed-air ES systems are possible, depending on the storage pressure Figure 3.2. In sliding pressure systems Figure 3.2a, pressure increases as the store is charged and decreases as the stored air is released, between maximum and minimum pressures. In compensated pressure systems Figure 3.2b, an external force is used to keep the storage pressure constant throughout the operation [8].

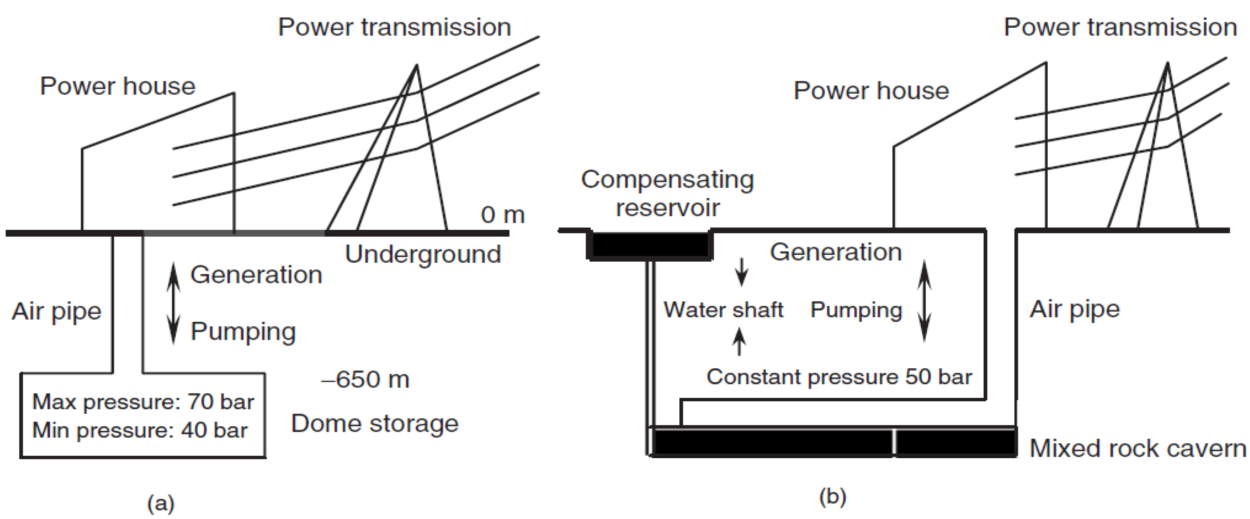

Figure 3.2. Two general categories of compressed-air ES systems

***Advantages:**

- Fast start-up
- Capable of storing huge amounts of energy
- Fast response times
- Inexpensive way to store energy
- Requires sealed storage caverns
- Competing against other storage needs (natural gas, hydrogen).

***Disadvantages:**

The major disadvantage of CAES facilities is their dependence on geographical location. It is difficult to identify underground reservoirs where a power plant can be constructed, is close to the electric grid, is able to retain compressed air and is large enough for the specific application. As a result, capital costs are generally very high for CAES systems. Also, CAES still uses a fossil fuel (gas) to generate electricity. Consequently, the emissions and safety regulations are similar to conventional gas turbines. Finally, only two CAES facilities currently exist, meaning it is still a technology of potential not experience.

3.2.1.3 Flywheel storage

Most of the modern flywheel energy storage systems include a heavy rotating cylinder supported on a stator by magnetically levitated bearings that eliminate the bearing wear and increase the system life. In order to maintain the system efficiency, the drag force should be reduced by operating the flywheel system in low vacuum conditions.

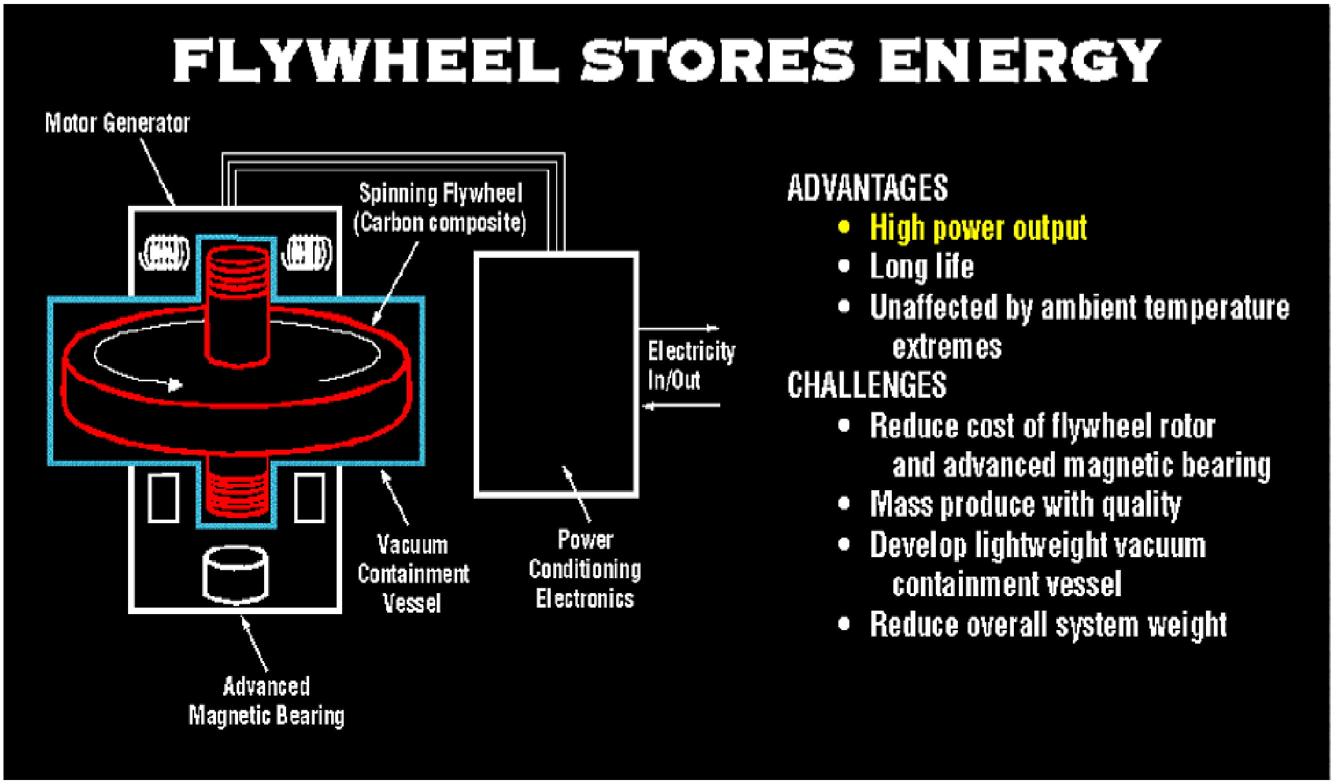

Figure 3.3 Flywheel stores energy

3.2.2 Electrochemical energy storage

Electrochemical energy storage covers all types of Batteries, store electrical energy in form of chemical energy. Batteries are classified as primary and secondary. Primary batteries are used only one time and are not possible to be recharged, whereas secondary batteries are rechargeable for several times like the lead-acid battery. At present batteries are produced in many sizes for wide spectrum of applications. Common commercially accessible secondary batteries according to used electrochemical system can be divided to the following basic groups: Standard batteries (lead acid, Ni-Cd) modern batteries (Ni-MH, Li–ion, Li-pol), special batteries (Ag-Zn, Ni-H2), flow batteries (Br2-Zn, vanadium redox) and high temperature batteries (Na-S, Na–metal chloride).

Table 3.1 Comparison of Different Battery Energy Storage Systems

	Lead acid	Nickel cadmium	Sodium sulphur	Lithium ion	Sodium nickel chloride
Achieved/demonstrated upper limit power	Multiple tens of MW	Tens of MW	MW scale	Tens of kW	Tens/low hundreds of kW
Specific energy (Wh/kg)	35 to 50	75	150 to 240	150 to 200	125
Specific power (W/kg)	75 to 300	150 to 300	90 to 230	200 to 315	130 to 160
Cycle life (cycles)	500 to 1500	2,500	2,500	1,000 to 10,000+	2,500+
Charge/discharge energy efficiency (%)	~80	~70	up to 90	~95	~90
Self discharge	2 to 5% per month	5 to 20% per month	#	~1% per month	#

3.2.3 Electrical energy storage

3.2.3.1 Capacitor

Capacitors use physical charge separation between two electrodes to store charge. They store energy on the surfaces of metalized plastic film or metal electrodes. When compared to batteries and super capacitors, the energy density of capacitors is very low – less than 1% of super capacitors, but the power density is very high, often higher than that of a super capacitor. This means that capacitors are able to deliver or accept high currents, but only for extremely short periods, due to their relatively low capacitance.

3.2.3.2 Super capacitor

Super capacitors are very high surface area activated carbon capacitors that use a molecule-thin layer of electrolyte, rather than a manufactured sheet of material, as the dielectric to separate charge. The super capacitor resembles a regular capacitor except that it offers very high capacitance in a small package. Energy storage is by means of static charge rather than of an electrochemical process inherent to the battery. Super capacitors rely on the separation of charge at an electrified interface that is measured in fractions of a nanometer, compared with micrometers for most polymer film capacitors. The lifetime of super capacitors is virtually indefinite and their energy efficiency rarely falls below 90% when they are kept within their design limits. Their power density is higher than that of batteries while their energy density is generally lower. However, unlike batteries, almost all of this energy is available in a reversible process.

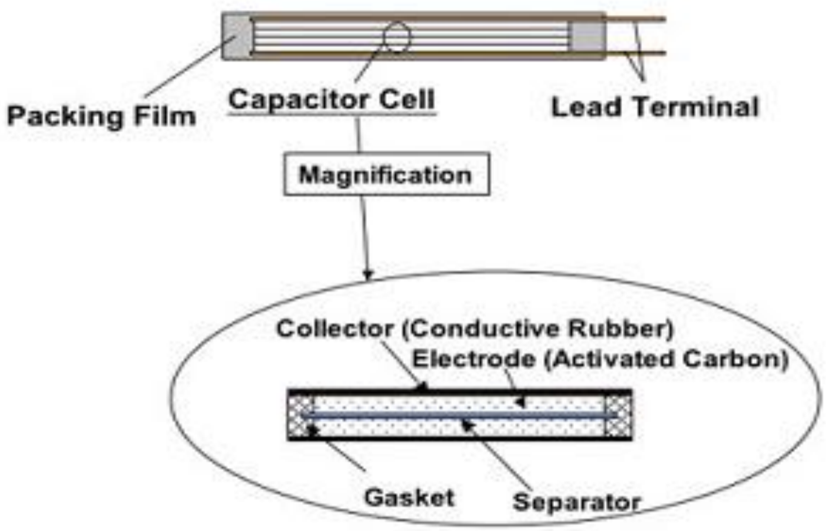

Figure 3.4. Super capacitor Energy Storage

3.2.3.3 Superconducting magnetic energy storage (SMES)

Superconducting Magnetic Energy Storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cooled to a temperature less than its superconducting critical temperature. A typical SMES system consists of superconducting coil, power conditioning system and cryogenically cooled refrigerator. The Superconducting Magnetic Energy Storage systems have a high efficiency.

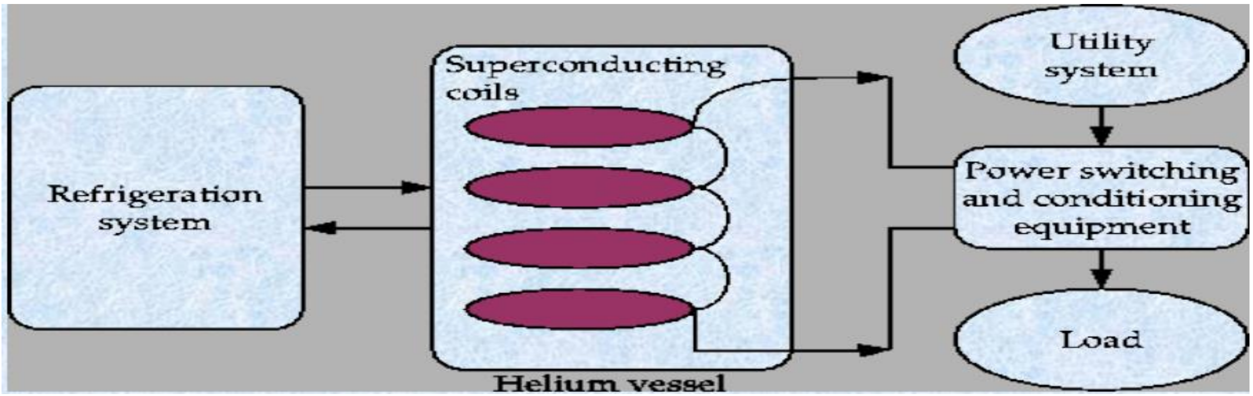

Figure 3.5. Superconducting magnetic energy storage

***Advantages**

- Fast respond times
- Capable of partial and deep discharges
- No environmental hazard

***Disadvantages**

The most significant drawback of SMES is its sensitivity to temperature and High energy losses (~12 percent per day) with very expensive production and maintenance.

3.2.4 Thermal energy storage

Thermal (energy) storage systems store available heat by different means in an insulated repository for later use in different industrial and residential applications, such as space heating or cooling, hot water production or electricity generation. Thermal storage systems are deployed to overcome the mismatch between demand and supply of thermal energy and thus they are important for the integration of renewable energy sources. Thermal storage can be subdivided into different technologies: storage of sensible heat, storage of latent heat, and thermo-chemical and absorption storage. There are three main types of TES systems:

• Sensible

• Latent

• Chemical (sorption and thermochemical)

3.2.4.1 Sensible TES

The storage of sensible heat is one of the best-known and most widespread technologies, with the domestic hot water tank as an example. The storage medium may be a liquid such as water or thermo-oil, or a solid such as concrete or the ground. Thermal energy is stored solely through a change of temperature of the storage medium. The capacity of a storage system is defined by the specific heat capacity and the mass of the medium used. In sensible TES systems, energy (or heat) is stored or released by heating/cooling a liquid or solid storage material through a heat transfer interaction. This heat transfer can be expressed as [8].

$$Q = mc_p\Delta t \qquad (3.6)$$

Where **m** and $\mathbf{c_p}$ denote the mass and specific heat of the storage material and Δ**t** is the temperature difference before and after the storage operation. Examples of materials typically used as a storage medium are water, air, oil, rocks, bricks, concrete, sand and soil.

3.2.4.2 Latent TES

Latent heat involves the change of a substance from one phase to another at a fixed temperature. In latent TES systems, energy is stored during the phase change (e.g. melting, evaporating and crystallization). Due to the specific heat of a typical media and the high enthalpy change during phase change, the latent heat change is usually greater than the sensible heat change for a given system size. Latent heat storage materials are usually useful over a small temperature range [8]. The stored energy during a latent storage process can be evaluated as

$$Q = mL \qquad (3.7)$$

Where **m** denotes the mass and **L** is the specific latent heat of the phase change material (PCM). Examples of PCMs are water/ice, paraffin, eutectic salts, and some polymers. An example of an industrial PCM is the hand warmer (sodium acetatetrihydrate). PCMs are usually packed in tubes, plastic capsules, wall board and ceilings and they are supplied mainly in three shapes: powder, granulate and board.

3.2.4.3 Comparison between Sensible and Latent TES

Latent thermal energy storage requires less volume than sensible thermal energy storage. In addition, latent thermal energy storage can store a huge amount of thermal energy with a small change in temperature, however, latent thermal energy storage still facing many problems concerning the materials used to perform the storage process such as high cost, low thermal conductivity and stability of thermo physical properties after many cycling.

3.2.4.4 Advantages of Thermal Energy Storage (TES) Systems

In the early days of air-conditioning, electricity was plentiful and cheap, which enabled the building industry to provide almost all commercial buildings with comfort cooling. As a result, comfort cooling is standard in almost all of today's commercial buildings. As the global economy continues to grow, demand for energy and electricity will increase with it, and air conditioning for buildings is a major contributor to that growth.

- Thermal energy storage (TES) systems cool a storage medium and then use that cold medium to cool air at a later point in time.
- Using thermal storage can reduce the size and initial cost of cooling systems, lower energy costs, and reduce maintenance costs.
- If electricity costs more during the day than at night, thermal storage systems can reduce utility bills further.
- Systems can be sized to eliminate compressor energy use during periods when electricity is most expensive, but most systems are designed to simply augment mechanical cooling in order to limit peak demand.

3.2.4.5 Economics of using TES, When to decide for TES

TES may be economical if one or more of the following conditions exist:

- High energy demand costs
- Energy time-of-use rates
- High daily load variations
- Short duration loads
- Infrequent or cyclical loads
- Capacity of cooling equipment has trouble handling peak loads

3.2.4.6 Effective applications of thermal energy storage include:

Electrical power use management by shifting the cooling load to off-peak hours and reducing peak load reducing required capacity of building and process cooling systems, or helping existing cooling equipment to handle an increased load.

Water storage systems are often used in new large cooling system applications in conjunction with cogeneration and/or district energy systems. Water-ice storage is the most common cooling storage in smaller applications. Because latent heat storage (phase change between water and ice) has a smaller volume, it is often chosen for retrofit applications with limited space.

In general, the buildings that offer the highest potential are offices, retail, and medical facilities.

3.2.4.7 Performance/Costs

Thermal energy storage systems are installed for two major reasons:

a) Lower initial project costs

b) Lower operating costs

Initial cost may be lower because distribution temperatures are lower and equipment and pipe sizes can be reduced. Operating costs may be lower due to smaller compressors and pumps as well as reduced time-of-day or peak demand utility costs. The economics of thermal storage is very site- and system- specific. A feasibility study is generally required to determine the optimum design for a specific application. TES projects often profit from unexpected benefits that are secondary to the primary reason for an action. For example, a well-designed TES air conditioning application may experience reduced chiller energy consumption, lower pump horsepower, smaller pipes, high reliability, better system balancing and control, and lower maintenance costs.

3.2.4.8 Chemical Thermal energy storage

3.2.4.8.1 Thermochemical energy storage

Energy is stored after a dissociation reaction and then recovered in a chemically reverse reaction. Thermochemical energy storage has a higher storage density than the other types of TES, allowing large quantities of energy to be stored using small amounts of storage substances. Energy storage based on chemical reactions is particularly appropriate for long-term storage applications, e.g., seasonal storage of solar heat, because the process involves almost no energy losses during the storing period. Storage is usually done at ambient temperatures. In general, a TES cycle includes three main processes, Charging, Storing, and Discharging.

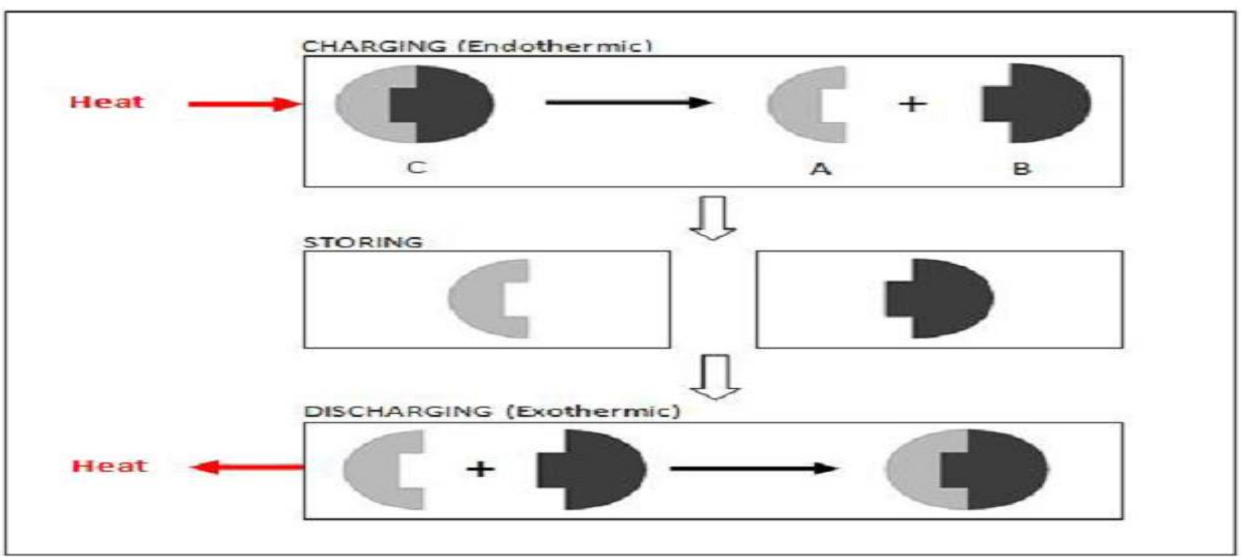

Figure 3.6. Processes involved in a thermochemical energy storage cycle:

Charging: The charging process is endothermic. Thermal energy is absorbed from an energy resource, which could be a renewable energy resource and/or conventional energy sources like fossil fuels. This energy is used for dissociation of the thermochemical material, and is equivalent to the heat of reaction or enthalpy of formation. After this process, two materials (A and B) with different properties are formed that can be stored. The reaction during charging can be written as:

$$C + heat \rightarrow A + B \qquad (3.8)$$

Storing: After the charging process, components A and B are separately stored with little or no energy losses. The materials are usually stored at ambient temperatures, leading to no thermal losses (except during the initial cooling of components A and B after charging). Any other energy losses are due to degradation of the materials.

Discharging: During this process, A and B are combined in an exothermic reaction. The energy released from this reaction permits the stored energy to be recovered. After discharging, component C is regenerated and can be used again in the cycle. The discharging reaction can be written as:

$$A + B \rightarrow C + heat \qquad (3.9)$$

3.2.4.8.2Absorption system

Sorption systems (adsorption and absorption) are based on a chemical processes and thus are also considered chemical heat storage. Adsorption occurs when an adsorptive accumulates on the surface of an adsorbent and shapes a molecular or atomic layer. The adsorptive can be a liquid or gas while the adsorbent can be a solid or liquid. Absorption is a process that occur when a substance is distributed into a liquid or solid and forms a solution [7].

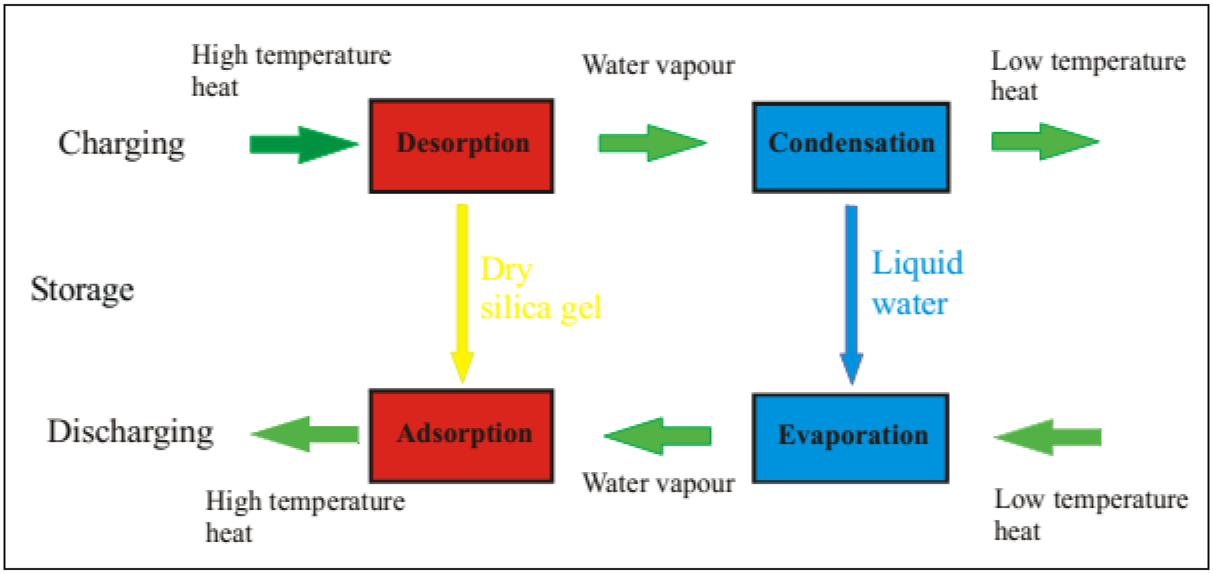

Figure 3.7. The physical principle of sorption

This type of storage is called indirect storage, and it is not independent from the environment: energy has to be released to the environment in charging mode and taken from the environment in discharging mode [14].

Adsorption heat storages allow for nearly loss-free heat storage over a long period of time. After charging, the storage tank can cool down to ambient temperature, but the adsorption enthalpy stays stored for as long as the two components (sorption material and working fluid) are kept separate.

3.2.4.8.3 Comparison of Thermochemical TES and Other TES Types

The different types of thermal energy storage systems are quantitatively contrasted and compared in Table 3.2, considering a range of relevant performance parameters and factors [7].

Table 3.2. Comparison of different types of TES based on various performance factors.

Performance parameter	Type of thermal energy storage		
	Sensible TES	Latent TES	Chemical TES
Temperature range	Up to: • 110°C (water tanks) • 50°C (aquifers and ground storage) • 400°C (concrete)	20-40°C (paraffins) 30-80°C (salt hydrates)	20-200°C
Storage density	Low (with high temperature interval) 0.2 GJ/m^3 (for typical water tanks)	Moderate (with low temperature interval) 0.3-0.5 GJ/m^3	Normally high 0.4-3 GJ/m^3
Lifetime	Long	Often limited due to storage material cycling	Depends on reactant degradation and side reactions
Technology status	Available commercially	Available commercially for some temperatures and materials	Generally not available, but undergoing research and pilot project tests
Advantages	• Low cost • Reliable • Simple application with available materials	• Medium storage density • Small volumes • Short distance transport possibility	• High storage density • Low heat losses • Long storage period • Long distance transport possibility • Highly compact energy storage
Disadvantages	• Significant heat loss over time (depending on level of insulation) • Large volume needed	• Low heat conductivity • Corrosivity of materials • Significant heat losses (depending on level of insulation)	• High capital costs • Technically complex

Adapted from several sources, including www.preheat.org and Wettermark (1989).

Case Study

4 .1 Cooling load calculation for the selected building:

4.1.1 Introduction

Elobied City is located on latitude 13º—10′ north and longitude 30º—14′ east and height above sea level is 574m. Also it has a continental climate, and the hottest months are April, May and June, therefore the maximum temperature was reached 45.8ºC in April 2003.The coldest months are December, January and February, the temperature was reached 4ºC in1993.

The study applies energy accumulation to save the power, a building at the University of Kordofan in Elobied had been selected as case study, and its exterior dimensions are 2.7m in height and 30m x 30m in width. Applied heat accumulation to reduce the cooling load of the building which would lead to saving in the air - conditioning energy consumption.

4.1.2 Methods of cooling load calculation

For a thorough calculation of the zones and whole-building loads, one of the following three methods should be employed:

a. Transfer Function Method (TFM): This is the most complex of the methods proposed by ASHRAE and requires the use of a computer program or advanced spreadsheet.

b. Cooling Load Temperature Differential/Cooling Load Factors (CLTD/CLF): This method is derived from the TFM method and uses tabulated data to simplify the calculation process. The method can be fairly easily transferred into simple spreadsheet programs but has some limitations due to the use of tabulated data.

c. Total Equivalent Temperature Differential/Time-Averaging (TETD/TA): This was the preferred method for hand or simple spreadsheet calculation before the introduction of the CLTD/CLF method [10].

Used method (b) to calculate the cooling load, in May at 9:00am, 1:00pm, 3:00pm, and 6:00pm.

4.1.3 Design conditions

To calculate the space cooling load, detailed building information, location, site and weather data, internal and outdoor design conditions are required. In Alobied the design conditions is:

In summer:

Inside design temperature Ti =24ºC

Relative humidity =50%

Outside design temperature To =43ºC

4.1.4 Components of cooling load

The total building cooling load consists of heat transferred through the building envelope (walls, roof, floor, windows, doors etc.) and heat generated by occupants, equipment, and lights. The load due to heat transfer through the envelope is called as external load, while all other loads are called as internal loads. The total cooling load on any building consists of both sensible as well as latent load components. The sensible load affects the dry bulb temperature, while the latent load affects the moisture content of the conditioned space.

4.1.4.1 External Cooling Load

External loads consists of heat transfer by conduction through the building walls, roof, doors and glass, all these are sensible heat transfers.

At first: Calculate the heat transfer and over all heat transfer coefficient (U) for walls, roof, door, windows, by using equations below:

$$U=1/((1/Fo)+\Sigma(Si/\lambda i)+(1/Fi)) \quad (4.1)$$

$$Q=U*A*(CLTD)_{correct} \quad (4.2)$$

$$(CLTD)_{correct}=(CLTD+LM)K+(25.5-Ti)+(Tm-29.4) \quad (4.3)$$

Where :

CLTD: cooling load temperature difference ºC, this factors are used for adjustment to conductive heat gains from walls, roof, floor and glass. This value were calculated from tables at Appendix according to month, day, hour, latitude.

LM =CLTD correction for latitude and month were calculated from Appendix.

U (W/m^2 ºC) = over all heat transfer coefficient.

Fo (W/m^2 ºC) = external thermal conductivity coefficient.

Fi (W/ m^2 ºC) internal thermal conductivity coefficient, values are taken from tables available in Appendices.

S (m) = thickness.

λ = Thermal conductivity (W/m ºC), values were taken from tables available in Appendices.

(25.5 – Ti) = indoor design temperature correction.

(Tm – 29.5) = outdoor design temperature correction.

Ti = Indoor room temperature.

Tm = Mean outdoor temperature.

T max = Maximum outdoor temperature.

Tm = Tmax – (Daily Range) / 2 = 43-(15/2) =35.5 ºC.

And the area were calculated from architectural plans.

K: color factor:

K=1 dark color

K=0.5 light color

K =0.85 medium color

Lm = 0.55 taken from Appendix.

4.1.4.1.1 Heat transfer from the roof:

The material of the roof, thickness and thermal conductivity are shown in table below:

Table 4.1. Thickness and conductivity of the roof

Material	Thickness(m)	Conductivity λ(W/m ºC)
Tiles	0.019	1.2
Cement plaster	0.02	0.72
Concrete	0.2	1.57
Sand	0.1	1.72

F0=22.7 W/m^{2} °C.

F1=6.13 W/m^{2} C.

Then over all heat transfer coefficient U=2.2918 W/m^{2} °C.

Lm = 0.55 taken from Appendix.

K =0.5 for light color.

$Q = U * A * (CLTD)_{correct}$

A =900 m^{2}

Table 4.2. Values of CLTD, $CLTD_{correct}$ and heat transfer from the roof at different hours.

Time	9:am	1:00pm	3:00pm	6:00pm
CLTD	5	31	39	37
$CLTD_{correct}$	10.375	23.375	27.375	26.275
Q(W)	21399.7	48213.7425	56464.22	54401.6

4.1.4.1.2 Heat transfer from the walls:

Table 4.3. Material, thickness and conductivity of the walls

Material	Thickness(m)	Conductivity λ(W/m² Cº)
Common brick	0.33	0.72
Cement plaster	0.025	0.72
Stone	0.12	1.7

Find over all heat transfer coefficient U for wall.

F_0=34 W/m^{2} C, Fi =8.29 W/m^{2} C.

U = 1/ ((1/34) + (0.33/0.72) + (0.025/0.72) + (0.12/1.7)).

U =1.4 W/m^{2} C.

Lm_N =2.8

Lm_E = -0.725

Lm_S = -3.8

Lm_W = -0.725

All these values taken from Appendix.

K=0.83 medium color.

$(CLTD)_{correct} = (CLTD+LM)*K + (25.5 – Ti) + (Tm – 29.4)$.

$Q = U * A * (CLTD)_{correct}$

Table 4.4. Values of CLTD and $CLTD_{correct}$ at different hours.

Direction	CLTD 9:00am	CLTD 1:00pm	CLTD 3:00pm	CLTD 6:00pm	CLTD correct 9:00am	CLTD correct 1:00pm	CLTD correct 3:00pm	CLTD correct 6:00pm
N	5	5	5	7	14.074	14.074	14.074	15.734
E	8	12	13	15	13.64	17	17.8	19.448
S	7	6	8	11	10.256	9.426	11.086	13.576
W	10	8	8	11	15.298	13.638	13.638	16.128

Table 4.5. Heat transfer from the walls at different hours

Direction	U (W/m^2 C)	Area(m^2)	$Q_{9:00am}$ (W)	$Q_{1:00pm}$ (W)	$Q_{3:00pm}$ (W)	$Q_{6:00pm}$ (W)
N	1.4	111	2187.1	2187.1	2187.1	2445
E	1.4	74.657	1425.65	1772.45	1859.2	2032.7
S	1.4	111	1593.8	1464.8	1722.72	2109.7
W	1.4	74.657	1597	1425.44	1425.44	1685.7
Total			6803.57	6848	7194.5	8273

4.1.4.1.3 The heat transfer from glass:

Solar load through glass has two components: (a) Conductive and (b) Solar transmission. The cooling load equations for glass are:

(a) Conductive $Q_{Glass\ Conductive} = U * A * CLTD_{Glass\ Corrected}$

(b) Solar Transmission $Q_{Glass\ Solar} = A*(SHGF)*(SC)*(CLF)$. (4.4)

$Q_{Conductive}$= Conductive load through the glass.

Q_{Solar}= Solar transmission load through the glass.

(a) Conductive heat gain:

$Q=U*A*(CLTD)_{correct}$

$(CLTD)_{correct} = (CLTD)+(25.5 - Ti)+(Tm - 29.4)$.

The type of glass used is single, then the overall heat transfer coefficient at 3mm from the table U=6.08 W/m^2 K and for solid wood door at thickness 50mm =1.29.

The total area of the glass =11.4m^2

Table 4.6. Values of CLTD, CLTD $_{correct}$ and Conductive heat gain for glass

Time	9:00am	1:00pm	3:00pm	6:00pm
CLTD	1	7	8	7
CLTD $_{correct}$	8.6	14.6	15.6	14.6
QW	596	1012	1081.3	1012

(b) Solar Transmission Q $_{Glass\ Solar}$

$Q_{Glass\ Solar} = A*(SHGF)*(SC)*(CLF)$.

SHGF: Solar Heat Gain Factor.

SC: Shading Coefficient takes from tables at appendix.

CLF: Cooling load Factor, this factors are used for adjustment to heat gains from internal loads such as lights, occupancy, power appliances, also were taken from tables at appendix.

Table 4.7. Heat transmitted through glass

Direction	CLF 9:00am	CLF 1:00pm	CLF 3:00pm	CLF 6:00pm	SC	SHGF	Area (m^2)
N	0.55	0.72	0.72	0.75	0.95	137	1.575
E	0.49	0.32	0.26	0.19	0.95	139	0.9
S	0.24	0.56	0.5	0.32	0.95	126	5.94
W	0.14	0.21	0.4	0.52	0.95	145	0.9

Table 4.8. Heat transmitted through glass

$Q_{9:00am}$ (W)	$Q_{1:00pm}$ (W)	$Q_{3:00pm}$ (W)	$Q_{6:00pm}$ (W)
396.9	690	706.8	584

4.1.4.1.4 Heat transfer through the Wood

The door is made from solid wood then:

U =1.29 from appendix.

A =58.365m^2.

Q =UA (Tm-Ti).

Table 4.9. Values of heat transfer through the Wood

$Q_{9:00am}$ (W)	$Q_{1:00pm}$ (W)	$Q_{3:00pm}$ (W)	$Q_{6:00pm}$ (W)
865.84	865.844	865.84	865.84

4.1.4.2 Internal Cooling Loads

The various internal loads are consist of sensible and latent heat transfers. The lighting load is only sensible.

4.1.5.2.1 The heat transfer from people

$$Q_s=q_s*n*CLF \quad (4.5)$$

$$Q_L=q_L*n \quad (4.6)$$

where:

Q_s, Q_L: sensible and latent heat gain.

q_s, q_L: sensible and latent gains per person are 59 and 73

n: number of people.

Assumed the number of people available is 100 person, and the values of CLF at 9:00am, 1:00pm, 3:00pm, 6:00am are zero, 0.79, 0.86, and 0.93 respectively.

Table 4.10 Values of sensible, latent and total heat gain for people

Heat transfer	$Q_{9:00am}$	$Q_{1:00pm}$	$Q_{3:00pm}$	$Q_{6:00pm}$
Q_s	0	4661	5074	5487
Q_L	7300	7300	7300	7300
Total	7300W	11961W	12374W	12787W

4.1.4.2.2 The Heat transfer from lighting

Qs=W*CLF*N*Fu. (4.7)

Where:

Qs = net heat gain from lighting.

W= lighting capacity (W).

N = numbers of lamp.

CLF= cooling load factor =0.79 from Appendix.

Q = 20*0.78*160*1= 2496W.

Fu = Lighting use factor.

4.1.4.2.3 Heat transfer from equipment

Qs=N*P (4.8)

N =number of equipment.

P= power of equipment.

In the building found 17 computer advices and only printer.

The power of computer and printer are 200W.

Q_{comp} =200*17 =3400W.

Q_{print} =1*200 =200W.

Q total =3400+200 =3600W.

4.1.4.2.4 Heat transfer from ventilation air

Ventilation air is the amount of outdoor air required to makeup for air leaving the space due to equipment exhaust, exfiltration and/or as required to maintain Indoor Air Quality for the occupants. The heat is usually added to the air stream before the cooling coil and has no direct impact on the space conditions. The additional cooling coil load is calculated as follows:

$Q_{sensible}$= 0.35 x airflow x ΔT

Q_{latent}= 0.87 x airflow x ΔW

Where

Airflow rate. = 10(L/s)*number of people =10*100 =1000(L/s).

ΔT =43-24 =19 ºC

ΔW = Humidity ratio of outdoor air minus humidity ratio of indoor air temperature (Wo- Wi) from psychometric chart at 24ºC, 43 ºC when the relative humidity 50%

ΔW= 0.0275-0.0092 = 0.0183Kg/Kg.

Table 4.11. Values of sensible and latent heat for ventilation air

Time	$Q_{9:00am}$	$Q_{1:00pm}$	$Q_{3:00pm}$	$Q_{6:00pm}$
Qs	6650	6650	6650	6650
QL	15921	15921	15921	15921
Total	22571W	22571W	22571W	22571W

Table 4.12. Total of cooling load calculations of the building at different hours

Components	9:00am	1:00pm	3:00pm	600:pm
Walls	6803.57	6848	7194.5	8273
Roof	21399.7	48213.7425	56464.22	54401.6
Conductive Heat Gain	596	1012	1081.3	1012
Transmitted through glass	369.9	690	706.8	584
Heat transfer from wood	865.84	865.84	865.84	865.84
People	7300W	11961W	12374W	12787W
Lighting	2496	2496	2496	2496
Equipment	2200	2200	2200	2200
Ventilation	22571W	22571W	22571W	22571W
Total	64602W 64.6kW	96857.58 96.9KW	105953.66W 106KW	100790.44W 100.8KW

4.2 Air conditioning of the building with the help of accumulation

As shown from the cooling load calculations of the building, the month of May was selected as the hottest month in the summer, the peak cooling load is 106 kW occurs at 3:00pm. The building is occupied from 9:00am to 6:00 pm for 6 days a week. The selection of the type of accumulation of heat energy to shave the load of the building and hence use a unit of smaller capacity will save energy, by using the suitable substance for accumulation, such as ice, chilled water, or eutectic salt.

4.2.1 Selection of the air conditioning units

Two options were taken to select the suitable units to provide the cooling load of the building at different operations, for the purpose of allowing the comparison between the system with accumulation and without it.

4.2.1.1 Unit for the system without accumulation

In this option, the unit operates with full load to provide the direct cooling load to the building, since the design of unit is selected based on the peak cooling load of 106 kW which occur at 3:00pm. Therefore, the values of the enthalpies are calculated from the table for R134a at evaporating temperature at -2°C and condensation temperature at 50°C.

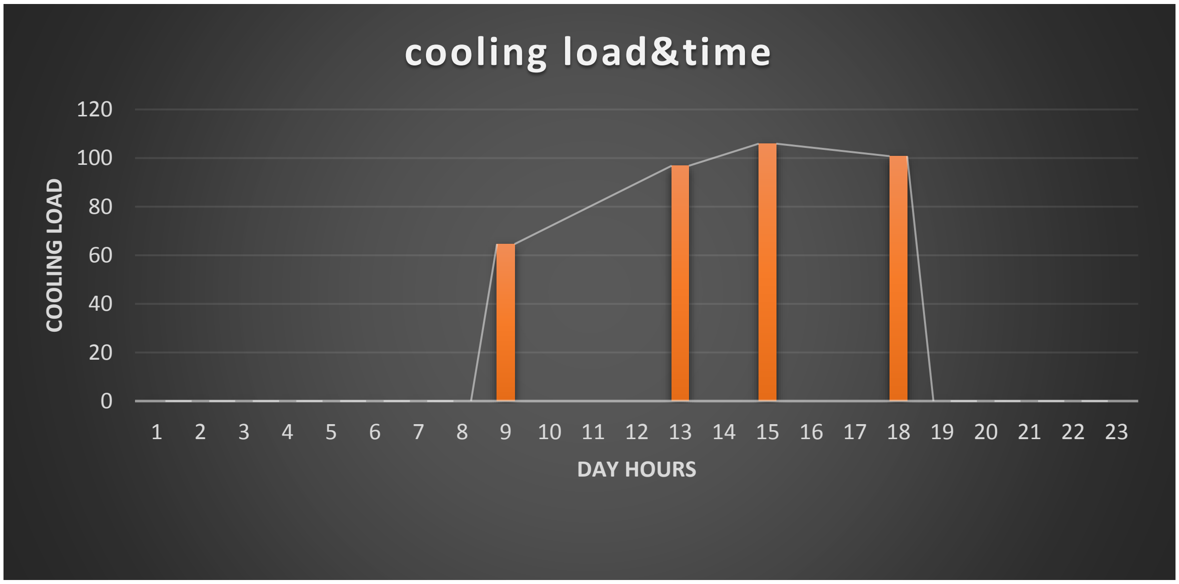

Figure 4.1 Relation between cooling load and hours

4.2.1.1.1 Refrigeration cycle

The amount of refrigerant mass flow rate, work and coefficient of performance (COP) can be calculated by the following equations.

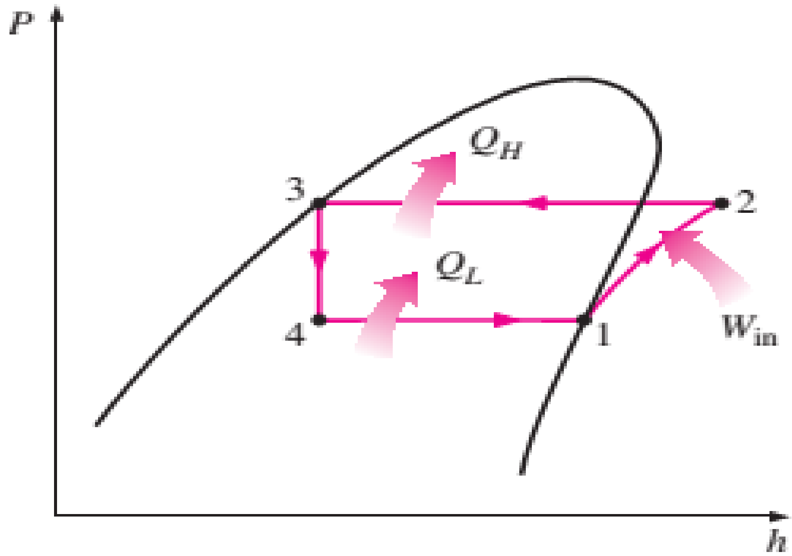

Figure 4.2. Refrigeration cycle

The values of the enthalpies are taken from the tables at appendix for R134a

$m_r = \frac{Q}{(h1-h4)} = \frac{106}{(249.32-123.5)} = 0.8425\ kg/s.$

m_r = refrigerant mass flow rate

Q = the amount of energy supplied by the chiller.

- The compressor power consumption is:

$W_{comp} = m_r\ (h2 - h1) = 0.842(290\text{-}249.32) = 34.27$ kW.

- Daily cooling load requirement for ten hours = 34.27*10 =342.7 kWh.
- The Coefficient of Performance (COP) of refrigeration system is:

$$(\text{C.O.P}) = \frac{Qevap}{(Wcomp)} = \frac{106}{34.27} = 3.093.$$

4.2.1.2 Unit for the system with accumulation

On the design day, a partial-storage system uses both the chiller and the ice storage tanks to satisfy the cooling load requirement. The chiller operates at a reduced capacity, and the cooling loads above this capacity satisfied by melting ice. The selection of the chiller depends on the following assumptions:

- The chiller operate to store 60% from the total load capacity.

- Total daily cooling requirement: 900 kWh = total cooling loads of the building during operating hours for the design day.
- Storage efficiency factor (assumed): 0.94.
- Store charge period: 7 hours, started from 10:00 pm to 5:00 am.
- Store discharge period: 10 hours, started from 9:00am to 6:00pm.
- Maximum peak cooling load: 106kW.

4.2.1.2.1 Store capacity

First it is estimated that, the store capacity of 60%.and assume the store efficiency factor of 0.94.Then daily generation requirement is determined.

900*0.6 =540 kWh

540*(1/0.94) =574 kWh

Therefore the storage capacity is 574 kWh.

4.2.1.2.1.1 Chiller duty (ice store)

Firstly, the duty required from the chiller to serve the ice store must be established. For a 7 hours charge period;

574kWh/7hours =82 kW

Therefore, chiller capacity = 82kW (ice store mode).

4.2.1.2.3 Chiller duty (maximum)

To determine the maximum duty required from the chiller, the store capacity must be removed from the peak day time load to leave the day time chiller duty;

Peak cooling load = 106 kW

Store duty available = 574 kWh/ 10 hours =57.4kW

Therefore chiller capacity =106 –57.4 = 48.6 kW (day time mode).

This means that the chiller operating with two regimes:

Firstly: The chiller has been selected for a maximum duty of 82 kW in ice store mode.

Secondly: the chiller operate to provide 48.6 kW during the daytime and remainder meeting by ice storage.

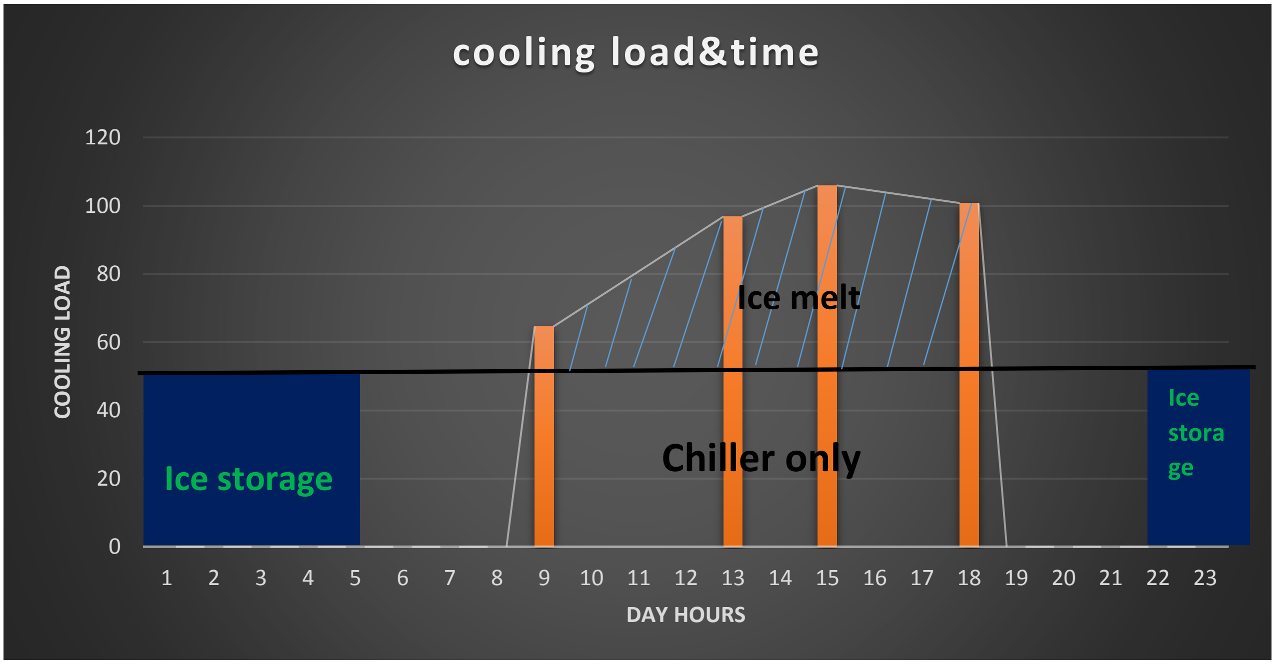

Figure 4.3. Described the shaving load details

4.2.1.2.4 Refrigeration cycle

In this case, the system should operate in two refrigeration cycles.

The first case, when the chiller operates at daytime (48.6 kW day time mode). The refrigerant used is R134a at evaporating temperature -2°C and condensation temperature at 50°C. Second case, when the chiller operating at night to produce the ice for later use (82Kw ice store mode), at evaporating temperature -12°C and condensation temperature at 35°C. Therefore the amount of refrigerant mass flow rate, work and coefficient of performance (COP) can be calculated by the following equations.

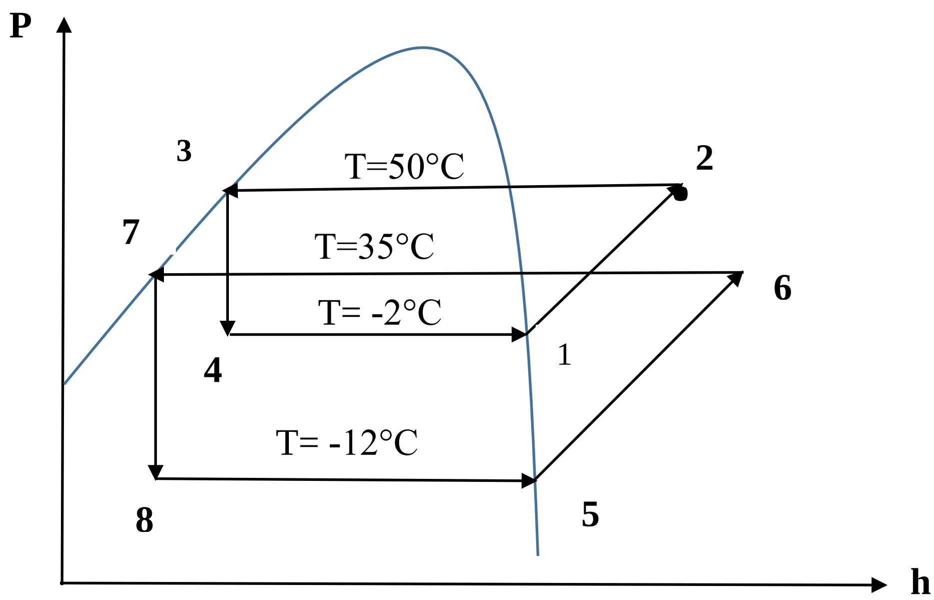

Figure 4.4. Refrigeration cycle for the system with accumulation

4.2.1.2.4.1 First regime:

- The amount of refrigerant mass flow rate:

$$m_r = \frac{Q}{(h1 - h4)} = \frac{48.6}{(249.32 - 123.5)} = 0.386\ kg/s$$

Q = the amount of energy must be provided by the chiller

- The compressor power consumption is:

$W_{comp} = m_r\,(h2 - h1)$ = 0.386(290-249.32) = 15.71 kW

- Daily cooling load requirement =15.71*10 = 157.1 kWh
- The Coefficient of Performance (COP) of refrigeration system is:

$$(C.O.P) = \frac{Qevap}{(Wcomp)} = \frac{48.6}{15.71} = 3.093$$

4.2.1.2.4.2 Second regime: The accumulation of ice:

- The amount of refrigerant mass flow rate is the same (the same unit):

$$m_r = \frac{Q}{(h5 - h8)} = \frac{Q}{(243.334 - 100.87)} = 0.386 kg/s$$

Q = 0.386(243.334-100.87) = 55 kW

Q = the amount of energy must be providing by the chiller

- The compressor power consumption is:

W_{comp} =m_r $(h6 - h5)$ = 0.386(268.7-243.334) = 9.8 kW

- Daily cooling load requirement =9.8*7= 68.6 kWh.
- The Coefficient of Performance (COP) of refrigeration system is:

$$(C.O.P) = \frac{Qevap}{(Wcomp)} = \frac{55}{9.8} = 5.61$$

Therefore:

The total daily cooling load requirement from whole units =157.1+68.6 =225.7 kWh.

The percentage is (342.7-225.7/342.7) =0.341=34.1%.

From the above calculations, it is found that the daily cooling load requirement from the unit for the system without accumulation (342.7kWh) is greater than the unit for the system with accumulation (225.7 kWh). Therefore the unit for the system with accumulation would be preferred for the building, because by less power input it can provide the load requirement and will save energy reducing 34.1% from the total required (kWh), also the 82kW unit will cost less than the 106 kW.

4.2.2 The operation strategy of the selected system:

The selected unit and the system with accumulation according to the above is shown in Figure 4.8 below, and would operate with two regimes.

First:

The unit is operating at a capacity of 48.6 kW during the daytime at the regime of 50 ºC condensing temperature and -2 ºC evaporating temperature, to provide the cooling load of the building from 9:00am to 6:00pm, by chilled water 6/12 ºC.

Second**:**

The unit is operating by store capacity 55 kW for 7 hours started from 10:00pm to5:00am at night to provide the sufficient amount of ice to be used to shave the peak load, the unit will operate at a regime of -12 C evaporating temperature and 35 ºC condensing temperature using glycol as a medium. The temperature of the glycol leaving the chiller and entering the ice storage tank is -8°C and return at -4°C. The unit control should be modified to work with these two regimes by the manufacturer according to the request of the user.

There are three heat exchangers in the system selected for heat transfer as follows:

First a counter flow heat exchanger, the temperature of glycol entering at 2 °C and leaving at 8ºC, while the chilled water to the building entering the heat exchanger at 12ºC .and leaving at 6ºC, as shown in Figure 4.5 below:

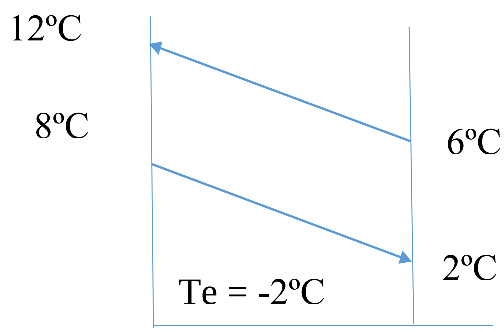

Figure 4.5. Counter flow heat exchanger

Second is the reservoir. To produce the ice the temperature of glycol enter the heat exchanger at -8 °C and leaves at -4 °C while the water solidifies into ice at 0 °C. From the other side and during melting time the chilled water will enter the reservoir at 12 °C and leaves to the building at 6 °C, as shown in Figure 4.6 below

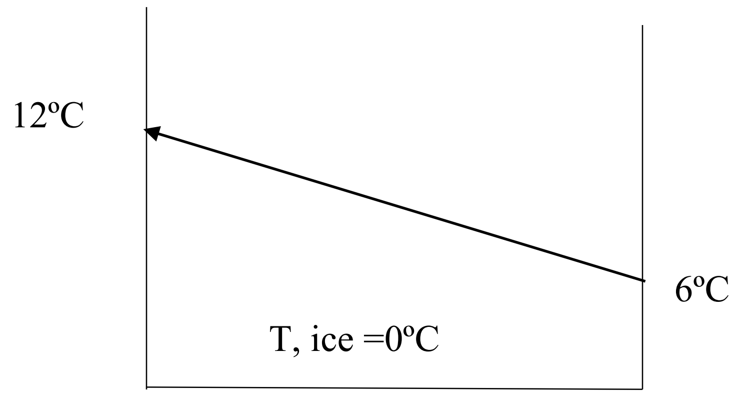

Figure 4.6. Heat exchanger in reservoir

Third is the evaporator during the storage regime when the glycol enters the evaporator at -4 °C and leaves at -8 °C while the evaporation is at -12 °C. As shown in Figure 4.7 below:

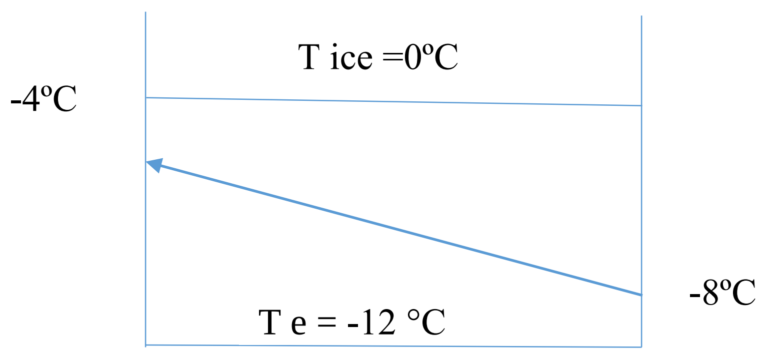

Figure 4.7. Heat exchanger in evaporator

Fourth is the evaporator during the day regime when the glycol enters the evaporator at 8 °C and leaves at 2 °C while the evaporation is at -2 °C.

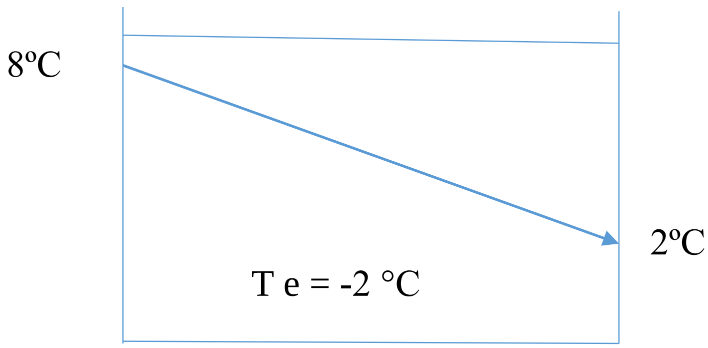

Figure 4.8. Heat exchanger when the glycol enters and leaving the evaporator

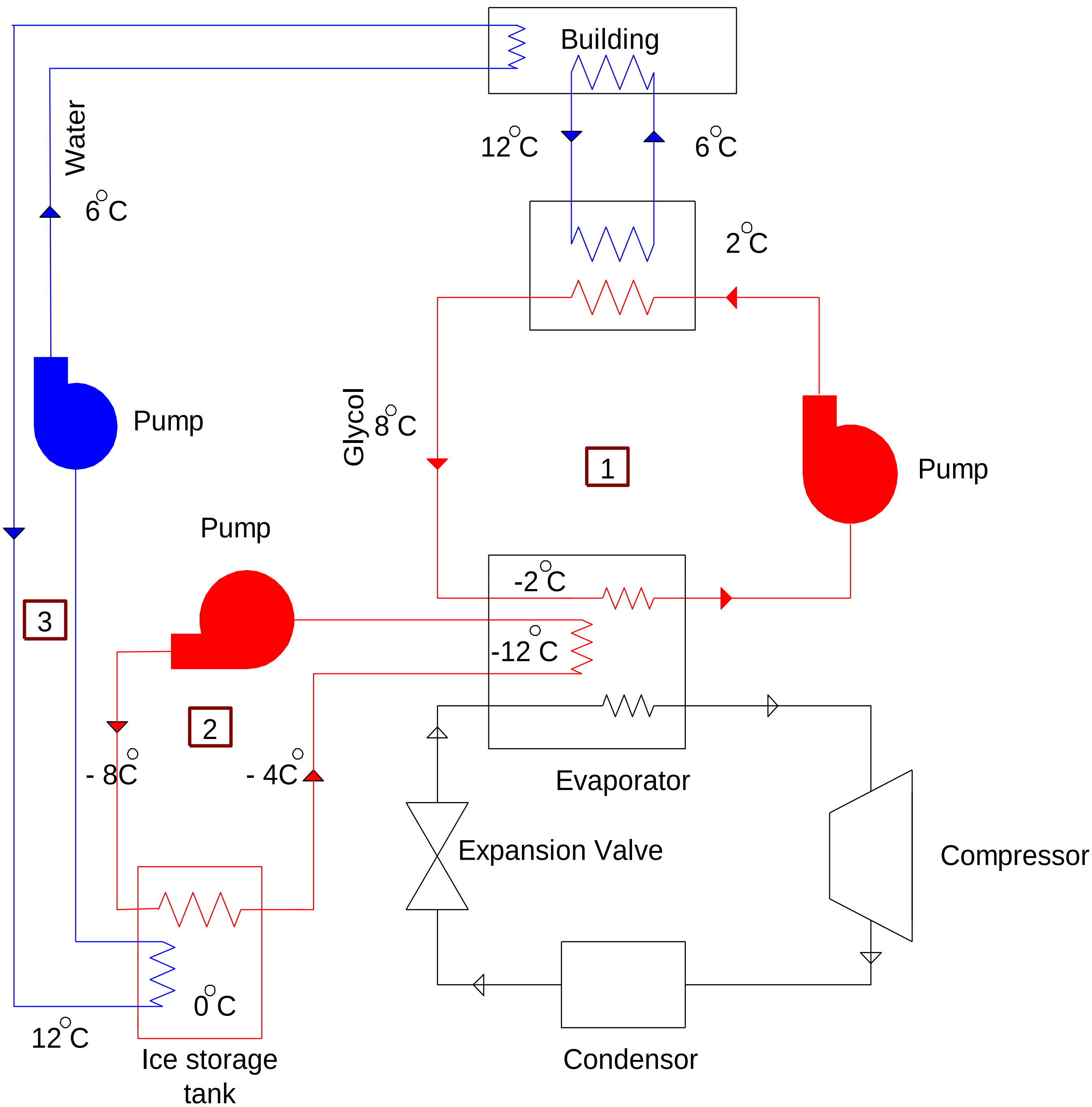

Figure 4.8. Operation strategy of the selection unit

Conclusion and Recommendations

5.1 Conclusion:

According to collected data about the climate of the case study area and the energy consumption during summer season, and comparison between the consumed power with the accumulation system and without it, the chiller unit with accumulation provides the sufficient load by small unit capacity which reduce about 34.1% from the total cooling load required by (kWh) compared with a conventional system.

5.2 Recommendations:

To improve further the operation and efficiency of the chiller units system in order to reduce the energy consumption it is recommended that:

a. Use chiller units with high coefficient of performance.

b. Use chiller units with good capacity control system according to the requirement of the building from energy consumption during the operation hours for increasing and decreasing load.

c. For the unit with accumulation can be recalculated, by using mathematical analysis at different area to select the optimum at different hours.

d. It is clear from the amount of available solar energy in Elobied that accumulation can be used for different applications and with different substances.

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