Energy Performance of Earth Sheltered Spaces in Hot-Arid Regions

أداء الطاقة في الفضاءات التحت أرضية في المناطق الحارة الجافة

By

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ABSTRACT

The issue of global warming and climate change has stirred an unprecedented campaign in the building industry to minimize its impact on the environment. Earth sheltered spaces represent the long-gone pattern of living and sheltering against dangerous and harsh environment. Nowadays and despite the stigma of negative thoughts associated with the underground spaces, people in America, Europe, Asia and Australia are still using these spaces.

This research is focusing on the underground spaces energy performance in Abu Dhabi/ UAE, and its potentials for reducing the cooling load since the buildings in UAE are cooling dominant. The hypothesis of the research is that underground spaces consume less energy for cooling and heating load in comparison to the above ground conventional spaces. Soil temperatures are calculated using simplified heat equation developed by LABS, IES-VE software used for simulating a model of underground space configurations and compared to the same model base case of above ground space to assess the cooling and heating saving potentials. Additional measures are introduced to increase the percentage of energy saving and enhance performance through the incorporation of thermal insulation and introducing of day lighting.

Simulation result shows high saving potentials of underground spaces when compared to the above ground in some configurations; furthermore, different saving percentages achieved for each configuration with regards to depth. Additional savings attained from thermal insulation and day lighting. The research shows that the calculation of soil temperature is essential in predicting the cooling/heating load of the underground spaces.

The research concluded that underground spaces represent a practical solution to reduce the sum of cooling load consumed in conventional above ground buildings in areas with harsh climate as the case of Abu Dhabi/ UAE.

الملخص

لقد شجعت ظاهرة التغير المناخي الباحثين والمختصين في قطاع التصميم والانشاء في البحث على بدائل تساهم في خفض الاثر البيئي الذي تخلفه أنماط البناء الحالية على البيئة. تعتبر الكهوف و الفظاءات التحت أرضية من أقدم أنماط الفضاءات التي استعمرها الانسان ووفرت له الحماية من الأخطار الخارجية والبيئة القاسية و بالرغم من أن نمط البناء تحت الارض مازال مرتبطا بمفاهيم سلبية عن هذه الفظاءات الا انها مزالت مستخدمة وبكفاءة في أمريكا و أوربا واسيا واستراليا وبأستخدامات مختلفة.

هذا البحث يركز على أداء الطاقة في الفضاءات التحت أرضية في المناطق الحارة الجافة وبالأخص في أمارة أبوظبي في دولة الامارات العربية المتحدة والامكانيات التي يوفرها هذا النمط في تقليل حمل التكيف حيث ان حمل التكييف هوالمهيمن على استهلاك الطاقة في ابنية المناطق الحارة الجافة. لقد افترض البحث أن نمط البناء التحت أرضي يستهلك طاقة أقل مقارنتا بالابنية ذات نمط البناء التقليدي (فوق الارض). تم أستخدام برنامج الحلول البيئية المتكاملة IES-VE اصدار 6.4 لاحتساب احمال التكييف والطاقة المستهلكة من خلال محاكاة نماذج مختلفة من الفضاءات التحت ارضية ذات الاستخدام السكني ومقارنتها بنفس النموذج من نمط البناء التقليدي (فوق الارض). الأحمال المحتسبة تغطي أربعة فترات زمنية تمثل فترات الاعتدال والانقلاب المناخي. تم احتساب درجات حرارة الأرض وباعماق مختلفة على مدار السنة من خلال استخدام معادلة LABS المبسطة و باستخدام برنامج Microsoft Excel 2007.

أضهرت نتائج الدراسة أنخفاض ملحوض في حمل التكييف وبنسب مختلفة وبحسب طبيعة النموذج من حيث علاقة الفضاء المباشرة بالارض. لتحسين أداء الطاقة في الفضاءات التحت أرضية تم أختبار اثر اضافة العازل الحراري الى الغلاف الخارجي للفضاء وبسماكات مختلفة حيث اضهرت النتائج وجود امكانية تحقيق خفض أضافي في حمل التكييف, كما جاءت النتائج متفاوتة من حيث سماكة العازل الحراري و علاقة الفضاء المباشرة بالارض. من جهة أخرى, أظهرت الحسابات زيادة في الطاقة المستخدمة في انارة الفضاءات التحت ارضية مقارنة بالفضاءات التقليدية فوق الارض وعليه تم اختبار امكانية توفير الانارة الطبيعية من خلال استخدام أنابيب ذات جدران داخلية عاكسة للأشعة الشمسية تعمل على سوق الانارة الطبيعية الخارجية الى الفضاءات التحت أرضية. تم احتساب شدة الانارة الطبيعية الواردة الى الفضاء التحت أرضي باستخدام برنامج SkyVision v.1.2.1 وقد اضهرت نتائج المحاكات خفض حمل التكييف و الطاقة الكهربائية المستخدمة في الانارة لفترات الاعتدال والانقلاب ماعدا فترة الانقلاب الشتوي بين 18-24 كانون الاول حيث أن شدة الانارة الطبيعية الواردة بواسطة الانبوب لم تحقق معيار الانارة التصميمي المعتمد في الفضاءات السكنية.

لقد استخلص البحث موائمة هذا النمط من البناء وامكانيته على خفض حمل التكييف بنسب معتبرة وأن هذا النمط يعد بمميزات كبيرة تخدم قطاع التشييد من ناحية خفض استهلاك الطاقة بالاضافة الى الاثار البيئية الايجابية الاخرى التي يوفرها مقارنة بنمط البناء التقليدي (فوق الارض).

ACKNOWLEDGEMENT

First and foremost, I would like to show my gratefulness to the creator of mankind. I praise and thank God for the success and blessings he bestowed on me. I would like to offer my sincere appreciation to those who supported me during this endeavor, to those who have gave up their time to make this project a true and to all my colleagues for standing by me. Moreover, we pass our regards and express my most sincere gratitude to the ‘Remarkable people’ at BUiD staff. Many thanks go to Professor Bassam Abu Hijleh for his support and guidance through this research.

Without doubt and as the Japanese proverb states “it is easier to rule a kingdom than a family”, I thank our beloved parents, wife, brothers and sisters, for embracing me with the greatest support and help.

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1 CHAPTER ONE

INTRODUCTION

1.1 Carbon, Energy and Environment

Earth natural resources are under pressure and in nonstop depletion due to unwise extraction, reckless practices and the life style human adopts. Fossil fuel is depleting, fresh water withdrawal is mounting, forests shrinking, topsoil is eroding and fishery is getting scarce, in another word our eco-system is under great pressure. Our cities are running on cheap fossil fuel in all aspects of life from agriculture, industry, transportation to buildings. The energy that stored for a millions of years in the earth is being squandered in just 100-200 years (Dunster et al, 2008).

Carbon in the atmosphere plays an important role in the planet temperature to insure life and biodiversity of Flora and Fauna on the earth, figure 1.1.1 showing the correlation between CO_2 and earth temperature. The release of Carbon in the atmosphere cycle naturally balanced without human interference. The main activity of human interference to the Carbon cycle or to the breaking the natural Carbon equilibrium is through the burning of fossil fuel which adds 6 billion tones of CO_2 to the atmosphere beside what added by the natural process. There is an agreement between climate change scientists that 90% of climate change is due to human activity and mainly to the burning of fossil fuel based-energy (Smith, 2005).

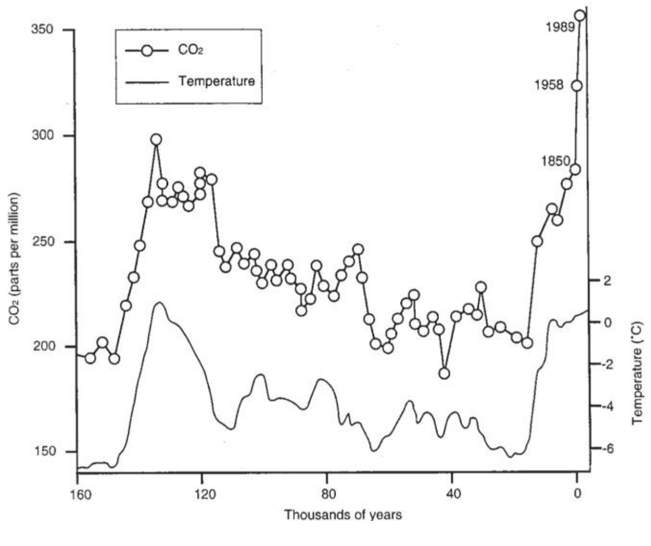

Figure 1.1.1 The relation between CO2 concentration in the atmosphere and earth temperature (Smith, 2005)

The near history of 1970s oil crises has helped to shift the attention to the green design and more researches were done on other sources of renewable energy, in 1980s the second shock already hit and this time is the climate change were ozone layer depleted in some location from the sphere, the green house gases and global warming become a phenomenon, scientists predict that if the same amount of present CO_2 production continue the consequences shall be catastrophic in the near future (Roaf et al, 2001).

The built environment is the most individual polluter and damaging factor to our planet earth, in the developing countries it consume more than half the energy it produce and more than half the global generated gases that contributing to the climate change for the built environment (Roaf et al, 2001). Population is expected to double by 2080 in return oil production has reached to its beak as shown in figure 1.1.2 and that might lead to political and security issues beside an increase in the oil prices due to demand.

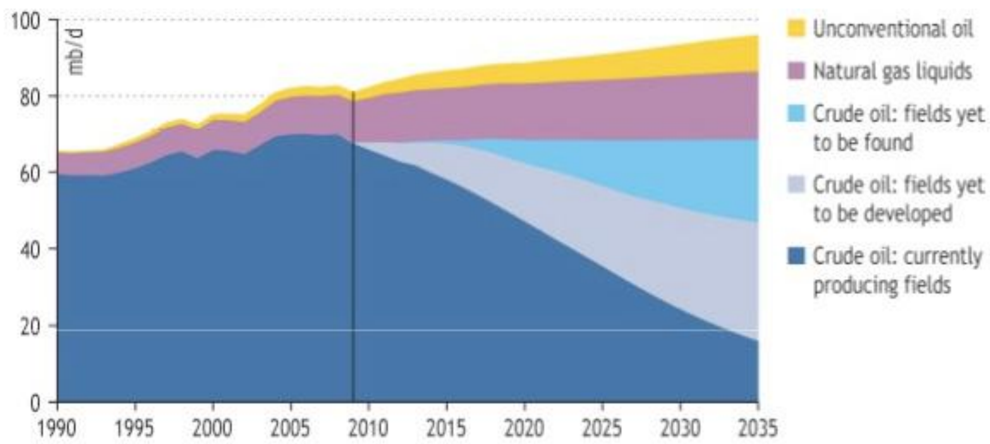

Figure 1.1.2 World oil productions by type with future scenario. Source: http://en.wikipedia.org/wiki/Peak_oil

Smith (2005) argues that the earth receive an amount of 178,000 terawatt, this amount of energy is more than 15,000 times the amount of energy the globe is consumed in an annual average, 20% of that amount is reflected to the universe, 50% is absorbed and re-radiated and 30%

goes in the hydrological cycle. Only 0.6% of the received energy is used in the photosynthesis; therefore is in the hand of Architect, planners, decision makers and service engineers to make use and get benefits of this free energy instead of utilizing and burning the fossil fuel and jeopardizing the balances eco-system of our planet earth.

1.2 Sustainability and Low Energy Buildings

The term Sustainability as defined by Bruntland Commission "Allows people to meet the need of the present without compromise the ability of the future generations to meet their own needs" (Sustainable Communities Task Force report, 1997). To enhance the eco-system and reducing the negative impact of human, first is to know how manage the environmental system through earth science, environmental science and conservation of the bio-system, second approach is to know how manage the human consumption on resources (Sustainability-wiki), hence, the integration between Social, Economic and Environment representing the three pillars of Sustainability.

In 1915 the American geographer Ellsworth Huntington write about the integral relation between climate and civilization, the theory has encouraged many writers in the 1940s to write about climate, energy and nations. In that time Markham emphasis on the climate control to the harsh climate Queensland in Australia to maintain its progress hence the hot and humid climate lowering the workers efficiency and the debate was on the size and amount of heating and Air-conditioning of the spaces. In the 1970s the relation between climate and buildings has changed from providing thermal comfort condition spaces for working and living to how to provide energy efficient building that need less energy to meet specified level of comfort whilst at the present time the relation took more political aspect and the focus was more on how averting the climate change through cutting of greenhouse gas emission (Williamson et al, 2003).

Santamouris (2007) indicated that high ambient air temperatures and heat waves cause catastrophic problems to people living in buildings with improper heat conditions or people how live in low socio-economic status. It is estimated that over 30,000 death cases occurred in Europe as a result of 2003 heat wave, furthermore, the heat wave increased the demand on electricity by 10% in comparison to 2002. As shown in Figure 1.2.1, Energy efficient and passive cooling buildings might be the right solution and an efficient pay off to overcome the heat waves and climate change extremes.

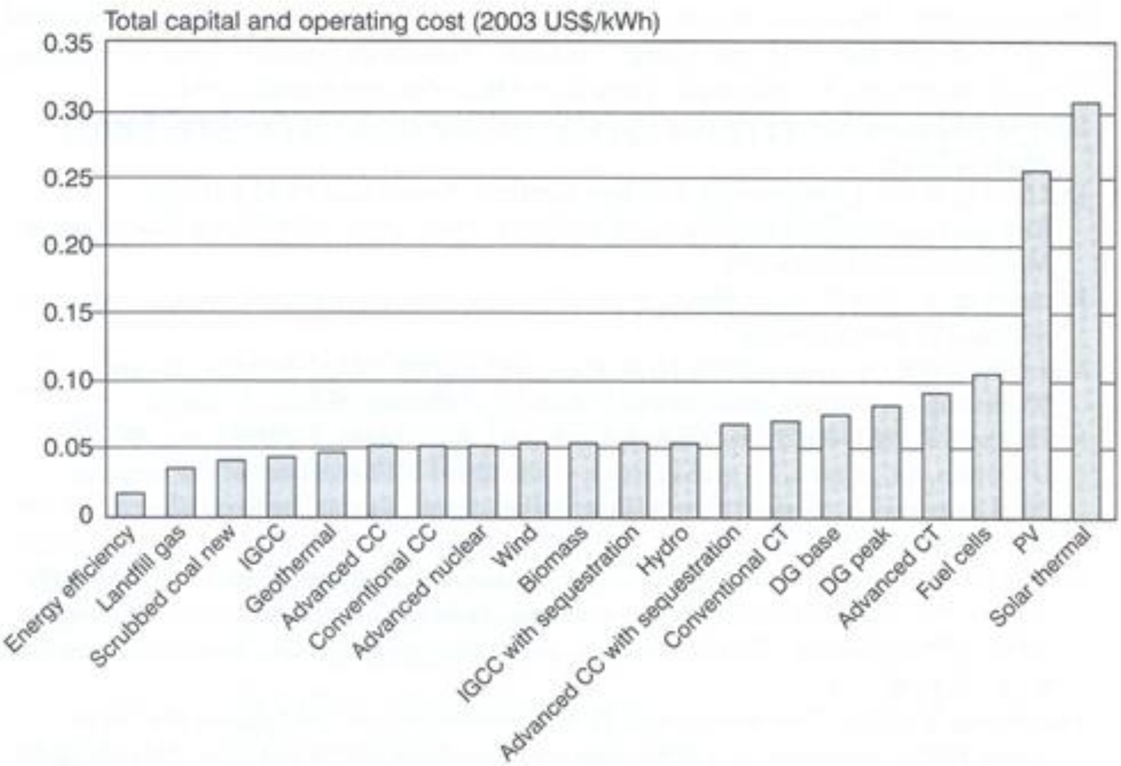

Figure 1.2.1 Capital cost and maintenance of alternative energy options. Santamouris, 2007

1.3 Outlook on UAE and Abu Dhabi Electricity present & Future

According the Living Planet Report 2010, UAE is coming first for its highest footprint, the report as shown in figure 1.3.1 claims that if everyone in the world live at the same level of the resident of UAE, and then the bio-capacity of 4.5 earths are needed to sustain their needs and CO_2 emission.

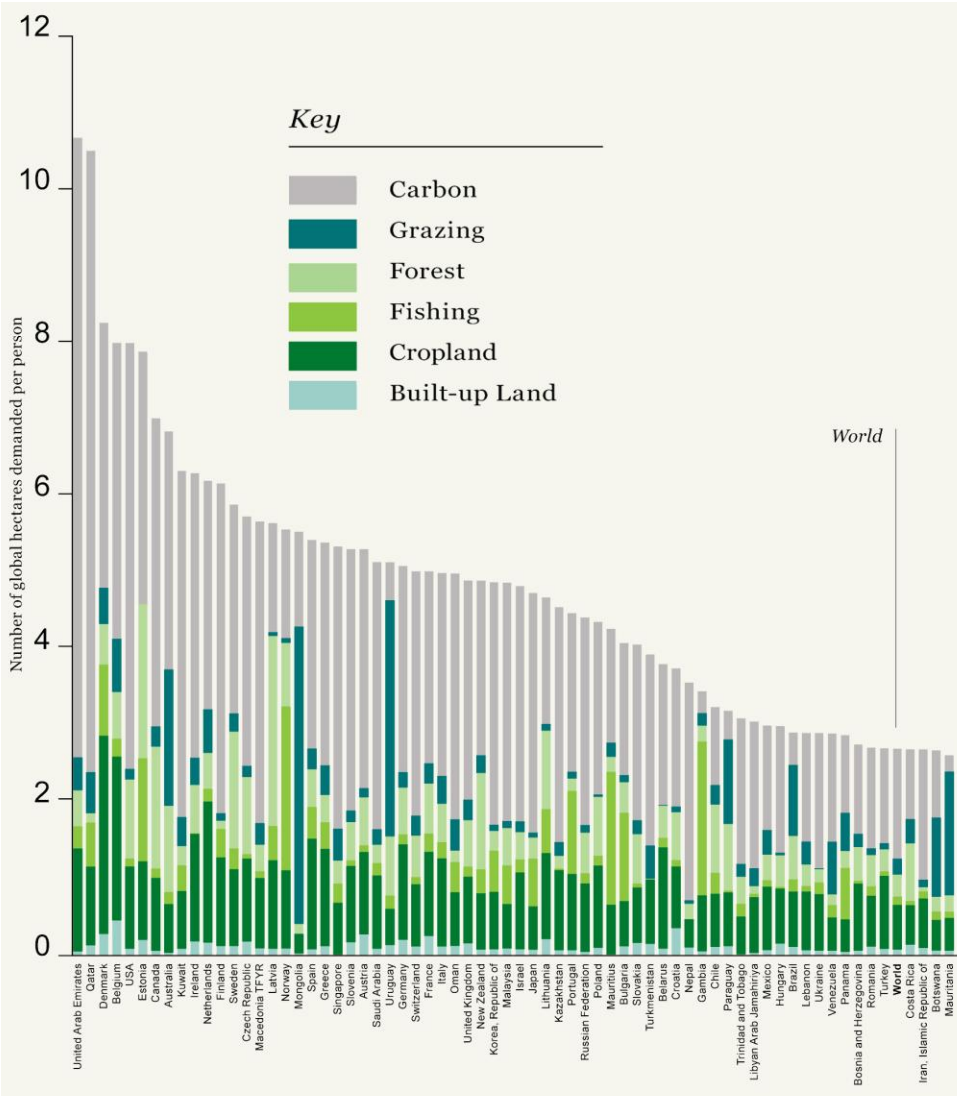

Figure 1.3.1 Caption shows the Ecological foot-print per country per person. Living Planet Report (2010).

The increasing in tourism, the massive real estate project under construction and rapidly growing number in population, all these factors have placed huge pressure on the electricity sector and this demand has been translated into more investment in power generation. While the electricity capacity was 9600 MW in 2001 the electricity capacity has jumped to 16,670 MW in 2009 (UAE year book 2009). The industry are expecting the demand will be more in next coming years as shown in figure 1.3.2 that shows the future demand in Abu Dhabi emirate and northern emirates to year 2030.

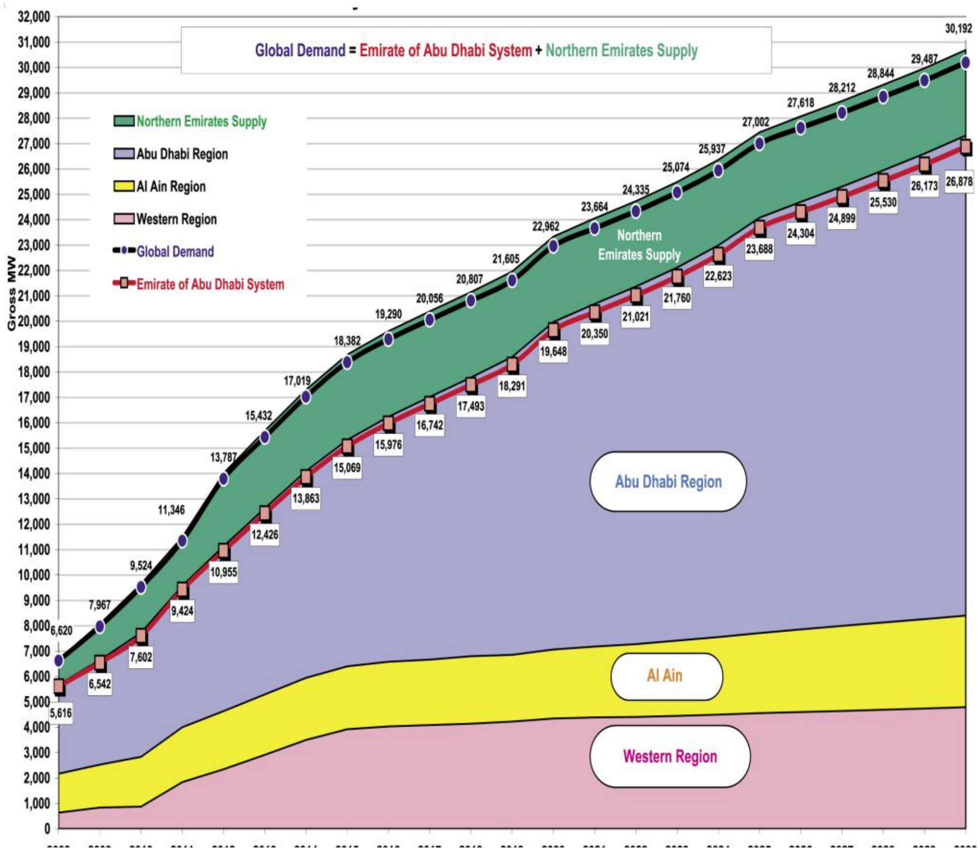

Figure 1.3.2 Abu Dhabi and northern emirates electricity future demand. Statistical Report www.adwec.ae

Despite the fact that the local government of Abu Dhabi is putting plans and initiatives to reduces the increasing demand on electricity through investigating the feasibility of other renewable resources of energy as solar power for instances through Masdar initiative and Estidama Building Rating System, the designer and construction industry processional can play an important role to reduce energy demands through design and construct efficient energy buildings, the lack or the negligence of designers, planners and construction sector professionals in the climatic and environmental design principals have aggravated the situation of energy demands. Building sector is responsible on emitting of 50% of CO_2 from the total emitted to the environment (Roaf et al, 2001) keeping in mind that the main gas in the greenhouse gases is CO_2 coming from burning of the fossil fuel as shown in figure 1.3.3.

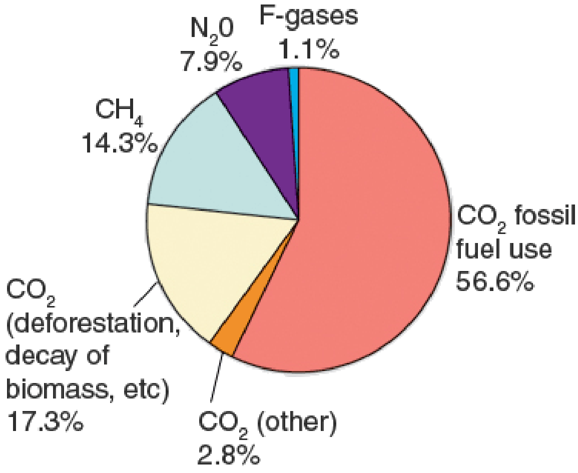

Figure 1.3.3 Percentages of global greenhouses gases 2004. www.epa.gov

1.4 Earth-sheltered spaces – Historical background

1000's years back, caves were the first shelters occupied by humans to protect them from harsh climate and secure them from dangers, humans learned with time that spaces surrounded with mass of earth whether underground or inside a mountains are providing warmth in cold weather while keep them cool in hot weather. Underground living found in China, Turkey Tunisia and Libya southern France, southern Italy, Iran, India and south eastern parts of US managed to overcome the extreme climates of the cold weather in winter or the hot deserts in summer moreover, as a prove to its success, some of these below ground spaces are still occupied till now.

It is relatively clear from fossils that the Neanderthal and the modern Homo sapiens have used caves as living spaces 50,000 years ago (Carmody & Sterling, 1993), while the Chinese has used the underground spaces for more than 4,000 years ago (Golany, 1995). According to john & Raymond 1993, a semi below spaces village found in 1953 belong to 6,000 years ago called Banpo in Xian province. Cappadocia in Turkey is of immense significant type of underground spaces and settlement, it includes dwellings, churches and towns and it reach its peak in the 10th & 11th century of the Byzantine period.

The Chinese cave dwellings are represents the beginning of the Chinese civilization when the Neolithic man shifted from nomadic life style to more socially village style of living. Although the configuration of the Chinese cave dwellings (see figure 1.4.1) has been shaped by the environmental constraints of soil, climate, terrain and physical forms, it’s the farmers who created these spaces and they were always keen to live in harmony with their natural resources to maximize their survival. In the times of warring and dynasties conflict, the cave dwellings used by refuges and homeless besides; it used to shelter the military troops even to the near past when it used by the red army to evade the Japanese air raids (Golany, 1990).

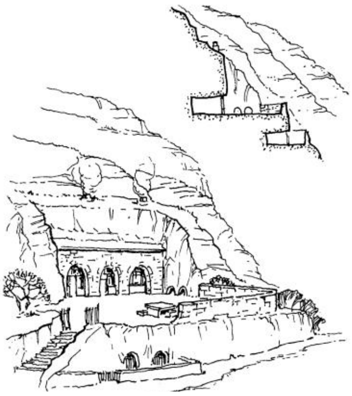

Figure 1.4.1 Chinese cave dwellings. (Wang & Liu, 2001)

Earth sheltered spaces in North Africa found in Siwa oasis to the east in Egypt and it basically used as burial ground, to the west in Libya, villages of Nalut, Gharyan and Ghadamis near the Tunisian border and in Sabratha the Roman city which seems that the Romans settlers have influenced by the native Barbers and in Bulla Regia in north Tunisia as shown in figure 1.4.2. The area witnessed a conflict between the nations that settled in the North Africa from Phoenician, Romans, Barbers, and Vandals from Spain, Twarq and Arabs. Southern Tunisia is of great importance in earth sheltered communities hence, traditional underground settlements still existed in open atrium-style dwellings in Matmata and hill side-style dwellings in Guermessa, Ghenini and Douiret (Carmody & Sterling 1993).

Figure 1.4.2 Underground atrium dwelling built by Romans in north Tunisia in Bulla Regia. (Carmody and Sterling, 1993)

In France, archeological findings shows that the human at the prehistoric ages lived in cave first then start excavating champers in the mountain's sides, in the middle ages the underground spaces used for defensive purpose near villages. The eighteenth century was the peak of the earth sheltered dwellers in France and by the 20th century over 20,000 people lived in caves, in the last two decades, the Parisian shows more interest in the cave dwellings and start using them as cottages for holidays besides its historical and cultural importance. In Spain, the Iberian civilization lived in the underground spaces before 25,000 years ago; caverns in Granada province are inhibited since the sixteenth century and in 1982 survey, 8,639 occupied caves registered. It is estimated that over 80,000 people are living in caves in Spain (Carmody & Sterling, 1993).

In the United States the underground spaces inhibited by native American as well as the European settlers. The In the mid of the last century and early, a new movement of environmental design responsive architecture emerged in the US the idea was to explore new way of life style, Earth sheltered spaces was one of the explored frontiers. Example of earth sheltered spaces development is seen in Frank Lloyd Wright in 1930s and 1940s has inspired the new generation of architects to explore this type of spaces. With oil shock of the 1970s, the shortage of energy supplies have indices the tendency to energy saving buildings and dwellings, earth sheltered spaces got more attention and this time the construction of spaces were energy motivated. Although the main purpose of such spaces is the energy saving the environmental integration, security and hazardous protection from earthquakes, hurricanes and windstorms were more advantages to build these spaces (Boyer & Grindzik 1987).

In the 1980s, the interest of the public in energy saving residential construction witnessed a retreat including earth sheltered spaces, the issues associated with the earth sheltered spaces for instance, waterproofing, initial cost, poor architectural design all these issues have resulted in less interest of the construction industry to adopt this type of buildings (Carmody & sterling, 1993).

1.5 Earth-sheltered Communities- Historical background

As a living example of the earth sheltered spaces success. There are three major communities are still using below-ground spaces and they have experienced thousands of years living underground. These communities are common in their location in the arid and semi-arid climate area, the accumulated experience and historical evolution and their adjustment to the harsh environment (Golany, 1995).

The largest concentration of community where 35-40 million people are living in below- ground dwellings known as the Chinese Cave Dwellings (Golany, 1995). It is located in the northern and north west of China in the Shanxi, Henan, Gansu, Shaanxi and Ningxia provinces. The provinces are arid to semi-arid; soil and climate have played an important role in the design and distribution of the cave dwellings.

The second largest community of below-ground spaces is scattered over Matmata plateau as shown in figure 1.5.1, in the southern Tunisia and Sahara desert. It contain around 20 fortified communities are existed and ranging between few thousands living in Matmata and few hundred in the southern-most villages (Golany, 1995). The climatic stress of the region was the prime motivation along with the soil condition besides, the continues conflict encourage occupants of this area to resort to defensive approach in building their dwellings and dig out the earth as a result to that the environmental, economic, social and security conditions have affected the way they choose the site and design their housing (Golany, 1988).

Figure 1.5.1 Matmata under-ground spaces aerial view (Golany, 1995)

Cappadocia city as shown in figure 1.5.2 is the third largest community, it is located in central Turkey and it exist more than rural and town communities (Golany, 1995). It reached depths of 8-10 floors below ground and it contains several kilometers of tunnels excavated in the volcanic tuff, these tunnels leads to roams in different sizes, food storages, livestock spaces, and shafts for ventilations (Carmody & Sterling, 1993).

Figure 1.5.2 View showing the Cappadocia city in Turkey. www.wikipedia.com

1.6 Research Structure

The research structure shall be divided into chapters as followings:

Chapter one is an introduction to the case of energy, Carbon and Environment where the relation and the consequences has been overviewed. The need for sustainability and low energy buildings as response to the climate change is discussed. An introduction to the genesis of earth sheltered spaces and communities and the conditions behind the evolution of such building type.

Chapter two and through the literature review will focus in more details on the aspects of the earth sheltered spaces, the underground spaces configuration, thermal performance, the theory of heat thermal storage, the advantages and disadvantages of the earth sheltered spaces, usage and the future of these spaces.

Chapter three is an extensive revision on the reviewed methodologies from previous researchers done on this subject. Different types of methodologies shall be evaluated based on its applicability, suitability and its limitations. Research methodology and parameters of the dissertation is to be selected based on the reviewed papers. The software selected for the research is discussed extensively.

Chapter four will discuss the mathematical model of subsurface temperature and the predicted underground soil temperature graph generated. The generated underground soil temperature will be utilized in creating temperature profiles for each configuration of the underground spaces for the software simulation to predict the energy performance for each configuration and compare it to the above ground space/building.

Chapter five will discuss the results and findings from the energy simulation software and compare it to each research parameter so that the best performance and the best case identified moreover, the effect and results from other passive techniques enhancement are discussed and reviewed.

Chapter six will provide the final conclusion based on the results and findings beside a highlight on the main factors and aspects that affecting the earth sheltered performance. Recommendation along with more future studies on the subject proposed.

2 CHAPTER TWO

LITERATURE REVIEW

2.1 Advantages & disadvantages of earth-sheltered spaces

To investigate the practicality, the suitability and major problems associated with earth sheltered housing construction a research funded by Minnesota state legislator and conducted in 1977, the research concluded that there is no technical hindrance in the construction of earth sheltered housing although, two major issues were identified, first the public acceptance, second is the lack of information on the energy performance of this type of construction (Al Temeemi & Harris, 2003).

2.1.1 Advantages

The thermal performance of soil is the main and most important aspect of the underground spaces, it consume less energy through reduce heat gain and heat loss (Golany, 1995). In hot-arid region, the cooling load is the main cause of energy consumption in buildings; sub surface climate is much milder than the above ground environment, thus; the soil surrounding underground spaces has the potentials to reduce the needed energy for cooling through preventing the heat transfer from ambient air to the underground space due to the soil mass. According to Carmody & Sterling (1993) the slow response of soil thermal mass provide a range of energy conservation benefits; it reduce the conduction losses from building envelope in cold climate, reduce the heat gain through building envelope and increase the earth cooling contact in hot climate, reduce the peak heating and cooling loads. Khair-El-Din (1991) indicate that the earth sheltered spaces energy conservation in comparison to the above ground spaces is distinguish and that ascribes to the lower heat loss due to infiltration, especially in building of bad construction quality where significant amount of energy lost through cracks a case is likely less to happen in the earth sheltered spaces. The case of less infiltration has been supported by Jacovides et. al. (1996), Mihalakakou et al. (1997) and Al- Mumin (2000).

Beside the energy performance there are additional advantages as well; the environmental aspect is an advantage in the construction of earth sheltered spaces. According to Golany (1995) underground spaces preserve land and environment and ground spaces for green and open spaces. It causes less damage to the local and global environment. The results from preserving the natural environment is less rain water runoff which important to groundwater replenish. The reduction in rain water runoff is reflected in less storm water sewage infrastructure, detention basins and treatment facilities; Furthermore, the reduction in run-off reduces the potentials of floods (Carmody & Sterling 1993).

The inner environment in earth sheltered spaces is quieter than the above ground conventional buildings, the level of noise and vibration coming from outside is lowered and the impact on the occupants is minimal. This advantage offer potentials to sites near noisy locations e.g. airports or highways.

The earth sheltered spaces provide save environment through the protection against the extreme weather e.g. hurricanes, tornadoes, lightning strikes and hail besides external fires spread from houses or forests fire. In the time of earth quake, the above ground structure is more prone to the danger of collapse than the underground spaces cause the ground motion on the surface is amplified, furthermore; the underground spaces is designed to take the load of the massive soil on top of it, hence the earth quake loading may not add more load on the structure and so that it will be less likely to collapse. According to Yucheng & Liu (1987) the Chinese cave dwellings are having fair resistance to earth quakes.

The annual temperature stability of earth sheltered spaces might be suitable for some certain industries that require stable thermal temperatures e.g. film and wine industry. Mazarron & Canas (2009) argues that wine has been traditionally matured in underground cellars in Spain due to the stability of thermal condition of these spaces.

The visual impact of underground spaces is an advantage if compared to the above ground spaces. The underground spaces maintain the quality of sensitive sites and it is less obtrusive to the environment. The increasing tendency of placing utility services underground is in fact a visual impact decision.

Land cost of underground spaces is reduces due to dual use of land or building on low priced plots e.g. slope land (Golany, 1995). Maintenance cost is reduces in the underground spaces in comparison to the above ground construction. It saves the finishing materials cost and in addition to that the envelope is protected against external weather elements. Furthermore, the underground spaces is less subjected to expansion and contraction due to soil temperature stability which ultimately less thermal cracks whereas the direct expose of the above ground building to solar radiation and heat are subjecting the building to cracks, discoloration of exterior paint and degrading roofing material which required periodical maintenance to keep its function (Al-Temeemi & Harris, 2003).

2.1.2 Disadvantages

As any alternative building type, earth sheltered spaces seems to have disadvantages and drawbacks despite the energy and forthcoming benefits. In fact, to adopt the idea of living underground, there is some social and psychological issues need to be clarified and overcome. According to Al-Temeemi & Harris (2003), Aughenbaugh claims that the main impediment to the adoption of earth sheltered housing is the planners themselves, they think that the public will not accept the idea of living underground whereas he believes that the public will accept and adopt earth sheltered living style if they well informed and educated on the benefits of the earth sheltered buildings provides. Golany (1995) also indicated that people have had bias and negativity against the earth sheltered spaces and this negativity derived from historical believe that the underground spaces was always linked to poverty and backwardness. Furthermore, the poor design quality and bad implementation of the underground spaces have erected the negative image, whereas all most all the problems of the underground spaces can be solved through good design and incorporating of technology to overcome underground spaces problems. Al-Mumin (2000) claims that the concept of building totally underground spaces in Kuwait is very unusual due to the negative perception since the underground space environment associated with dull, gloomy, stuffy and the issue of drainage problem have discourage the public to construct such spaces.

Living or working underground generate negative feelings, the negative feelings in general include darkness, humid, stale air, feel of entrapment and fear of collapse. The idea of having less or no window in the underground spaces contributes to the feeling of isolation. Disconnecting from outside environment and the lack of stimulation coming from sun and weather changing add to the sense of claustrophobia and captivity, besides the feeling of disorientation and difficulty to find the exit points. The physiological concern comes from the lack of natural lighting and poor ventilation. According to Xueyuan & Yu (1988) a survey has indicated that when people are accustomed to live in surface environment, their psychological and physiological states demonstrate changes when enter to the underground spaces. The level of CO_2 and its effect on space occupiers also investigated and the results shows that as the level of CO_2 concentration rise the feeling of being in indispose or unwell increase, in general the feeling mode, degree of discomfort and working efficiency negatively affected.

The cost of earth sheltered spaces is a matter of controversial in literatures. Researchers claim that the cost of the underground spaces is higher in comparison to the conventional surface buildings of the same size and quality. The main reason for extra cost in the underground ground spaces ascribes to the extra load imposed on the structure and that necessitate more concrete and steel which is in general more costly if compared to the wood frame houses or even to the conventional system. However, the case of costly underground spaces is not conclusive, where many authors have shown in their literatures that the cost of the underground spaces is the same to the above ground buildings. In some cases the cost was more competitive and in other literatures authors claims that the cost of the underground spaces is less than the conventional above ground spaces. The reason for the cost argues is that the underground spaces and especially in regions of extreme climates, the saving in energy efficiency is reflected in less size for mechanical air conditioning system beside the saving come from elevation finishing materials, all that saving might offset the cost of structure (Al-Temeemi & Harris, 2003).

Carmody and Sterling (1993) argues that the underground spaces might have safety issue disadvantage when the ability to evacuate the underground spaces in case of internal fire or explosion might impede in deeper spaces since the entry/exit points are limited. Permanent changes and embodied energy are disadvantages due to the difficulty adapt and renewed if compared to the above ground building beside the issue of embodied energy, where more energy is needed to excavate, transport the soil, manufacture and install the extra building materials.

2.2 Configuration & Terminology

The underground spaces have brought the interest of a wide variety of disciplines and practitioners e.g. architects, planners, engineering specialties. So it is of great importance to classify and provides standard terminology for the underground spaces to be easily described, analyzed and researched by practitioners. Carmody & Sterling (1993) expound in the classification of the underground spaces and gave different categories for theses spaces based the function, the geometry which include sub classification e.g. fenestration, depth, and project site. What concern us and for the purpose of this research, the author found that the fenestration classification is more interesting which concerns the research subject of earth sheltered spaces. Figure 2.2.1 is showing the classification of underground spaces based on its fenestration and the classification of the underground spaces in relation to the ground surface.

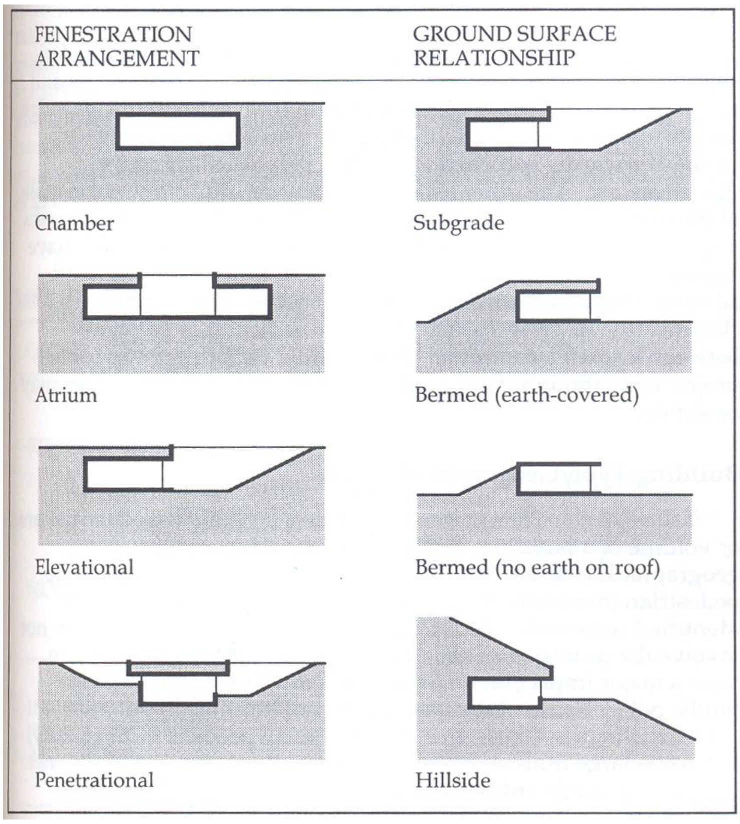

Figure 2.2.1 Illustration showing classification of underground spaces based on its fenestration and spaces relation to the ground surface (Carmody & Sterling, 1993).

Boyer & Grondzik (1987) indicate that the current generation of earth sheltered spaces has conserved the many advantages gained from the historical predecessor besides amenities what the present offer. Different formats and configuration developed to accommodate to variety of regions environments. Whether the space is sheltered with earth or whether partially or fully excavated in the ground the geological constraints of the site is an important aspect in the decision of underground space format. Flat site, sloped site, high water table, loess soil, expensive clay soil or rock strata all previous aspects play an important role in earth sheltered configuration. Different types of plan layout might consider in addition to soil cover and that include elevation, atrium and penetration as shown in figure 2.2.2. The architectural design priorities and constraints is another set of consideration of the earth sheltered spaces e.g. orientation to sun, direction to view, avoid external source of noise, site access and egress requirements and neighbors.

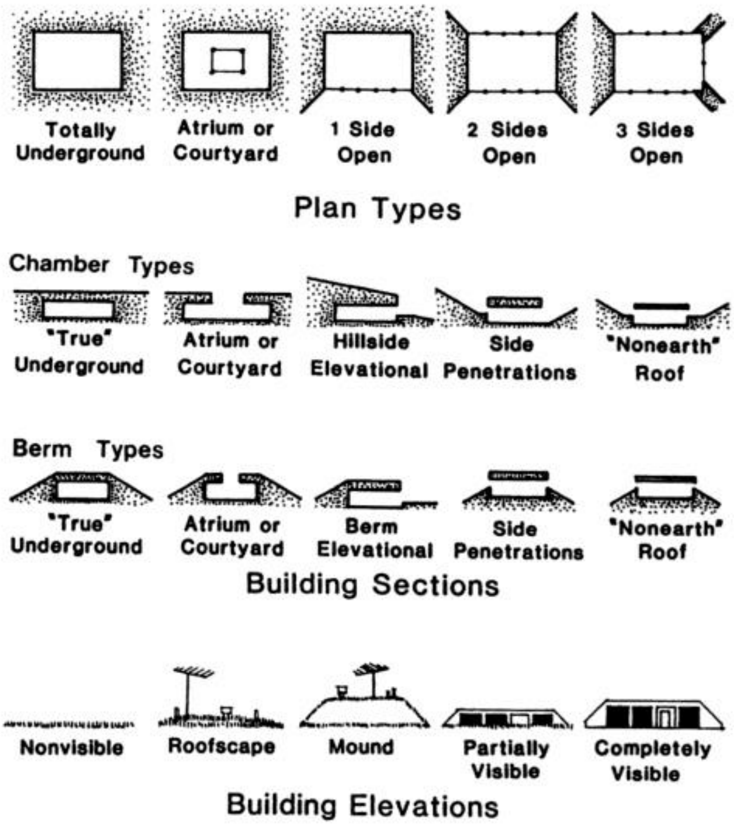

Figure 2.2.2 Illustrate different types of architectural considerations to the earth sheltered spaces (Boyer & Grondzik, 1987)

Golany (1995) indicates that there are three factors that lead to different format and configuration of earth sheltered spaces which is the degree of relation to the ground, the local climate and the availability of material. A long list of terminology used to describe these different forms and configuration. The term of earth sheltered habitat represent to a spaces above ground and covered with a layer of earth of 1m thick, and this term widely used in the U.S. Semi-below ground space represent a spaces constructed partially in the ground and the other part above ground, this type is very old and was adopted in the Neolithic villages in China and Japan. Subsurface space represent spaces constructed below ground and the distance between roof and soil surface is very small, this type historically used by native Barbers tribe in North Africa and then the Romans adopted from the Barbers and adopted in the north Tunisia. Below-ground spaces represent spaces that constructed at depth about 3m and more from the soil surfaces to the underground ceiling, in this type there is no need for building material and this type represent the common underground spaces used by human in history and this kind can be found at cliff sides and flat sites as well, it can be found in Cappadocia in Turkey and the open bit houses in China. Geo Spaces represent the type of fully integrated deep spaces that might reach to 80m deep and it represents an innovative concept of underground structures developed in Japan.

2.3 The soil temperature and soil thermal behavior

Khair-El-Din (1991) state that earth is a lousy insulator and the underground spaces saves energy due to the fact that earth is a great temperature moderator. Furthermore; Golany (1995) assert that soil has two separate functions against energy and thermal behavior. Soil works as insulator if a layer of soil used to envelope a space but if a mass of soil utilized the soil works as thermal retainer.

Placing building partially or totally in direct contact with soil has energy saving potentials for heating and cooling due to the soil that works as temperature moderator. In summer, the heat gain is reduced and the space loses heat to cool earth and in winter, the heat loss is reduces and the spaces gain heat from warm earth. The mechanism of storing heat summer in soil earth and cooling the space naturally then return the stored heat to the space in contact with the soil in winter is defined by Anselm (2007) as the passive annual heat storage.

According to Golany (1995) earth sheltered spaces have an independent and stable ambient micro climate from the outdoor fluctuated air temperature and there is a strong relation between the depth and the temperature fluctuation, so that, the greater the depth the less fluctuation. At a depth of 10m the temperature is seasonally and diurnally stable at around 10Co with small variation between summer and winter as shown in figure 2.3.1.

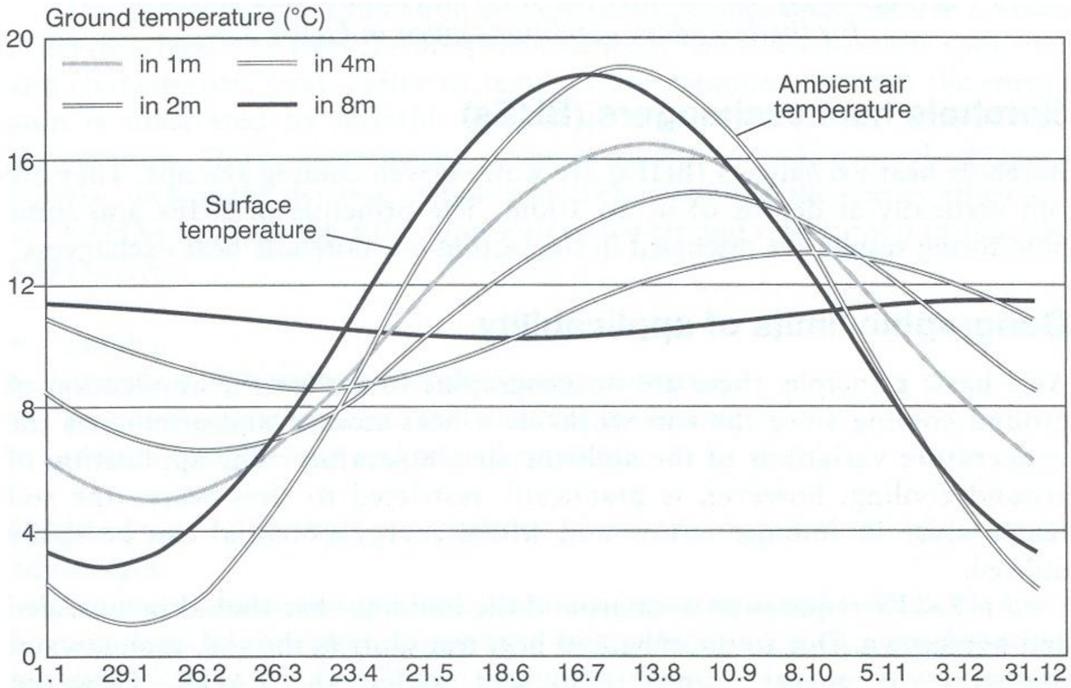

Figure 2.3.1 Graph shows the relation between ambient air and underground temperature (Santamouris, 2007)

The daily solar radiation is directly affecting the surface temperature between 5 and 7cm but up to depth of 10m there is continues seasonal fluctuation movement of heat that decrease to below and increase to surface, Khair-El-din (1991) claims that at more depths the earth responds to annual temperature change than the daily temperature fluctuation and that change occur with significant delay, according to Golany (1995) at depth of 10m the soil temperature is constant seasonally and diurnally around 10^{o}C with modest fluctuation between seasons. The sun is the main heat source for the soil temperature up to 10m depth, although the solar radiation is the source of heat gain and loss of soil temperature, there is other factors affecting the thermal behavior of soil e.g. the soil composition whether it is rock, sand or clay and the density of that soil, beside the ground cover and water containment.

The ground temperature is ruled by two boundaries, the cycle annual pattern of the surface temperature and the constant temperature at few meters depth. While the surface temperature is affected by the solar radiation, color of the surface (albedo) reflectivity, water content and surface cover, the underground temperature is represent the long-term annual average of the surface temperature (Givoni, 1994).

The long-wave radiant loss depends on the soil surface temperature; therefore it is maximum in summer and minimum in winter. The heat flow downward from the surface in summer and upward from depth in winter and this cycle movement ascribe to the radiant balance between solar gain and long-wave loss, if positive the heat flow down (in summer) and if negative the heat floe up to the surface (in winter).

2.4 Issues affecting the earth sheltered spaces performance

Earth sheltered spaces performance are affected by the climate it surround it, soil temperature is the climate that affecting the earth sheltered spaces performance. In the other hand soil temperature is affected by external solar radiation and the ambient air temperature. Whether the structure is earth sheltered space, semi underground or totally underground, there is some aspects that might affecting the spaces performance.

2.4.1 Orientation

Orientation in earth sheltered spaces concern windows and doors, the climate of the region and topography might decide the form or the configuration of the earth sheltered spaces. The orientation of openings comes in responding to energy conservation and solar utilization as the case in the cold climates. However, other considerations might be more important in directing earth walls of the sheltered spaces openings, view and landscape, site topography, ventilation and natural lighting aspects that need to be considers. As shown in figure 2.4.1, Silvia and Ignacio (2004) reported that the door in the traditional wine cellars in Spain is oriented to the North direction to allow fresh air easily introduce to inner space.

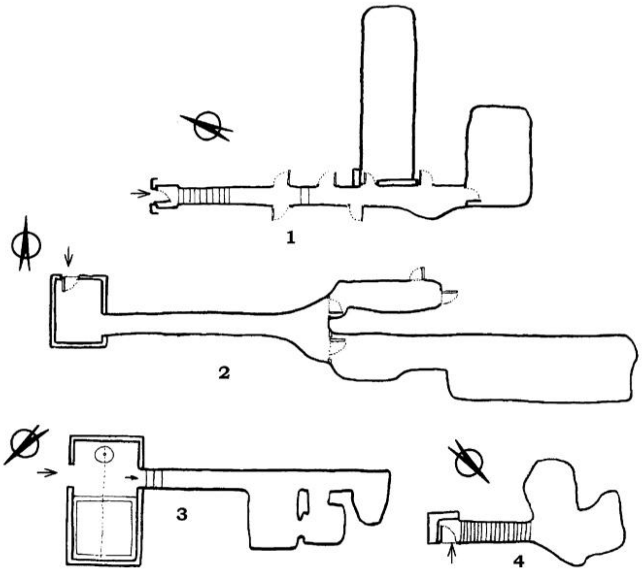

Figure 2.4.1 Illustrate layouts of traditional Spain's wine cellars door orientation. (Silvia & Ignacio, 2004)

Proper orientation of earth sheltered spaces with consideration to sun and wind could have significant energy savings. In the cold climates the southern orientation of the façade is necessary for energy conservation and solar utilization for heating of inner spaces, the southern orientation comes more important in cold climate but have sunny days in winter, besides, the solid north façade protect the space from cold wind and reduce infiltration. In hot summer climate, avoiding solar radiation and induce cross ventilation are the aspects that need more consideration when designing the earth sheltered spaces. Khair-El-Din (1991) suggested single elevation exposure of the earth sheltered space to north in hot climate to minimize the solar heat gain or south in cold climate to increase the heat gain and leaving the three elevations buried with earth.

2.4.2 Ventilation

Natural ventilation is an important consideration provision in earth sheltered spaces due to the conservation of energy importance especially in hot arid regions beside it is importance in mitigating the psychological affect on its occupants. Natural ventilation provide thermal comfort and enhance the indoor air quality of inner spaces of the underground structures, furthermore, natural or mechanical ventilation is important to get rid of the moisture that infiltrate to the inside underground spaces and the moisture generated from occupants and their daily activities. In summer the underground earth and walls are cool and its temperature is lower than the ambient temperature, when the relative humidity of the air is high and when the surface temperature drops significantly below dew-point the condensation occurs especially with low flow rate/exchange of air. Condensation in underground spaces damaging building material and provide flourish environment to develop the fungi, mold and mildew especially with the absence of natural lighting. Dehumidification, continuous air movement and increase of ventilation are enough to minimize or eradicate the condensation problem in the underground spaces. Another approach to prevent condensation through circulating the external air in buried pipes in the cool soil, hence the system work as a dehumidifier in one hand and cool the air temperature at the other hand.

Beside the mentioned benefits of natural ventilation there are constrains. It might be difficult to achieve natural ventilation in the underground space if the space is few meters underground whereas if the space is above ground and sheltered with earth the natural ventilation is quite possible and in this case the cross ventilation is achievable. Natural ventilation in hot arid region is a source of heat gain and discomfort in summer season, natural ventilation should avoid the hot season.

2.4.3 Natural lighting

The provision of natural light is regarded as an enhancement to the inner space. Providing of natural lighting in underground spaces is more important than the case of above ground spaces. Carmody & Sterling (1993) indicates that in different three studies, the natural lighting is the preferred as a prime source for illumination in office buildings by workers. While, Bouchet and Fontoynont (1996) reported that a small amount of natural day lighting of 50- 300 lux shall improve the amenity of the underground spaces significantly. The significance of providing natural lighting in the earth sheltered spaces is the psychological aspect. The stigma of seclusion and darkness are always associated with this kind of spaces due to lack of windows and natural lighting. Other issues in the underground spaces are the lack of stimulation, variety and disconnect from outside, however, providing natural lighting to the underground spaces changing the feeling of space dramatically. The slow but continuous movement of sun and the changing of light intensity because of the clouds stimulation the spaces occupants and provides information on time and outside weather and ultimately emphasis the connection with outside world.

There is a set of good examples and solutions of natural lighting suitable for underground spaces for example; vertical skylight is a practical option to consider as natural lighting provision in hot arid region, light pipes principles might be a practical solution for deep underground spaces. While Jenkins and Muneer (2003) states that artificial lighting consume 13% of domestic energy, Oakley et al (2000) claims that utilizing of day lighting in buildings can save about 20-30% of total energy consumption, light pipes/wells is one solution of guiding day lighting to building interior. Figure 2.4.2 showing section in a light pipe

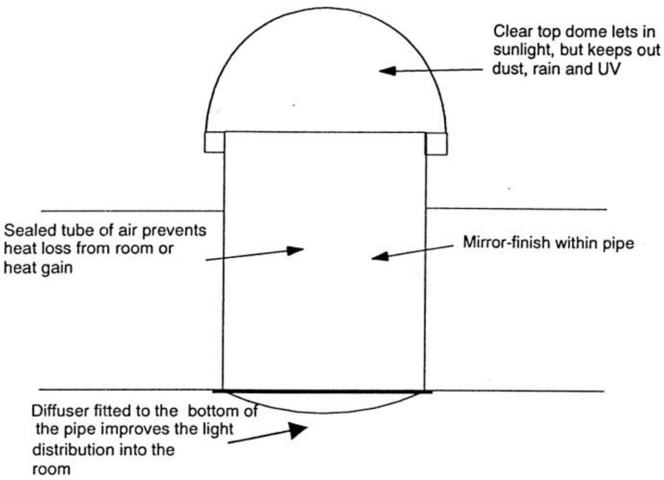

Figure 2.4.2 Showing section of the light pipe, G. Oakley et al (2000)

Shin et al (2011) argues that using of light pipes in underground spaces where windows and sky light are inadequate, brings luminance without the use of artificial lighting and ultimately saving the day lighting energy and reduce consumption. Shao et al (1997) claims that light pipe transmit less solar energy to the illuminated interior when it compared to sky light or window whereas Jenkins and Muneer (2003) asserts that light pipes allowing day-light to building without glare issue or unnecessary heat gain/loss, it is hard to find data on how much heat gain/loss the light pipe incur to the building. .

According to the Environment agency- Abu Dhabi report (2008), the United Arab Emirates has the highest sunshine hours around the world; table 2.1 is showing the amount of monthly sunshine hours in Al-Ain area. According to Jenkins and Muneer (2003), Rosemann and Kaase (2004) and Shin et al (2011), the Introducing natural lighting to underground spaces reduces the energy consumed for illumination purposes. Light pipes or tubular day-lighting devices shall be examined to verify the feasibility of this system on the underground spaces.

Table 2.1 Monthly solar radiations of Al-Ain Area. (Environment Agency- Abu Dhabi, 2008)

Station	Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Al Ain	Extreme maximum	560	656	767.9	837.7	862.4	882.1	829.1	794.3	752	670	566	554
	Daily Average	433.3	540.8	606.3	738.8	794.8	790.9	733.9	723.3	677.2	589.4	482.4	428.3
	Extreme minimum	43	235	85	224.7	358.5	557	407	515.2	446.6	230	256	78.9

2.4.4 Soil surface cover

Soil surface cover has been discussed in literatures as a technique to modify and enhance the cooling potentials of the earth sheltered spaces especially in hot regions where cooling is of the most important. These techniques for instance, vegetation, irrigated gravel or mulch works to reduce and eliminate the direct soil heat gain from solar radiation, minimize heat gain from ambient air through shading, buffering and increase the evaporative cooling effect. In hot arid regions the net radiant gain in summer is greater than in winter thus; shading by vegetation reduces and attenuate the amount of solar radiation absorbed by surface and ultimately reduces the long wave radiant exchange. Boyer and Grondzik (1987) reported that it is possible to lower the soil temperature about 5.5^{o}C at depth of 1.2 if the soil is covered with verdant grass. It is worth mention that vegetation should not allowed to reduce the evaporation cooling effect of soil, dense vegetation such as lawn or dense low shrubs maintain a layer of stale saturated layer of air above the soil, that layer prevent the evaporation from soil take place and ultimately reduces evaporation and cooling effect.

2.4.5 Irrigation, precipitation and ground water

Heat flow downward mainly take place by conduction, however it is not the only mode of heat transfer. Heat transfer via convection happened by rain, water permitting and irrigation, the effect on the subsurface temperature depends on the time/season of watering, if the watering occur in winter it will lower the soil temperature, while if the watering happened in summer it will raise the soil temperature, furthermore, the increase of soil water content increase the thermal conductivity of the soil and ultimately increase the heat transfer factor. The irrigation of soil in summer lowers the surface temperature of soil by evaporation while elevating the subsurface soil temperature if the water penetrates deep. Night and early morning irrigation might be good techniques in lowering the subsurface soil temperature in hot arid regions.

Underground water consideration effect the configuration of the underground space and its design details, in areas where water table is low and below the required floor level, the underground space could be completely or partially placed underground without expensive water proofing to its envelop, whereas, in areas where water table is near the ground surface as the case of Abu Dhabi Island (due to proximity to the sea) it is more practical to place the structure above ground bermed and covered with soil.

2.4.6 Soil diffusivity

Soil diffusivity is derived from dividing the soil conductivity by the product of soil density and specific heat (k/pc). Water content and heat capacity are the main factors affecting the soil conductivity, soil conductivity is higher in wet soil and it is higher if the soil composed of clay than sand. Water content is variable whether the water table high or deep, furthermore it varies from surface to deep layers of the same area, this variation beside soil composition make it difficult to define soil diffusivity or measure it in laboratory. The only practical and accurate soil diffusivity could be get from actual site measurements of the annual soil temperature at different depth levels. Measuring soil diffusivity is very essential in predicting the soil temperature via simplified formulas in different depth levels and day of the year.

2.4.7 Thermal insulation effect

Insulation materials distorting the normal process of heat transfer from soil surface and vice versa, placing of insulation material in soil or around underground space elongate the time for heat to in to/out from the spaces. Boyer and Grondzik (1987) claims that the decoupling of underground space envelope from the soil mass by using of insulation material can reduce the energy saving potentials of earth significantly, consideration should be taken for the selection of water proofing membrane and internal finishes in order to avoiding thermal decoupling. Givoni (2006) state that direct coupling between the building and the soil and no insulation material used (except for water proofing) in regions with mild or warm winter and the building envelope should be made from dense material; however, in regions with minimum temperature around 5^{o}C and the diurnal average temperature about 10^{o}C some thermal resistance from the envelope might be practical to minimize the heating load. Furthermore, underground spaces in regions of cold winters must be insulated. Staniec and Nowak (2009) results shows that thermal insulation is very effective in winter as it protect the building from cold winter soil and unpractical in summer as it prevent the building cooled naturally by soil.

2.5 Prediction of Subsurface temperature profile

Golany (1995) mentioned that to date there is no universal formula to predict or identify at which depth that summer temperature arrives in winter and winter temperatures arrives in summer. Nevertheless, the soil temperature could be fairly estimated if the climate conditions, soil density, soil composition and water content taking into account. It is important to quantitatively estimate the different depths soil temperature in measuring the energy performance and cooling potentials whether passively or mechanically of the earth sheltered spaces. Al-Temeemi and Harris (2001) reported that the prediction of subsurface temperature profile as a function of time and depth is a useful tool to understand the underground climate potentials especially in areas of harsh climate.

Mihalakakou et al (1996) predicted the daily and annual variation of the subsurface temperature through the use of transient heat conduction differential equation (1) and the energy balance equation which include the convective energy exchange between air and soil, the absorbed solar radiation by soil, the surface latent heat flux by evaporation and the long wave radiation.

$$\frac{\partial^2 \mathrm{T(z,t)}}{\partial \mathrm{z}^2} = \frac{1}{\mathrm{a}} \frac{\partial \mathrm{T(z,t)}}{\partial \mathrm{t}} \qquad (1)$$

Kumar et. al. (2006) utilized a simplified analytical 2D Fourier equation (2) to predict the sub surface temperature of different earth sheltered spaces configuration in Delhi, India.

$$\frac{\partial^2 \theta}{\partial \mathrm{X}^2} + \frac{\partial^2 \theta}{\partial \mathrm{Y}^2} = \frac{1}{\alpha} \frac{\partial \theta}{\partial \mathrm{t}} \qquad (2)$$

Staniec & Nowak (2009) predicted the subsurface ground temperature for the purpose of simulating the energy performance of earth sheltered space, the researchers used the 3D transient heat conduction equation (3) which known as Fourier equation beside the absorbed energy by solar radiation, latent heat by evaporation and long wave energy by radiation.

$$\frac{\lambda}{\rho c_{p}}\left(\frac{\delta^2 T}{\delta x^2}+\frac{\delta^2 T}{\delta y^2}+\frac{\delta^2 T}{\delta z^2}\right)=\frac{\delta T}{\delta t} \quad (3)$$

Akubue (2007) mentioned that Klaus has calculated the amount of loss energy using equation (4) based on the concept that the earth sheltered spaces losing heat to external air or ground water via soil or directly to the ground water.

$$\mathcal{Q}_T = A_{total}\frac{\vartheta i-\vartheta OT}{RAL}+\frac{\vartheta i-\vartheta GW}{RGW}\ [W] \quad (4)$$

Kenneth Labs has developed an equation (5) to predict the sub surface temperature profile at any depth based on the ground surface variation equation, since the annual wave temperature of the ground surface proliferated into the soil creating sinusoidal pattern of temperature variation at different depths (Watson & Labs, 1983).

$$T_{(x,t)} = T_m - A_s\, e^{-x\sqrt{\pi/365\alpha}}\ \cos\left\{\frac{2\pi}{365}\left[t-t_0-\frac{x}{2}\sqrt{\frac{365}{\pi\alpha}}\right]\right. \quad (5)$$

2.6 The Usage of underground and earth-sheltered spaces

The use of underground spaces for residential purpose is the oldest and might be the first known usage of such spaces, nevertheless, underground spaces offers a wide range of potentials that make it functional and some times more efficient than the conventional above ground spaces; some of major use of underground spaces and systems are to be reviewed. Underground spaces used for the religious purpose long time before as resort from persecution or for the mystery consideration, nowadays churches being built underground for the aesthetic aspect. Modern recreational facilities constructed and community centers constructed underground e.g. swimming pool, ice skating, running tracks, gymnasium halls, hockey rings and multipurpose halls. Sishu, (1987) reported that entertainment activities and recreation facilities constructed underground in some Chinese cities due to the lack of such space and as a need and response to the transformation of these communities, the lack of above spaces has encouraged the designer and planner to go underground since such spaces does not necessitate the need for external view e.g. museums, theaters and cinemas.

The use of underground spaces for commercial and retail purposes are lately seen in North America, Europe and Japan, the high land price in the urban centers and the proximity to existing to these centers have encouraged the development of underground facilities, besides the aesthetic aspect. Office building constructed underground to preserve energy and in some cases to minimize the environmental impact on the site epically when it constructed in the old site and city centers. Educational institutions and libraries built as underground spaces or as earth sheltered spaces in North America to provide natural learning environment especially in elementary schools or to explore the low energy potentials in these spaces as the case in Minnesota state university, the lack of area site at Harvard entice the designer to place the library facilities underground.

The underground spaces offer three major principals that make it very appropriate to use it as industrial facilities, the protection potentials encouraged to develop underground industrial facilities in UK, Europe and Japan especially at the advent of aerial shelling at the 1st and 2nd world wars. The other aspects is the potential of special attribute such as the stable thermal conditions, low level of infiltration, high floor capacity and high security that is highly required by some specialized industries. These specials requirements and attributes could be provide above ground but at the same time it will be costly, while it is much cheaper if such industries went underground as the case of wine cellars in Spain.

Underground transportation and urban utility systems were very important to develop advance transportation system and efficient infrastructures of urban developments, tunnels, canals, railways and subways. In 1843 the first railroad tunnel completed in London. According to Carmody and Sterling (1993) the Babylonians developed underground water supply canals 2500 B.C. the underground utilities is a huge market due to the continuous development and replacement of the underground networks. Underground water and sewage network are protected against frost, beside the underground provide the required spaces for pipes size, although the practice of electrical and telephone networks are use overhead system, the aesthetic pressure in most new development forced to put such systems underground.

The use of underground spaces for military, security and defense might the most historical aspect of underground usage after residential, Matmata and Cappadocia are the best examples of use of underground spaces for defense usage. Many defense tunnels and command centers developed underground especially at the time of the 1st & 2nd world wars, civil defense shelters against bombs shelling and radiation protection.

2.7 Future of Earth sheltered spaces

By dissipating knowledge and educate public, Architects and planners is very essential to elevate the historical negative image associated with earth sheltered spaces, Building underground can enhance the quality of our cities through reduce pressure on environment and spare more green areas, create more dense city center and communities and developing more efficient transportation networks. The potentials of energy saving and thermal efficiency of earth sheltered spaces are more affective if it comes in mass development rather than individual space development.

Earth sheltered spaces could be the next frontier that planners need to explore and might hold solution to the problems that our cities are facing nowadays. The unplanned expansion and growth of cities have produced unfriendly urban environment. Noise, pollution and scarce open spaces are the most symptoms cities of today are suffering. Durmisevic (1999) indicate that by the advent of the 21st century, over 50% of earth population will be settled in cities. Cities should be well prepared to assimilate this number of people through providing spaces to live in and services to sustain the city function. With dawn of the new millennia, sustainable development and compact city are the new approach to sustainable development; underground spaces create space for recreation and social activities aboveground and at the same time crate spaces underground for different uses e.g. shops, entertainment and transportation. The advantages of underground spaces offers to our cities are tremendous; use of space efficiently, effective transportation, less congestions, more green and recreational spaces, less noise, less pollutants and improved air quality.

Montreal city in Canada is an extraordinary example of the development of underground spaces. A network of 30km corridors tunnels and public spaces, well integrated with above ground buildings. The underground spaces are designed for pedestrian while the above ground left for traffic. This separation is a respond to the need to provide comfortable public spaces in the sever climate of North America beside the need to create more spaces in the city as a response to the pressure of the city center. The Montreal underground spaces deemed to be very effective and successful cause the design of these spaces have overcome the negative issues of the underground spaces through the integration of above ground building and utilize it as access to the underground spaces and by that reduce the sense of descend and provide more safety through control. The variety of spaces colors and materials have mitigated the feeling of monotony beside the introduction of natural lighting in some areas have strength the connection with above environment. The use of transparent elements has offered visual contact with external environment and enhanced the feeling of direction and reduced the feeling of entrapment and lost. Belanger (2006) emphasis that the success of the Montreal city venture of underground development has encouraged the city of Toronto to follow suit, with a network of 30km of underground pedestrian corridor and spaces extended for six blocks under the city of Toronto serving 100,000 person daily, shops and recreation spaces create a city with in a city.

Golany (1995) reported that the geo-space city is the new concept for the underground space where multi and variety of land use are included in the sub surface. This innovative concept of multipurpose structure of underground spaces that reach to depth of more than 80m was first introduce by the Japanese architects and the purpose of this new concept of urban approach is to overcome the deficiencies of present cities and enhance the quality of life of city occupiers. Geo-spaces cities can solve two of the major problems of urban centers, first, it provide a new dimension for extension and development which it is so difficult to achieve in above ground cities due to the lack of open areas and the pressure that impose on the green open spaces, second, the combination of land use in relatively small area on a multi layer activities which provide more efficient to manage and ultimately reduce the cost of services and infrastructures, this approach of development of underground spaces contrasting to the case of the above ground urban development that become difficult to manage and control due geographic dispersion.

The concept of the Geo-spaces is to complement the above ground city instead of replacing it, actually the Geo-spaces devised to solve some of the problems associated with above ground urban development. The solutions that the Geo-spaces offers are the elimination of the above ground transportation network and move it to underground level, the benefit is of two fold first remove pollutant source and second, spare above space for environment enhancement. Remove of all types of services and infrastructure to Geo-spaces levels without compromising its efficiency and maintenance accessibility, affective handling and transportation of goods from above ground to Geo-spaces through the incorporation of technology. The habitats should introduce to slope area to receive light, sunshine and ventilation, while move other land use that need no outside connections to below levels in the Geo-spaces. Integration of the natural environment into the Geo-spaces as much as possible is very important to improve the quality of life. The Geo-spaces is the organic integral part of the above city and this integration comes from cohesiveness and integration of land use pattern of the Geo-spaces. Geo-spaces should be leveled with diversified land use according to the degree of human activity and involvement, the shallower the depth the greater the human activity and vice versa.

2.8 Abu Dhabi Climate and Soil characteristics

United Arab Emirates stretched over a land approximates to 83,000 km2, the area of Abu Dhabi Emirate is 85% of the total area of UAE as shown in figure 2.8.1. Abu Dhabi geographic location fall at is located at 24 o 28' 00" N, 54 o 22' 00" E. The environmental condition of Abu Dhabi deemed to be extremely harsh, the surface is dominated by sand dunes and some grave lands, the dunes height in some places reach up to 250m which is the highest in the world. The summer is hot and dry, temperatures normally exceed 45^{o}C, the winter is mild and cooler with very little irregular rain fall.

Figure 2.8.1 Map illustrate UAE and Abu Dhabi (Environment Agency Abu Dhabi 2008).

The soil of Abu Dhabi Emirate is sand in general with high infiltration rate; the bulk density is ranging between 1740-1370 kg/m3. Soil in arid regions considered being dry, however a level of moisture might vary and found in some areas based on soil type, landscape, runoff areas and rain level. There is very little information on soil temperature regime of Abu Dhabi soil, nevertheless, Environment Agency Abu Dhabi (2005) indicates that in general the mean annual soil temperature of Abu Dhabi emirates is 22^{o}C or higher at depth of 50cm from surface, and the difference between mean summer and mean winter is higher than 6^{o}C.

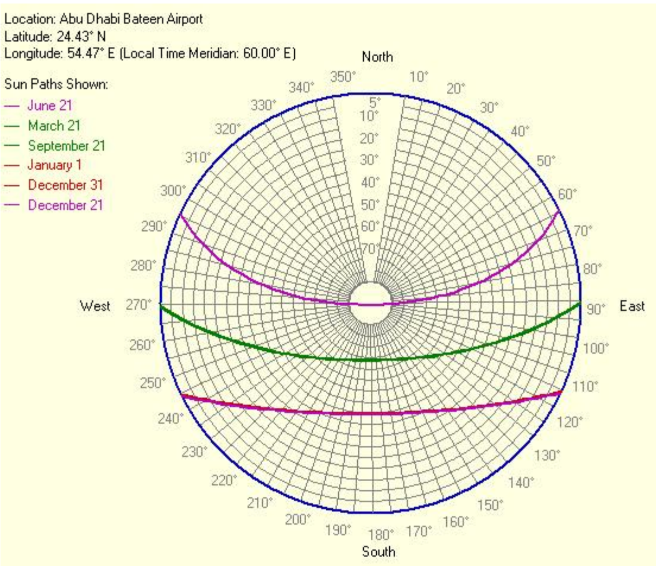

Figure 2.8.2 Abu Dhabi area Stereograph (IES-VEt Software)

Temperature in Abu Dhabi is fluctuated through the year, this change in temperature exhibit the seasonal change, from December till mid March is the cooler period (winter) and from mid June to September is the hot period (summer). Table 2.2, the mean dry bulb temperatures are at the minimum in January and February then rapidly rise in March and April, the rise is continue but on a slower pace till it reach the maximum in July and August 33.9oC and 34.2^{o}C respectively, then the temperature again decline in December to 20.8^{o}C. Temperatures also are different in coastal areas from inner areas due to the affect of sea-land breeze and the south western area wind.

Table 2.2 The table is showing the monthly statistics with extreme registered temperatures of Abu Dhabi International airport area (Environment Agency Abu Dhabi 2008)

Station	Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adia	*Ext Max Db Temp*	34.3	35.9	43	44.7	46.9	48.5	48.7	49.2	47.7	43.1	37.9	33.8
	Mean Max Db Temp	24.3	25.6	29.1	34.1	39.1	40.8	42.2	42.6	40.4	36.3	31.0	26.4
	Mean Db Temp	18.6	19.8	22.6	26.6	30.9	32.8	34.7	35.0	32.6	28.9	24.5	20.5
	Mean min Db Temp	12.8	14.1	16.4	19.5	23.1	25.4	28.2	29.0	26.1	22.3	18.2	14.7
	Ext Min Db Temp	5.6	5.4	8.4	11.2	16.6	19.8	22.2	23.8	19.9	14.6	12	7.5

Start at low level in the day and increase gradually and reach up to 70-80% after midday the decline again to reach 35-50%. Relative humidity in winter is 10% higher than summer as shown in figure 2.8.3, beside the level of humidity is higher in the coastal areas that the inner areas.

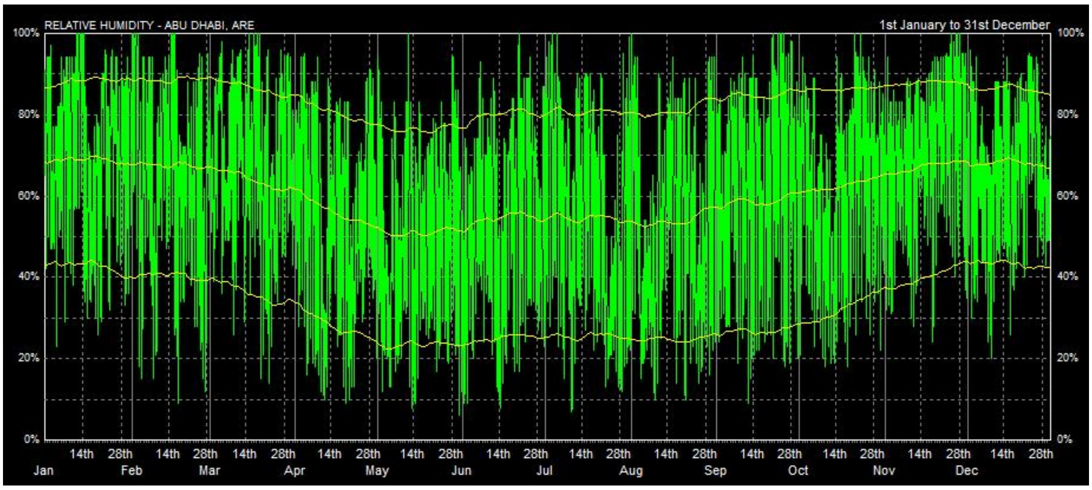

Figure 2.8.3 Shows the relative humidity in Abu Dhabi throughout the year (Ecotect Software)

It's reported that the Arabian Peninsula and the North African desert are the areas that receiving the highest amount of solar radiation. Abu Dhabi emirate is not an exception where sky is clear and the cloud affect is at the minimum and the monthly mean daily sunshine range is 8.4 hour in winter and 11.6 hour in summer, the number of sun shining hours around 3600 hours yearly. Figure 2.8.4 shows the solar radiation level throughout the year in Abu Dhabi that seems relatively stable.

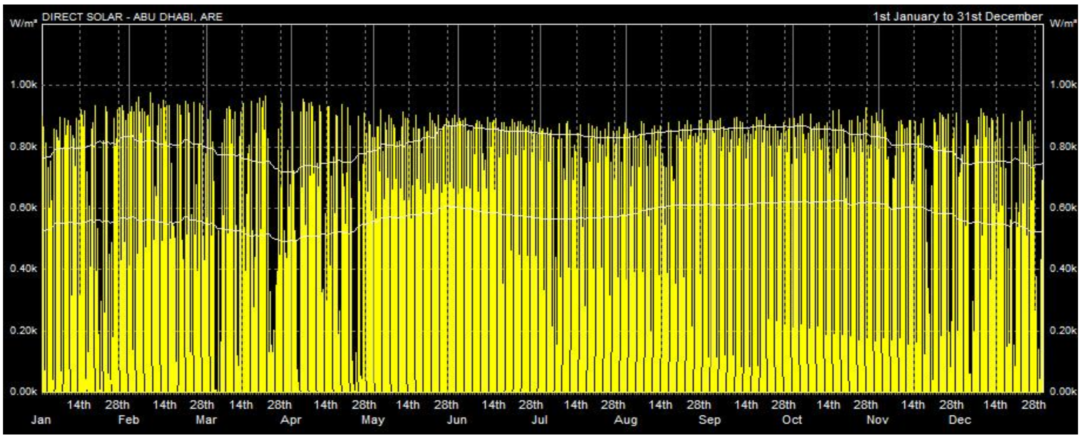

Figure 2.8.4 Solar radiations throughout the year in Abu Dhabi (Ecotect software)

Rainfall is mostly occur in winter months beside a chance for rainfall in July and August especially in the southern east area of Abu Dhabi, table 2.3 is showing the monthly statistics of rain fall in Abu Dhabi international airport satiation. February and March registered the highest level of rain around the year.

Table 2.3 The table is showing the monthly rain fall level registered from Abu Dhabi international airport (Environment Agency Abu Dhabi 2008)

Station	Elem /Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADIA	*Monthly Total amount*	267.3	585.3	430.1	184.9	4.8		20.2	4.1		5.4	32.5	192.6
	Monthly extreme rainfall	68.1	202.4	109.2	56.2	4.8	0	18.2	3.6	0	5.4	18.4	54.9
	Monthly Mean rainfall	11.1	24.4	17.9	7.7	0.2	0	0.9	0.2	0	0.2	1.4	8.4
	Ext Max 24Hrs Rainfall (mm)	37.8	120	50.2	56.2	4.8		18.2	3.6		5.4	11.3	18.6

Figure 2.8.5 is showing the monthly wind direction and wind temperatures in Abu Dhabi where the northwest wind is prevailing all over the year with a chance of southern wind plowing.

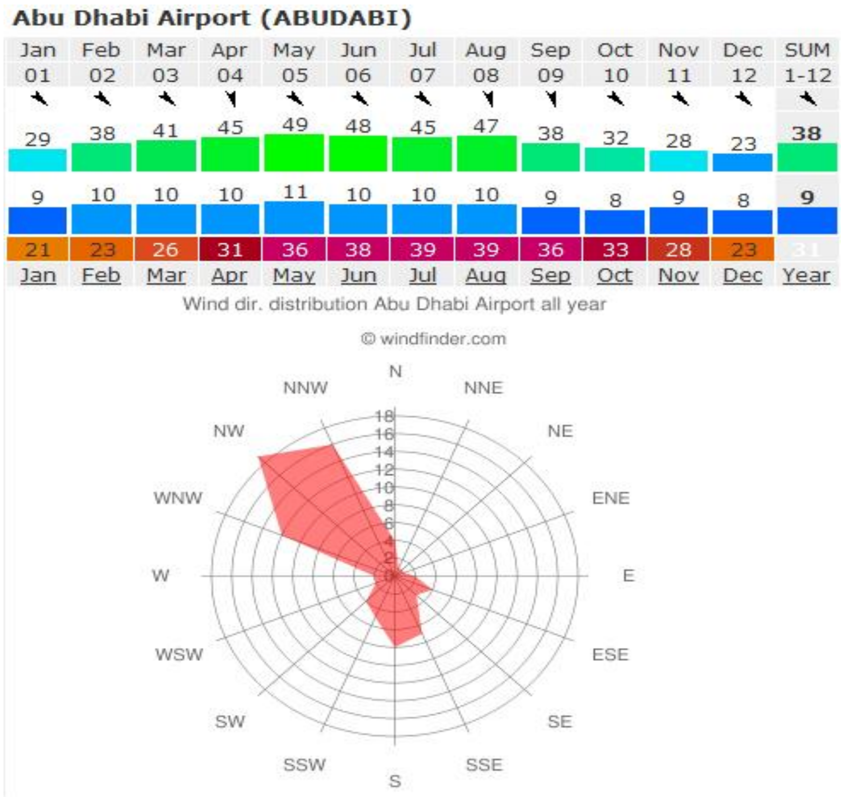

Figure 2.8.5 Wind rose of Abu Dhabi International airport (www.windfinder.com)

2.9 Research aim and objectives

The aim of this research is to investigate the energy performance of the earth sheltered spaces in hot arid regions and taking Abu Dhabi Emirate as a case of research. The research aim to shed some light on the subject of earth sheltered spaces and its applicability and suitability in Abu Dhabi, UAE since the earth sheltered spaces have proved historically its efficiency in providing low energy habitable spaces in harsh climates and especially in the hot arid region.

As the region enjoys cheap energy and significant amount of fossil fuel produce and reserves, we should remember that this fuel shall be depleted by the end of this century as many scientists predicts beside our commitment as human against the earth and our next generations obliges us to approach wise strategies and affective plans to overcome the obstacles that the future hold if we continue the state of business as usual in our daily life style and from that the motivation for this research has come to explore the forgotten legacy of our ancestors and human cultures in creating spaces that consume low energy and achieve livable and sustainable environment.

Through the literature review, history of earth sheltered spaces genesis and evolution reviewed, the advantages and disadvantages were analyzed to comprehend the potentials as well as the hindrance of type of construction. The configuration and format of earth sheltered spaces are listed and the factors behind the different earth shelters formation have been explained. Soil thermal characteristics and its behavior in different climates has been investigated to understand how the soil as climate environment transfer the temperature from surface to the underground spaces and the factors and the elements affects soil behavior and ultimately the underground spaces performance.

The research focus is on energy consumption of different earth shelter space configurations in comparison to the same above ground conventional space. For that purpose, different configuration of the same spaces characteristics proposed and simulated after predicting the underground soil temperature. The parameters affecting the performances of the earth sheltered space were tested and analyzed to optimize the energy performance of these spaces.

To achieve the aim of this research the following objectives shall be fulfilled:

- Mathematically predict the underground soil temperature of selected area in Abu Dhabi Emirate.
- Simulate different types and configuration of earth sheltered spaces, analyze and compare its energy performance to the above ground spaces.
- Define and test the variable parameters that affecting the energy performance of the earth sheltered spaces to optimize spaces performance.

- Identify the best configuration along with the most appropriate parameters that represent the ideal case earth sheltered space to Abu Dhabi climate and soil characteristics as well.

3 CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Methodologies of previous researches

Different methodologies where reviewed from literatures in the subjected of earth sheltered from previous researches. Qualitative and quantitative approach were adopted, monitoring and measurements, calculating, mathematical, simulations and surveying. Since the energy consumption is the investigated subject, qualitative approach is to be reviewed and inferences need to be made from these methodology approaches.

3.1.1 Measurement & Monitoring Methodology

Measurement and Monitoring methodology is accurate but necessitate a prototype for this purpose, it might give results for a few days or all over the year according to the research plan.

Jacovides et al (1996) in their research in Athens/Greece of the potentials of soil in heating and cooling have measured the soil surface temperature of bare and short grass covered soil. Standard thermometers were used in depths of 0.3, 0.6, 0.9 and 1.2m with data loggers and the observation time were on 8:00, 14:00 and 20:00. The daily data were averaged to obtain the annual surface temperature. As shown in figure 3.1.1, when contrasting the annual measured data of both types of soil it found that in winter months the same temperature has been registered while in summer the gap was 8^{o}C lower in the short grass covered soil. The measured data shows the difference between the air temperature and the bare soil temperature and the short grass covered soil in winter and summer season.

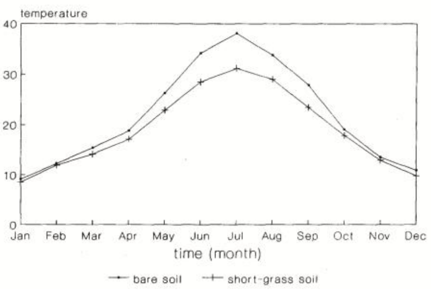

Figure 3.1.1 Mean monthly surface temperature of bare and short grass covered soil (Jacovides et. al., 1996)

Fourier techniques were utilized by Jacovides et al (1996) to predict the surface and ground temperature of different depths assuming that the soil are homogeneous with constant physical properties. The comparison of the observed data with the predicted data from Fourier techniques has show a quite accuracy, the researchers shows that the Fourier analysis can be used to predict soil temperatures at depths more than 1.2m to utilize to assess the soil heating and cooling potentials.

Silvia and Ignacio (2004) had monitored the thermal performance of the traditional underground wine cellars in Ribera Del Duero in Spain an area known for high quality of wine production. The aim of the research was to study the differences between temperature and relative humidity of the inside and the outside of different types of cellars. The researcher used three types of measuring instruments, data logger to measure temperature and humidity inside the cellar, data logger to measure the external conditions and a pyranometer to measure the solar irradiance. Four wine cellars from two different villages were monitored at two times, from 1-7 July and 8-15 August 2003 in Morcuera village and from 7-21 July and 1-14 December 2003 in Alcubilla del Marques village. The temperatures are registered on different points in the cellars to investigate the influence of depth on the findings.

The registered temperatures from Morcuera area shows that in the bottom of the cellars was always lower than on top and the inside temperature was similar and the variation is smaller in summer on the cellar bottom but the contrary in winter when the top cellar temperatures variation was similar. Therefore, the thermal performance of these cellars are better in summer than winter a fact that caused by the high relative humidity in summer time. The results from Alcubilla del Marques shows that the thermal performances of both cellars are similar despite different orientation and that might ascribe to the similarity of cellars typology and the soil; furthermore, one of the cellars showed an interesting results when the mean temperature in winter was higher than the summer due to the layer of soil around it.

Fernando and Ignacio (2009) have studied the annual thermal behavior of the same configuration of three underground wine cellars of the same area that studied by Silvia and Ignacio. The method based on monitoring of the cellars for the whole year of 2007, where external air temperature, internal temperature and humidity and the undisturbed ground temperatures (on depths of 1, 3, 5.5 and 7 m) monitored by sensors with data logger. The researchers were to validate the hypothesis that the cellar's inside temperature are effected by two factors which is the ground temperature surrounding the cellar and the ventilation. The findings as shown in figure 3.1.2 shows that when the external temperature is higher than the inside (spring & summer period), the response of the wine cellar was perfect in providing the required environment for the viticulture process and the temperature is mainly depends on the soil surrounding the cellar since the ventilation has no effect on the inside temperature due to gradient effect, while when the external temperature is lower than the cellar internal temperature (autumn & winter period) and the external temperature approaching the internal temperature and in this case the internal temperature is affected by the soil temperature surrounding the cellar and the outside temperature through ventilation but the change in temperature was not that effective since the lower temperature does not affect the quality of wine.

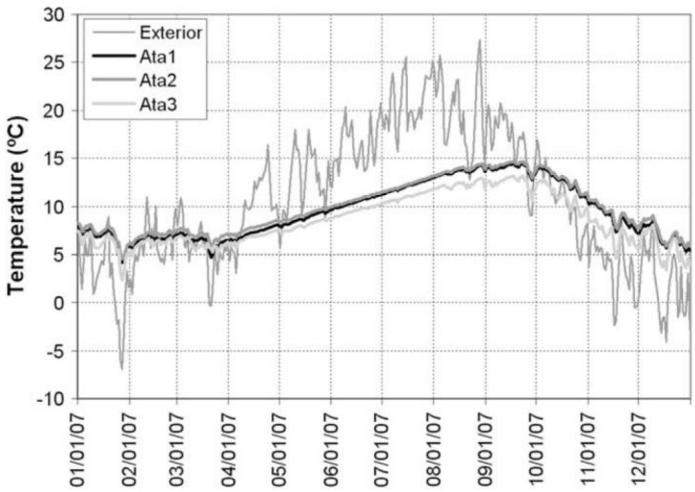

Figure 3.1.2 Daily average external and internal air temperatures in the three cellars (Mazarron and Canas, 2009)

in summer the wine cellars temperature are more stable while in winter the oscillation of temperature is more which led to the assumption that there is a difference in the thermal behavior of the wine cellars in the time of changing of the external temperature from winter to summer and vice versa.

Ip and Miller (2009) adopted monitoring method in exploring the performance of the EARTSHIP design in Stanmer in Brighton/ UK completed in 2006. The monitoring period covers one year, the researchers implanted 9 sensors in two groups as shown in figure 3.1.3. the first group where in the rammed earth wall and puts at different heights and depth to form a grid and the purpose was to measure the flow of heat and the gradient temperature of the wall from inside out and vice versa beside the vertical ingredient. The second group of sensors where located in the kitchen and main room to measure the air temperature and relative humidity.

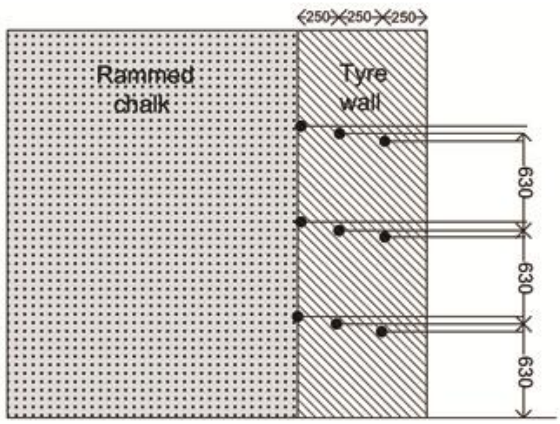

Figure 3.1.3 Section in the wall showing the location of temperature sensors (Ip and Miller, 2009)

The measurements as shown in figure 3.1.4 that the EARTHSHIP moderating the harsh winter temperature with small amount of heating is required which may cover from the occupants and the appliances after space occupation. The researcher suggested long term monitoring to understand the space performance in a better way.

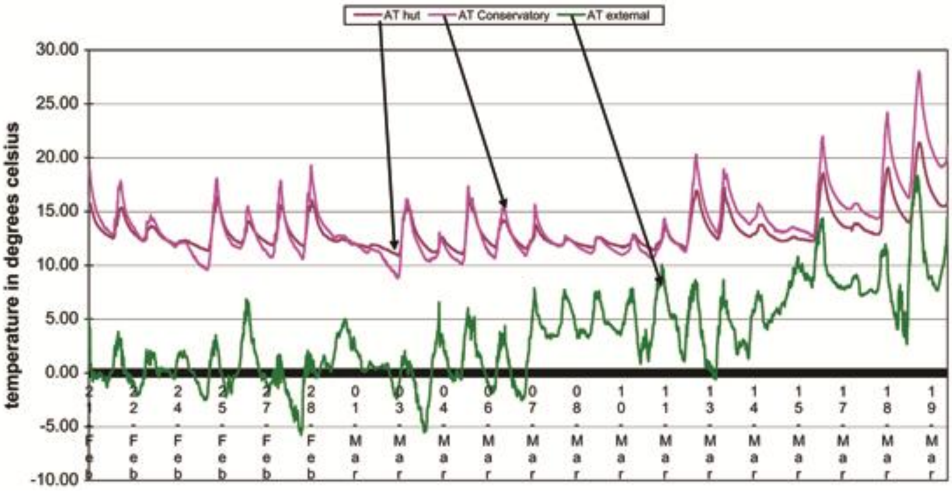

Figure 3.1.4 Internal and external measurement in earth sheltered space in winter (Ip and Miller, 2009)

Grindley and Hutchinson (1996) used thermocouples and pyrometers to investigate the performance of EARTHSHIP used as an office space as shown in figure 3.1.5 located in Los Alamos in New Mexico, USA built in 1996. The monitored data was from 21st. to 23rd of June 1996; this short period of monitoring was for comparing the exterior summer temperatures with the internal temperature besides calibrating the computer model output. Measured temperatures were between 24-29°C indicates that the space temperature is hot. The heat gain is ascribed to glazing at the front elevation and external shading strategy might be good solution to overcome this drawback. Figure 3.1.6 showing daily comparison of ambient and internal measured and predicted temperature.

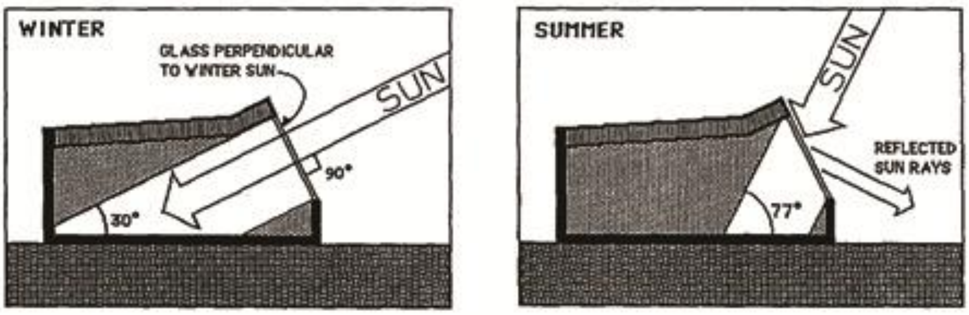

Figure 3.1.5 Section in Earthship office space showing sun angle in summer and winter (Grindley and Hutchinson, 1996)

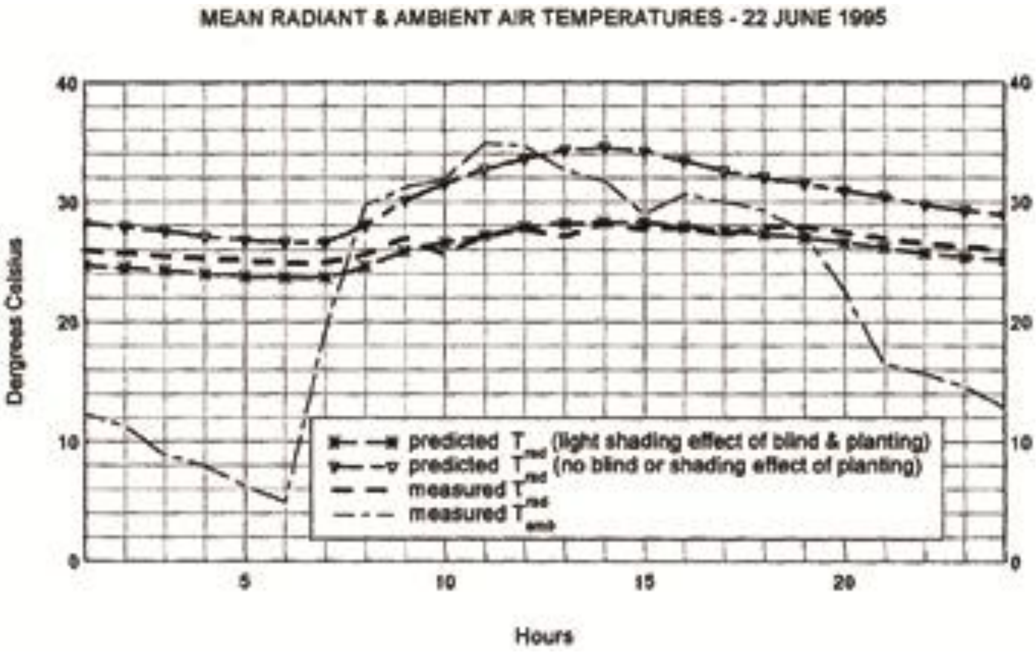

Figure 3.1.6 Comparison of ambient and internal measured and predicted temperature (Grindley and Hutchinson, 1996)

3.1.2 Simulation Methodology

Using simulation software in predicting Earth sheltered spaces is quite challenging, soil temperature need to calculated first and then integrated in the software used for that purpose.

Al-Temeemi and Harris (2002) use simulation method to predict the heat transfer through an underground wall and compare it to above ground wall. Heat Net is software used for purpose of simulation, the software is developed by Multi Verse Solution and Herriot Watt University, the tool measures the heat transfer through a medium. Underground soil temperature mathematically calculated using Lab equation which used to measure the soil temperature in different depths and times. The simulation results show considerable reduction in heat transfer with increase of depth in the underground wall in comparison to the above ground wall, figure 3.1.7 is showing the simulated result of internal air and wall temperature and compare it to the external air and wall temperature.

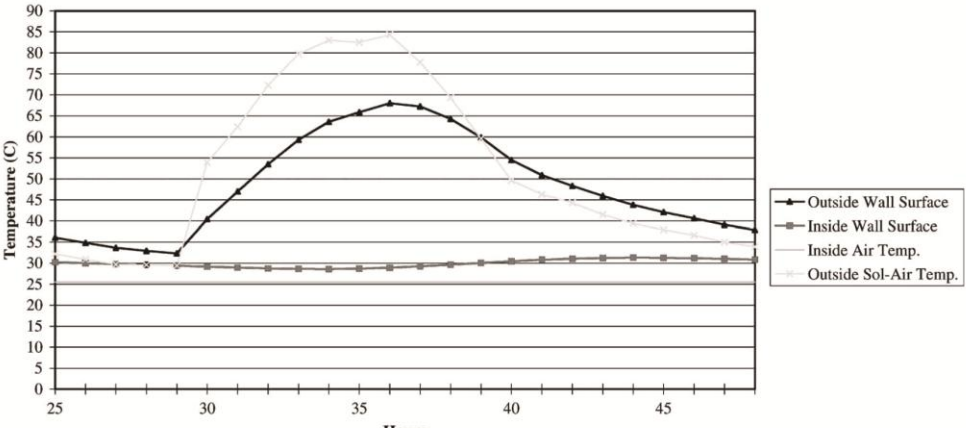

Figure 3.1.7 Comparison of outside air and wall temperature with inside air and wall temperature (Al-Temeemi and Harris, 2002)

In a research by Kumar et al (2006), the researchers predicted the energy performance for five different configurations of space structures, on grade structure, berm structure, uni-slop structure, bi-step structure and underground structure. Fourier equation used to predict the heat transfer through the surfaces of the underground and different profile of underground temperatures of different depths resulted; then the predicted model was coupled with TRANSYS environment software to predicting the heat transfer through structures in direct contact with earth. The result shows that the deeper the spaces the better in conserving energy and vice versa, the heat flux loss was little in underground structure while was bigger in the slab on grade structure. The researchers also found that the heat loss at the structure corner is more from the center of the slab and that might trigger more need of research on the better use of insulation in different and effective location of the structures to minimize the heat loss and conserve more energy. Figure 3.1.8 is showing comparison between ambient air temperature and different types of structures in direct contacts with earth.

Moreover, the results from simulation were verified through experimental figures measured from slab on grade structure named solar house in the Indian Institute of Technology in New Delhi (IITD), ten sensors were placed to measure temperature and humidity, the sensors spread on the spaces corners and the center and the measured data show small margin of difference from the results obtained from simulation.

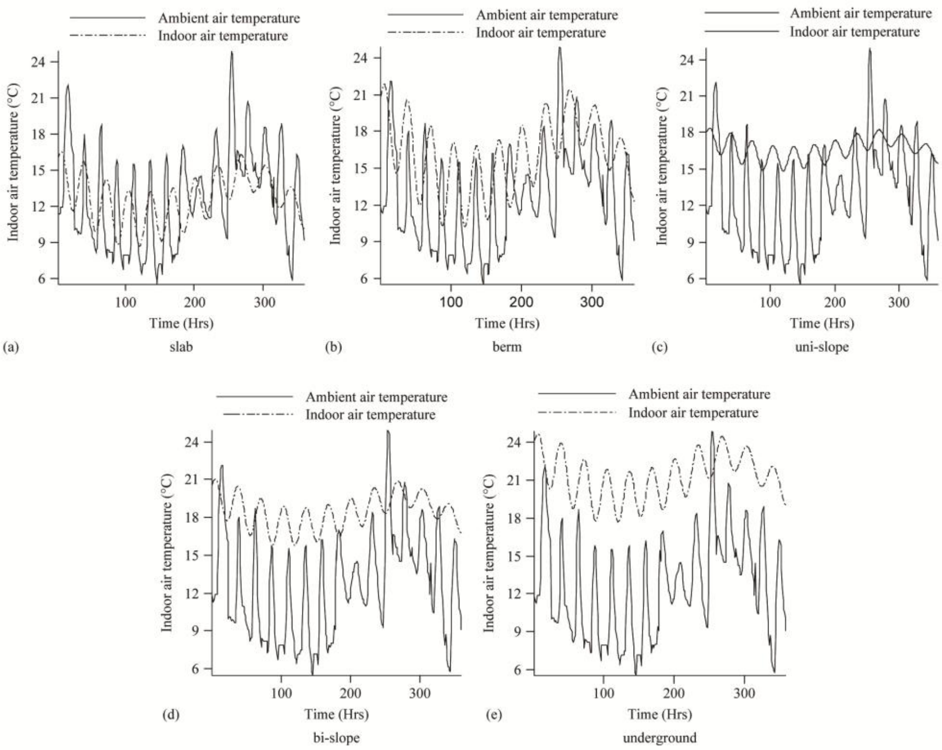

Figure 3.1.8 Comparison of ambient air and internal temperature of different earth sheltered spaces result (Kumar et al, 2006)

Kruis and Heun (2007) analyzed the performance of the EARTHSHIP housing in four different climates, Anchorage/ Alaska (Continental Sub-arctic), Grand Rapid/ Michigan (Humid Continental), Albuquerque, New Mexico (Dry- Arid) and Honolulu/ Hawaii. The purpose of this research was to assess the feasibility of the EARTHSHIP houses since the concept of this type of earth sheltered spaces is to perform sustainably in all climates. The researchers modeled the EARTHSHIP using Energy Plus to verify its performance. Inside operative thermal comfort set between 21^{o}C and 28^{o}C. to verify the simulation results indoor and outdoor temperatures are measured, the results shows in figure 3.1.9 shows good agreement between the simulated data and the recorded in New Mexico and Honolulu.

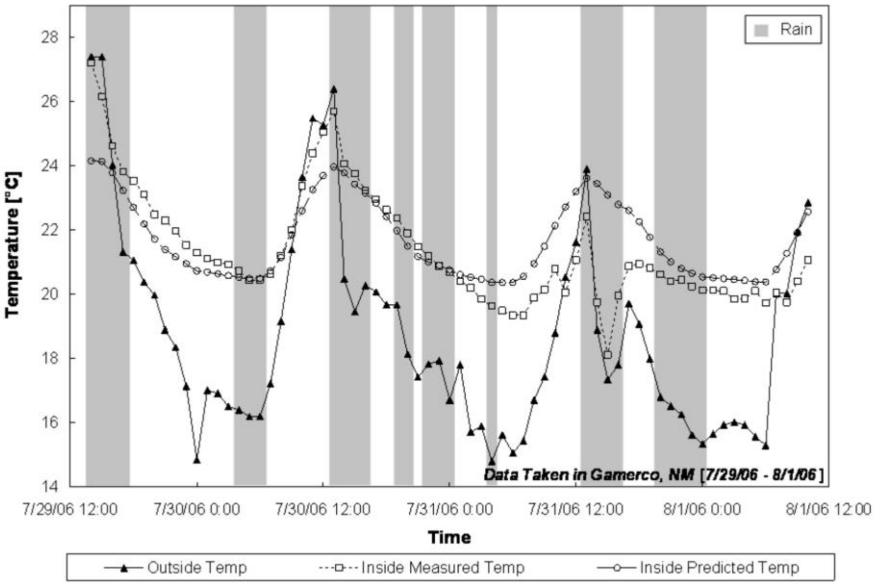

Figure 3.1.9 Comparison of temperatures predicted inside model and the actual measured temperature of the EARTHSHIP IN New Mexico (Kruis and Heun, 2007).

While in Anchorage and Grand Rapid the results shows that in winter the inside temperatures are not comfortable and an auxiliary heating source should be provided despite that it shows a reduction in heating energy consumption.

Staniec and Nowak (2009) have investigated the energy performance of earth sheltered space in comparison to above ground space in Poland. The characteristics of the earth sheltered space and the above ground spaces are the same in area, height, building material, orientation and glazing area. Research parameters were set for 5, 10, 20 & 30cm of thermal insulation and soil cover of 0.5, 1, 1.5, 2 & 2.5m sheltering the space. Soil heat transfer calculated with FlexPDE then the results exported to Energy Plus software to simulate energy consumption. Results shows that the heating energy load for the earth sheltered space and the above ground is less with thicker soil cover and insulation but the thicker thermal insulation reduces the soil influence. The cooling energy load seems to be more with the increase of the thermal insulation and that ascribes to the thermal insulation hence it block the building from being cool naturally from the soil in summer; Furthermore, it found that the soil cover does not show reduction to the cooling load to the earth sheltered spaces. The reduction in energy consumption was presented in graphs and percentage which gave clear idea on each space performance (figure3.1.10).

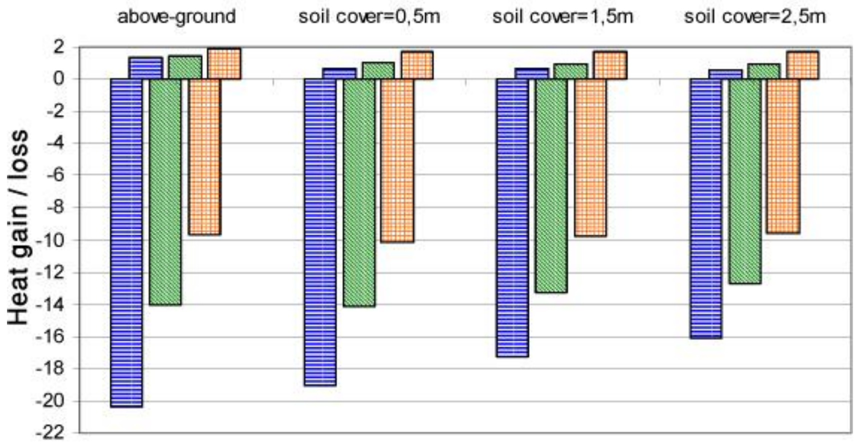

Figure 3.1.10 Annual values of heat gain/loss of different earth cover thickness compared to above ground (Staniec and Nowak, 2009)

3.1.3 Mathematical and Analytical Methodology

Heat exchange between sun, sky and air temperature with building interior is not affected in the above ground interior, the case is different in the underground spaces, where the heat exchange is affected by the properties of thermal and physical characteristics of soil, it might be difficult to predict the cooling potentials of soil but in the other hand, estimation of ground temperature of the ground is relatively simple (Watson & Labs 1983) and ultimately determine the cooling potential of the ground as a heat sink medium.

The soil climate has been poorly studied and very little soil temperature data available worldwide and the recorded soil temperature data are developed by researchers for their individual need. In US, Canada and Greece soil temperatures are being recorded for some years and these data is strongly depend on the local climate condition and the soil properties of the area of record in another word, it is valid only locally (Silvia and Ignacio Oct. 2005).

Mathematical model is essential to predict the soil temperature profile and from the literature review it is found that Fourier equation (1) and Labs equation (5) are majorly used to predict the soil temperature profile in specific time of the year and in determined depth of soil.

Fourier equation (3) is a simplified three dimensional mathematical heat conduction equation for multi-frequency input incorporating moister distribution model (Kumar et al 2006). The equation assumes that soil thermal diffusivity is constant along time and depth of soil (Silva & Ignacio 2005).

Labs equation (5) is derived from the work done by Kusuda and Achenbach in 1965 were 47 different station registered the soil temperature in the US and the registered soil temperature at each station were analyzed by least-square procedure to obtain a best fit to the simplified sinusoidal temperature model (Silva & Ignacio 2005). The mathematical model was developed by Lab to predict the long-term annual pattern of soil temperature in different time and depth for different soil types and properties; furthermore, the method is sufficiently accurately since it is based on existing field measurements of different regions (Akubue 2007).

A.A. Al-Temeemi and Harris (2001) predicted the subsurface profile temperature of Kuwait city utilizing Labs equation, they assumed that the subsurface environment is milder than the above harsh hot environment and that what the results shows. The results presented in a graph showing the annual average temperature and different depths temperatures of soil as shown in figure 3.1.11.

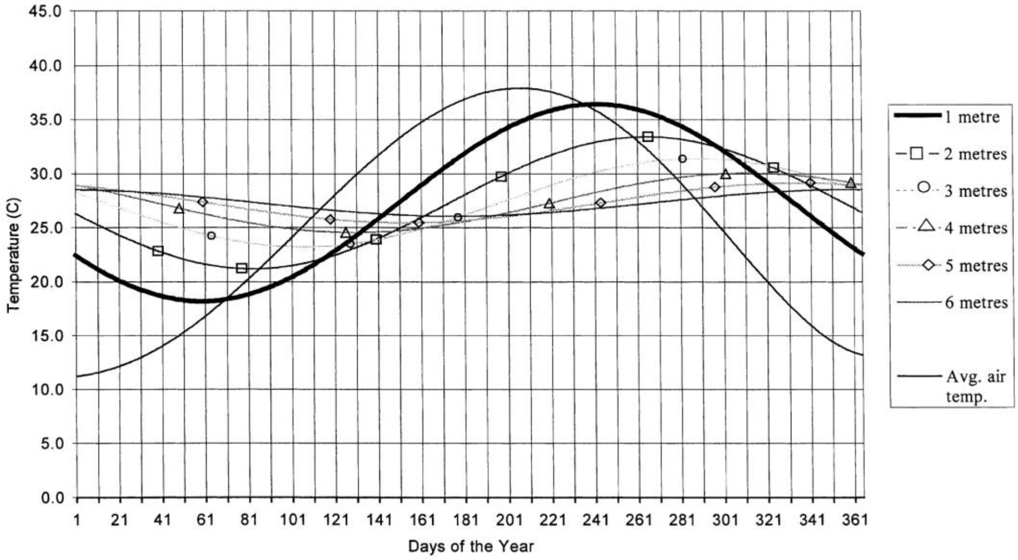

Figure 3.1.11 Average daily air temperature and various subsurface temperatures (A.A. Al-Temeemi and Harris, 2002)

The graph shows that when air temperature is 41°C the subsurface temperature at depth 1m is 36°C at the same day and at depth of 10m is 27°C where the temperature is almost constant. The researchers showed that using the data in building heat- transfer can lead to energy saving. Time lag is calculated based on the resulted data. Furthermore, when they applied the degree-day concept to calculate the percentage of energy saving they found out that at depth of 5m the reduction of energy consumption was about 57% compare to the above ground buildings besides, at depths more than 5 m no significant reduction in energy can be made.

Wang and Liu (2001) have studied the thermal performance the Courtyard Style Cave Dwelling (CSCD) in north china through modeling of the mean air temperature and the air temperature amplitude. The mean air temperature model was driven from a set of equation of heat balance for the courtyard and the cave rooms, whilst the air temperature amplitude based on the theory of thermal stability of space envelop. To validate the findings from modeling the courtyard and the caves room temperatures are measured for three days and deviation percentages calculated. Furthermore, the researchers conducted parametric study where nine parameters were studied to investigate the influence of each parameter on the mean air temperature and the air temperature amplitude in the courtyard and the cave room. The results revealed the most important factors that affecting the thermal performance of the CSCD.

Silvia & Ignacio (2004) predicted the soil temperatures of the traditional wine cellars in Spain utilizing Labs equation. The researchers recorded the temperatures in the cellars using instrument with data logger. The temperatures are registered in winter and summer. The recorded data used to compare it against the predicted temperatures. The comparison has been done by using the statistical indices where index of agreement (d) and the estimator of error known as Root Mean Square Error (RMSE); Furthermore, the researchers has introduce some changes to Labs equation to determine the parameters that effecting temperature inside the cellars which is the average annual ground temperature since this parameters is effecting by the solar radiation and heat gain and lose, water evaporation and heat exchange. Four hypotheses suggested based on the average annual ground temperature where a factor between 0.56^{o}C to 2.78^{o}C is added to the average annual air temperature. The two indices are calculated for each hypothesis and the good agreement is that when the (d) value is near to 1 and RMSE around 0. It is worth mentioning that the researchers have neglected the effect of ventilation on the agreement/ disagreement between the analytical and the recorded temperatures.

Mazzaron and Canas (2008) have suggested modification to Labs equation in their research on the wine cellars in Morcuera village of Soria province in Spain. As they applied the equation strictly to predict the underground soil profile, they found out that the results are different from the experimented; furthermore, the goodness of the results is analyzed by two statistical values, the index of agreement (d) and the estimator of error the route mean square error (RMSE) to evaluate how much the predicted results match the reality. The annual average RMSE for the cellars is 2.3^oC and the estimator index is 0.8. They ascribed that to the distortion of the cellar itself and inner air mass, the adapting average temperature, phase lag and depth. They suggested different calculation to some of its variables to correct the distortion. To avoid structure distortion and inner air mass the value of phase constant t_0 adjusted and the depth x of calculated as an average height. After adopting these modifications the average RMSE is 0.9^oC and the d index is above 0.96.

The researchers have shown that the proposed sinusoidal model is usable to determine the inside air temperatures of the traditional wine cellars with the suggested modification to the Labs equation. It is worth mentioning that the registered data covers 2 years of 2006 and 2007 was very essential in contrasting it against the predicted temperatures and in calculating RMSE and the index of agreement (d). Furthermore, the findings could be integrated in simulation software to predict energy performance and heat transfer in the earth sheltered spaces.

3.2 Selection of research methodology

From the previous revision of researches methodologies, computer simulation shall be the adopted research methodology to assess the earth sheltered spaces performance. The advantages of computer simulation are as follows:

- Time saving.
- Saving of money in comparison to other methodology.
- Availability of tools.
- Flexibility of selecting simulation period whether for specified time or for whole year period.
- Capability of simulating different scales of models.
- The variability and simulation of different parameters.

The utilizing of Building Performance Simulation tools BPS by architects are increasing and this ascribe to the followings:

- The need for BPS tools to create sustainable and high performance building.
- The importance of early stage decision making on building energy performance.
- The advancement and development in the simulation software.
- Developing of more Architect friendly BPS software.

The challenges of simulation methodology are the accuracy of results, behavioral uncertainty and validation which still need more investigation. Malkawi, (2004)

3.3 Selection of simulation software

Crawley et al (2008) has tested around 20 simulation software available in the market, the capabilities and features of the software examined based on the information available from software developer and the tested features were envelope, internal zones, infiltration, ventilation, solar and natural lighting, air flow, renewable energy, electrical systems, HVAC system and equipment, climate and data availability, validation, compatibility and link to other software, measuring of emissions, results and reporting and user interface.

Table 3.1 Comparison of different types of simulation software (Crawley et al, 2008)

Table 1
Zone loads (11 of the 21 rows from Table 2 of the report)

	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES 〈VE〉	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Interior surface convection																				
• Dependent on temperature	X	X					P		X		X	X	X		X	X	X	X		X
• Dependent on air flow	X						X		P		X		X		X			X		E
• Dependent on surface heat coefficient from CFD									E		E		X							
• User-defined coefficients (constants, equations or correlations)		X	X	X	X				X		E	R	X		X	X	X	X		X
Internal thermal mass	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Automatic design day calculations for sizing																				
• Dry bulb temperature	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
• Dew point temperature or relative humidity			X	X		X	X		X	X		X	X	X				X	X	
• User-specified minimum and maximum			X	X		X	X		X	X		X	X	X	X			X	X	
• User-specified steady-state, steady-periodic or fully dynamic design conditions			X									X	X	X				X	X	X

X feature or capability available and in common use; P feature or capability partially implemented; O optional feature or capability; R optional feature or capability for research use; E feature or capability requires domain expertise; I feature or capability with difficult to obtain input.

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In table 3.1 IES-ve software achieved all the features of the zone load parameters.

Atia et al (2009) surveyed 10 different energy simulation software used by users with Architectural background like Architect educators, fresh graduate students, designers and professional Architects working in USA. The survey based on the Architect friendly tools, figure 3.3.1 showing that IES-ve has got the highest ranking among the other software and the strength of IES-ve comes from graphical user interface GUI and template driven approach, in another word IES-ve offer default values and templates that facilitate quick entry and supported progress of thermal performance analysis through the whole process from quick answers at the early design stage to later detailed design stage.

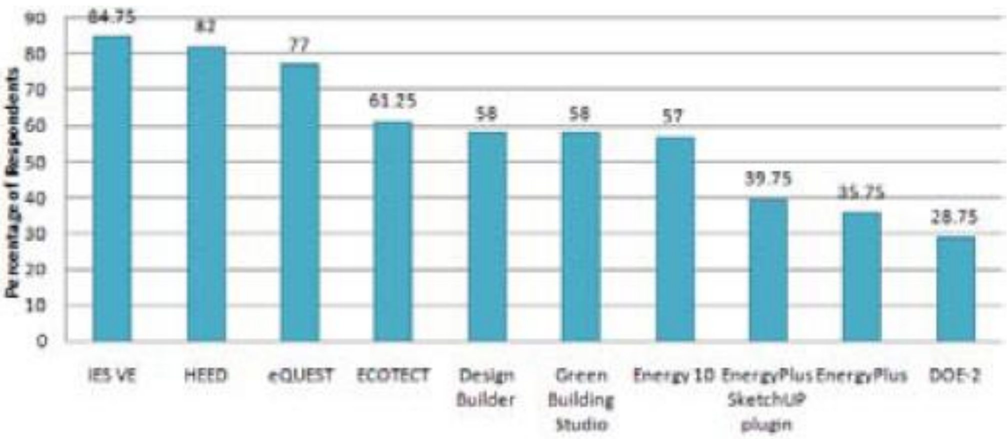


Figure 3.3.1 Ranking of IES-ve against the surveyed software (Atia et al, 2009)

The IES- Virtual Environment building performance analysis suite tools used by Architect and engineers to facilitate a sustainable design process through quantitative data on the building performance of different design options. Building mass and forms, the climate, occupancy, natural resources, material and services all components are tested to estimates the feasibility of the energy saving strategies and renewable energy technologies.

3.4 Integrated Environmental Solution- Virtual Environment IES-ve

IES-ve is a suite of integrated building assessment and analysis tools. Building geometries and forms and has built in climates data, materials, system and services, renewable energy, occupancy and natural resources that taking into account and assess the performance of the building in terms of its energy, renewable and CO_2 emission. IES-ve is also has the ability in showing compliance with building rating system (LEED, BREAM, Energy STAR) beside producing and issuing UK energy performance certificates (www.ies-ve.com).

Figure 3.4.1 shows that IES-ve suites consist of four tires structure (VE-Ware, VE-Toolkit, VE-Gaia and VE-Pro) each tire is designed to suite different design stage or user experience.

VE-Ware: free application accessed using plug-ins for sketch-up and Revit, it assess building energy and co^2 emission through dynamic thermal simulation.
VE-Toolkits: very useful in early design stage on sustainability and to get quick results and feedback.
VE-Gaia: through step by step smart navigation it offers a work flow environment from modeling to reported results furthermore; it enable users to undertake complex models simulation easily and effectively.
VE-Pro: the most powerful, flexible and in depth dynamic assessment and analysis tool. The navigation work flow available at Gaia suite also is an option available for VE-Pro

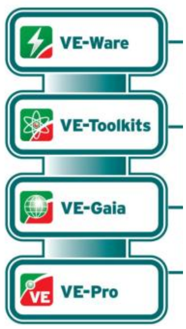


Figure 3.4.1 IES-ve software tires www.ies-ve.com

According to Crawley (2008) IES-ve is an integrated suite of application linked through user interface. The single applications of IES-ve include:

- ModelIT- used for creating and editing of forms
- ApacheCalc- used for loads calculation & analysis
- ApacheSim- to calculate the thermal details
- MacroFlo- to predict the natural ventilation
- Apache HVAC- component-based HVAC
- SunCast- shading visualization and analysis
- MicroFlo- 3D computational fluid dynamics
- FlucsPro/Radiance- lighting design simulation
- DEFT- model optimization
- LifeCycle- life-cycle energy and cost analysis
- Simulex- building evacuation analysis

It offers highly graphical outputs beside the central data models that allow analysis to be performed in an integrated way and results are shared amongst applications that insure more information and refine to the simulation (IES-ve Product Overview).

For the purpose of this research IES-ve Pro shall be utilized as the simulation tools to analyze and assess the energy performance of the earth sheltered spaces. IES-ve allows the user to input the physical construction data and thermal properties of the building materials for the walls, floors and ceilings with a wide range of built-in weather data files for different locations.

IES-ve software .The choice of Building Performance Simulation (BPS) software tools used for this research is wide and the selection of the right tool should have characteristics and features that apply for the simulation parameters.

3.5 Methodology framework and parameters

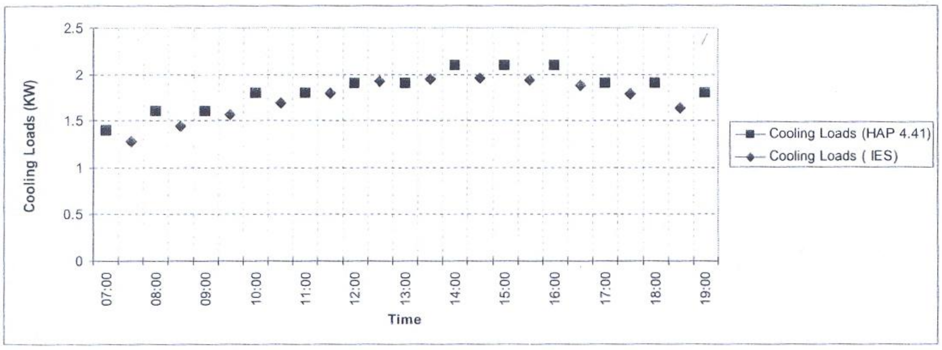
In order to investigate the energy performance of the earth sheltered spaces in hot arid region, the city of Abu Dhabi shall be the investigated case. The first step is testing defined and specific parameters of different configuration of earth sheltered spaces and compares its performance to an above ground space of the same parameters. The second step of test shall investigate earth sheltered spaces performance against three main parameters that is affecting the energy performance of such spaces which is orientation, ventilation and natural/artificial lighting. The purpose of the second step of testing is to determine how further passive strategies might enhance the energy performance of these type of spaces. Regarding the orientation case, the sheltered spaces shall be examined against north, south and north and south orientation. The ventilation test shall examine the earth sheltered spaces against three modes of ventilation; the open case, closed case and night ventilation. The last testing parameters are the natural/artificial lighting where different lighting strategies that conform to different earth sheltered configurations.

3.6 IES-ve Software Validation

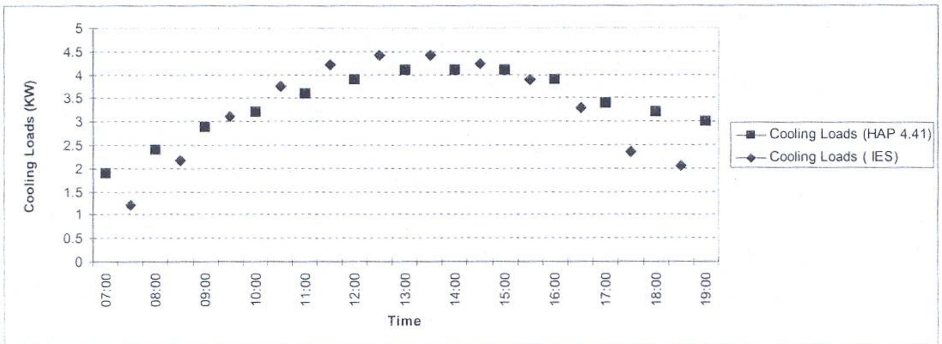
Al most all simulation software results are not 100% accurate which is one of the short comes of the simulation research methodology and concern, in the other hand an acceptable and relatively small variation in these results may be of satisfactory to the author. IES-ve software has gone under different validation and credential process by governmental and professional association e.g. Communities and local government (CLG), American Institute of Architecture (AIA) and Energy Balance Evaluation (EBE) (Shareef and Abu Hejleh 2010).

The researched model shall be validated and tested by technical advisor from IES-ve team and results shall be subject.

Model and software validation were verified to validate the results provided by IES-VE. Models have been verified and validated throw direct support from IES-VE support team, training and face to face coaching conducting to overcome any difficulties might occur in the process. IES-VE software has been used for calculating the cooling load in buildings commercially and academically. Hammad and Abu Hijelh (2010) utilized IES-Ve for calculating the cooling load in buildings. Figure 3.6.1 is showing comparison of calculating cooling load of a model in December using IES-VE software against HAP4.41, the cooling load is calculated from 7:00 am to 7:00 pm and the results demonstrate relatively well agreement in total load. Shareef and Abu Hijleh (2010) utilized IES-VE software for calculating cooling load



IES and HAP cooling loads in June



IES and HAP cooling loads in December

Figure 3.6.1Results of cooling load by IES and HAP (Hammad and Abu Hijleh, 2010)

3.7 Research limitations

Through literature review it is found that some limitations to research that might affect the research findings and results that need to be identified. Soil thermal properties is essential in calculating and predict the soil temperature at different depths and time; besides, soil thermal properties is varying from site to another according to the soil location natural properties. So that, investigating soil thermal properties is essential in predicting the energy performance of this type of spaces.

Literature review has shown that there is a margin between the predicted/ simulated results and the directly measured results in underground spaces due to space geometry and space configuration. Using the root mean square error RMSE and index for agreement methods assist in rectifying the final results and enhance the accuracy of these results. The difficulty of finding underground spaces and doing site measuring in the UAE represents a limitation to the simulation results of the research where these measuring are essential in calculating the RMSE and the index of agreement and ultimately adjusting the predicted and simulated results.

4 CHAPTER FOUR

MODEL SET UP AND SIMULATION

4.1 Introduction

In this chapter, the research site is selected to calculate and predict the soil temperature profile using Labs equation, the predicted temperature then compared it to the registered annual average air temperature registered at the nearest weather station to the research site. The model is to be set for simulation along with its properties; the temperature profile of the walls in direct contact with earth in different configurations and depths shall be predicted with some modification to the Labs equation, then the results are used in the simulation software to predict the energy performance of the underground spaces.

Variables theoretically affecting the earth sheltered space performance are tested through model simulation to find whether it enhance or not the energy performance and its weight on thermal performance of these spaces and compare it to each other. Ultimately have an idea on the variables that affect the most on the thermal performance of these spaces.

4.2 Mathematical model of soil temperature profile

As shown in the previous discussion on the soil thermal behavior in chapter 2, that soil temperature profiles differ from site to another, each site has its own temperature profile due to micro climate condition and soil properties. For that reason the research site is selected so that all input data and results are ascribed specifically to the selected site.

The mathematical calculation utilizing equation derived by Labs shall be conducted to generate the sub surface temperature in different depths and in certain days (Watson and Labs, 1983).

$$T_{(x,t)} = T_m - A_s\, e^{-x\sqrt{\frac{\pi}{365\alpha}}} \cos\left\{\frac{2\pi}{365}\left[t - t_0 - \frac{x}{2}\sqrt{\frac{365}{\pi\alpha}}\right]\right\} \qquad (5)$$

T(x,t) is the subsurface temperature on depth x (in meter) on day t of the year in day.

T_m is the mean surface ground temperature.

A_s is the annual temperature amplitude at the surface where x=0 in C^o.

e the Euler's number which is 2.71828.

x is the depth of the underground in meter.

t the time of the year in day,

t_0 is the phase constant, the day of minimum surface temperature.

α is the soil thermal diffusivity (m2 per day).

The selected area of research is located in the Emirate Abu Dhabi in area called Asab in the Western Region on the way between Hamim and Abu Dhabi as shown in figure 4.2.1

Figure 4.2.1 The location of investigation area in Asab (Google earth.com)

Table 4.1 is showing the climate data of ASAB area taken from Abu Hamrah metrological station located 40 km to the east of ASAB area, the geographical location of ASAB is 23 17’ 16” N and 54 13’ 44” E and the area altitude is 150m above sea level, this data will be used in the calculation of soil temperatures profile. The mean annual air temperature of ASAB area is 28.3^{o}C.

Table 4.1 The climate data of Asab area in Western Region (www.ncms.ae)

Station : Bu Hamrah / المحطة : بوحمرا — Data Period: (الفترة) 2003 - 2008 — Long. :(خط الطول) 54 31 48 E — Lat. :(خط العرض) 23 30 21 N — Alt. :(الإرتفاع) 150 m

Month الشهر	Temperature (°C) درجة الحرارة			Relative Humidity (%) الرطوبة النسبية			Rainfall (mm) معدل كميات الأمطار	Wind Speed (Km/h) سرعة الرياح		Soil (°C) درجة حرارة التربة			Solar Radiation (wh/m^2) الإشعاع الشمسي
	Max.	Mean	Min.	Max.	Mean	Min.	Mean	Mean	Max.	Max.	Mean	Min.	Total
Jan	32.1	17.8	04.7	100	61	11	0.5	16	71	25.6	22.1	17.3	978381
Feb	34.9	20.2	05.8	100	54	6	2.2	16	52	29.1	24.0	15.5	1097126
Mar	40.0	24.1	05.7	100	43	1	0.8	16	90	35.2	27.6	20.1	1373439
Apr	43.6	28.7	13.2	100	37	2	21.3	16	62	38.7	31.3	27.6	1449733
May	47.5	33.4	15.5	100	32	1	0.3	16	60	43.9	35.8	28.5	1582721
Jun	48.2	35.2	20.2	100	35	1	1.2	16	77	44.7	38.8	33.0	1521980
Jul	48.5	36.6	23.0	100	35	2	0.5	16	59	45.6	40.5	33.4	1467179
Aug	48.6	36.9	24.2	100	38	3	0.0	14	76	46.1	41.6	36.6	1458455
Sep	47.0	33.6	21.1	100	45	2	0.0	13	77	44.4	38.8	34.2	1371499
Oct	42.1	29.6	17.2	100	50	4	0.0	12	48	37.9	34.9	29.0	1288767
Nov	36.8	24.4	12.0	100	57	9	0.1	12	44	34.3	30.1	23.9	1039607
Dec	32.0	19.2	05.5	100	64	18	5.4	13	46	28.9	24.7	16.5	939025

According to Al Temeemi and Harris (2000), 1.7^{o}C is added to the average annual temperature to approximate the surface soil temperature, thus the mean surface temperature of ASAB area is 30^{o}C. The As can be estimated by taking one-half of the difference between January and July monthly average temperature and adding 1.1^{o}C. Mean annual temperature of January is 17.8^{o}C while 36.6^{o}C for July, thus the As equal 14.7^{o}C. t_0 represent the lowest surface temperature in a day in the year, as per the theory of periodic heat conduction, the phase of solar radiation wave lags behind the cyclical wave of surface temperature by 1/8 of the annual cycle, or 46 days of the annual cycle. Since the lowest solar radiation day comes in December 21of the year (Watson and Labs, 1983) the t0 value equal to day 36 as indicated by Al-Temeemi and Harris (2001) and (2002), whereas Mazzarron and Canas (2008) used 34.6 as t0 value.

Thermal diffusivity α is calculated by dividing the soil thermal conductivity k (in W/m K) by specific heat capacity c (in J/kg K) and soil density ρ (in kg/m3). Thermal diffusivity of soil is difficult to predict with accuracy in soil, because the variable components are affecting by the moisture content of the soil (Watson and Labs, 1983). The soil diffusivity is represented in the below equation (Al-Temeemi and Harris, 2001):

$$\propto = \frac{k}{\rho c} \qquad (6)$$

From the data collected on soil thermal conductivity it is found the soil conductivity is changing from place to place due to the difference in soil composition (sand, silt, sandstone...etc.) beside it is changing in the same soil type as depth and time changing (Baruch Givoni, 2006), hence it is important to measure the soil conductivity with depths and take its average.

Appendix (A) shows the measured thermal conductivity of Asab area taken on three levels 0.5, 1.5 & 2.5m, the readings is 0.25 w/m.k, 0.28 W/m.K and 0.26 W/m.K respectively, so the average soil conductivity is 0.26 W/m.K. Specific heat capacity is 1270 j/kg k (www.hukseflux.com) for a dry sand and the average soil density value 1538 kg/m3 (Appendix-1), the resulting soil diffusivity equal 0.011 m2/day.

Equation (5) is applied to predict the soil temperatures profile at different depths and at any day of the year, Excel software from Microsoft used to calculate the equation (detailed results of depth 1m is shown in appendix B). Figure 4.2.2 shows the results of the calculated underground temperature at depth 0.5, 1, 2, 3, 4, 5 and 6m. Figure 4.2.2 also shows the underground temperatures against the average air temperatures registered at the Asab area, Buhamra station (Appendix B). Figure 4.2.2 shows that when the mean air temperature is 38.1^{o}C in July 13th the soil temperatures at depth of 0.5m, 1m, 2m, 3m, 4m, 5m & 6m are 34.5^{o}C, 30.0^{o}C, 26.9^{o}C, 27.3^{o}C, 28.0^{o}C, 28.3^{o}C & 28.4^{o}C respectively at the same day.

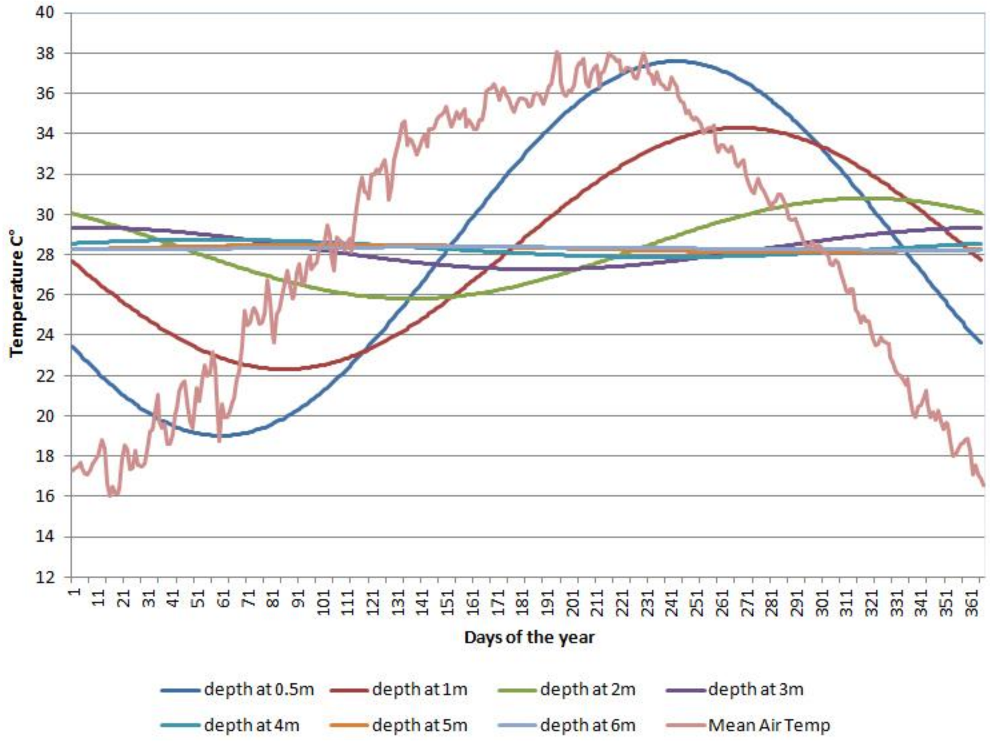


Figure 4.2.2 Annual average air temperature and daily soil temperatures profile at different depths

Hence the temperature of soil is attenuated as we go more in deeper soil but to some certain depth, besides, when the maximum ambient air was 38.1^{o}C on day July 13th the maximum soil temperatures of different soil depths were as shown in table 4.2.

Table 4.2 The maximum and minimum soil temperature at different depths (equation 5)

Depth	**Minimum Temp.**	**Date /day in year**	**Maximum Temp.**	**Date / day in year**
0.5	19.0	1st of March	31.6	31st of Aug.
1	22.3	27th of March	34.3	25th of Sept.
2	25.8	17th of May	30.8	15th of Nov.
3	27.2	7th of July	29.3	5th of Jan.
4	27.8	27th of Aug.	28.7	25th of Feb.
5	28.1	17th of Oct.	28.5	17th of April
6	28.2	7th of Dec.	28.4	7th of July

From Table 4.2, we can infer that the more we go in depth the soil temperature tend to be more constant and stable as we can see at depth of 6m where temperature is ranging between 28.2°C to 28.4°C all over the year. The results from figure 4.2.2 is very important, on one hand it advocate and proof the hypothesis that the soil is offering a milder environment to the underground and earth sheltered spaces if compared to the above surface environment and in the other hand the application of the of the Labs equation and its results can be used in simulation software with defined model to measure the energy performance of these spaces.

Figure 4.2.3 is showing imposed of findings from figure 4.2.2 and the results obtained by Al-Temeemi and Harris (2001) in terms of sub surface soil temperatures and the thermal behavior of soil in time and depth, this agreement has validated and enforced the credibility of utilizing equation (5) in predicting the sub surface soil temperatures.

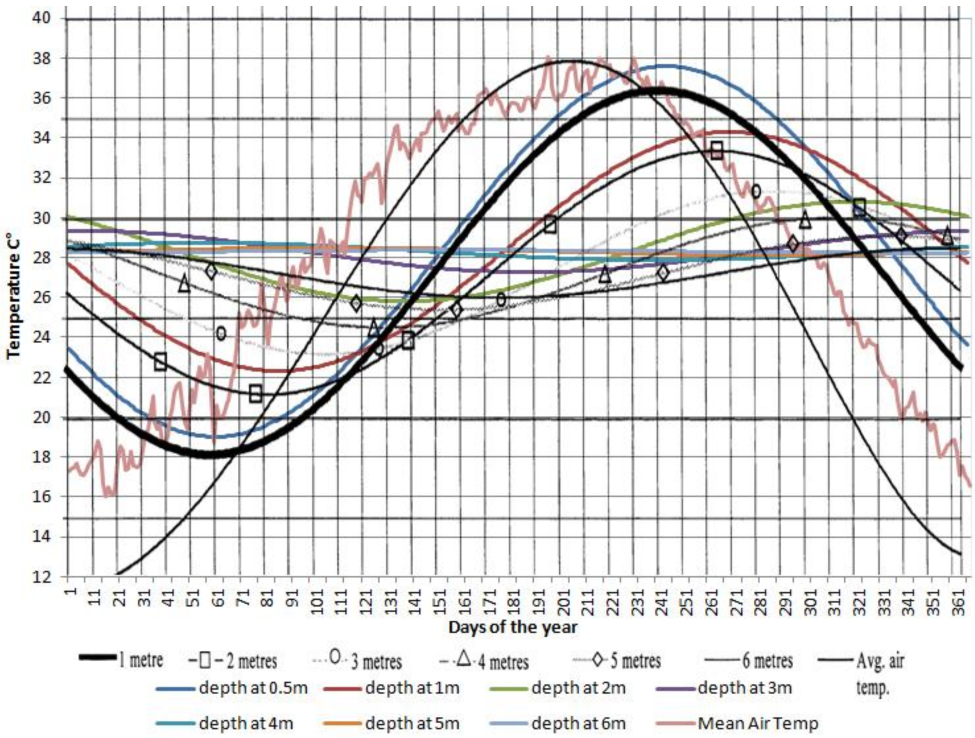
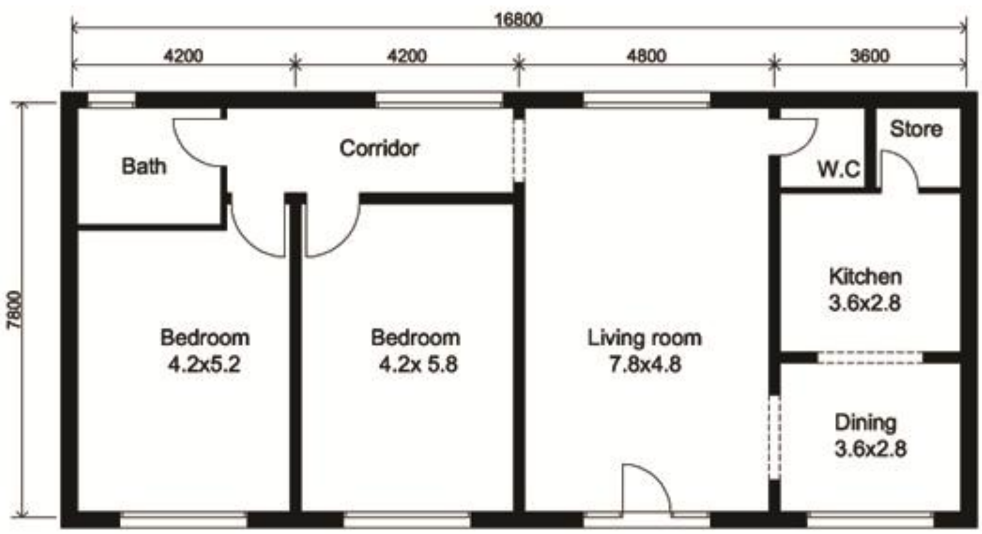


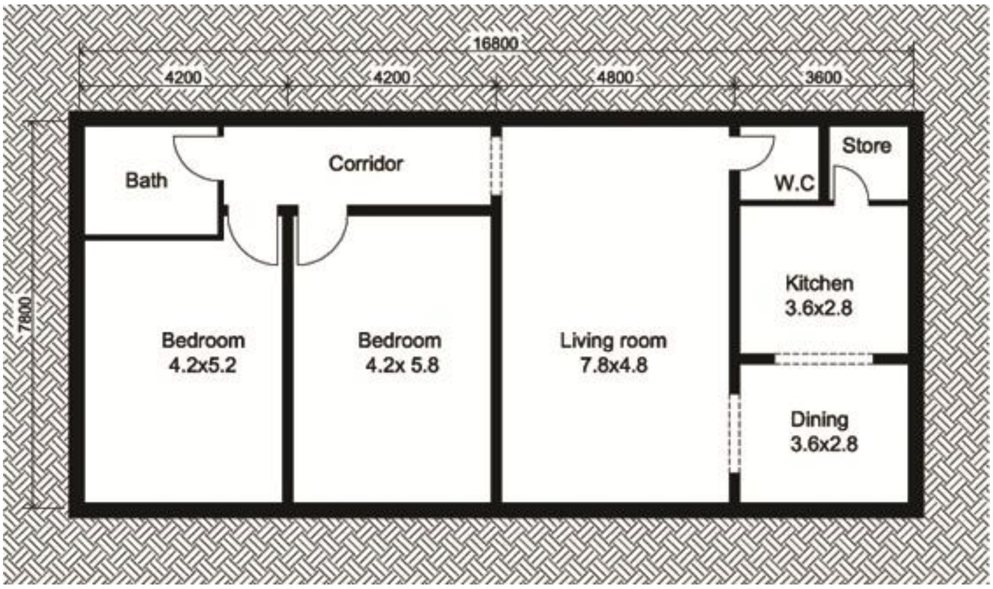
Figure 4.2.3 Showing in color the annual average air temperature and daily soil temperatures profile at different depths from equation (5) of ASAB site in UAE and the soil temperatures profile in black from a site in Kuwait city finding by Al- Temeemi and Harris (2001)

4.3 Model setting

Since the soil temperature at depth of 6.0m is nearly stable, a one storey residential building has been selected as a model where the fluctuation of soil temperature is occurring between surface and -6.0m deep and going beyond this depth shall add no value to the research, figure 4.3.1 shows the plan layout of the ground floor; the total area is 131 m2 and the floor height is 3.0m. The building is going to be simulated for different depths up to 6m from the model floor where at such depth the soil weight necessitate reinforced concrete walls with thickness of 30 cm to sustain the structure, the same is applied for the slab and the floor concrete slab thickness is 20 cm, water proofing treatment applied to all surfaces in direct contact with earth. The internal partition is concrete hollow blocks and all internal walls finished with 2 cm cement plastering. Variations to the model are applied in terms of external walls specifications to adjust to different scenarios of simulations for underground and above ground building. The total glazed area for the above ground building case is 29.5 m2 which represent 20% of the total elevations area.



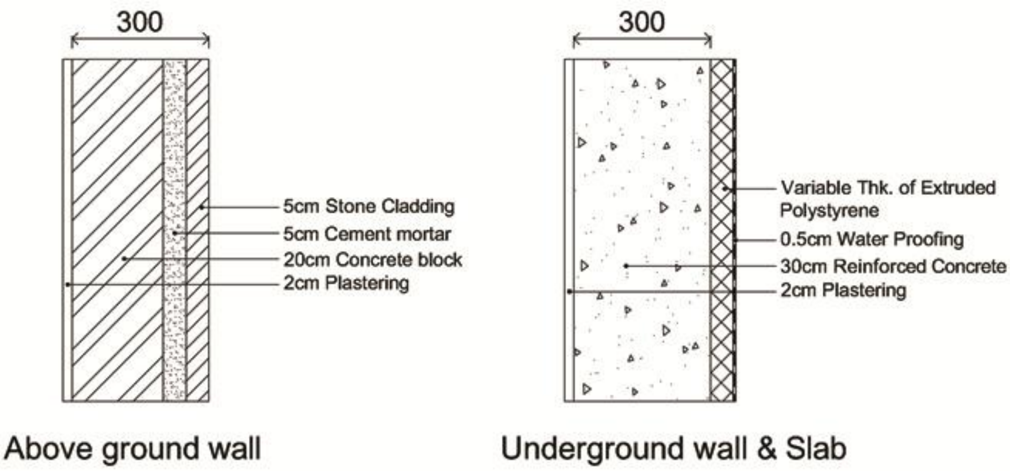
(a)

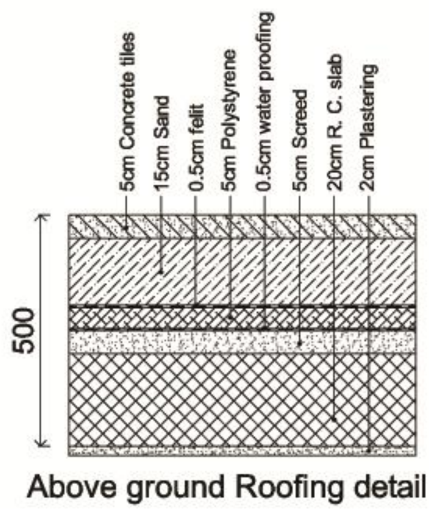


b)

Figure 4.3.1 Showing model layouts (a) as the above ground and semi-underground model and (b) as the underground model (Author design)

The model performance is compared to above ground model of the same area and height. Figure 4.3.2 showing the construction of the above ground, the underground walls, and roof and floor ground construction elements. The wall and roof construction element in the underground are different due to the lateral and soil weight the underground wall and roof exposed to which necessitate change the thickness and composition.





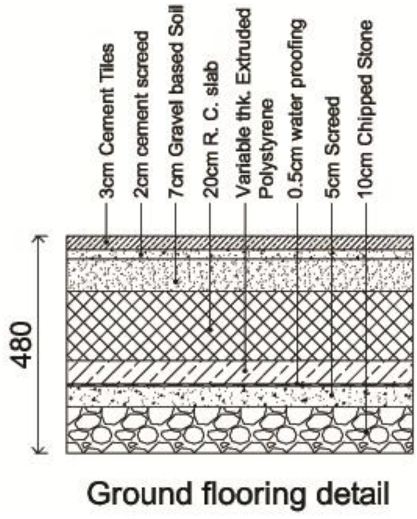


Figure 4.3.2 Showing the details of the above ground wall, the underground wall, roof details of the above wall and the floors detail used in both for the models construction

The above ground space wall and roof are typically in residential buildings in Abu Dhabi. Wall thickness is 30 cm for both cases and the construction materials are shown in figure 4.3.2. The U-values of the above ground and underground model construction elements are shown in Table 4.3.

Table 4.3 Models construction materials U-value (IES-VE)

configuration	Construction element	U-value (w/m^2k)
Above ground space	roof	2.4066
	wall	1.4657
	floor	1.2506
Underground space	roof	2.0438
	wall	1.9257
	floor	1.2506

4.4 Models simulation and variables

The Integrated Environmental Solution- virtual environment (IES-VE) software V. 6.4.0.2 is used to simulate different model configurations and scenarios to measure the energy performance of the earth sheltered spaces. The software is developed to measure energy performance of the above ground buildings around the year or to any specific period and the software has the ability to perform with one hour step. The software could be used to measure the underground buildings with the integration of underground soil temperature as the environment/climate where heat gain/loss transfers to inner spaces through underground space envelop. The interior thermal conditions are set to 19^{o}C for heating and 24^{o}C for cooling. Since the predicted underground soil temperature is above 19^{o}C, heating shall be off continuously while the cooling shall be on continuously.

Table 4.4 Simulation scenarios matrix

Space configuration	**Configuration**	**Insulation (in cm)**				**Lighting**
		5	**10**	**20**	**30**	
Base case	**O**					**O**
0-1.5m Semi underground	**O**	**O**	**O**	**O**	**O**	
0-3m Surface underground	**O**	**O**	**O**	**O**	**O**	
0.5-3.5m underground	**O**	**O**	**O**	**O**	**O**	
1.5-4.5m underground	**O**	**O**	**O**	**O**	**O**	
3-6m underground	**O**	**O**	**O**	**O**	**O**	**O**

Table 4.4 summaries the simulation scenarios that shall examine the energy performance of different underground spaces configuration and variables that might enhance these spaces performance. Due to research time constraint the simulation shall run for one week in four seasons 18th -24th of March, 18th -24th of June, 18th -24th of September and 18th -24th of December. The dates are covering the equinox and solstice.

4.4.1 Underground configuration

Simulations scenarios are shown in figure 4.6, models are set in different depths to investigate the different types of underground configurations, 0-1.5m semi underground, 0-3.0 surface underground, 0.5-3.5m, 1.5-4.5m and 3-6m as maximum depth since the soil temperature at that depth and beyond is constant as shown in figure 4.4.1.

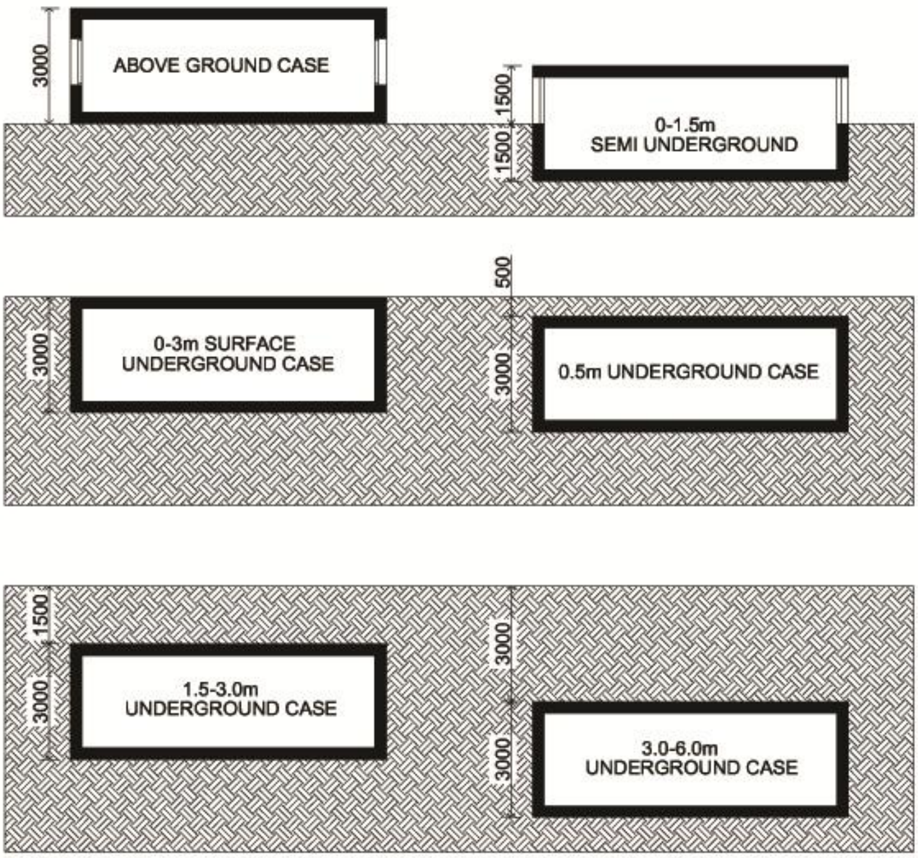


Figure 4.4.1 Showing the model section of above ground, semi underground and underground space configuration

The predicted underground soil temperatures cannot be used directly in to the IES-VE software due to the variation in the soil temperature with depths consequently the underground wall is subjected to variance temperatures with depth. Therefore, the average temperature of each wall at different configurations needs to be calculated. According to Mazarron and Canas (2008) equation (7) the average temperature of the underground wall profile is to be calculated and the results used in the

IES-VE, the average temperature profile is ranging from the top of the wall at (a) to the bottom of the wall at (b). By integrating equation (5) with depth consideration and dividing by the height of the wall (b-a), equation (5) can be expressed as:

$$T_{(a-b,t)} = T_m + \frac{A_s}{(b-a)r\sqrt{2}}\, e^{-xr} \times \cos\left[\frac{2\pi}{365}\left(t - t_0 - x\sqrt{\frac{\pi}{365\alpha}}\right) - 45.6\right]_{b}^{a} \qquad (7)$$

Where $r = \sqrt{\pi/365\alpha}$

a is the upper depth of the underground wall

b is the lower depth of the underground wall

Results from equation (5) and equation (7) are shown in Appendix (C) where daily underground roofs, walls and floors temperatures at various depths and time are tabulated to represent the input temperatures into the IES-VE for the modeling period of one week. Table 4.5 is showing an extract from Appendix (C) where the wall temperature calculated from equation (7) for March season from 18th-24th, the calculated underground soil temperatures data shall be supplied to IES-VE software. The temperatures are tabulated based on the day of the year and depth and grouped to correspond to the simulation periods.

Table 4.5 Summary of equation (7) results for a wall temperature from 18th-24th March, extract from Appendix (C)

Period	Day in equation	Day in calendar	Underground walls temperatures C°				
			X=0 a=0, b=1.5	X=0 a=0, b=3	X=0.5 a=0.5, b=3.5	X=1.5 a=1.5, 0=4.5	X=3 a=3, b=6
March	77	18	21.90	24.40	25.70	27.70	28.50
	78	19	22.00	24.40	25.70	27.70	28.50
	79	20	22.00	24.40	25.60	27.70	28.50
	80	21	22.10	24.40	25.60	27.70	28.50
	81	22	22.20	24.50	25.60	27.60	28.50
	82	23	22.30	24.50	25.60	27.60	28.50
	83	24	23.40	24.50	25.60	27.60	28.50

4.4.2 Insulation

The models shown in figure 4.6 of semi-underground and underground configurations are simulated with the addition of extruded polystyrene as insulation material to the space envelope with thickness of 5cm, 10cm, 20cm and 30cm. The previous thermal comfort settings and material characteristics are kept the same in the simulation. The purpose of incorporating insulation is to investigate the practicality of using the insulation materials in the underground spaces in direct contact with earth in the hot-arid regions and specifically its affect on the cooling load. The U-values of the walls, floors and roofs with the addition of the insulation material are shown in Table 4.6.

Extruded polystyrene is widely used in the above ground construction as insulation material, while insulation materials are rarely used in underground construction.

Table 4.6 U-values (W/m2K) of underground construction with extruded polystyrene insulation materials (IES-VE calculations)

Space element	Insulation Thickness (cm)			
	5	10	20	30
Roof	0.4638	0.2616	0.1397	0.0953
Wall	0.4575	0.2596	0.1392	0.0951
floor	0.2420	1.363	0.1339	0.0926

4.4.3 Lighting

Light pipes utilized in underground spaces to investigate the energy saving potentials. Figure 0.1 shows a section of underground space with installation of 3m high light pipe and 0.75m diameters width, the light pipe collector is a double pane Acrylic circular dome that reduces solar heat gain to the minimum, the pipe body made of high reflective Aluminum and the diffuser is a translucent circular dome.

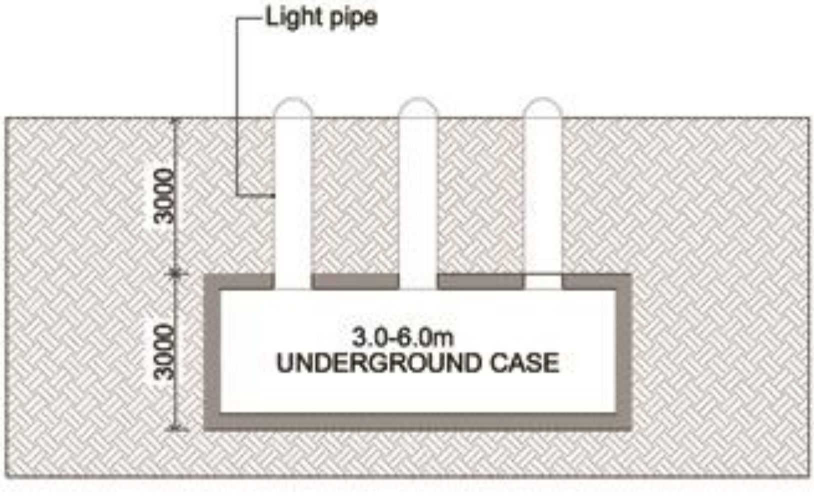


Figure 0.1 Shows light pipe installed in 3-6m underground space (Author)

SkyVision software v1.2.1 (http://www.nrc-cnrc.gc.ca) has been used to calculate the luminance of the light pipe can guide to the underground space under sunny sky condition since the UAE has the highest sunshine hours the globe (Environment Agency- Abu Dhabi, 2008). Results from SkyVision v1.2.1 software shows that luminance of light pipe efficiency is decreasing with the increase of pipe height; therefore, the light pipe is installed to 3-6m underground to investigate the deepest configuration.

The light pipe luminance calculated for day-lighting hours from 7:00 am-18:00 pm and for the periods of 18th-24th of March, June, September and December, the results are tabulated in Appendix E. Figure 4.8 is showing the Daily profile of day-lighting scenario based on the light design criteria of 300 lx, where value of (0) is given when the luminance from the light pipe is < 300 lx hence the artificial lighting is needed and value of (1) is given when the luminance is ≥ 300 lx hence the day-lighting is available and no artificial lighting is needed. Weekly profiles created based on the daily profile and the results from Appendix E.

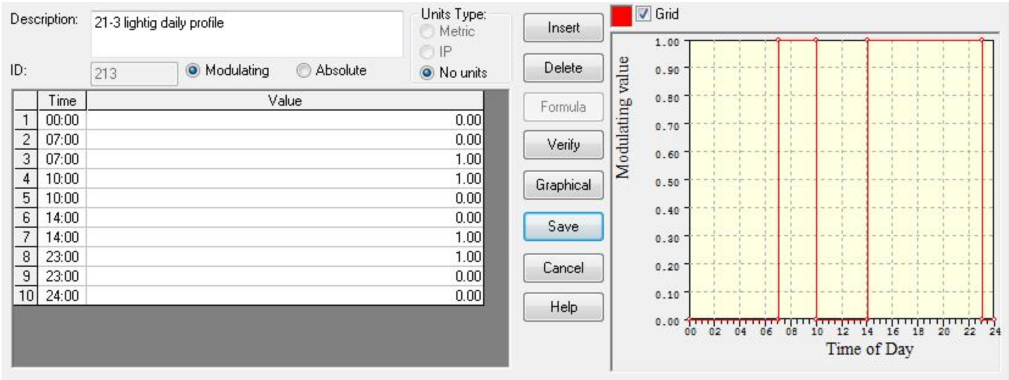


Figure 0.2 Shows daily profile of day-lighting scenario for 21st of March

Figure 0.2 is showing the daily profile of the above ground base case scenario, where artificial lighting is switched off averagely for the four simulation periods from 23:00pm to 17:00 am.

The simulation shall be carried out to calculate the energy consumed for lighting purpos and the percentage of energy saving with the incorporation of light pipe system. Furthermore the percentage of saving in cooling load due to the reduction of heat gain from artificial lights is investigated; the light pipe might generate heat gain in the underground space due to solar transmittance and the soil engulfing the pipe. Measures for light pipe e.g. pipe insulation and double pane of light pipe collator provided to reduce the heat gain to the minimum. Though literature review shows that light pipe generate little heat gain to inner spaces, the heat gain from light pipes is neglected due to lack of information on this subject.

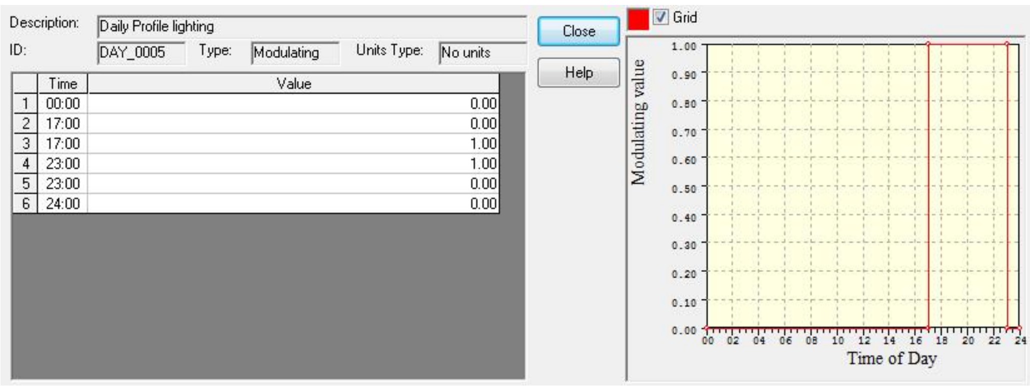


Figure 0.1 Shows daily profile of day-lighting scenario of the above ground model

4.5 Models Simulation conditions, operation and assumptions

The model is simulated with the above ground building conditions to compare its energy performance against different underground building configurations. The simulation will run for 1 week for four periods from 18th - 24th of March, June, September and December covering the equinox and solstice. The weather data utilized in the whole simulation process, the built in weather file of AL-AIN international airport has been used due to the similarity of climate conditions and site altitude.

The model is design to accommodate a small family of 4 persons; the maximum sensible heat gain is 90w/person. The thermal conditions are set to be constant at 24^{o}C for cooling to be on continuously and off continuously for heating, the infiltration rate is set at 0.25 ACH and humidity control is set between 30-70 percent. According to ASHREA 90.1, 2004 lighting power density for residential purposes is set to 10w/m2, equipment power density 2.5W/m2 and daylight dimming level to 300 Lux. The glazing type is double pane 6mm glass clear glass floats with 12mm air gab and the U-Value is 2.8777W/m2 (IES-VE Software).K. Humidity control is set on 30% minimum and 70% maximum. The thermal condition of the inner spaces divided in two types, living spaces and service spaces, the difference between them is that the services spaces cooling profile has been set off continuously since the spaces usage is very rare for the store case and the practice for bathroom case, while set on continuously for the living spaces.

The pattern of residential spaces operation is defined and specified through profiles, Apache pro (IES-VE) has two types of profiles. These two types of profiles are the modulating profile and the absolute profiles. The Modulating profile is used to modulate input data and it is appropriate for gain, ventilation rates, scheduling plants and window opening, the value ranging between 0-1 through time of one day. Whereas the Absolute is used to specify time variation of variables e.g. supply temperatures and set points it take the form of time series of physical variable (APpro, IES-VE website). Whether modulating or absolute, the daily profile assembles the weekly profile which in turn might assemble the annual profile through the repetition of the weekly profile. Figure 4.5.1 is showing the modulating and absolute profiles.

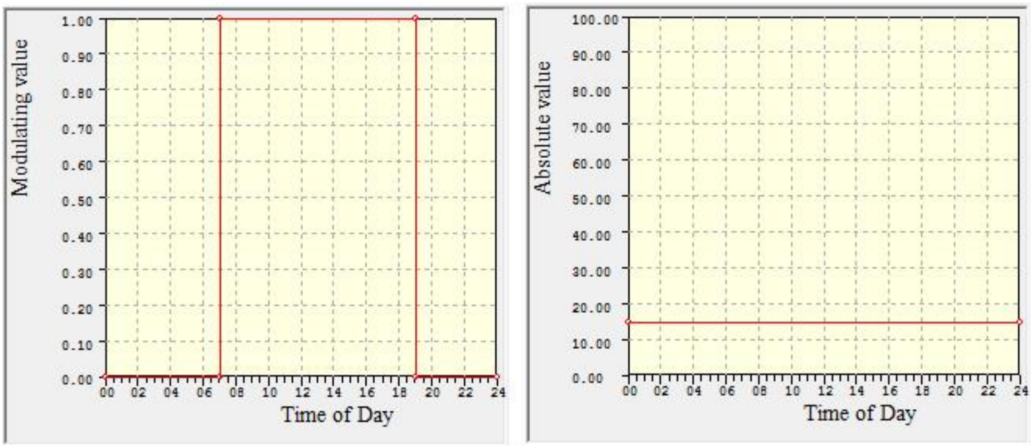


Figure 4.5.1 Shows the different between the modulating profile and the Absolute profile, IES-VE Software.

The temperatures of soil at different depths and time that extracted from equations (5) and (8) and tabulated in Appendix C are used to generate absolute daily profiles representing the supply temperature at that day. Figure 4.5.2 is showing the absolute daily profile.

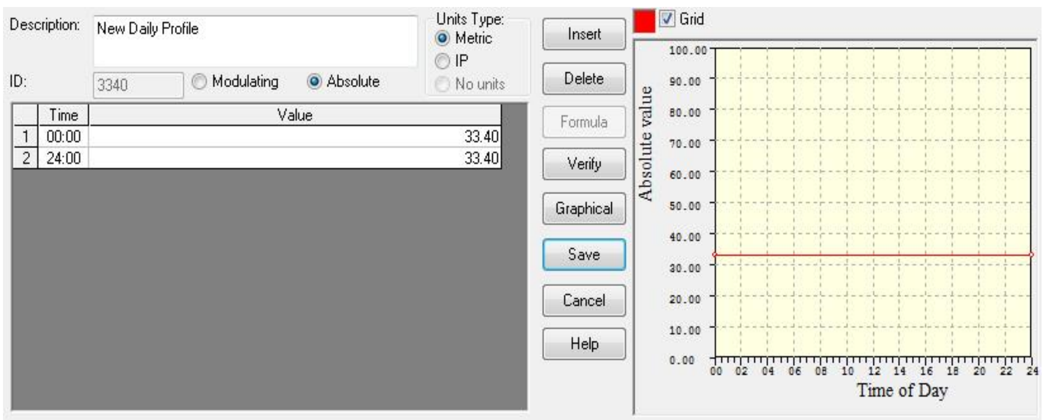


Figure 4.5.2 Showing the Absolute daily profile of the supplied temperature of 33.4Co for wall in March 21st. (IES-VE)

These daily profiles are assembled to generate the weekly profiles that will be used for the simulation periods from 18th-24th of March, June, September and December. Each created weekly profiles represent the temperature imposed on the underground space construction element (roof, wall or floor) in time and depth. Figure 4.5.3 is showing the weekly profile of supplied temperature to the underground space floor at level 1.5m in March.

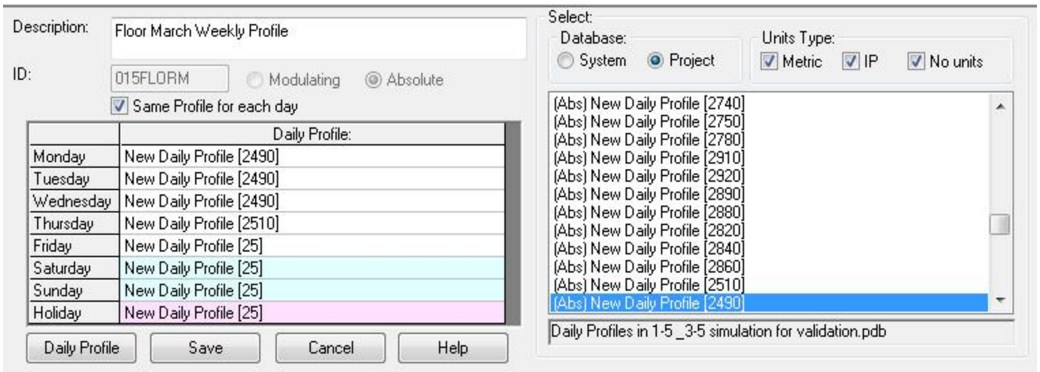


Figure 4.5.3 Absolute weekly profile is showing the supply temperature to the floor for the period from 18th-24th March (IES-VE)

For the purpose of model simulation a space operation profile created using modulated profile, Figure 4.5.4 illustrate the daily profile of Space operation where it set to be 100% occupied from 4:00pm to 7:00am and 40% occupied from 7:30am to 4:00pm, the profile is applicable for above ground and undergrounds spaces.

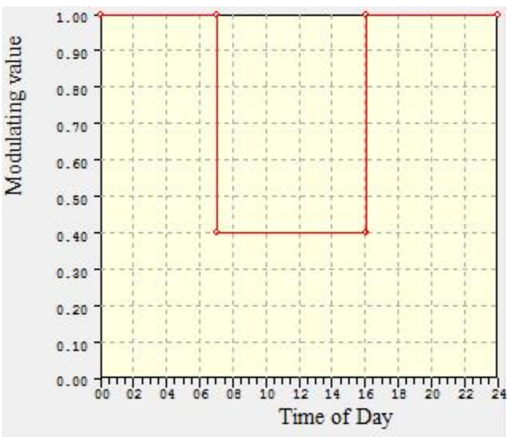


Figure 4.5.4 Daily profile of space occupation for above ground and underground cases, IES-VE Software.

Figure 4.5.5 illustrate the weekly profile of space operation where the space operated using the daily profile for the days from Sunday to Thursday, while for the days of Friday, Saturday and holidays the space is assumed to be 100% occupied.

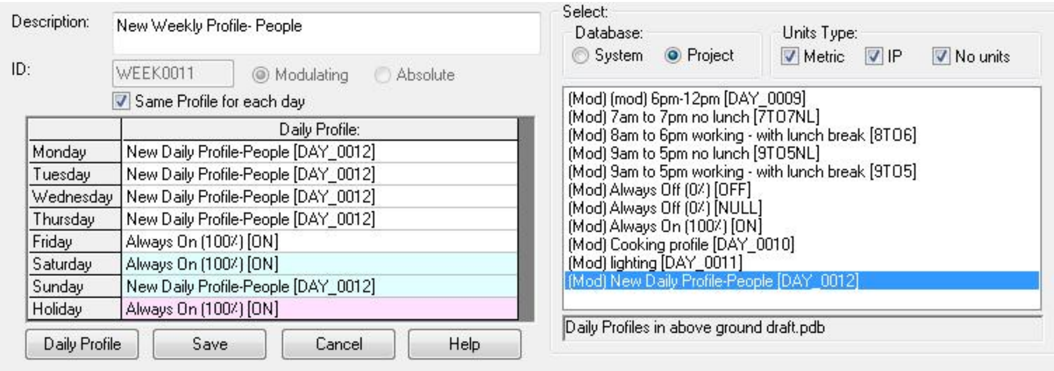


Figure 4.5.5 Showing the weekly profile for spaces operation for above ground and underground cases, IES-VE Software.

5 CHAPTER FIVE

RESULTS AND DISCUSSION

In this chapter, the results obtained from the simulation of the base case and different configurations and scenarios of earth sheltered spaces are described and analyzed. Snapshots of graphs as shown in Appendix F are taken; numerical findings are tabulated and transformed to charts to illustrate the underground spaces performance. Cooling load is the main criteria to evaluate the earth sheltered spaces performance since there were no heating conditions was supplied to these spaces due to the fact that the sub surface temperatures extracted from the mathematical model was above 19 Co; besides the lighting load is calculated to evaluate the amount of energy consumed in lighting and compare it to the above ground base case scenario.

5.1 Configuration scenarios results

The above ground base case simulated against different types of underground configurations. The simulations run for one week from 18th-24th in March, June, September and December. Simulation graphs are presented in Appendix-D; Results are summarized and charts are generated. In general the results show a good agreement to the hypothesis of the underground spaces and the soil attenuation behavior against the ambient above ground temperatures.

5.1.1 March 18th-24th

The cooling load in the above ground base case and the configurations of the underground spaces were various as shown in figure 5.1.1. It shows that the best performance of underground spaces was in the configuration semi underground with 57% less in cooling load while worst performance was in the 1.5-4.5m and 3.0-6.0m underground configuration. In March the ambient air temperature ranging between 13Co-32Co from 18th- 22nd and from 25Co-38Co from 23rd- 24th of March (IES-VE weather file); While the subsurface temperatures are above 25 in most configuration except for the 0.5-3.5m where the soil temperature in contact to roof surface was between 19.4Co- 19.7Co.

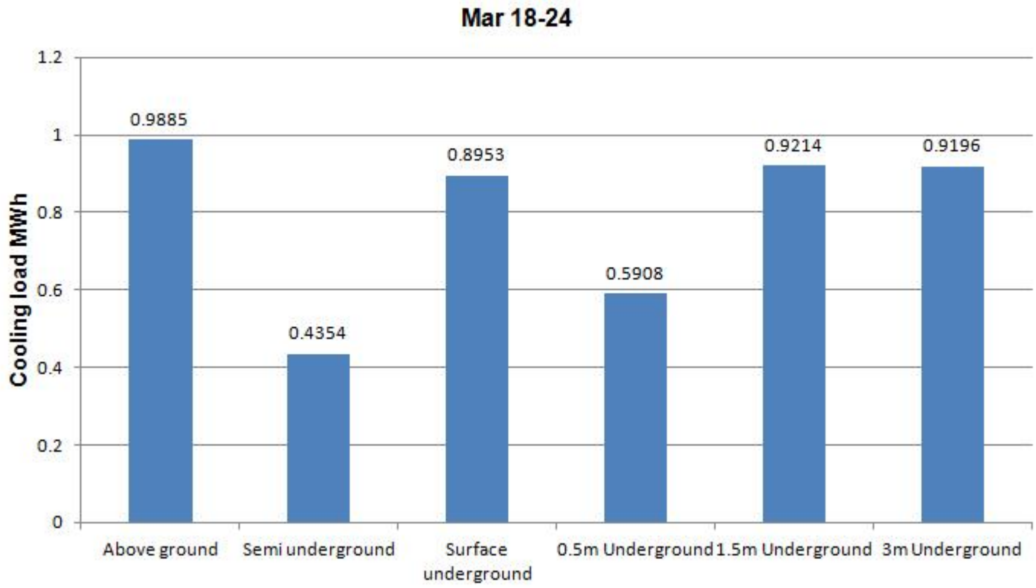


Figure 5.1.1 Cooling load for the period of 18th -24th March, the above ground base case and underground configurations

In the case of March period, the underground spaces performs well for semi underground and 0.5-3.5m underground compared to the above ground spaces. The good performance is attributed to the fact that the partially space contact with soil loss heat from inner space to the cool soil at day time since the soil layer is effected by the coolness of night time of March period besides, no artificial lighting is used at day time thus no additional heat gain from artificial lighting. The cooling load of surface underground space is affected partially by the additional gain of artificial lighting and the heat gain from the exposed roof to the solar radiation. Whereas the case is different in 0.5-3.5m configuration since the 0.5m soil cover is performed perfectly and reduced the cooling load, the 0.5m soil cover has moderated the external ambient are and stabilized it at 19.4-19.7^{o}C as shown in table C.1 in Appendix C. The configurations of 1.5-4.5m and 3.0-6.0m underground cooling load did not demonstrate significant reduction because the subsurface temperature is higher than the soil temperature at shallow depths and the heat gain from soil in deep underground spaces is more.

5.1.2 June 18th-24th

Figure 5.1.2 showing the performance of the underground spaces. The best performance was achieved at depth of 3-6m underground with saving of 49.9% whereas the worst performance was the surface underground space with saving of 21.6%. In June 18th- 24th the ambient air temperature between 25°C- 43°C (IES-VE weather file) while the underground soil temperatures are ranging between 26°C-34°C, in general the temperatures at depths of 1.5m and beyond were between 26°C-28°C whereas ambient air temperature at higher level and the soil covered underground spaces at shallow depths and near the surfaces are affected by ambient air temperature more than the soil at deeper depths; and that justify the good performance of the deep space of configuration 3.0-6.0m and 1.5-3.5m despite the space heat gain from the soil and ultimately the constant need for cooling. Surface underground space and semi underground space perform worst compare to other configurations; the justification of this performance is due to heat gain of the hot summer season from soil that easily affected by ambient air and the exposed part of semi underground space.

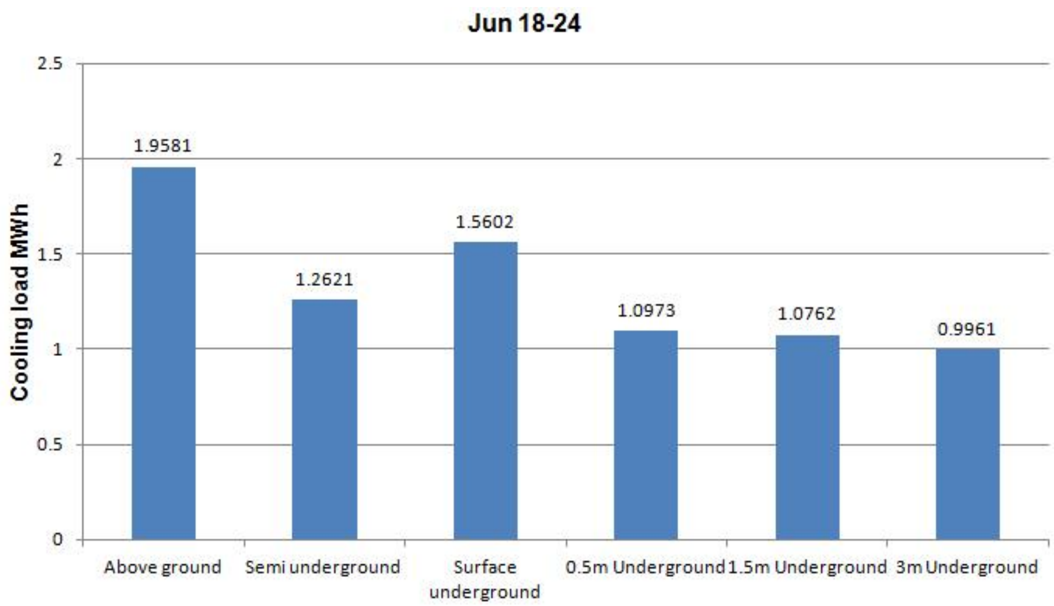


Figure 5.1.2 Cooling load for 18th -24th of June, the above ground base case and underground configurations

5.1.3 September 18th-24th

The performance of the underground spaces in this period came none consistent and the saving in cooling load was slightly less than June period in general. Best performance achieved at the 3.0-6.0m underground space configuration and the attained was 47.6% saving. In this month the worst performance was in the surfaces underground and the semi underground although the attained saving was 19.2% and 30.4% respectively.

The ambient air temperature in this period of September is ranging between 25^{o}C- 40^{o}C (IES-VE weather file), the high exterior temperature effect the spaces near the surfaces where semi and the surface underground spaces are affected by the ambient air temperature and the inner space gaining heat. While at deeper spaces performed the better and less cooling load is needed hence the heat cycle has departed these depths and the heat gain of inner space at the minimum. Figure 5.1.3 showing the base case and the underground spaces performance along with cooling load achieved for each case.

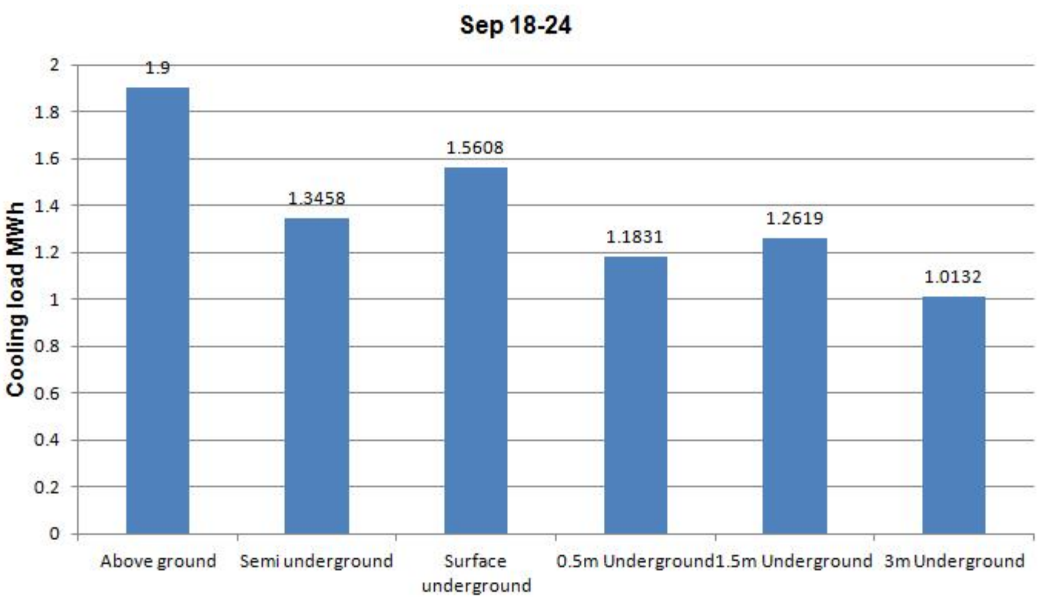


Figure 5.1.3 Cooling load for 18th -24th of September, the above ground base case and underground configurations

5.1.4 December 18th-24th

The cooling load at deeper underground spaces have witnessed a raised when compare to the base case and the spaces that near to the surface. The semi underground cooling load is the lowest to all other configurations as shown in figure 5.1.4. The underground spaces performance were completely the opposite from the periods and that increase in cooling load ascribe to the fact that the heat of summer temperature reaches the underground spaces while the ambient air in December 18th-24th is ranging between 15^{o}C-29^{o}C (IES-VE weather file).

Despite the fact that the sub soil temperature at the levels of 3.0m-6.0m underground were stable at the 27^{o}C-28^{o}C (Appendix B), the underground space is gaining heat from the soil the case which is not the same for the above ground space (Base case), the increase in cooling load for 1.5-4.5m and 3.0-6.0m were 22.3% and 8.0% respectively. Furthermore,

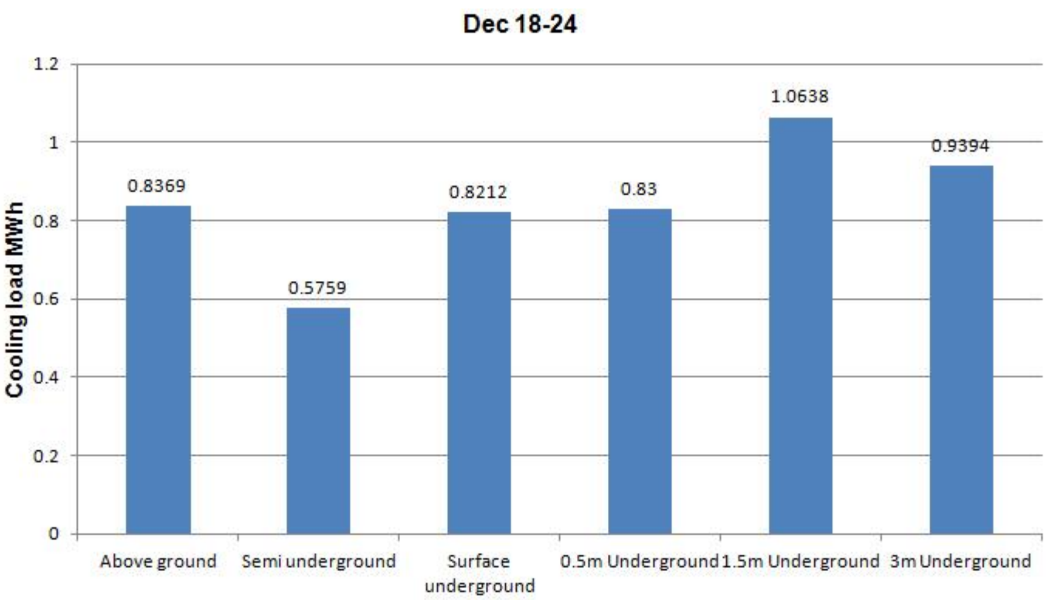


Figure 5.1.4 Cooling load for 18th -24th of December, the above ground base case and underground configurations

The semi underground configuration has achieved significant cooling saving of 33.8% while the surface underground and 0.5-3.5m underground saving were not that significant hence both achieved 5.6% and 4.6% respectively.

5.1.5 Summary on spaces configuration

Figure 5.1.5 summarizes the performance of all scenarios; figure 5.1.5 shows that the underground spaces performed well in the hot season especially for deeper spaces while in the cool season the performance was fluctuate where saving was less and in some cases the cooling load was more from the above ground base case. The soil behavior of the site study performs as a shelter against the high temperature especially at the hot season and the soil shows no cooling potentials to the underground spaces.

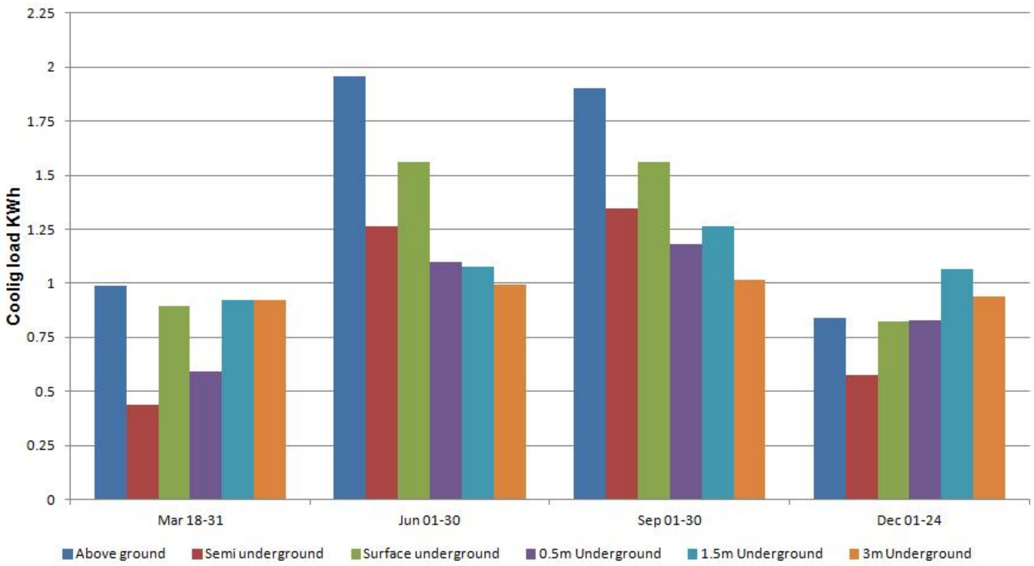


Figure 5.1.5 Comparison of all configurations in respect to the four seasons of simulation

Soil temperatures average where above 30s^{o}C at depth of 0.5 in the hot season while at depth of 6.0m the temperature became stable at 27^{o}C-28^{o}C consequently the need for cooling in the underground spaces is needed all around the year and the simulation periods. The simulation results are agreed with the findings by Al-Temeemi and Harris (2002). Staniec and Nowak (2009) fond that the thicker soil cover of more than

0.5m does not enhance the cooling load and its influence is neglected, this disagreement with Al-Temeemi and Harris findings is ascribed to the fact that Staniec study has been conducted in cold climate whereas Al-Temeemi study has been conducted in hot region.

Table 5.1 shows numerically the percentage of reduction/saving and increase in the cooling load of the different underground spaces configuration against the above ground base case on each simulation period. The saving referred to with (-) mark and the increase in load referred to with (+) mark.

Table 5.1 The percentage of saving and extra cooling load.

Configuration	March 18^{th}-24th	June 18^{th}-24th	September 18^{th}-24th	December 18^{th}-24th	average
Semi underground	-55.9%	-35.5%	-29.1%	-31.1%	-37.9%
Surface underground	-9.4%	-20.3%	-17.8%	-1.8%	-12.3%
0.5m Underground	-40.2%	-43.9%	-37.7%	-0.8%	-30.6%
1.5-4.5m Underground	-6.8%	-45.0%	-33.5%	+21.3%	-15.8%
3-6m Underground	-6.9%	-49.1%	-46.6%	+10.9%	-22.9%

The selected simulation periods represent the four seasons of the year and the results might expand to cover the year. The average percentage of cooling load savings showed that the semi underground space has gain higher percentage of saving, while surface underground space has gained the lowest saving percentage. Besides, the table is showing none uniform behavior in terms of soil cover thickness and the achieved saving percentage.

The ground temperature at shallow depth was significantly affected by ambient air temperature but with increase in depth it approached a steady-state value at 10 m.

5.2 Thermal Insulation Material

All types of underground configuration are simulated with addition of 5, 01, 15, 20 and 30cm of extruded polystyrene as insulation material. The simulations scenarios have been conducted for the same periods of March, June, September and December. The results are tabulated and shown table D.1 in Appendix D; charts have been generated and summarized for the purpose of discussion as follows. All numerical savings in cooling load resulted from the addition of thermal insulation are compared against the same space configuration without the addition of thermal insulation.

5.2.1 March 18th-24th

The performance the underground spaces with addition of thermal insulation for this period has shown different trends as shown in figure 5.2.1. In the semi underground case the insulation has increased the cooling load by 1.4%, 1.4, 2.2% and 1.4% for the addition of 5, 10, 20 and 30cm of thermal insulation respectively, the increase of cooling load is ascribed to the fact that the thermal insulation has reduced the cooling potential of soil especially in this period where soil temperature is ranging between 22.9^{o}C-23.4^{o}C.

3.0-6.0m underground space performed the best where the percentage of saving in cooling is25.5%, 30.6%, 33.5% and 35.4% for 5, 10, 20 and 30cm thermal insulation respectively. Thermal insulation performed well in deeper spaces as shown in figure 5.6. Soil temperature at deeper levels is higher than the surface soil due to the time lag and heat cycle travel from outside. Thermal insulation breaks the direct contact of the space envelope from the soil and reduces the heat gain of inner spaces and ultimately reducing the cooling load required to maintain the interior thermal comfort. In shallow deep spaces the thermal insulation works the same but the effect is the opposite where it reduce the heat loss of the inner spaces from to the cool soil and ultimately increase the cooling load of the underground space.

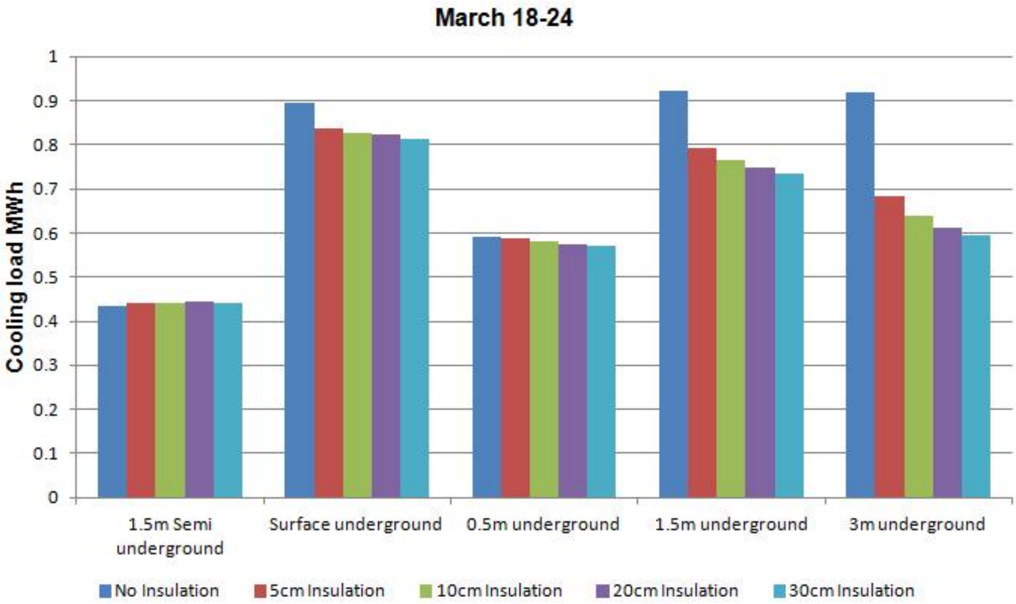


Figure 5.2.1 Cooling loads of models with thermal insulation in March 18th-24th

5.2.2 June 18th-24th

All underground spaces performed well with increase of thermal insulation especially for configurations of 0.5-3.5m, 1.5-4.5m and 3.0-6.0m. Whilst the configuration of semi underground and surface underground achieved the worst as shown in figure 5.2.2.

0.5-3.5m configuration saving percentages are 24.8%, 29.6%, 32.8% and 38.2%, the saving is against the addition of 5, 10, 20 and 30cm of thermal insulation respectively. The semi underground configuration achieved the lowest percentages in cooling saving; the figures are 6.2%, 7.2%, 7.8% and 8.1%. the weak performance of the semi underground spaces is in fact due to the exposure of spaces to the exterior condition of the hot season unlike the other configuration e.g. 0.5-3.5m underground configuration.

3.0-6.0m space performance was less from March period and that might ascribed to the soil temperature where it was less from March and that is due to the departure of heat wave cycle which resulted less soil temperature and ultimately the heat loss of space to soil reduced.

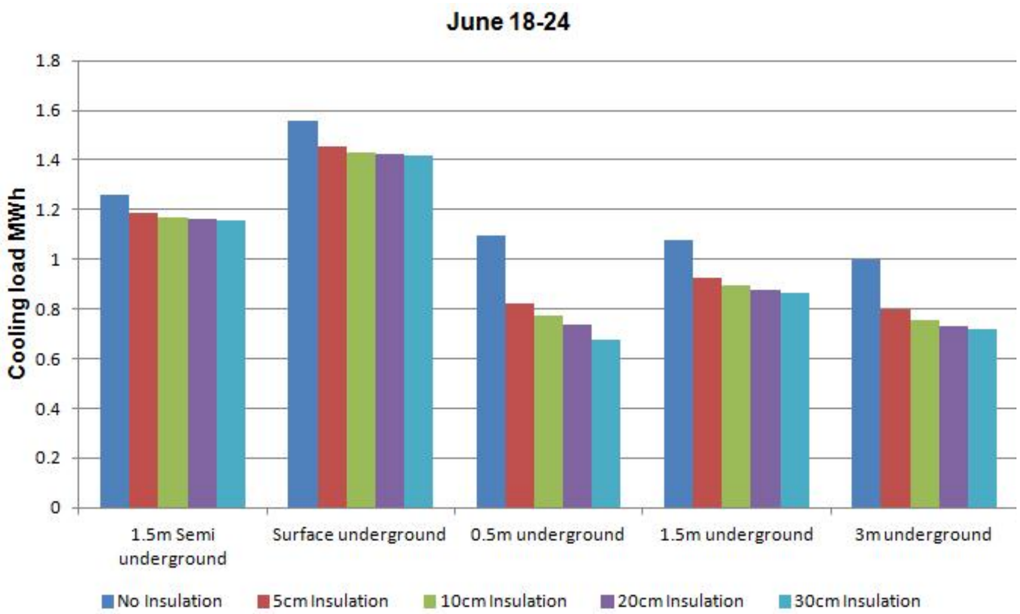


Figure 5.2.2 Cooling loads of models with thermal insulation in June 18th-24th

5.2.3 September 18th-24th

Figure 5.2.3 shows that the performances of the underground spaces hence in this period performance come consistent, in general all configurations performed well although semi underground whereas 0-3.0m surface underground spaces performed less if compared to other underground configurations.

Best energy saving achieved in 0.5-3.5m underground space, with percentages of 24.4%, 31.3%, 35.9% and 40.5% for addition of 5, 10, 20 & 30cm of thermal insulation respectively. While the lowest performance achieved in 0-3.0m surface underground space with percentages of 10.8%, 12.7%, 13.8% and 14.4% or addition of 5, 10, 20 & 30cm of thermal insulation respectively.

In this period the percentages of saving in cooling load of all underground configurations were better than previous periods of March and June except for 3.0-6.0m underground spaces where slim saving achieved when compared to June period and this saving is due to the heat cycle that start reaching deeper depths.

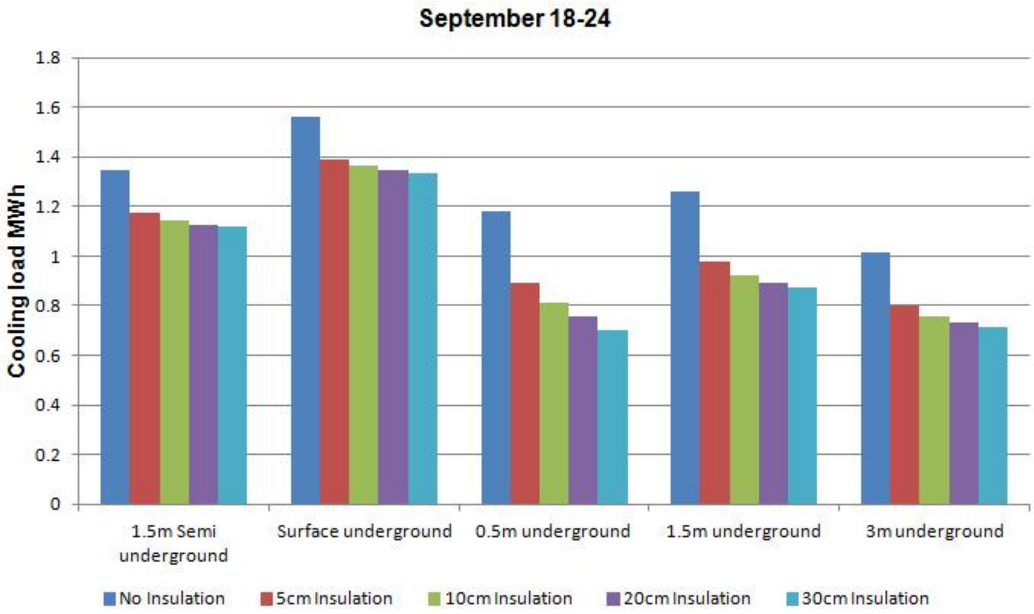


Figure 5.2.3 Cooling loads of models with thermal insulation in September 18th-24th

5.2.4 December 18th-24th

The percentages of saving in cooling load are the highest in comparison to all previous simulated periods and better saving is achieved at deeper configuration as shown in figure 5.2.4. The underground space at level 3.0-6.0m has achieved the best saving in cooling load with percentages of 26.4%, 31.6%, 34.6%, and 36.5% for 5, 10, 20 and 30cm thermal insulation whereas the lowest saving achieved by 0-3.0m surface underground configuration with percentages of 15.4%, 18.6%, 19.9% and 21.5% for 5, 10, 20 and 30cm thermal insulation.

Despite the fact that 1.5-4.5m and 3.0-6.0m underground spaces cooling load without the use of thermal insulation were above the base case whereas 22.3% and 8.0% increased respectively in December period, the addition of thermal insulation has reduced the cooling load at percentages of 21.7%, 26.0%, 28.8% and 29.9% for the depth at 1.5-3.0m and 26.4%, 31.6%, 34.6% and 36.5 for the depth of 3.0-6.0m underground with the use of 5, 10, 20 and 30cm thermal insulation respectively. Best performance achieved at 3.0-6.0m depth since the heat wave reached that level and the soil temperature at the high level.

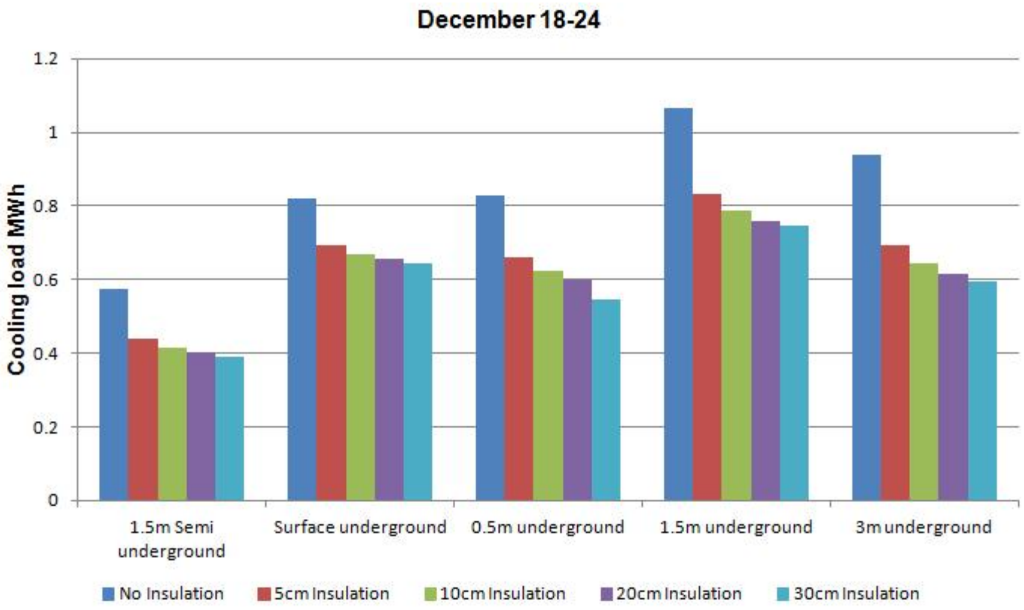


Figure 5.2.4 Cooling loads of models with thermal insulation in December 18th-24th

5.2.5 Summary on Thermal insulation

Generally, the addition of thermal insulation with different thicknesses to the envelope of the underground spaces has enhanced the thermal performance and additional saving in energy of the cooling load achieved. And that ascribed to the fact that the soil temperature at deferent depths was mostly near or above the cooling set point. The thermal insulation performed well in hot season and deeper underground spaces However; in cool season the performance was not that significant if not worse as the case of March period for the semi underground configuration as well as December period for the configurations near to surface and This is due to the fact that the insulation is disconnecting the envelope of the underground space from the soil and reducing the space heat loss and cooling effect of soil in these two periods where the soil temperature is less or near the cooling set point. Minimizing the heat loss from space to the soil consequently increasing the cooling load thus the designers should incorporate measures to enhance the cooling effect of soil and increase the space heat loss to cool soil saving and reduce the effect of thermal insulation in cool season.

Table D.1summaries the percentages of savings in cooling load for all scenarios and periods. It is clearly obvious that thermal insulation performed well in deeper levels than the near surface underground spaces. This pattern of performance is justifiable since the deeper levels temperature is and higher than the near surface soil temperature so that the heat gain of deep inner spaces from soil has been reduced with the addition of thermal insulation.

The interesting observation in thermal insulation is that the 5cm thickness of thermal insulation can achieve more than 65% of what the 30cm thickness achieve in most cases thus cost effective study might be employed to balance the amount of saving in cooling load against the selected thickness of thermal insulation.

5.3 Lighting

Simulation of 0-3m underground space carried out for one week from 18-24th of March, June, September and December to measure the energy saving potential of electricity with the use of light pipes day-lighting guide system. The results are compared against the case of using artificial lighting along the simulation period. Figure 5.3.1 is showing each period against the base case.

The saving in electricity is varying from period to another due to the amount of illuminance received from the light pipe that affected by the length of the day. March and September period saving percentages are 25% of the base case, while June period registered the maximum saving at 31%. December period shows no saving potentials since the illuminance level from the light pipe did not reach the lighting design criteria of the space.

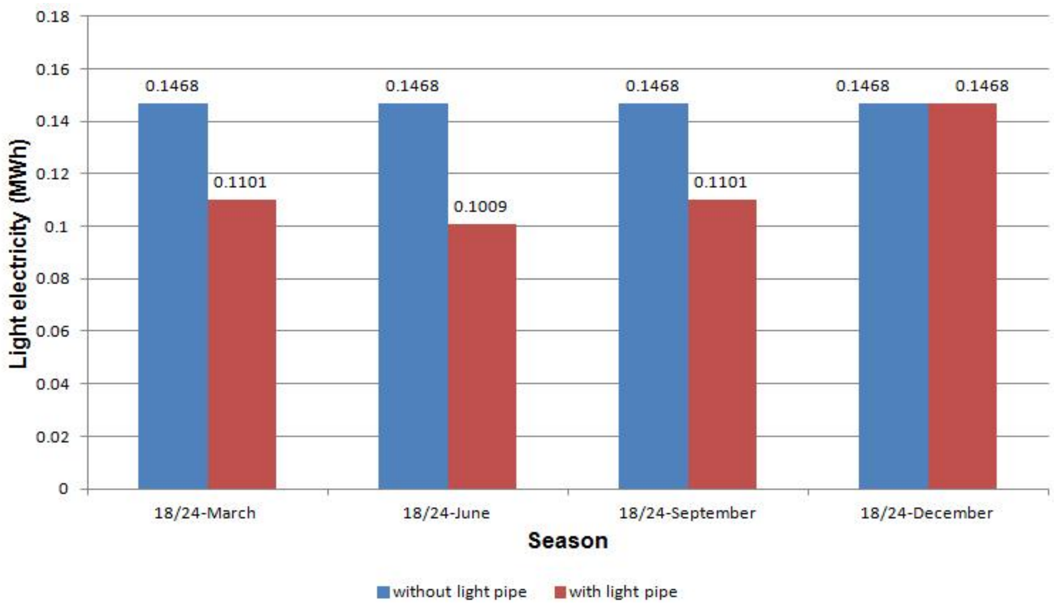


Figure 5.3.1 Lighting energy comparison of 0-3m underground space for four seasons

Figure 5.3.2 is showing the amount of natural lighting received by light pipes at four seasons for the days of 21st of March, June, September and December. The simulation is neglecting the illuminance below 300 lx. Table E.1 and E.2 from Appendix E are showing a plentiful of illuminance between 1-299 lx as the case of December where the amount of natural did not exceed the 300 lux level.

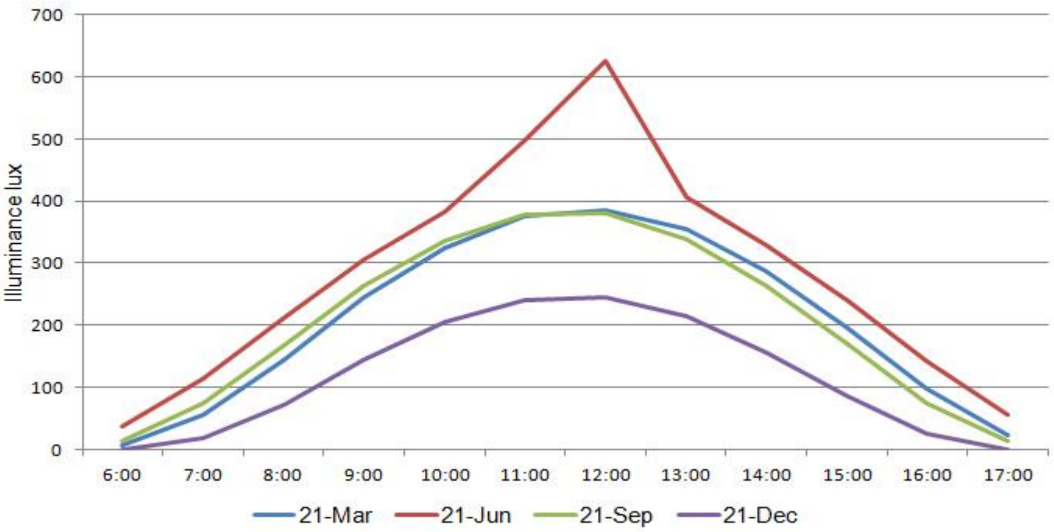


Figure 5.3.2 Daily Illuminance in lux at solstice and equinox from light pipe of 3m height and 0.75m dia. at 3-6m underground space for solstice and equinox

In the other hand, this amount of illuminance (>300lux) represent a good possibility for adding more saving and reduce consumption in electricity. It is estimated that additional saving in artificial lighting of 12% for the periods of March, June and September, and 17% for December period could be achieved if photo cell sensors utilized.

The reduction in artificial lighting has another advantage in reducing the cooling load. Less hours of artificial lighting means less heat gain from lighting source. Figure 5.3.3 is showing the amount of cooling load comparison.

Although the reduction in cooling load was not that significant where 2.8%, 3.3% 2.6% saving achieved for March, June and September, respectively, the light pipe has saving potentials when incorporated in underground spaces.

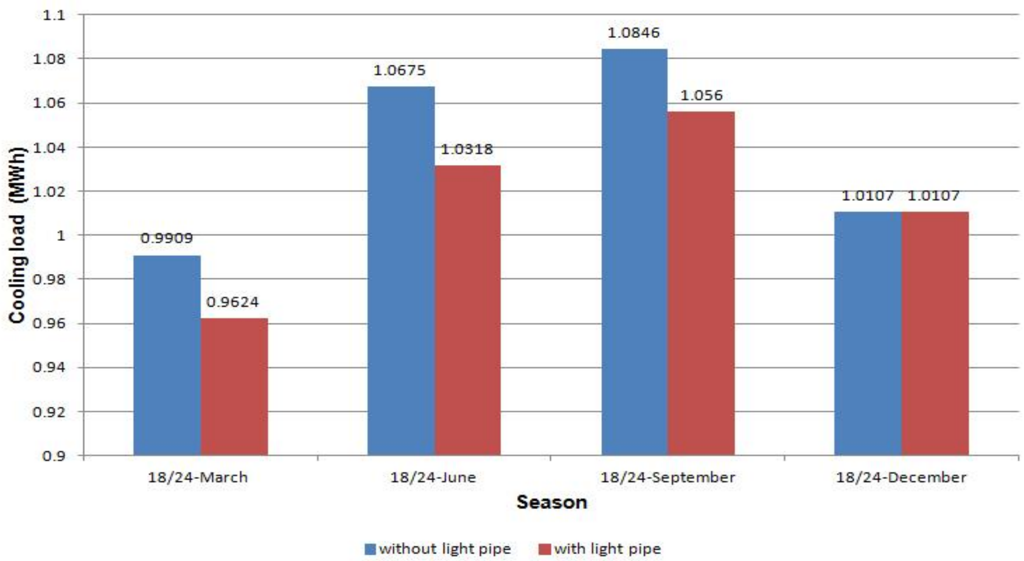


Figure 5.3.3 Cooling load comparison of 0-3m underground space for solstice and equinox

6 CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The models assessment and analysis of the underground spaces has concluded that buildings when partially or fully placed in the ground and become in direct contact with soil are work better in terms of energy performance in comparison to above ground buildings. The simulation shows that cooling load reduced considerably when compared to the conventional above ground building. Furthermore, results showed additional reduction in cooling load and lighting energy consumption is possible when thermal insulation and natural day lighting introduced.

Soil temperatures are calculated using LABS equation where soil thermal properties are essential in the calculation. Furthermore, soil thermal properties is variant from site to another so that prior investigating of site soil thermal properties is essential to predict the energy performance of the underground spaces. The predicted site soil temperature at level -6.0m tend to be constant thus any space beyond this depth and to some extent shall perform the same since the heat gain/loss between the space and the soil is constant too.

The soil temperatures at various depths in general were above the comfort level and soil demonstrates no cooling potentials for ASAB area. At the other hand, the stability of soil temperature at depth and the attenuation and moderation of ambient temperature by soil have played an important role in achieve savings and reducing the cooling load. Semi underground, 0.5-3.5m and 3-6m performed better than 0-3m and 1.5-4.5m. The results does not support the concept of increasing soil cover shall necessarily increase the saving or enhance the spaces performance; although the study prove the potentials of underground spaces in saving energy and reducing the cooling load when compared to the above ground spaces in the hot regions.

Thermal insulation and introducing of daylight to underground spaces present additional saving potentials to underground spaces. The thermal insulation thickness shall be investigated and decide prior incorporated it where small thickness of 5cm has performed better when compared to

30cm. thermal insulation performance was weak in March period for semi-underground space where it reduced the cooling potential of soil through reducing the heat loss from inner space to the soil; furthermore, results shows that thermal insulation is more effective in deeper spaces than the shallow spaces.

Light pipes has double benefit to underground spaces, it reduce the electricity lighting at daytime and reduce the cooling load by eliminating the heat gain from artificial lighting alike.

6.2 Recommendations

The research has been conducted for specific periods and location. The findings gave a sight on the energy performance of such spaces on these specific periods, it is highly recommended to calculate and predict the annual energy performance of the underground spaces to have a clear vision on the total energy performance and calculate the total energy consumed throughout the year and compare it to the same above ground model.

The saving potentials of energy in underground spaces come in line with the UAE approach to reduce the CO_2 emission and apply the principals of sustainable buildings. Abu Dhabi in particular is applying the Estidama Pearl Rating system; underground spaces represent a good opportunity for Planners, Architects and Engineers in saving energy and achieving certified sustainable buildings.

The literature review demonstrates a good opportunity to enhance the cooling potentials of the soil and further reduction in cooling load of the underground spaces through extend the base of research on the techniques might be applied. These techniques include covering the soil with a layer of pebbles or mulch, use of vegetation or the use of water sprinkler to cool down the soil temperature at deeper levels.

The field of underground spaces is vast and immature especially in our region and more work is needed in this field, future works might include the followings:

- Investigating energy performance of above ground earth sheltered spaces with different soil thicknesses on top; this type of spaces has the potential to incorporate natural ventilation and natural day lighting easily and with no extra cost which might present a potential for additional saving in energy consumption and lessening the negative side of seclusion and disconnecting from external environment.
- Encourage universities, institute and research establishments working in the field of building, environment and energy in establishing underground spaces as part of establishment facility, the benefit is doubled since these facilities are offering a measurable example that can be more studied and investigated, furthermore, the measured findings might be compared to simulated, calculated and predicted data which give more confidence to the researcher, architect and planner in supporting the argument of the earth sheltered spaces.
- It is highly encouraged to investigate and research new sites with different thermal soil properties to predict the effect of soil properties on energy performance
- The practicality of creating underground communities, the cost/benefits and sustainability issue.
- Finding data on thermal soil properties are difficult especially for soil diffusivity hence it is varies from site to site and in depth. Although the Environment Agency-Abu Dhabi has created UAE soil map, soil diffusivity is not included in the map. It is highly recommended to include soil diffusivity in UAE map.
- The high potential of energy savings in underground spaces necessitate a research on the cost of construction of such space to evaluate the cost/benefit when compared to energy saving.

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APPENDICES

Appendix A

Soil investigation report for ASAB area shows Soil Thermal Resistivity on underground levels of 0.5, 1.5 & 2.5 (Arab Center for Engineering Studies ACES).

CERTIFICATE OF SOIL THERMAL RESISTIVITY

Owner		**Report No.**	
Contractor		**Date Reported**	5/26/2010
Consultant		**Sample No.**	**TR-01**
Project No.		**Request No.**	-
Project Name		**Client Reference**	-

Material Description	SANDY	**Test Id. No.**	**TR-01**
		Circuit	-
Source	Site	**Span**	-
Test Location	**TR-01**	**Depth @ Test**	0.5m

Test Method	IEEE Std. 442-1981	**Date Tested**	5/19/2010
Test Method Var.	Nil	**Tested By**	
Remarks	-		

Soil Density	
Dry Density@ Test	1.572 g/cm^3
Test Method	ASTM D 1556-07

Moisture Content	
Moisture Con-t@ Test	0.1 %
Test Method	ASTM D 2216-05

Test Results:

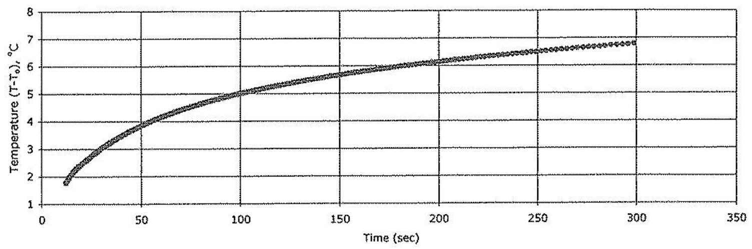
Probe Type	TP07	**Heater Voltage**	3 Volts
Probe Serial #	215	**Initial Temperature**	32.2 °C
Resistance	82.92 Ω / m	**Time**	9:52:48
Cycle Duration (H)	300 sec	**Heating Power (Q)**	4.98 Watts / m

Readings	Conductivity (Watts / m.K)					Standard Deviation
	0.5H	**0.6H**	**0.7H**	**0.8H**	**Average (λ)**	
	0.25	0.25	0.25	0.25	0.25	0

Computations:

$$\varsigma = \left(\frac{1}{\lambda}\right) \qquad \lambda = \frac{Q}{4\pi(T_2 - T_1)} \ln\left(\frac{t_2}{t_1}\right)$$

ς - thermal ressistivity, [m.K / Watts]
λ - thermal conductivity, [Watts / mK]
Q - power consumption of heater wire, [Watts / m]
$T_{1\&2}$ - temperature rise, [°C]
$t_{1\&2}$ - test time, [sec]



SOIL THERMAL RESISTIVITY(100/λ): 404 °C.cm/W

CERTIFICATE OF SOIL THERMAL RESISTIVITY

Owner		**Report No.**	
Contractor		**Date Reported**	5/26/2010
Consultant		**Sample No.**	
Project No.		**Request No.**	-
Project Name		**Client Reference**	-

Material Description	Sandy	**Test Id. No.**	**TR-01**
		Circuit	-
Source	Site	**Span**	-
Test Location	**TR-01**	**Depth @ Test**	1.5m

Test Method	IEEE Std. 442-1981	**Date Tested**	5/19/2010
Test Method Var.	Nil	**Tested By**	
Remarks	-		

Soil Density	
Dry Density@ Test	1.528 g/cm^3
Test Method	ASTM D 1556-07

Moisture Content	
Moisture Con-t@ Test	0.1 %
Test Method	ASTM D 2216-05

Test Results:

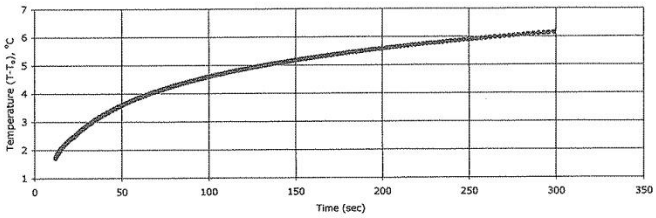
Probe Type	TP07	**Heater Voltage**	3 Volts
Probe Serial #	215	**Initial Temperature**	32.9 °C
Resistance	82.92 Ω / m	**Time**	10:01:18
Cycle Duration (H)	300 sec	**Heating Power (Q)**	4.98 Watts / m

Readings	**Conductivity (Watts / m.K)**					**Standard Deviation**
	0.5H	**0.6H**	**0.7H**	**0.8H**	**Average (λ)**	
	0.28	0.28	0.28	0.28	0.28	0

Computations:

$$\varsigma = \left(\frac{1}{\lambda}\right) \qquad \lambda = \frac{Q}{4\pi\left(T_2 - T_1\right)}\ln\left(\frac{t_2}{t_1}\right)$$

ς - thermal ressistivity, [m.K / Watts]
λ - thermal conductivity, [Watts / mK]
Q - power consumption of heater wire, [Watts / m]
$T_{1\&2}$ - temperature rise, [°C]
$t_{1\&2}$ - test time, [sec]



SOIL THERMAL RESISTIVITY(100/λ): 356 °C.cm/W

CERTIFICATE OF SOIL THERMAL RESISTIVITY

Owner		**Report No.**	
Contractor		**Date Reported**	5/26/2010
Consultant		**Sample No.**	
Project No.		**Request No.**	-
Project Name		**Client Reference**	-

Material Description	Sandy	**Test Id. No.**	**TR-01**
		Circuit	-
Source	Site	**Span**	-
Test Location	**TR-01**	**Depth @ Test**	2.5m

Test Method	IEEE Std. 442-1981	**Date Tested**	5/19/2010
Test Method Var.	Nil	**Tested By**	
Remarks	-		

Soil Density	
Dry Density@ Test	1.516 g/cm^3
Test Method	ASTM D 1556-07

Moisture Content	
Moisture Con-t@ Test	0.2 %
Test Method	ASTM D 2216-05

Test Results:

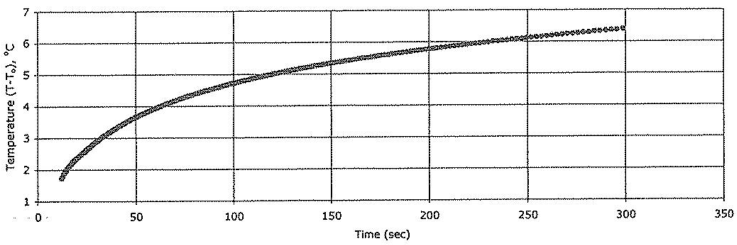
Probe Type	TP07	**Heater Voltage**	3 Volts
Probe Serial #	215	**Initial Temperature**	33.6 °C
Resistance	82.92 Ω / m	**Time**	10:08:38
Cycle Duration (H)	300 sec	**Heating Power (Q)**	4.98 Watts / m

Readings	**Conductivity (Watts / m.K)**					**Standard Deviation**
	0.5H	**0.6H**	**0.7H**	**0.8H**	**Average (λ)**	
	0.26	0.26	0.26	0.26	0.26	0

Computations:

$$\varsigma = \left(\frac{1}{\lambda}\right) \qquad \lambda = \frac{Q}{4\pi(T_2 - T_1)}\ln\left(\frac{t_2}{t_1}\right)$$

ς - thermal ressistivity, [m.K / Watts]
λ - thermal conductivity, [Watts / mK]
Q - power consumption of heater wire, [Watts / m]
$T_{1\&2}$ - temperature rise, [°C]
$t_{1\&2}$ - test time, [sec]



SOIL THERMAL RESISTIVITY(100/λ): 388 °C.cm/W

Appendix B

Daily \mean Temperature (C^o) Buhamra Period: 2003-2010 (National center for metrology and seismology NCM)

Table B 1 Daily mean temperatures from Bu Humra station

Station	Month	Day	Mean Temperature Daily (C°)
Buhamra	1	1	17.3
Buhamra	1	2	17.4
Buhamra	1	3	17.5
Buhamra	1	4	17.6
Buhamra	1	5	17.4
Buhamra	1	6	17.1
Buhamra	1	7	17.1
Buhamra	1	8	17.3
Buhamra	1	9	17.6
Buhamra	1	10	17.8
Buhamra	1	11	18.0
Buhamra	1	12	18.3
Buhamra	1	13	18.8
Buhamra	1	14	18.4
Buhamra	1	15	16.6
Buhamra	1	16	16.0
Buhamra	1	17	16.5
Buhamra	1	18	16.2
Buhamra	1	19	16.2
Buhamra	1	20	16.4
Buhamra	1	21	17.8
Buhamra	1	22	18.6
Buhamra	1	23	18.3
Buhamra	1	24	17.3
Buhamra	1	25	17.4
Buhamra	1	26	18.2
Buhamra	1	27	17.6
Buhamra	1	28	17.6
Buhamra	1	29	17.5
Buhamra	1	30	17.6
Buhamra	1	31	18.4
Buhamra	2	1	19.2
Buhamra	2	2	19.3
Buhamra	2	3	20.2
Buhamra	2	4	21.1
Buhamra	2	5	19.7
Buhamra	2	6	19.4
Buhamra	2	7	19.6
Buhamra	2	8	18.6
Buhamra	2	9	18.6
Buhamra	2	10	19.0
Buhamra	2	11	20.1
Buhamra	2	12	20.3
Buhamra	2	13	21.2
Buhamra	2	14	21.6

Station	Month	Day	Mean Temperature Daily (C°)
Buhamra	7	2	35.4
Buhamra	7	3	35.4
Buhamra	7	4	35.9
Buhamra	7	5	36.0
Buhamra	7	6	35.9
Buhamra	7	7	35.6
Buhamra	7	8	35.5
Buhamra	7	9	35.9
Buhamra	7	10	36.3
Buhamra	7	11	36.4
Buhamra	7	12	37.3
Buhamra	7	13	38.1
Buhamra	7	14	37.8
Buhamra	7	15	36.5
Buhamra	7	16	36.0
Buhamra	7	17	35.9
Buhamra	7	18	36.1
Buhamra	7	19	36.1
Buhamra	7	20	36.4
Buhamra	7	21	37.3
Buhamra	7	22	37.5
Buhamra	7	23	37.5
Buhamra	7	24	37.7
Buhamra	7	25	36.5
Buhamra	7	26	36.4
Buhamra	7	27	37.0
Buhamra	7	28	37.3
Buhamra	7	29	37.4
Buhamra	7	30	36.3
Buhamra	7	31	37.0
Buhamra	8	1	37.1
Buhamra	8	2	37.4
Buhamra	8	3	38.0
Buhamra	8	4	37.9
Buhamra	8	5	37.8
Buhamra	8	6	37.6
Buhamra	8	7	37.7
Buhamra	8	8	37.1
Buhamra	8	9	37.1
Buhamra	8	10	37.3
Buhamra	8	11	37.3
Buhamra	8	12	37.2
Buhamra	8	13	36.8
Buhamra	8	14	36.7
Buhamra	8	15	37.0

Station	Month	Day	Mean Temperature Daily (C^0)
Buhamra	2	15	21.7
Buhamra	2	16	20.6
Buhamra	2	17	19.7
Buhamra	2	18	19.4
Buhamra	2	19	20.7
Buhamra	2	20	21.4
Buhamra	2	21	20.7
Buhamra	2	22	21.7
Buhamra	2	23	22.5
Buhamra	2	24	22.0
Buhamra	2	25	22.1
Buhamra	2	26	23.1
Buhamra	2	27	22.4
Buhamra	2	28	21.1
Buhamra	2	29	18.8
Buhamra	3	1	20.6
Buhamra	3	2	19.9
Buhamra	3	3	19.9
Buhamra	3	4	20.3
Buhamra	3	5	20.7
Buhamra	3	6	20.9
Buhamra	3	7	21.8
Buhamra	3	8	22.2
Buhamra	3	9	23.5
Buhamra	3	10	25.2
Buhamra	3	11	24.5
Buhamra	3	12	24.7
Buhamra	3	13	25.2
Buhamra	3	14	25.3
Buhamra	3	15	25.1
Buhamra	3	16	24.5
Buhamra	3	17	24.6
Buhamra	3	18	25.1
Buhamra	3	19	26.8
Buhamra	3	20	25.8
Buhamra	3	21	24.0
Buhamra	3	22	23.7
Buhamra	3	23	25.0
Buhamra	3	24	25.3
Buhamra	3	25	26.0
Buhamra	3	26	26.6
Buhamra	3	27	27.2
Buhamra	3	28	26.5
Buhamra	3	29	25.8
Buhamra	3	30	26.0

Station	Month	Day	Mean Temperature Daily (C^0)
Buhamra	8	16	37.6
Buhamra	8	17	38.0
Buhamra	8	18	37.6
Buhamra	8	19	37.0
Buhamra	8	20	36.9
Buhamra	8	21	36.5
Buhamra	8	22	37.1
Buhamra	8	23	36.8
Buhamra	8	24	36.5
Buhamra	8	25	36.4
Buhamra	8	26	36.2
Buhamra	8	27	36.2
Buhamra	8	28	36.8
Buhamra	8	29	36.6
Buhamra	8	30	36.3
Buhamra	8	31	35.9
Buhamra	9	1	35.6
Buhamra	9	2	35.6
Buhamra	9	3	35.0
Buhamra	9	4	35.2
Buhamra	9	5	34.8
Buhamra	9	6	34.7
Buhamra	9	7	34.8
Buhamra	9	8	34.7
Buhamra	9	9	34.5
Buhamra	9	10	34.0
Buhamra	9	11	34.2
Buhamra	9	12	34.3
Buhamra	9	13	34.3
Buhamra	9	14	34.4
Buhamra	9	15	33.5
Buhamra	9	16	33.1
Buhamra	9	17	33.5
Buhamra	9	18	33.4
Buhamra	9	19	33.3
Buhamra	9	20	33.1
Buhamra	9	21	33.4
Buhamra	9	22	33.0
Buhamra	9	23	32.6
Buhamra	9	24	32.3
Buhamra	9	25	32.6
Buhamra	9	26	32.7
Buhamra	9	27	31.9
Buhamra	9	28	31.5
Buhamra	9	29	31.2

Station	Month	Day	Mean Temperature Daily (C⁰)	Station	Month	Day	Mean Temperature Daily (C⁰)
Buhamra	3	31	27.0	Buhamra	9	30	31.0
Buhamra	4	1	27.5	Buhamra	10	1	31.4
Buhamra	4	2	26.6	Buhamra	10	2	31.8
Buhamra	4	3	26.7	Buhamra	10	3	31.3
Buhamra	4	4	27.6	Buhamra	10	4	31.2
Buhamra	4	5	27.9	Buhamra	10	5	30.9
Buhamra	4	6	27.3	Buhamra	10	6	30.6
Buhamra	4	7	27.4	Buhamra	10	7	30.3
Buhamra	4	8	27.6	Buhamra	10	8	30.6
Buhamra	4	9	28.3	Buhamra	10	9	30.6
Buhamra	4	10	28.5	Buhamra	10	10	30.9
Buhamra	4	11	28.7	Buhamra	10	11	31.0
Buhamra	4	12	29.5	Buhamra	10	12	30.7
Buhamra	4	13	28.9	Buhamra	10	13	30.4
Buhamra	4	14	27.9	Buhamra	10	14	29.8
Buhamra	4	15	27.2	Buhamra	10	15	29.7
Buhamra	4	16	28.8	Buhamra	10	16	29.7
Buhamra	4	17	28.7	Buhamra	10	17	29.8
Buhamra	4	18	28.6	Buhamra	10	18	29.4
Buhamra	4	19	28.2	Buhamra	10	19	29.1
Buhamra	4	20	28.6	Buhamra	10	20	28.6
Buhamra	4	21	28.8	Buhamra	10	21	28.4
Buhamra	4	22	28.1	Buhamra	10	22	28.3
Buhamra	4	23	29.3	Buhamra	10	23	28.6
Buhamra	4	24	30.4	Buhamra	10	24	28.6
Buhamra	4	25	31.2	Buhamra	10	25	28.3
Buhamra	4	26	31.9	Buhamra	10	26	28.4
Buhamra	4	27	31.1	Buhamra	10	27	28.4
Buhamra	4	28	31.1	Buhamra	10	28	28.1
Buhamra	4	29	30.8	Buhamra	10	29	28.1
Buhamra	4	30	32.0	Buhamra	10	30	27.8
Buhamra	5	1	32.0	Buhamra	10	31	27.5
Buhamra	5	2	32.2	Buhamra	11	1	27.5
Buhamra	5	3	32.1	Buhamra	11	2	27.7
Buhamra	5	4	32.4	Buhamra	11	3	27.6
Buhamra	5	5	32.7	Buhamra	11	4	27.1
Buhamra	5	6	31.8	Buhamra	11	5	26.7
Buhamra	5	7	30.7	Buhamra	11	6	26.2
Buhamra	5	8	31.4	Buhamra	11	7	26.1
Buhamra	5	9	32.7	Buhamra	11	8	26.3
Buhamra	5	10	33.2	Buhamra	11	9	26.3
Buhamra	5	11	33.7	Buhamra	11	10	25.3
Buhamra	5	12	34.5	Buhamra	11	11	25.1
Buhamra	5	13	34.6	Buhamra	11	12	24.6
Buhamra	5	14	33.4	Buhamra	11	13	24.9

Station	Month	Day	Mean Temperature Daily (C⁰)
Buhamra	5	15	33.7
Buhamra	5	16	33.7
Buhamra	5	17	33.4
Buhamra	5	18	33.0
Buhamra	5	19	33.3
Buhamra	5	20	33.7
Buhamra	5	21	34.0
Buhamra	5	22	33.4
Buhamra	5	23	34.2
Buhamra	5	24	34.2
Buhamra	5	25	34.3
Buhamra	5	26	34.7
Buhamra	5	27	34.9
Buhamra	5	28	34.9
Buhamra	5	29	35.2
Buhamra	5	30	35.3
Buhamra	5	31	34.8
Buhamra	6	1	34.3
Buhamra	6	2	34.7
Buhamra	6	3	35.1
Buhamra	6	4	34.8
Buhamra	6	5	35.0
Buhamra	6	6	35.2
Buhamra	6	7	34.4
Buhamra	6	8	34.7
Buhamra	6	9	34.5
Buhamra	6	10	34.3
Buhamra	6	11	34.2
Buhamra	6	12	34.7
Buhamra	6	13	34.7
Buhamra	6	14	35.3
Buhamra	6	15	36.1
Buhamra	6	16	36.2
Buhamra	6	17	36.3
Buhamra	6	18	36.5
Buhamra	6	19	36.2
Buhamra	6	20	35.6
Buhamra	6	21	36.2
Buhamra	6	22	36.3
Buhamra	6	23	36.0
Buhamra	6	24	35.7
Buhamra	6	25	35.3
Buhamra	6	26	35.1
Buhamra	6	27	35.4
Buhamra	6	28	35.7
Buhamra	6	29	35.7
Buhamra	6	30	35.7
Buhamra	7	1	35.7

Station	Month	Day	Mean Temperature Daily (C⁰)
Buhamra	11	14	24.7
Buhamra	11	15	24.7
Buhamra	11	16	24.4
Buhamra	11	17	23.9
Buhamra	11	18	23.5
Buhamra	11	19	23.6
Buhamra	11	20	23.9
Buhamra	11	21	23.7
Buhamra	11	22	23.6
Buhamra	11	23	23.5
Buhamra	11	24	22.9
Buhamra	11	25	22.6
Buhamra	11	26	22.2
Buhamra	11	27	22.1
Buhamra	11	28	22.0
Buhamra	11	29	21.8
Buhamra	11	30	21.5
Buhamra	12	1	21.8
Buhamra	12	2	20.8
Buhamra	12	3	20.1
Buhamra	12	4	20.0
Buhamra	12	5	20.4
Buhamra	12	6	20.5
Buhamra	12	7	20.8
Buhamra	12	8	21.2
Buhamra	12	9	20.6
Buhamra	12	10	20.0
Buhamra	12	11	20.2
Buhamra	12	12	19.8
Buhamra	12	13	20.3
Buhamra	12	14	19.8
Buhamra	12	15	19.3
Buhamra	12	16	19.7
Buhamra	12	17	19.6
Buhamra	12	18	18.8
Buhamra	12	19	18.0
Buhamra	12	20	18.1
Buhamra	12	21	18.3
Buhamra	12	22	18.6
Buhamra	12	23	18.6
Buhamra	12	24	18.8
Buhamra	12	25	18.9
Buhamra	12	26	18.3
Buhamra	12	27	17.1
Buhamra	12	28	17.5
Buhamra	12	29	17.1
Buhamra	12	30	16.9
Buhamra	12	31	16.6

Appendix C

Walls, roof and ground floors temperatures calculated from equation (5) for roof and ground floor slab & equation (7) for underground walls

Table C 1 Underground roof temperature from equation (5)

	Day in equation	Day in calendar	Underground roofs temperatures C°				
			X= 0 Roof level =1.5m	X=0 Roof level =0m	X= -0.5m	X= -1.5m	X= -3m
March	77	18	Roof above ground and exposed to external (From weather file)	Roof above ground and exposed to external (From weather file)	19.40	25.10	28.60
	78	19			19.40	25.00	28.60
	79	20			19.50	25.00	28.60
	80	21			19.50	25.00	28.60
	81	22			19.60	24.90	28.50
	82	23			19.60	24.90	28.50
	83	24			19.70	24.90	28.50
June	169	18	Roof above ground and exposed to external (From weather file)	Roof above ground and exposed to external (From weather file)	31.00	26.20	27.30
	170	19			31.10	26.20	27.30
	171	20			31.30	26.30	27.30
	172	21			31.50	26.30	27.30
	173	22			31.60	26.40	27.30
	174	23			31.80	26.50	27.30
	175	24			31.90	26.50	27.30
September	261	18	Roof above ground and exposed to external (From weather file)	Roof above ground and exposed to external (From weather file)	37.10	31.60	28.00
	262	19			37.10	31.60	28.00
	263	20			37.00	31.60	28.00
	264	21			37.00	31.70	28.00
	265	22			36.90	31.70	28.00
	266	23			36.80	31.70	28.10
	267	24			36.80	31.70	28.10
December	352	18	Roof above ground and exposed to external (From weather file)	Roof above ground and exposed to external (From weather file)	25.50	30.40	29.30
	353	19			25.30	30.30	29.30
	354	20			25.20	30.30	29.30
	355	21			25.00	30.20	29.30
	356	22			24.90	30.20	29.30
	357	23			24.70	30.10	29.30
	358	24			24.60	30.00	29.30

x= depth, a= upper wall depth, b= lower wall depth

Table C 2 Underground walls temperature from equation (8)

Period	Day in equation	Day in calendar	Underground walls temperatures C°				
			X=0 a=0, b=1.5	X=0 a=0, b=3	X=0.5 a=0.5, b=3.5	X=1.5 a=1.5, 0=4.5	X=3 a=3, b=6
March	77	18	21.90	24.40	25.70	27.70	28.50
	78	19	22.00	24.40	25.70	27.70	28.50
	79	20	22.00	24.40	25.60	27.70	28.50
	80	21	22.10	24.40	25.60	27.70	28.50
	81	22	22.20	24.50	25.60	27.60	28.50
	82	23	22.30	24.50	25.60	27.60	28.50
	83	24	23.40	24.50	25.60	27.60	28.50
June	169	18	32.30	29.60	28.00	27.40	28.10
	170	19	32.40	29.70	28.00	27.40	28.10
	171	20	32.50	29.70	28.00	27.40	28.10
	172	21	32.60	29.80	28.10	27.40	28.10
	173	22	32.70	29.90	28.20	27.40	28.10
	174	23	32.80	30.00	28.20	27.40	28.10
	175	24	32.90	30.00	28.30	27.40	28.10
September	261	18	34.60	32.20	30.90	28.90	28.10
	262	19	34.50	32.10	30.90	28.90	28.10
	263	20	34.40	32.10	30.90	28.90	28.10
	264	21	34.30	32.10	30.90	28.90	28.10
	265	22	34.30	32.10	30.90	29.00	28.10
	266	23	34.20	32.00	30.90	29.00	28.10
	267	24	34.10	32.00	30.90	29.00	28.10
December	352	18	24.20	26.90	28.60	29.20	28.50
	353	19	24.10	26.90	28.50	29.20	28.50
	354	20	24.00	26.80	28.50	29.20	28.50
	355	21	23.90	26.70	28.40	29.20	28.50
	356	22	23.80	26.70	28.40	29.10	28.50
	357	23	23.70	26.60	28.30	29.10	28.50
	358	24	23.60	26.50	28.30	29.10	28.50

x= depth, a= upper wall depth, b= lower wall depth

Table C 3 Underground floors temperature from equation (8)

	Day in equation	Day in calendar	Underground floor temperatures C°				
			X=0 Floor level = -1.5m	X=0 Floor level = -3m	X=0.5 Floor level = -3.5m	X=1.5 Floor level = -4.5m	X=3 Floor level = -6m
March	77	18	25.10	28.60	28.70	28.60	28.30
	78	19	25.00	28.60	28.80	28.60	28.30
	79	20	25.00	28.60	28.80	28.60	28.30
	80	21	25.00	28.60	28.70	28.60	28.30
	81	22	24.90	28.50	28.70	28.60	28.30
	82	23	24.90	28.50	28.70	28.60	28.30
	83	24	24.90	28.50	28.70	28.60	28.30
June	169	18	26.20	27.30	27.80	28.30	28.40
	170	19	26.20	27.30	27.80	28.30	28.40
	171	20	26.30	27.30	27.80	28.30	28.40
	172	21	26.30	27.30	27.80	28.30	28.30
	173	22	26.40	27.30	27.80	28.30	28.30
	174	23	26.50	27.30	27.70	28.30	28.30
	175	24	26.50	27.30	27.70	28.30	28.30
September	261	18	31.60	28.00	27.80	28.00	28.30
	262	19	31.60	28.00	27.80	28.00	28.30
	263	20	31.60	28.00	27.80	28.00	28.30
	264	21	31.70	28.00	27.80	28.00	28.30
	265	22	31.70	28.00	27.80	28.00	28.30
	266	23	31.70	28.10	27.90	28.00	28.30
	267	24	31.70	28.10	27.90	28.00	28.30
December	352	18	30.40	29.30	28.80	28.30	28.20
	353	19	30.30	29.30	28.80	28.30	28.20
	354	20	30.30	29.30	28.80	28.30	28.20
	355	21	30.20	29.30	28.80	28.30	28.20
	356	22	30.20	29.30	28.80	28.30	28.20
	357	23	30.10	29.30	28.80	28.30	28.20
	358	24	30.00	29.30	28.80	28.30	28.20

x= depth, a= upper wall depth, b= lower wall depth

Appendix D

Tabulated percentages result of energy savings with the addition of thermal insulation.

Table D 1 The percentage of energy saving in cooling load using 5, 10, 20 and 30cm thick of thermal insulation

Space configuration	Insulation thickness	March 18th-24th	June 18th-24th	Sept. 18th-24th	Dec. 18th-24th
0-1.5m Semi underground	5cm	+1.4%	-6.2%	-12.7%	-23.5%
	10cm	+1.4%	-7.2%	-14.9%	-28.0%
	20cm	+2.2%	-7.8%	-16.4%	-30.0%
	30cm	+1.4%	-8.1%	-17.0%	-32.2%
0-3m Surface underground	5cm	-6.3%	-6.9%	-10.8%	-15.4%
	10cm	-7.7%	-8.1%	-12.7%	-18.6%
	20cm	-8.1%	-8.8%	-13.8%	-19.9%
	30cm	-9.0%	-9.2%	-14.4%	-21.5%
0.5-3.5m Underground	5cm	-0.5%	-24.8%	-24.4%	-20.5%
	10cm	-1.7%	-29.6%	-31.3%	-24.8%
	20cm	-2.7%	-32.8%	-35.9%	-27.8%
	30cm	-3.2%	-38.2%	-40.5%	-34.3%
1.5-4.5m Underground	5cm	-14.0%	14.1%	-22.6%	-21.7%
	10cm	-17.1%	-17.0%	-26.9%	-26.0%
	20cm	-18.8%	-18.6%	-29.3%	-28.8%
	30cm	-20.2%	-19.8%	-30.8%	-29.9%
3-6m Underground	5cm	-25.5%	-20.0%	-21.1%	-26.4%
	10cm	-30.6%	-24.1%	-25.3%	-31.6%
	20cm	-33.5%	-26.4%	-27.7%	-34.6%
	30cm	-35.4%	-27.9%	-29.2%	-36.5%

Appendix E

Tabulated results of illiminance from 3m light pipe for four periods, 18th - 24th March, 18th -24th June, 18th -24th September and 18th -24th December.

Table E 1 Illuminance of 3m light pipe for March and June period

time	Illuminance (lux)													
	March							June						
	18 March	19 March	20 March	21 March	22 March	23 March	24 March	18 June	19 June	20 June	21 June	22 June	23 June	24 June
06:00	5	5	6	6	7	7	8	38	37	37	37	37	38	37
07:00	51	52	53	55	56	57	58	116	115	115	115	114	114	113
08:00	139	141	143	145	147	149	152	213	213	213	213	212	212	211
09:00	238	240	242	244	246	248	250	306	305	305	305	305	304	304
10:00	317	320	322	324	326	328	330	383	383	383	382	382	382	381
11:00	369	372	374	375	377	380	382	502	501	500	498	497	496	496
12:00	382	383	385	386	389	392	393	617	621	624	627	629	632	634
13:00	348	351	353	354	355	356	358	406	406	406	406	406	406	406
14:00	284	285	285	288	289	290	291	327	327	328	329	329	329	329
15:00	193	194	195	196	197	199	199	239	240	241	241	241	241	242
16:00	95	96	97	97	98	98	99	141	141	142	142	142	143	143
17:00	23	23	24	24	24	25	25	55	55	55	55	56	56	56

Table E 2 Illuminance of 3m light pipe for September and December period

time	Illuminance (lux)													
	September							December						
	18 September	19 September	20 September	21 September	22 September	23 September	24 September	18 December	19 December	20 December	21 December	22 December	23 December	24 December
06:00	14	14	14	14	13	13	13	0	0	0	0	0	0	0
07:00	76	75	75	74	73	73	72	20	19	19	19	19	18	18
08:00	171	171	170	169	168	167	167	75	74	73	73	73	72	72
09:00	266	265	264	263	262	261	260	146	145	145	144	143	143	143
10:00	340	339	338	336	335	334	333	208	207	207	206	206	205	205
11:00	385	382	380	379	378	376	374	242	241	241	241	241	241	241
12:00	385	384	381	380	378	375	373	244	244	244	244	244	244	245
13:00	343	341	339	338	335	333	331	213	213	213	214	214	214	215
14:00	270	268	266	264	262	260	257	155	155	156	157	156	158	158
15:00	177	174	173	170	168	166	164	83	84	84	85	85	86	86
16:00	80	79	77	75	73	72	70	25	25	25	26	26	26	27
17:00	16	15	15	14	13	13	12	0	0	0	0	0	0	0

Appendix F

Snap shots from IES-VE simulation showing the cooling load at 18th-24th of March, June, September and December for above ground base case, semi underground, surface underground, 0.5-3.5m underground, 1.5-3.5m underground and 3.0-6.0m underground configurations. The graphs include the addition of 5, 10, 20 and 30cm thermal simulation.

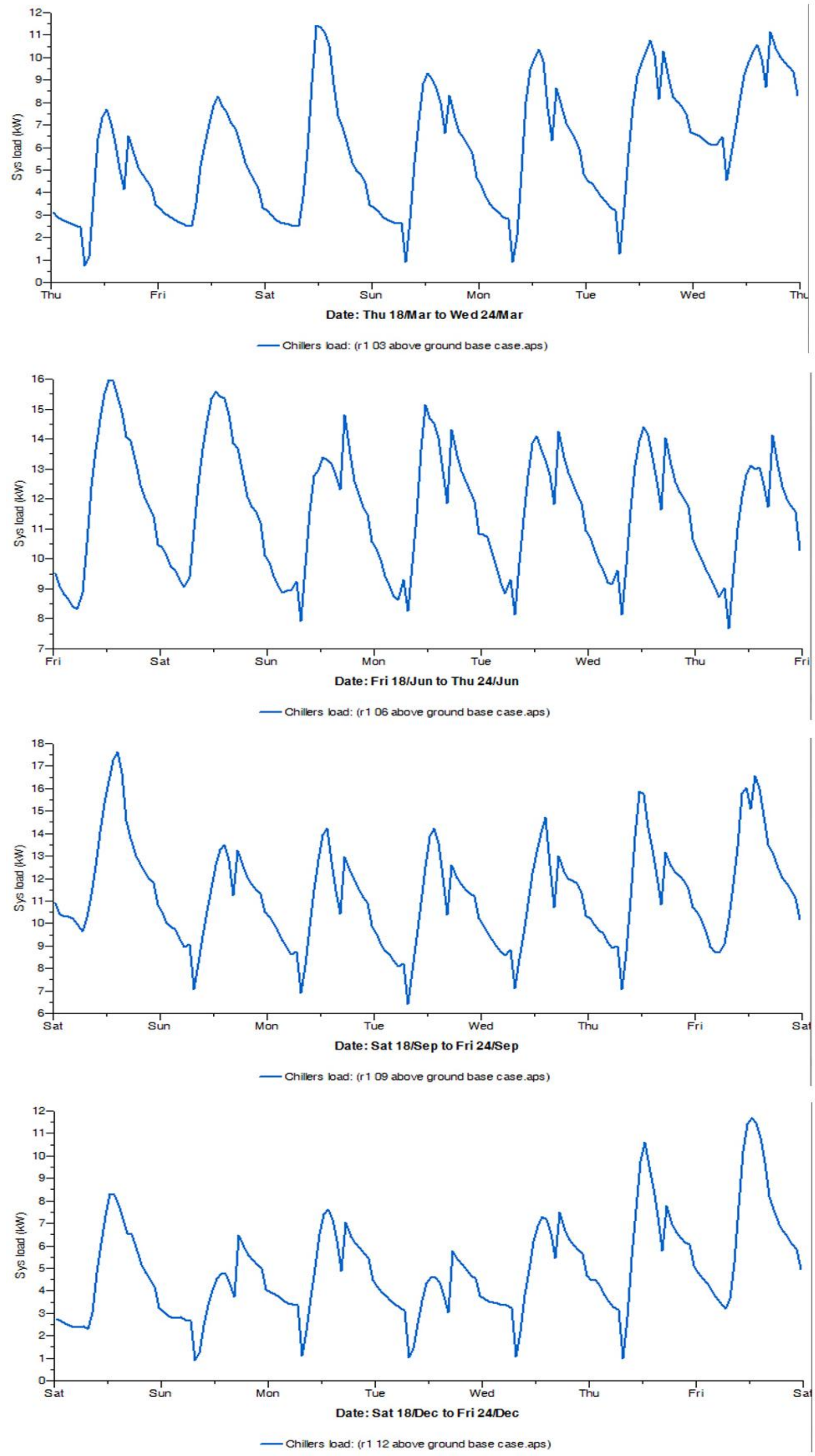


Figure F 1 Cooling load for above ground base case from 18th-24th March, April, September and December

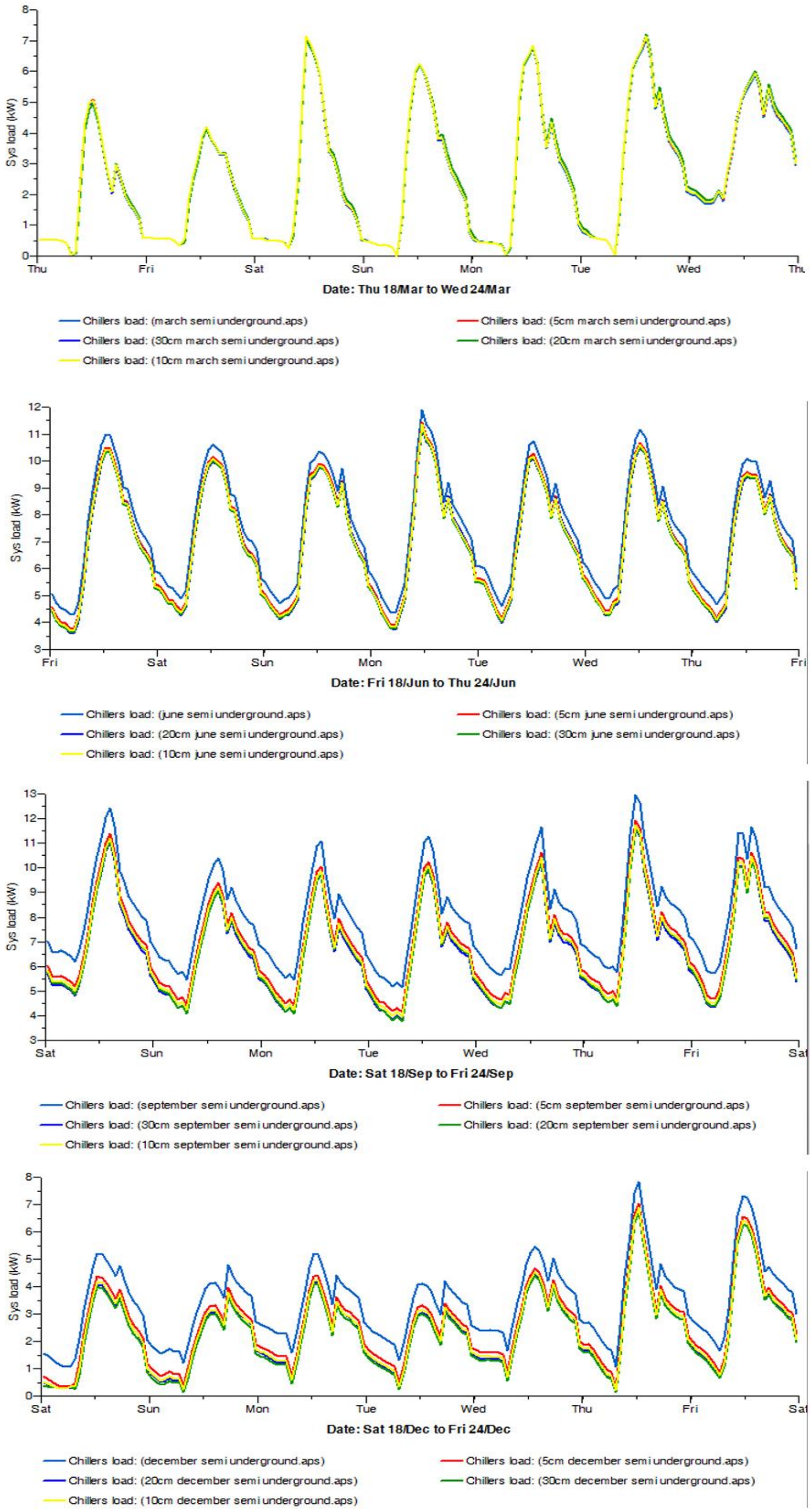


Figure F 2 Cooling load for semi underground configuration from 18th-24th March, April, September and December with 5, 10, 20 and 30cm thermal insulation

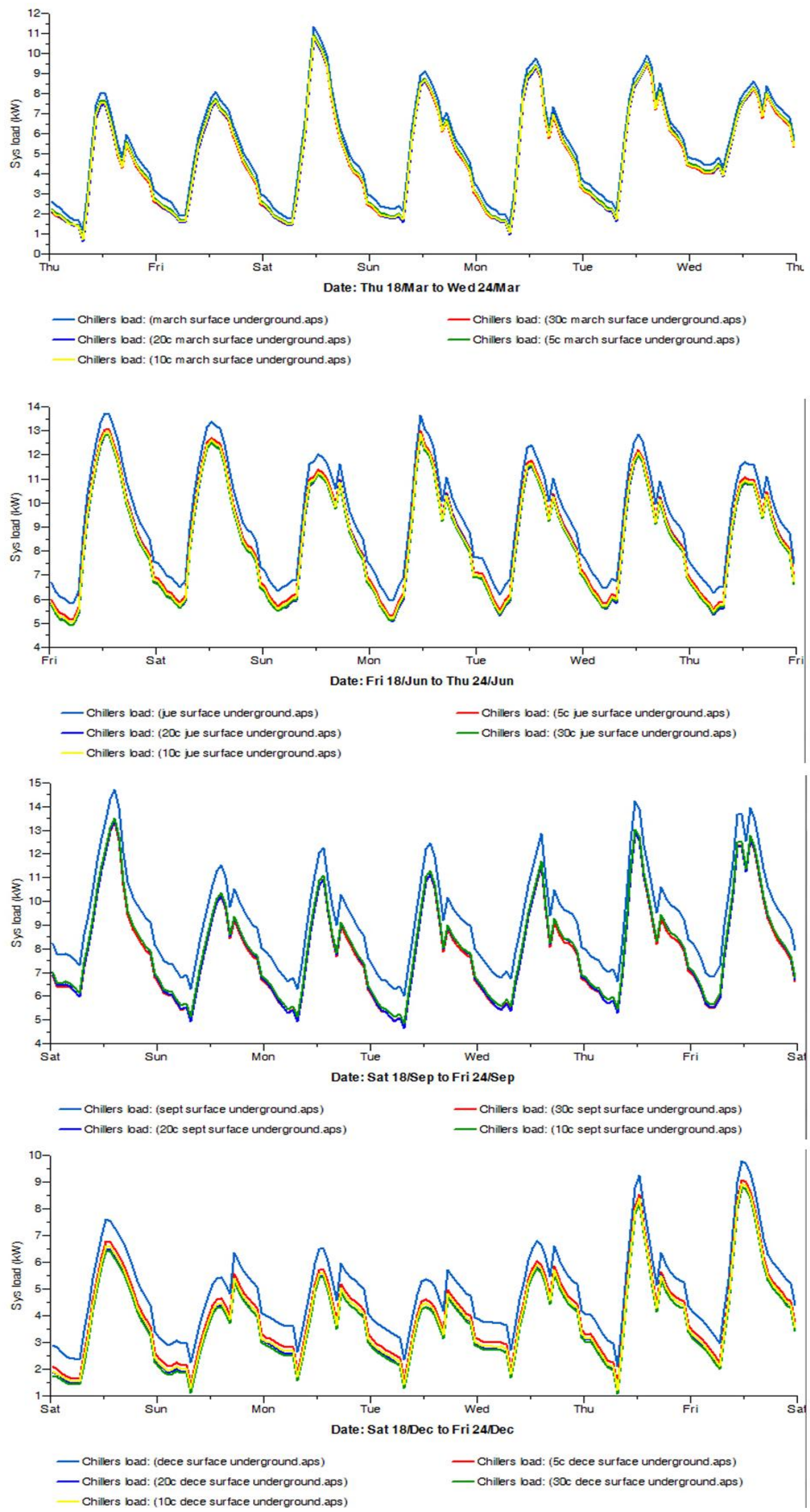


Figure F 3 Cooling load for 0-3.0m underground configuration from 18th-24th March, April, September and December with 5, 10, 20 and 30cm thermal insulation

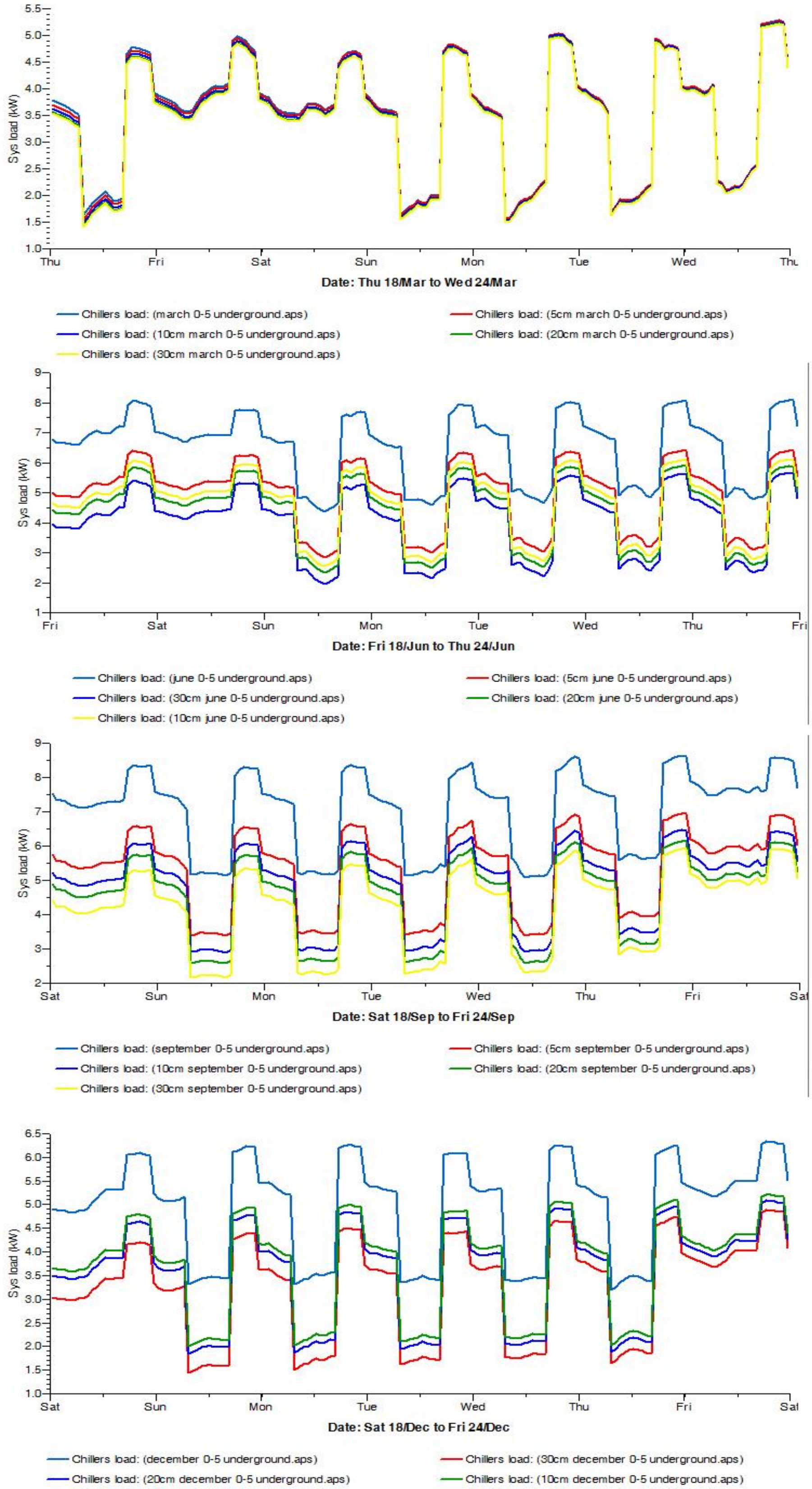


Figure F 4 Cooling load for 0.5-3.5m underground configuration from 18th-24th March, April, September and December with 5, 10, 20 and 30cm thermal insulation

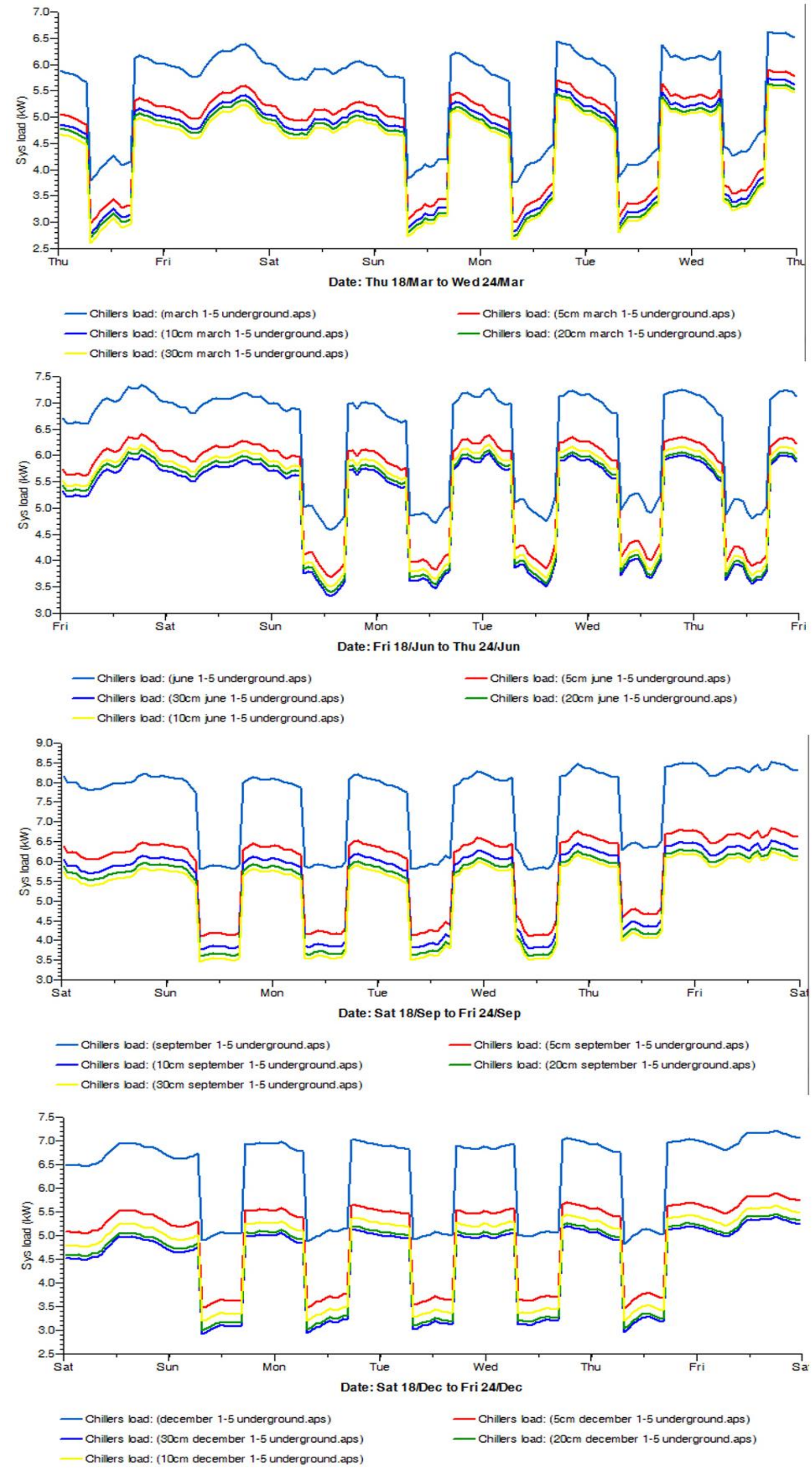


Figure F 5 Cooling load for 1.5-4.5m underground configuration from 18th-24th March, April, September and December with 5, 10, 20 and 30cm thermal insulation

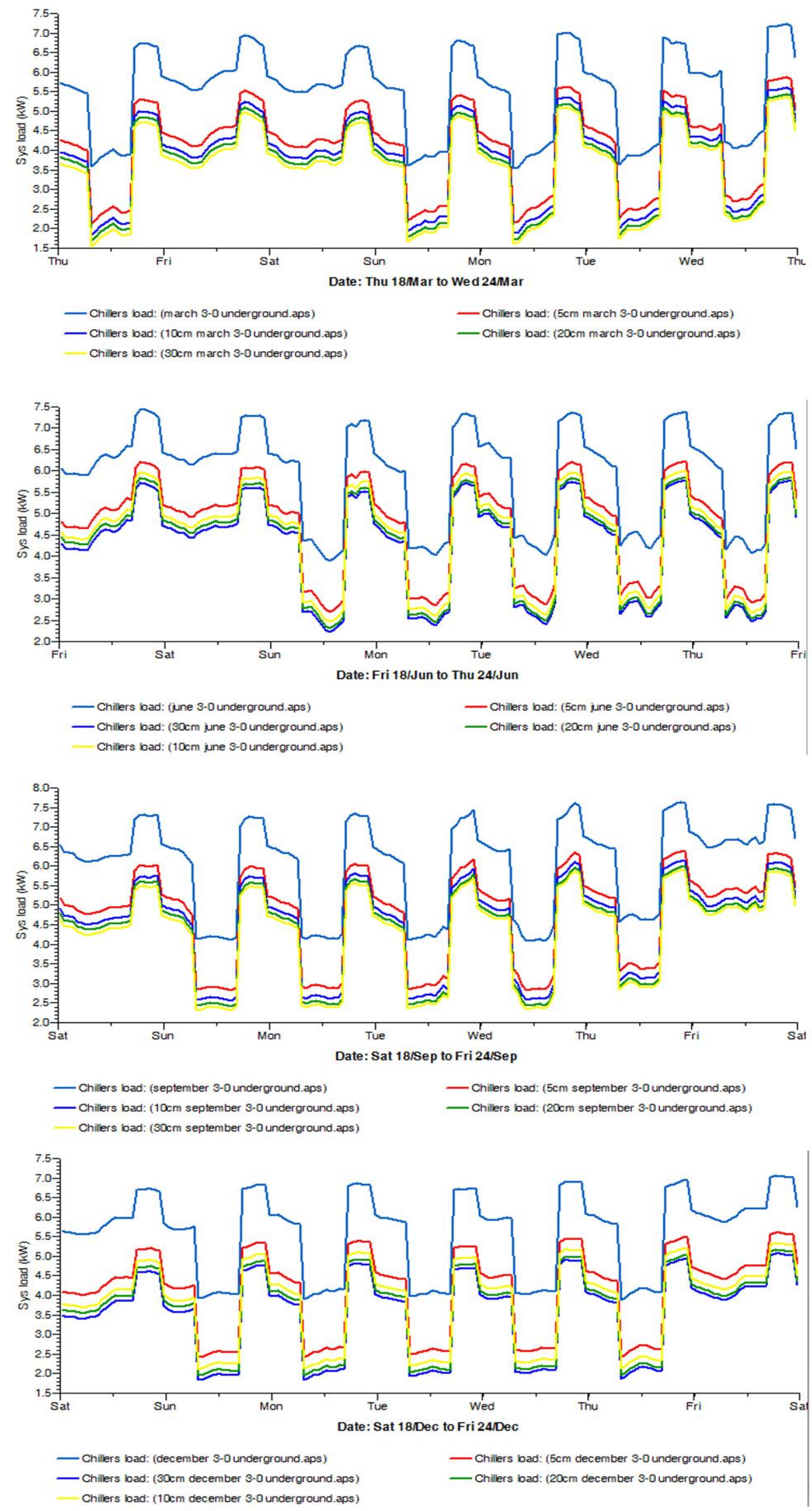


Figure F 6 Cooling load for 1.5-4.5m underground configuration from 18th-24th March, April, September and December with 5, 10, 20 and 30cm thermal insulation