How effective are earth tube systems in delivering net positive human well-being?

T. J. Butler
Archineers Consulting Ltd, Kelowna, BC, Canada

J. R. Littlewood
Cardiff Metropolitan University, Wales, UK

A. Geens
Chartered Institution of Building Services Engineers, UK

ABSTRACT: This paper will review building usage and present research carried out on health studies of buildings and occupants, in the context of standards of indoor environmental quality (IEQ). Through the investigation of conventional building heating, ventilation and air-conditioning (HVAC) systems, the performance and effectiveness of supplying fresh air – at prescribed air change rates – will be reported through case study review. The methods of earth coupling will be presented – drawing from the author's own projects in BC – and other projects in different climatic zones. The data gathered from monitoring of the earth tubes systems – including temperature, humidity and energy – will be presented and discussed in the context of net-positive healthier buildings. The paper will also acknowledge where further system analysis and modification may be required to provide fuller assurance that earth tube systems can deliver higher performance buildings that are net-positive with respect to human well-being.

Keywords: Earth tubes; net-positive; healthy; IEQ; sustainability; ventilation; well-being

1. INTRODUCTION

The paper will begin with a review of the way in which buildings are being designed, constructed and operated with respect to providing healthy internal environments for occupants. Reference will be made to published industry standards and recommendations associated with indoor environmental quality (IEQ). Specific focus will be made to air quality, CO_2 concentrations, humidity, moisture and mould.

In order to set a baseline for review, conventional engineered systems that provide heating, ventilation and air-conditioning (HVAC) will be assessed in terms of design in relation of the IEQ criteria. The author notes that the definition of 'conventional' is too ambiguous – and in his current experience as a practitioner – conventional methods can be used to describe highly energy efficient buildings as well as those that just meet minimal building code compliance. Therefore he will present a range of buildings that have different levels of performance standard and HVAC systems.

The concept of earth tube systems are fairly well known through the construction industry, although in the author's experience, the level of detailed required to implement a fully successful project is often lacking. One of the reasons for this is due to the cross-discipline design that is often led by the mechanical engineer, although the specification is more suited to the civil engineer who is more familiar with buried pipes. Similarly, this disconnect often repeats itself during construction, where the interface between earthwork and mechanical contractor requires a greater level of communication than would be expected on a standard project.

The dry Okanagan climate is ideal for the application of earth coupled ventilation systems to pre-heat/cool the incoming fresh air to a buildings HVAC system. These earth tube systems take a variety of different sizes, and at the Salmon Arm (Savings and Credit Union) building, there are 3no. 750Ø feeder pipes, into a single 1000Ø header. The concrete pipes are buried under the ground slab, with around 6 feet of soil on top (Figure 1).

Figure 1. SASCU earth tube system under construction, 2012.

As well as the coordination issues that need to be addressed, there have also been concerns about the air quality that emerges through the buried ducts – and whether there is a greater risk of mould-borne illness that could arise from condensation of humid air inside the tubes. There have been well-documented cases (Urbana, 2004) where the monitored resultant air quality has been at risk to health, and through investigations, there have been lessons learnt from these examples that should ensure that these mistakes are not repeated.

At the same time there are also monitored reports that show that earth tube systems improve indoor air quality, when compared to conventional systems (Fluckiger et al, 1998). This is especially true in climates that have extremes of temperature that result in high energy costs to condition outside air for ventilation purposes to mitigate health risks and to improve operational effectiveness. This is the goal of this paper, and the stream of the conference – that addresses creating a net positive effect upon health and well-being of building occupants.

Monitored data of earth tube systems from the author's own projects – in British Columbia (BC) will be presented to show the performance over different seasons. There will be specific focus on thermal performance – the delta T (ΔT) of the 'entering' outside air to the 'leaving' supply air to a building's ventilation system. Based on this ΔT, the operational costs will be compared with conventional systems.

Further added benefits will be examined to include, CO_2 concentration, humidity control and mould risk. The findings will indicate that within clear parameters of design, building use and climate, earth tubes systems, when compared to conventional systems, have the potential to provide a net-positive effect to human well-being and health.

The paper will conclude with further ongoing studies that are investigating how performance can be improved that would result in greater enhancement of health and well-being of building occupants.

2. BUILDING USE & HEALTH

2.1 *Occupancy*

One of the emerging trends of the 21st Century is that people are staying inside buildings for longer periods of time. According to Wargocki P, Fanger. O (1999) et al, in the US the occupancy figure is about 90% of the time. The impact of indoor living, is that people inhabit artificial 'man-made' environments for greater periods of time, and the impact upon their physiological needs being adequately met are being under investigation on many fronts both qualitatively and quantitatively.

2.2 *Sick Building Syndrome*

Sick building syndrome (SBS) as a term was first used in the 1980's through the World Health Organisation (WHO 1983 & 1986) and referred to illnesses of occupants of buildings that they worked or lived in. The term is now ubiquitous with any building that occupants do not feel well, and it is important to note that there are definitions that state exactly what is SBS.

2.3 *Indoor Environmental Quality (IEQ)*

The common indicators of performance are categorized through key performance indicators of Indoor Environmental Quality (IEQ) – and this includes cleanliness of air, light, acoustics and temperature. The purpose of this paper is to investigate the role that earth coupled ventilation systems can perform in improving IEQ with specific reference to air quality – through comparison of conventional ventilation systems. The goal is to see whether earth tube systems can provide a better quality of life – net positive in terms of health.

2.4 *Air quality*

The criteria being considered for air quality are measured in terms of concentration of carbon dioxide (CO_2) and humidity. The author recognizes that this limits the research that has been carried out by Fanger et al (1999) – where odor, moisture, Carbon monoxide, formaldehyde and other contaminants are listed. However, the purpose of this paper is to investigate the potential for earth tube systems to deliver an improved, net-positive indoor environment for health.

There are various standards across the world that lists recommended 'safe' concentrations of CO_2 within buildings. These include, World Health Organisation (WHO), American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE), have been researched widely throughout the world. The generally held view is that CO_2 levels should not exceed 600 parts per million. When CO_2 concentrations become too high, the occupants often complain of headaches, drowsiness and in the worst case, the building begins to be labeled as a source of "Sick Building Syndrome", which would result in costly repairs.

3. CONVENTIONAL HVAC

3.1 *Codes of Practice*

The author is a practicing engineer with fourteen years experience in the UK and now working in British Columbia, and since 2008. Through his work as an engineer, he has worked on a wide range of HVAC systems for a variety of building types including offices, hotels, retail, education, industrial and residential. The Codes of Practice for ventilation design are as follows:

- ASHRAE 62.1: Ventilation for Acceptable Indoor Air Quality;
- British Columbia Building Code (BCBC);
- Model National Energy Code for Buildings (MNECB).

The volumes of fresh air requirements are listed in cubic feet per minute (cfm) per person, and for typical buildings such as offices, the volume is 20cfm/person. According to ASHRAE 62.1, this volume of 20cfm per person, "prescribes supply rates of acceptable outdoor air required for acceptable indoor air quality. These values have been chosen to dilute human bioeffluents and other contaminants with an adequate margin of safety and to account for health variations among people and varied activity levels".

This is the volume used generally in the North American industry for design of HVAC systems and it compares well to European Standards of 10 litres per second (l/s) per person (Building Regulations, Part F, 2010).

3.2 *Typical HVAC Design*

The typical HVAC system – as common practice in 2012 – would be to calculate the fresh air requirements based on occupancy or floor area to get a total air supply rate. The next step would be to specify a mechanical air handling unit that is capable of supplying this volume of fresh air the building, whilst taking into account the static pressure losses associated with ductwork, dampers and supply grilles.

The thermal energy required to heat (or cool) the air is provided via heating coils / batteries at the air handling plant, which are served by a variety of thermal sources. These could include gas boilers, heat pumps, district energy or direct expansion (DX) refrigerant coils. The thermal output of the coils must have adequate capacity to meet the thermal demand of heating fresh air through all seasons.

The fresh air, once thermally moderated and supplied to the building occupants, becomes contaminated with the internal environment and must therefore be removed from the building. This is normally provided by a combination of exhaust fans – that draw the air out of the building – and by pressuring the building slightly to allow air to leak through the façade.

Heat recovery systems can be employed to collect the thermal energy on the exhaust air to preheat (or pre-cool) the incoming fresh air. There are a variety of heat recovery units available – with different efficiencies – and their application is becoming more mainstream as part of a drive toward energy efficiency.

4. THE EARTH TUBE SYSTEM

4.1 *Background*

The use of air ducts buried at a depth below the ground surface to moderate air temperatures are fairly well understood – at least in concept. There are examples of this system with origins from the Middle East, China and other locations with strong climatic seasonal variations.

The recent and growing popularity of earth tube in this era began with the work of John Hait in the Rocky Mountain Research Centre, (Hait 1983) on the Geodome house in Minnesota. The author first used the system on a project (Mile End Park) in England in 1998 comprising five earth-sheltered buildings.

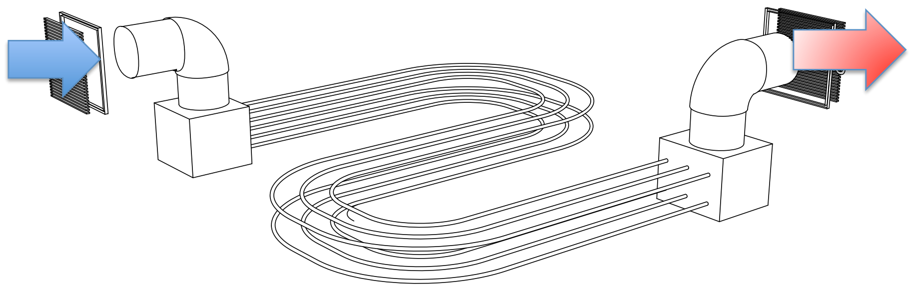


Figure 2: Earth tube system, with multiple pipes.

The principles of the system is that air is drawn through buried pipes in the ground to absorb some degree of the earths thermal energy – that is constant at about 6 feet deep, depending upon a number of criteria including: seasons, geography and geology (Figure 2).

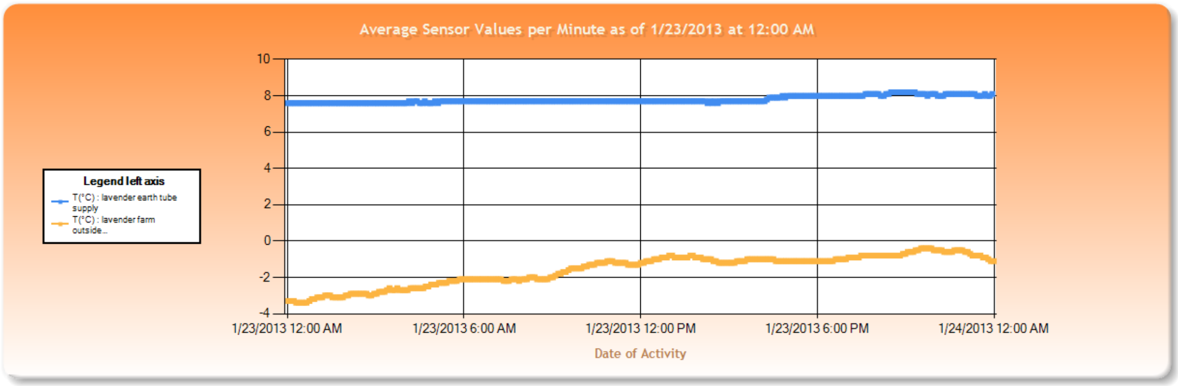
According to Hait (1983), the design of the system is dependant upon climate, soil and velocity. Further research carried out by Jacovides et al (1995) focuses more upon the system characteristics such as the pipe material, length, and diameter.

4.2 *Performance*

The performance of earth tubes for pre-heating/cooling varies from each site and location. For the purpose of this paper, the author has monitored data from two installations in the interior of British Columbia, to use as examples for winter operation. Summer time performance is available for only one of the projects as the sensors were not installed until autumn 2012, and the so the system is being monitored now.

4.3 *Lavender Farm*

The air is drawn though a parallel system of eight, 100mmØ rigid plastic ducts, one hundred feet long each. The air is used for drying lavender and other herbs between harvest and processing. The winter performance for a typical January day is shown in Figure 2.



This shows that temperature difference between outside air and delivered air is between 7-11°C. Another point to note is the steady temperature of the earth tube air supply at around a constant 8°C. The airflow rate is calculated as follows: Q = A * V;

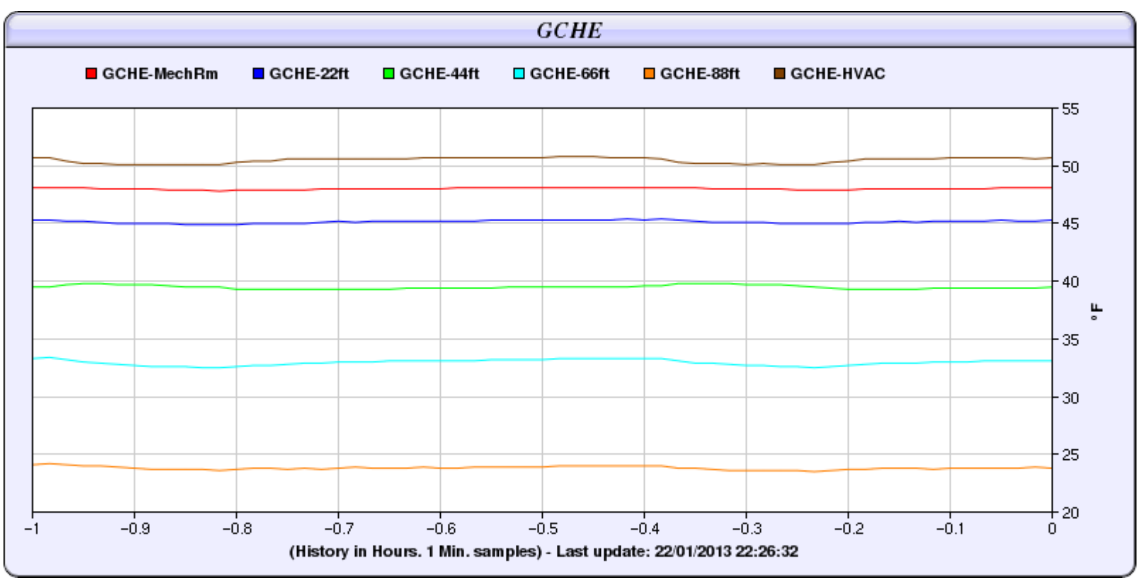
Cross-sectional area = 8 * (π * $(100/2)^2$) = 0.063 m^2

Velocity = 1.5 m/s

Volume = 0.1 m3/s, say 100 l/s

4.4 *Private House*

The air is drawn though a parallel system of seven, 100mmØ rigid plastic ducts, one hundred feet long each. The air is used as preheat to the geoexchange furnace to serve the dwelling. The winter performance for a typical January day is shown in Figure 3.



This shows that temperature difference between outside air and delivered air is between 26-28°F (15°C). Similarly to the Lavender Farm project the steady temperature of the earth tube air supply at around a constant 51°F (10.5°C). The airflow rate is calculated as follows: Q = A * V;

Cross-sectional area = $7 * (\pi * (100/2)^2) = 0.055\ m^2$

Velocity = 1.5 m/s

Volume = 0.08 m3/s, say 82 l/s

5 COMPARATIVE PERFORMANCE

5.1 *Conventional vs Earth Tubes*

The results show that for two different cases in the BC interior, a temperature difference (ΔT) of between 10°C and 15°C can be expected on the fresh air supply in winter, by passing the fresh air supply through the earth tube system (Table 1).

	Outside Air Temperature °C	**On-coil Temperature °C**	**Off-coil Temperature °C**	**ΔT °C**	**Heating Energy**
Conventional System	**-3 °C**	**-3 °C**	**24 °C**	**27 °C**	**100%**
Lavender Farm	**-3 °C**	**7 °C**	**24 °C**	**17 °C**	**63%**
Private House	**-3 °C**	**12 °C**	**24 °C**	**12 °C**	**44%**

Table 1.

The two earth tube systems show that there are significant energy savings available. The Lavender Farm saves, 37% and the Private House saves 56% of heating energy to bring the outside air up to an off-coil temperature of 24°C.

5.2 *Added benefits*

The off-coil temperature is observed at being relatively constant with respect to the outside air temperature. This means that when the temperature drops lower, then the ΔT will increase, and hence the heating energy savings will be greater.
The goal of the earth tube systems is to deliver fresh air that has been tempered by the earth's stable temperature, to save energy. By saving energy for heating (and cooling) it is more likely that the fresh air volumes will be maintained at a safe level.

6 NET POSITIVE

6.1 *Measurement*

The goal of achieving a net positive benefit to health and human well being through earth tubes systems will be measured and verified by indoor air quality. The scope of this paper is to present the results of monitored data from earth tube installations during winter to see how much potential energy savings are available.

This is important, for buildings of all sizes, as the cost of heating fresh air that is needed for comfort of occupants – can be significant during a Canadian winter. With higher energy costs, there is a temptation to reduce the fresh airflow into buildings during this season and hence put at risk the occupants health and well being. This is further problematic, especially on buildings where there is no heat recovery system installed as part of the ventilation plant.

6.2 *Healthier IEQ*

The results show that using earth tubes, the energy associated with heating fresh air for building supply is approximately reduced by half. This means that is more likely that the minimum safe requirements for health and well being will be met.
By looking at this the other way around, it means that the volume of fresh air could be doubled with no extra cost of heating energy.

This extra volume of fresh air would aid in flushing out further contaminants, moisture, mould and other gases that could build up. This is especially relevant in winter months when windows are closed and overall 'natural' ventilation benefits are at an all time low. Therefore with more reliance upon mechanical systems, they could double the energy flow at no extra cost – or provide the safe minimum for a 50% saving. Either way, the occupant will experience a net positive benefit in health.

10 FURTHER STUDY

The scope of the paper has focused on pre-heating winter air to reduce energy costs, and then to encourage higher volumes of fresh air to be supplied to buildings. The author recognizes that summertime cooling should also be presented – as this is a growing demand upon energy due to a number of factors such as climate change, longer occupied hours and growth in electronic equipment that give off heat. The systems monitored by the author have shown a summer performance in the range of 8-10°C: further study is required to gather more data and to determine the risks of heat saturation.

The earth tube system design and installation should also be tested to see how they would perform. Different criteria would involve, pipe materials, depth, air velocity etc.

11 CONCLUSIONS

The conclusions show that earth tubes can be used as a method of improving indoor environmental quality – and that this has a direct net-positive impact upon a person's health and well-being.

The current economic climate is such that simple, cost effective systems are required to assist in energy efficiency, construction costs and ultimately occupant safety. The earth tube systems are capable of satisfying these requirements.
Improved health and well-being is important to productivity, economics as well as psychological aspects associated with people, who as was shown are spending around 90% of their time inside buildings.

It will be important for any outstanding doubts or concerns about the air quality from the earth tubes to be addressed in order for a wider adoption of this system to be realised. This may include design guidance based on climatic zones that address humidity and how condensation can be controlled or avoided in the earth coupled system. Studies have shown that the interior of BC and Prairie Provinces (Lee, 2004) – where the air is drier than the coast – have beneficial tempering in both summer and winter.

There are also practical installation aspects to consider – as the construction process covers more that one single Division: mechanical – air handling plant sizing; civil – pipe laying; electrical – sensors and monitoring. It is essential that the interface between these components is clearly understood and managed through the design, construction and commissioning process.

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