Proceedings of 2nd Conference: ***People and Buildings*** held at Graduate Centre, London Metropolitan University, London, UK, 18th September 2012.
Network for Comfort and Energy Use in Buildings: http://www.nceub.org.uk

Study of the Parameters that affect the Performance of a Domestic Ground Tempered Ventilation System in various climates

Ester Coma Bassas
MSc Environmental design of buildings, Cardiff University, UK, archi@cardiff.ac.uk

Abstract
The effect of section, length, depth, material and spacing on the potential of buried ducts used in a ground tempered ventilation system is investigated. The most effective solution for each parameter is identified by measuring the air temperature and rate of airflow inside the duct. Calculations are made for hot, mild and cold climates. Thermal performance and CFD airflow simulations are done with HTB2 and WinAir software respectively. The results show that with appropriate settings the need for active systems for cooling or heating can be eliminated in some climates.

Keywords: ground tempered ventilation, earth air tunnel, underground air duct, passive ventilation.

1 Introduction
This paper investigates whether ground tempered ventilation (GTV) integrated into a passive design can reduce the heating or cooling demand of a building whilst ensuring thermal comfort. To avoid the need for an active system, this integration has to be done at the design stage. (Alemu, et al., 2012).

GTV has the benefit, over other passive strategies, of supplying heating in winter and cooling in summer, while ventilating the building (Misraa, et al., 2012). The system consists of buried ducts through which supply air, driven by natural convection, becomes pre-conditioned due to the temperature difference between the air and the soil, before ventilating the building. Although its ability to reduce energy demand has been widely proven, research on its potential applicability in residential buildings is still needed.

This system takes profit from the earth, which behaves as a huge storage medium thanks to its high heat capacity. Accordingly, it dampens variations in temperature which, despite the very long seasonal lags, ensures that the ground is warmer than air in winter and cooler in summer. Research studies (BGS, 2012) demonstrate that the ground's thermal capacity is such that its diurnal temperature variations are only appreciated down to a depth of 0.5 m from the surface and seasonal variations down to 6 m. Below this depth the temperature is stable and, as a rule of a thumb, is said to be equal to the mean annual air temperature. For this reason, the thermal performance of these systems should be evaluated in a climate with a mean annual air temperature slightly below the comfort temperature inside the building.

This paper is focused on a domestic building, and evaluates those properties of ducts and the ground that can affect the performance of its GTV system. This is done using two separate models of the underground system, one using software appropriate for analysis of heat flow and another with different software suitable for analysis of air flow.

2 Methodology

A GTV system ventilates the building with air that has achieved its delivery temperature after passing through ducts buried in the ground. Since the air circulates underground, the strategy does not affect the building design and ducts are aesthetically unperceived. In the current study, a standard size residential building is modelled.

The climate is critical as it dictates the stable temperature of the ground. Therefore, 3 climates with a different mean annual air temperature, and so a different deep soil temperature, are analysed (see Table 1 and Fig.1).

COLD [C] MAT <13˚C	**MILD [M]** 13˚C < MAT< 27˚C	**HOT [H]** MAT >27˚C
Edinburgh MAT=8.7˚C	Barcelona MAT=15.6˚C	Acapulco MAT=27.3˚C

Table 1: Climatic parameters used for the simulations. (MAT is mean annual air temperature).

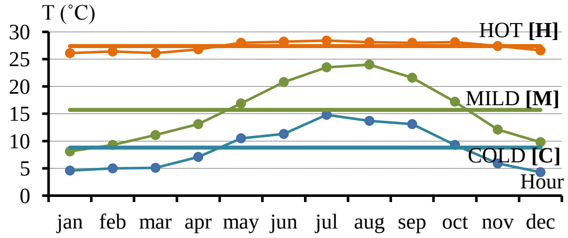

Figure 1. Monthly temp. (hashed line) and mean annual temp. (continuous line) for the 3 climates (USDE, 2012)

The proposed GTV is shown in Fig. 2. Outdoor air travels through the ducts to exchange heat with its walls, before it is released to the building's interior. Accordingly, heat is transferred to or from the soil by conduction across the walls of the duct and by convection to the air inside (Al-Ajmi, et al., 2006). The amount of heat exchanged depends on the parameters given in the first column of Table 2. This paper tests their effect on the performance by checking the air temperatures and the rate of airflow of the central duct at the point shown in Figure 2.

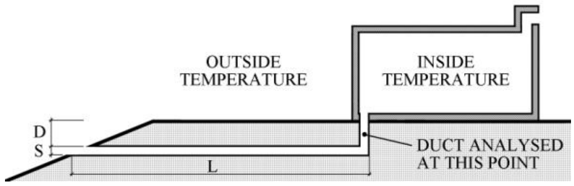

Figure 2. Model of the building, the underground duct and the soil environment. In the model there are 3 parallel ducts; this section is across the central duct.

Although this part is not analysed in this paper, the air is then directly supplied to the building through inlet vents at floor level, and extracted at top level through a similar number of outlet vents. In summer the system cools outside air at night when temperatures are lower, and supplies it to the building to cool its thermal mass. Otherwise, in winter it warms outside air during the day when temperatures are higher, and then supplies it to the building to warm its thermal mass.

PARAM.	**OPTIONS**	**RESULTS CODE**		
		[C]	**[M]**	**[H]**
Section [S] (mm²)	[1] = 250x300 mm	S1C	S1M	S1H
	[2] = 500x300 mm	S2C	S2M	S2H
	[3] = 750x300 mm	S3C	S3M	S3H
Length [L] (m)	[1] = 10 m	L1C	L1M	L1H
	[2] = 20 m	L2C	L2M	L2H
	[3] = 30 m	L3C	L3M	L3H
Depth [D] (m)	[1] = 2 m → M.A.T. ±3˚C	D1C	D1M	D1H
	[2] = 4 m → M.A.T. ±1˚C	D2C	D2M	D2H
	[3] = 6 m → M.A.T.	D3C	D3M	D3H
Material [M]	[1] = Metal	M1C	M1M	M1H
	[2] = PVC	M2C	M2M	M2H
	[3] = Concrete	M3C	M3M	M3H
Spacing [P]	[1] = 1 m	P1C	P1M	P1H
	[2] = 2 m	P2C	P2M	P2H
	[3] = 3 m	P3C	P3M	P3H

Table 2: The parameters used for the simulations. In grey, the starting value of each parameter which defines the Base Case

The underground system is modelled in Ecotect by dividing the duct in consecutively connected thermal zones, each 1m length. Thus, each piece of the duct has a temperature, giving more accuracy to the model. Then, it is exported to HTB2 (WSA, 2007) to run thermal performance more accurately, measuring the air and surface temperatures inside the duct for the 33 cases set out in Table 2: that is, the Base Case and 2 modifications of each parameter, all simulated in three different climates. Finally, the duct surface temperatures from HTB2 are copied to WinAir (WSA, 2005) CFD software, in which the system is modelled again to evaluate its airflow performance. More detail of the simulation design is given in the next section.

3 Results

The paper reports the results of heatflow and airflow simulations run respectively with HTB2 and WinAir software. First the HTB2 results on thermal performance are reported.

The first HTB2 simulations measure the inside air temperature and the duct surface temperature at the delivery end of the duct all over a year in each climate (see Fig3). The model analysed is the Base Case: a PVC duct with 500x300mm section, 20m length, 6m depth, and 2m spacing between ducts.

After that, two singular dates from each climate are chosen to represent summer and winter, being the average hottest and coldest day respectively (see Fig.3) The objective is to measure the diurnal variation of the air temperature inside the duct and compare it with the outside temperature (see Fig. 4). Again, the Base Case is analysed so that GTV can be compared in different climates.

Then the same air temperatures outside and inside the duct have been plotted for each hour in each climate, giving the linear relationships in Figure 5.

Now that a Base Case has been analysed, the next step is to see how changes in the parameters would affect the air and surface temperature inside the ducts. The changes made are those shown (and coded) in Table 2. The parameters are always returned to the Base Case between each change.

All the variations in the parameters are made for all three climates. However, in this paper, only the climate which shows the effect most clearly is shown.

The graphs in Figures 6 to 8 show the results obtained for the variations in section, length and depth respectively.

The depth alterations are evaluated by changing the temperature of the soil in HTB2. At 6m depth the soil is given a stable temperature equal to the mean

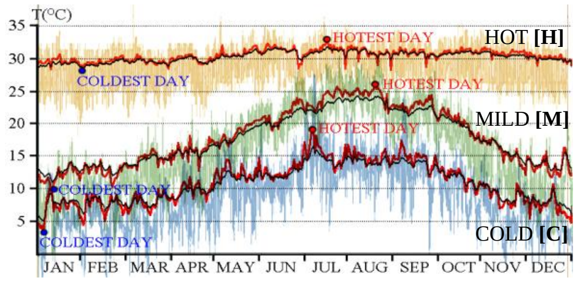

Figure 3: Annual distribution of air (red lines) and surface (black lines) temperature inside the duct for each climate. Outside temperature are plotted in lighter colours.

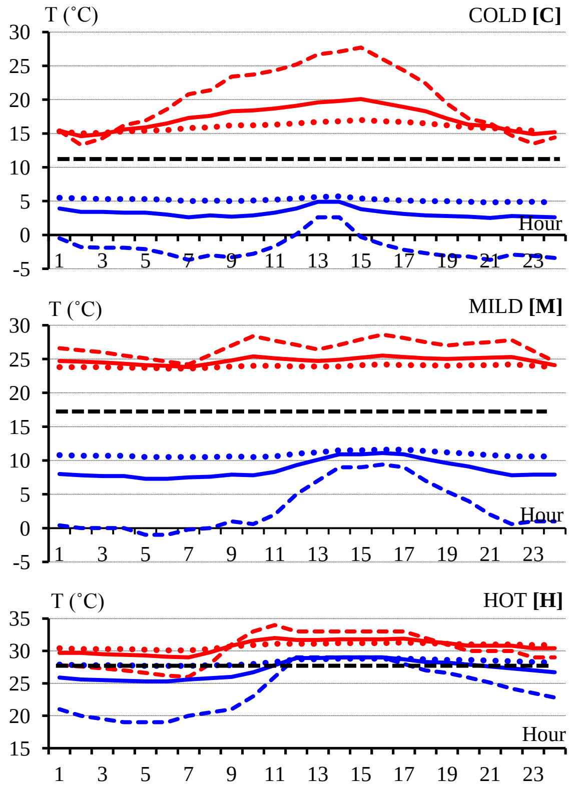

Fig. 4: Base Case. Hourly temperatures of the 3 climates in Summer (red) and in Winter (blue) for the average hottest and coldest day respectively. Hashed lines: Air temp. outside. Continuous line: Air temp. inside. Dotted line: Surface temp. of the duct. Hashed black line: MAT.

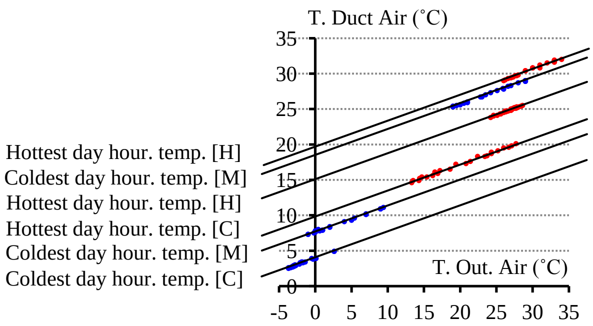

Figure 5: Correlation between air delivery temperatures and outside temperatures. The points plot the air temperature inside and outside the duct for each hour from the simulations illustrated in figure 4. Red points are hottest days and blue points coldest days for each climate. The black lines extrapolate the trends and are labelled by climate: Hot [H], Mild [M] and Cold [C].

annual temperature, whilst at 4m and 2m depths the temperature is made respectively 1˚C and 3˚C greater than the mean annual temperature in summer and cooler in winter (Hanova & Dowlatabadi, 2007) (see Table 3).

Table 3: Ground temperature variation with depth.

	GROUND TEMPERATURES (˚C)					
CLIMATE	COLD		MILD		HOT	
SEASON	S	W	S	W	S	W
2 m= MAT ±3˚C	11.8	6.8	18.7	12.7	30.4	24.4
4 m=MAT ±1˚C	9.8	7.8	16.7	14.7	28.4	26.4
6 m=MAT	8.8	8.8	15.7	15.7	27.4	27.4

Regarding changes in materials, the results are the same whether PVC, metal or concrete are chosen; only the PVC graphs have been shown here.

The last parameter evaluated is the space between the ducts. In the initial Base Case, the central duct, object of the analysis, had one duct on each side at 2m spacing. Now, the spacing is modified to 1m and 3m in new models exported to HTB2, giving the results shown in Figure 9.

Next, once all the parameters affecting the delivery temperature of the air have been analysed with HTB2, WinAir is used to analyse the efficiency of the air flow. By introducing duct temperature to the duct's surface in WinAir, an airflow simulation is obtained (see Fig.10). Though only the under-ground performance is analysed in this paper, the aim is to find whether the results obtained allow the system to work.

Changes in the duct's section, length and depth have been made in the WinAir model to test how these parameters affect the airflow. But according to the software, the air flow variation is almost imperceptible. Owing to that fact, the results are presented only graphically. Here, the Base Case model located in Barcelona is presented in summer.

4 Discussion

A preliminary look at the relationship between soil temperature and climate

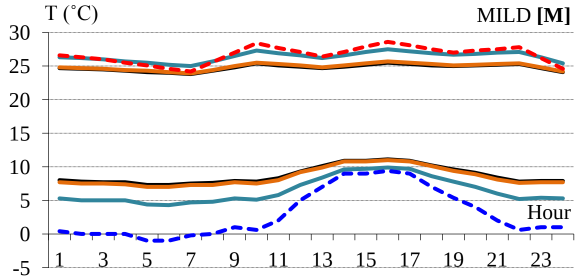

Figure 6: Section variations S1M, S2M and S3M. Hashed lines: Outside air temp. in summer (red) and winter (blue). Continuous lines: Air temp. inside the duct comparing S1M (blue), S2M or Base Case (black), and S3M (orange).

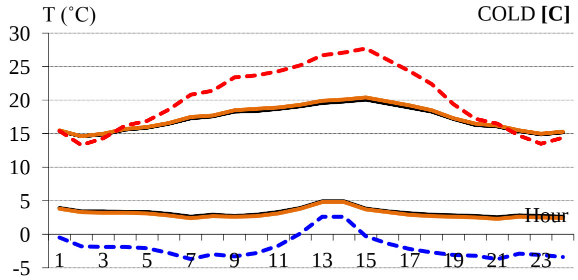

Figure 7: Length variations L1C, L2C and L3C. Hashed lines: Outside air temp. in summer (red) and winter (blue). Continuous lines: Air temp. inside the duct comparing L1C (blue), L2C or Base Case (black), and L3C (orange).

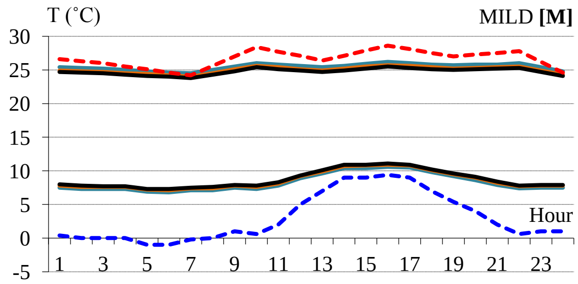

Figure 8: Depth variations D1M, D2M and D3M. Hashed lines: Outside air temp. in summer (red) and winter (blue). Continuous lines: Air temp. inside the duct comparing D1M (blue), D2M (orange) and D3M or Base Case (black)

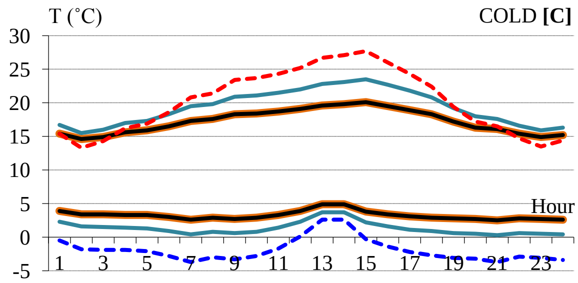

Figure 9: Spacing variation P1C, P2C and P3C. Hashed lines: Outside air temp. in summer (red) and winter (blue). Continuous lines: Air temp. inside the duct comparing P1C (blue), P2C or Base Case (black) and P3C (orange).

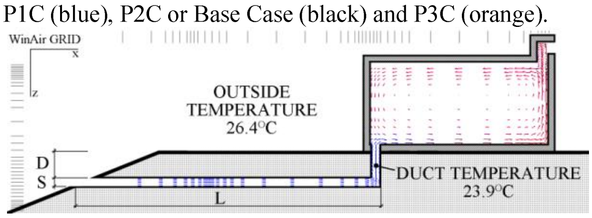

Figure 10: WinAir airflow simulation of the GTV system for the Base Case, in the mild climate and in summer.

suggests that Barcelona's annual average air temperature will give soil temperatures ideal for tempered ventilation allowing for internal gains. Because of this, its climate is selected for comparison in the simulations with a warmer and cooler climate.

The first stage analyses the annual performance of the buried duct of the Base Case, by plotting a graph of the annual duct temperatures for each climate (see Fig.3). These graphs show that the surface temperature of the duct remains relatively stable thanks to the beneficial effect of the earth, whereas the air temperature is significantly affected by fluctuations in the outside air supply temperature. The results show that useful air delivery temperatures can be achieved; thus active systems for cooling or heating could be dismissed in some climates. The climate for which the duct temperatures are closest to comfort levels is Barcelona.

The second stage finds when GTV is at its most efficient during the hottest and coldest day of each climate (see Fig. 4). The results confirm that the most appropriate climate is the one of Barcelona, as comfort can be achieved using GTV in the hottest day and nearly in the coldest one. Otherwise in extreme climates, GTV only offers comfort in one season, summer for the cold climate and winter for the hot, but offers big energy savings if the delivered air is used for pre-heating or pre-cooling. The graphs indicate when ventilation is sufficient:

- Mild climate: The airflow from the buried system can be used all day and night on summer days, while in winter it is sufficient on its own only from 11am until 7pm.
- Cold climate: GTV provides comfort during summer, when it can be used over 24 hours to reduce temperatures up to 8˚C. Additional heating is needed in winter, but with big energy savings because the air is almost 5˚C warmer.
- Hot climate: Although comfort conditions can be achieved in winter by using the preconditioned airflow, the strategy is not appropriate for this climate. The graph suggests that a night ventilation strategy would be much more efficient.

The outside and in-duct temperatures from Fig. 4 are compared in Fig. 5. For these series of hourly readings, the points obtained follow straight trend lines in parallel for the 3 climates and the 2 seasons. The linear trend in the simulations can be related to real dynamic situations by supposing that the hourly temperatures represent averages. This would only be the case at depths sufficient to have constant ground temperature. However, it was expected that summer and winter temperatures would be aligned in the same line for the same climate. Therefore, further research could be done to find a graph that could predict average air temperatures inside the ducts.

The fourth stage is to find the best design parameters:

- Section. This is the most influential parameter. The Base Case was S2. In the mild climate, S2 preconditions the air by 3˚C in summer and 8˚C in winter. By increasing this section to S3, the results are similar, just 0.3˚C more in summer and less in winter. However in section S3 more air flows through the duct, so the ventilation rate is higher. Otherwise, by reducing the section to S1, in the mild and cold climates the system is much less effective in both seasons, as less of the duct's surface is in contact with the ground. However, in the hot climate, S1 works as well as S2 during the day but better at night when outside air is cooler and exchanges less heat with the warmer surface of the duct.
- Length. The Base Case was 20m. Changing this does not have the effect expected. Air temperature remains almost the same whether the length is 10, 20 or 30 m.
  Only in the cold climate does the 30m duct precondition the air a little less, both in summer and in winter. More drastic changes with lengths of up to 100m could have been tested, but 30m is the maximum recommended (USDoE, 2012).

- Depth. The Base Case was 6m deep. The shallower ducts are a little less effective. However, the difference in delivery temperature between 2m and 6m is only 1˚C, in both seasons and in all climates. Therefore in situations where it can be difficult to excavate the ground deeply, 2m depth should be the most cost-effective solution.
- Material. This has no influence on the system since identical results are achieved for the 3 types of materials tested (aluminium, PVC and concrete) even though their thermal conductivities differed. Therefore, thermal performance does not have to be considered when selecting the material of ducts, although other aspects like cost, strength, corrosion resistance, and durability are more important. For example, PVC ducts perform almost as well as metal ducts, but they are easier to install and resist corrosion (US Department of Energy, 2012).
- Space between ducts. The duct placed 1 metre from adjacent ducts is less effective than when ones placed 2m or 3m away. This means that a distance of 1m is insufficient because the heat that the duct exchanges with the ground modifies the soil temperature within that range. Therefore, at least 2 metres of spacing between ducts is required in all the three climates.

The aim of the last stage, consisting of the WinAir airflow simulations, is to obtain a general idea of how a GTV system works and how its performance affects the building itself. However, any changes in air speed that occur when the parameters are modified were not reflected in the graphical results obtained from WinAir software. On account of that, a more accurate CFD software would be needed if further research has to be done on the airflow movement from the ducts to the building above ground.

5 Conclusions

This report focuses on a study of the parameters that affect the performance of a domestic GTV system. The research process followed and the results obtained can help architects who aim to achieve a passive building or want to reach a specific level of comfort as cost-effectively as possible. The information can also be used by other researchers and GTV providers to compare which areas of technological development have a greater impact on final performance. Accordingly, research on a section's shape and dimensions seems more beneficial than making innovations in materials.

Moreover, the approach used to compare climates and duct parameters can potentially be deployed by designers to improve the energy performance of a GTV system. Although this study is for the residential scale, this does not affect the final results as only the performance underground is tested. Therefore, further research could study the relation between the number of ducts and the building scale in different climates.

References

Al-Ajmi, F., Loveday, D. & Hanby, V., 2006. The cooling potential of earth-air heat exchangers for domestic buildings in a desert climate. *Building and Environment,* Volume 41, pp. 235-244.

Alemu, T., Saman, W. & Belusko, M., 2012. A model for integrating passive and low energy airflow components into low rise buildings. *Energy and Buildings,* Issue In press, corrected proof.

BGS, 2012. *Ground source heat pumps.* [Online] Available at:

http://www.bgs.ac.uk/reference/ gshp/gshp_report.html [Accessed 8th April 2012].

Hanova, J. & Dowlatabadi, H., 2007. Strategic GHG reduction through the use of ground source heat pump technology. *Environmental Research Letters,* 2(4).

Misraa, R. et al., 2012. Thermal performance investigation of hybrid earth air tunnel heat exchanger. *Energy and Buildings,* Issue In press, corrected proof.

US Department of Energy, 2012. *Earth Tubes.* [Online]. Available at:

http://www.energysavers.gov/your_home/ space_heating_cooling/index.cfm/mytopic=12460 [Accessed 7th April 2012]

WSA, 2005. *WinAir v1.4b.* Cardiff.

WSA, 2007. *HTB2 for Windows version 2.1 Beta.* Cardiff.