

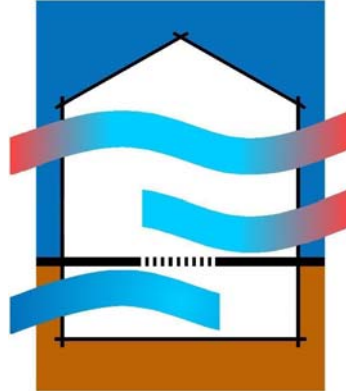
COOLHOUSE FINAL MONITORING REPORT

23rd January 2004

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Coolhouse



Final Monitoring Report Urbanização das Furnas January 2004

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1 Executive Summary

The Alma Verde development in Southern Portugal consists of a number of villas that have been built according to the Coolhouse specification; high thermal insulation, high quality double glazed, low solar input windows and ground tube cooling system. Three of these villas have been monitored over part of the cooling season and part of the heating season of 2003 for thermal stability and living conditions.

The monitoring shows that during the heating and cooling season of 2003 the villas have a very high level of thermal stability, the ground tubes provide coolth or heat to the building which removes the need for conventional air conditioning units. The fans required to pull air through the ground tubes use substantially less electricity than would be consumed by conventional air conditioning, this reduces the CO₂ emissions associated with electricity generation but allows the residents to have pleasant living conditions during periods of peak summer heat.

Internal room temperatures reflect outside air temperatures however, the Coolhouse system uses the ground heat sink to remove the peaks and troughs associated with external conditions to provide the pleasant living conditions.

Residents of the Coolhouse villas are very happy with the building quality, the sustainability aspect, and the anticipated low running costs of the dwellings. It is concluded that residents may operate the ground cooling system in a number of different ways, such as long or short periods, night purging, etc. and still achieve very acceptable internal temperatures.

The report concludes that according to this monitoring programme the Coolhouse technologies included with these dwellings are very successful and provide high comfort levels for low energy consumption.

2 Project Details

Urbanização das Furnas – Hotelaria e Turismo Limitada, trading as AlmaVerde Village & Spa, is a partner in the Coolhouse Project, Contract number NNE5-1999-00193, aiming to develop innovative ventilation strategies for zero or very low energy cooling for houses in Southern Europe as an alternative to air conditioning.

The research, thermal modelling and construction of six of the properties was completed in summer 2003. FaberMaunsell, in addition to coordinating the project, have completed a monitoring program over the latter part of the cooling season and the early part of the heating season of 2003. This was to investigate the internal temperatures of the dwellings, their energy consumption and the views of the inhabitants.

Each property uses fans to pull external air through ground tubes and into the insulated sub-floor plenum of the dwellings. This cooled fresh air is then supplied into the dwellings space through ventilation openings from the plenum from behind the skirting boards and into the rooms. Window mounted trickle ventilation enables ex-filtration and the buildings incorporate double height space and towers to promote a stack effect and help in the displacement of warmer air.

The skirting boards include a heated radiant circuit; this heated skirting is provided with hot water from the condensing boiler during the heating season to allow pre-warmed, external air into the dwelling. This prevents stuffiness within the building during the heating season while taking advantage of the heat pump effect of the ground heat sink.

Construction materials and thermal regulations currently prevalent in Portugal would waste much of the cooling potential of the Coolhouse strategy, lacking both significant insulation and thermal mass. The construction design strategy developed by Alma Verde to support Coolhouse employs high thermal mass with external insulation to eliminate thermal bridging and sustain thermal comfort, supported by thermally efficient windows with low-e solar control glazing and other solar shading devices.

3 Aim and General Description

3.1 AIM OF THE PROJECT

The aim of the monitoring project was to assess internal temperatures and the energy consumption of the cooling system within the dwellings. In conjunction with the partner sites elsewhere in Southern Europe; L'Aubier de Cybèle in France and Aler Pavia in Italy (a fourth site EL Greco, in Crete was discontinued as part of the study) the monitoring data aimed to find out whether the Coolhouse cooling system provided sufficient cooling to residential buildings to provide comfortable living conditions without resorting to conventional air conditioning.

3.2 DESCRIPTION OF THE MONITORING PROGRAM

Three houses were chosen to be monitored, the first house, number 54, was to become the show home of the development. The second, house 56, had been sold and at the start of the monitoring program was being completed i.e. having fixtures and fittings added and being painted internally. The third dwelling, house number 57, had been sold and was occupied by a retired couple who had been living there for a number of months before the start of the monitoring program.

Hobo H8 loggers were used to monitor temperatures and humidity in the three dwellings as shown below. An additional Hobo unit was installed on an external wall, sheltered from direct sunlight and weather, of house 54 to monitor outside air temperature and soil temperature. Ground tubes are buried 2 meters underground; monitoring the soil temperature at this depth in the same 'parcel' of land as the ground tubes gives an indication of the heat sink characteristics of the soil.

House 54

- One in the master bedroom.
- One in the secondary bedroom.
- One in the main living room.

- One on the air intake.
- One on the air intake after ground treatment.

House 56

- One in the main living room.
- One in the secondary living room (study).
- One in the master bedroom.

- One on the air intake.
- One on the air intake after ground treatment.

House 57

- One in the main living room.
- One in the master bedroom.

External monitoring

- One attached to an external wall, away from the prevailing sun direction to monitor O.A.T. and soil temperature at a depth of 2m.

Tiny Tag Plus Re-ed Count meters used in conjunction with Compact Electrical Unit Consumption Meters were installed in each of the fan rooms to monitor the kWh consumption of the fans and to obtain a load profile of when the Coolhouse system was operating.

The consumption electrical meters were wired into the main power supply for the fans to provide a visual account of the kWh consumption. These units gave an electrical pulse at a calibrated

rate whilst the fans were operating, the the Tiny Tag loggers monitored these pulses to produce a load profile.

House 54 is unique amongst the present Coolhouse villas in that it has two Coolhouse systems i.e. two sets of fans, two separate ground tubes, two controls etc. These systems supply air to separate areas within the house, one area being the master bedroom and the second bedroom and the other being the main living room, the second living room and the hallway area.

The monitoring program started officially on 14th July 2003, there had been preliminary monitoring during September 2002, however, this concentrated on establishing flow rates and observing the initial construction stage of the houses. In July 2003 the loggers were installed in the positions outlined.

During a week of intensive monitoring various different scenarios were experimented within the dwelling i.e. monitoring with windows and doors opened, with doors closed, with electric radiators on to simulate habitation. However, the construction method of the buildings i.e. highly insulated with high thermal mass resulted in long lag times between ventilation activity and response. This meant that long term monitoring would be more appropriate in order to study the site.

To achieve long term monitoring, which would take into account the lag times of the building, the temperature/humidity loggers were set up to monitor conditions every half an hour and left in-situ until 15th January 2004.

The Coolhouse system was set to operate at set times as shown below:

House 54	-	14:00 – 23:00	-	seven days a week.
Changed later to		18:00 – 06:00		
House 56	-	14:00 – 05:00	-	seven days a week.
House 57	-	14:00 – 06:00	-	seven days a week.

4 Installation and Commissioning

4.1 COMMISSIONING OF EQUIPMENT

The loggers used throughout the monitoring required very little commissioning work, the Hobos simply required their parameters to be set before being activated by a laptop.

The Tiny Tag units were as simple to install, there was a slight commissioning issue in that they have the ability to log kWh usage whilst recording load profile. Unfortunately, the logarithms that were required to do this were not available at the time of the installation; this resulted in them being used to only log usage profile.

The software that was required to activate and change the parameters of both loggers was purchased at the same time as the loggers, this was installed onto a laptop running Windows 2000.

The Electrical Unit Consumption Meters were installed by on site electricians. These were not particularly difficult to install but because they were required to be fitted to the main power supply of the fans it was felt that this should be done by a qualified electrician to comply with Health and Safety considerations.

4.2 PROBLEMS, SOLUTIONS AND SUCCESSES

The main problem encountered with the installation of the monitoring equipment involved the distance between the site office and the FaberMaunsell office i.e. Portugal and London. On-site employees were taught how to download data from the loggers; they were asked to complete a download once a month on all loggers and to email the data to FaberMaunsell's London office for analysis.

Unfortunately, there was a computer software conflict that prevented the onsite computers, which ran Windows XP, from performing this download. The distance between sites and time restrictions meant that only two site visits were possible throughout the entire long term monitoring programme, one in September 2003 and one during February 2004. This resulted in a longer period than desired between downloading data sets which increased the chances of loggers malfunctioning and not recording complete data sets.

When the final download was completed in February 2004 it was found that all the data sets had downloaded successfully with the exception of the Relative Humidity of the air intake logger of House 56. This channel of the logger had been damaged, maybe by dust clogging up the sensors, which caused an out of limits reading. Although this was disappointing it was not a disaster as house 54 returned full data, humidity is always very difficult to monitor accurately and during any monitoring programme a level of equipment failure is expected.

Problems that arose during the installation and commissioning of the monitoring programme were mainly caused by the slow rate of development with the construction progress. Monitoring was originally due to start in September 2002, when the monitoring team arrived on site it was discovered that unusually heavy rains had caused all the internal Adobe bricks to melt and need repairing. Although the team were able to do some spot checks of temperatures and air flows it was felt that the buildings were in a too rudimentary state to install the loggers for long term monitoring. Therefore, along with the architect team and site project managers, it was decided that the monitoring would be delayed until all the buildings were in an inhabitable state.

This resulted in the monitoring starting on the 14th July 2003 and the Long Term Monitoring starting on the 19th July. Problems during the first week of the monitoring were caused by the final fixtures and fittings being installed into the monitored houses, this meant that 'tradesmen' were working in all of the house, turning the power to the houses off as fixtures were being installed and not turning it back on again, leaving doors and windows open and changing the Coolhouse controls settings.

During the first week i.e. 14th to 19th scenarios were set up to see how the Coolhouse system reacted under different circumstances. These scenarios i.e. having an electric radiator operating to represent the amount of heat expelled by a human inhabitant, were undermined by the changes created by these trades people. However, the massive thermal lag of the buildings

meant that both the scenario inputs and the trades people interferences made very little difference to the performance of the buildings over such a short period.

The second problem associated with the commissioning was with the kWh meter installed in House 54 that served the bedroom area. This meter was suppose to measure all kWh consumed by the fans that serve the bedrooms of House 54. For some unknown reason, the dial on the meter did not 'roll over' to show the amount of kW consumed by the fan system but did give out pulses that were counted by the Tiny Tag logger. In House 54 both of the Coolhouse systems (house 54 contained two systems, one for the bedroom and one for the living area) were set to operate at the same times and they had the same fan sizes. Therefore the kWh consumption was assumed to be the same for both fan sets.

A further problem involved the O.A.T. sensor and the soil temperature sensor. Excavated soil was used to back fill the trenches dug to install the ground tubes two metres underground. At the time of back filling vertical drain pipes were installed into the trench and then back filled around, these vertical tubes allowed access to the soil at the same depth as the ground tubes so that when the monitoring program started a temperature sensor could be installed at the ground tube depth allowing monitoring of the heat sink activity. Unfortunately the landscape engineers, when preparing the land for the development of the garden, removed these vertical pipes.

This required new holes to be dug to the same depth as ground tubes and new tubes to be installed, this was done the week before the long term monitoring programme started and resulted in the soil depths being disturbed. In order to attempt to reduce the inaccuracy that this disturbance would have created to the soil temperature profile large amounts of water was poured down the vertical tube and onto the ground around to speed up the dispersion of heat.

During August 2003 the landscape engineers returned to site and finished landscaping the gardens, this included laying turf and completing the planting of the entire area. This planting included the installation of sprinkler system that operates at a set time every day, the rooting activity of the plants and the liberal watering of the gardens is thought to allow increased heat dispersion and allows any remaining heat introduced into the soil during the repeated digging of the soil to be dispersed.

Although the system is primarily designed to introduce coolth into the dwelling, there was also an element that during the heating season the ground tubes could introduce pre-warmed fresh air into the building. Ground tube treated air would pass over the radiant heating skirting boards around the perimeter of the buildings having been pre-warmed by the ground tubes and reduce gas consumption required to achieve the desired room temperature during the heating season. It had been hoped that this pre-warming element could be demonstrated during the long term monitoring from November onwards.

Unfortunately, due to problems with the original installation the boilers within the houses were not properly commissioned until Feb 12th 2004. This meant that the dwellings were unheated during the heating season of 2003/2004. Incoming air was being preheated by the ground tubes but without the additional heat provided by the radiant skirting the air was around 14°C and manifested itself as a cold draught. As such the residents of villa 57 turned the Coolhouse system off in October 2004 thus prevented any pre-heating affect being monitored. The Coolhouse system did carry on running according to the time settings in House 54 and 56 but again these buildings were unheated.

5 Monitoring Results

5.1 INTRODUCTION

As stated previously three dwellings were monitored, in order to present the results in a clear and concise manner the results will be shown in separate sections. Sections 6 - 8 will show graphical results of each individual dwelling showing internal temperatures of each monitored area in relation to external temperatures.

Where possible dwelling temperature is shown in relation to O.A.T. within the same graph. However, the amount of information displayed on the graphs (each logger collected data once every half an hour) means that this is not always possible as the graphs became too cluttered.

Section 9 shows the temperature difference between the inlet of the ground tube and the end of the ground tube, this allows the activity of a 'parcel' of air to be reviewed after it has travelled through the length of the ground pipe to see the level of heat transfer from the air to the soil that was achieved.

Section 10 shows the fan activity in all three dwellings.

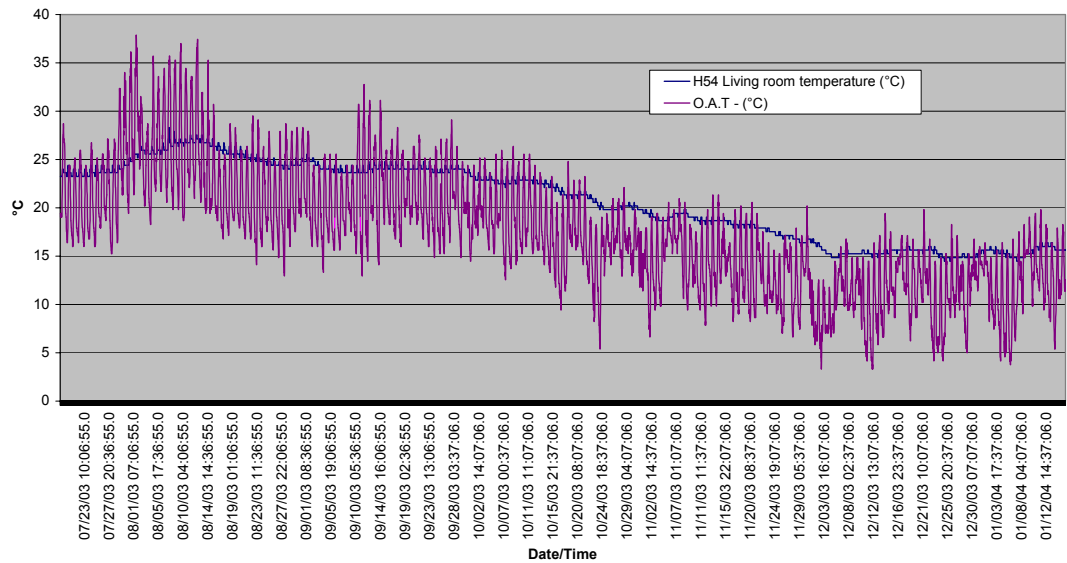
Section 11 shows calculations regarding the amount of Coolth potential that is available from the ground tubes

Section 12 outlines the suggested best method of using the ground cooling system.

Finally, section 13 states the conclusions that can be drawn from the monitoring program.

6 House 54

House 54 - Living area temperature against O.A.T.



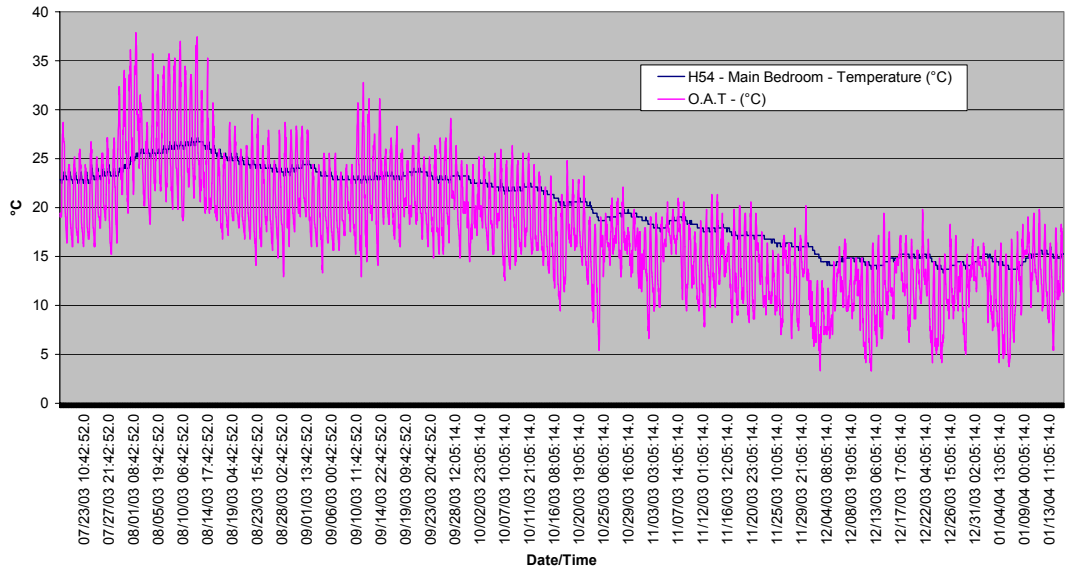
This graph shows the main living area of house 54, it can be clearly seen that the temperature of the room is related to the O.A.T. in that it raises and falls through out the year in conjunction with the seasons. However, the thermal mass, provided by the adobe bricks and low solar glazing creates a thermal buffer that prevents the peak outside air temperature from raising the internal temperatures to unpleasant levels.

This can be seen on the 1st August when O.A.T were peaking at around 37°C (in the shade) but internal temperatures were around 25°C i.e. ΔT was 12°C. This thermal mass can be seen to work in the opposite direction during the heating season with O.A.T. temperatures going as low as 5°C around the 23rd of December but with internal temperatures never dropping below 14.4°C.

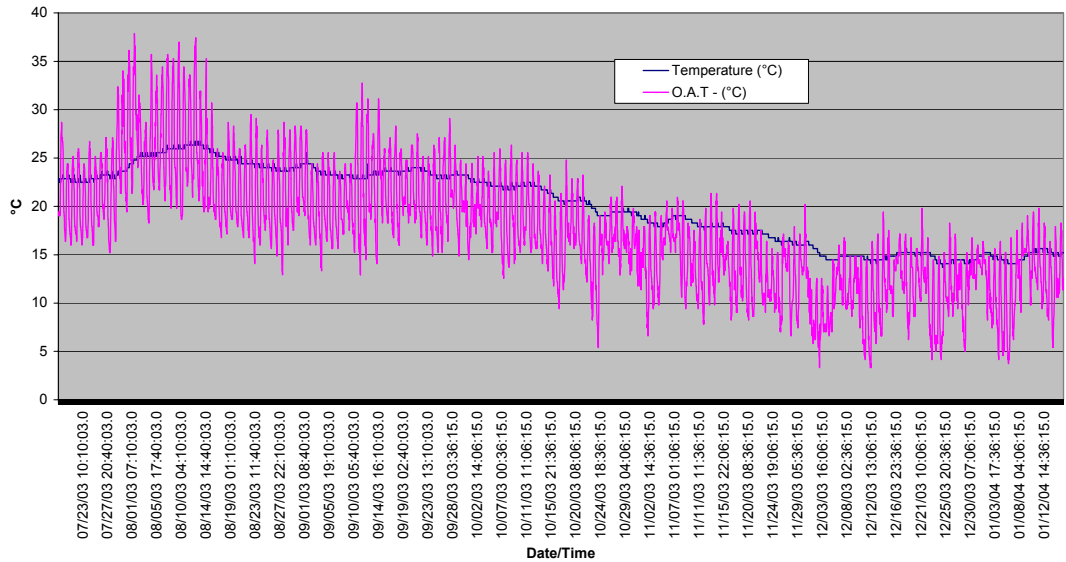
During the cooling season the Coolhouse ground tube system then provides a supply of coolth that helps to regulate the internal temperature and prevent breakaway temperature escalation that would be shown by increasing internal temperatures.

As the loggers were positioned in the main living area is not possible to see the definition of where the input of the Coolhouse ground tube 'coolth engine' starts and ends and where the effect of the high thermal mass starts. However, by looking at the graph entitled 'House 54 - Air Temperature after Ground Treatment' in Section 9 the temperature of a parcel of air before and after the ground treatment can be viewed, this shows that the ability and the cooling engine performance.

House 54 - Main bedroom temperature against O.A.T.



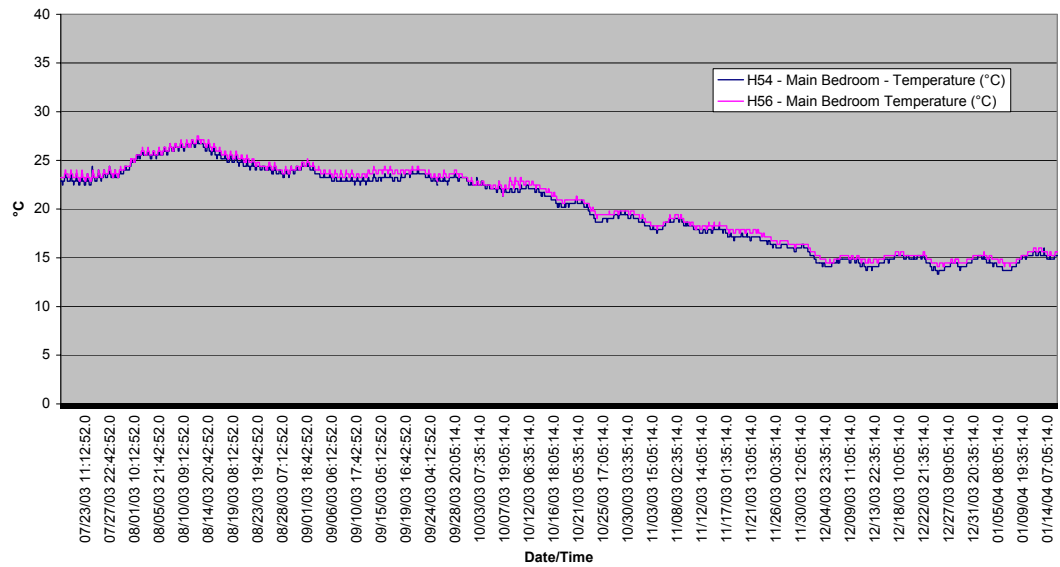
House 54 - Second bedroom temperature against O.A.T.



The two graphs above show that the relationship outlined within the main living area is repeated with the two bedrooms of house 54 (this dwelling is different to the other existing Coolhouse villas in that it has two sets of independent ground tubes serving the living area and the bedroom).

The graph overleaf shows the main bedrooms of houses 54 and 56, this graph shows the affect of the Coolhouse ground tubes at introducing coolth into the dwellings. Although the difference in the temperatures is not as great as it would have been had conventional air-conditioning been used in the bedroom of house 54 instead of Coolhouse it must be remembered that these villas are not occupied.

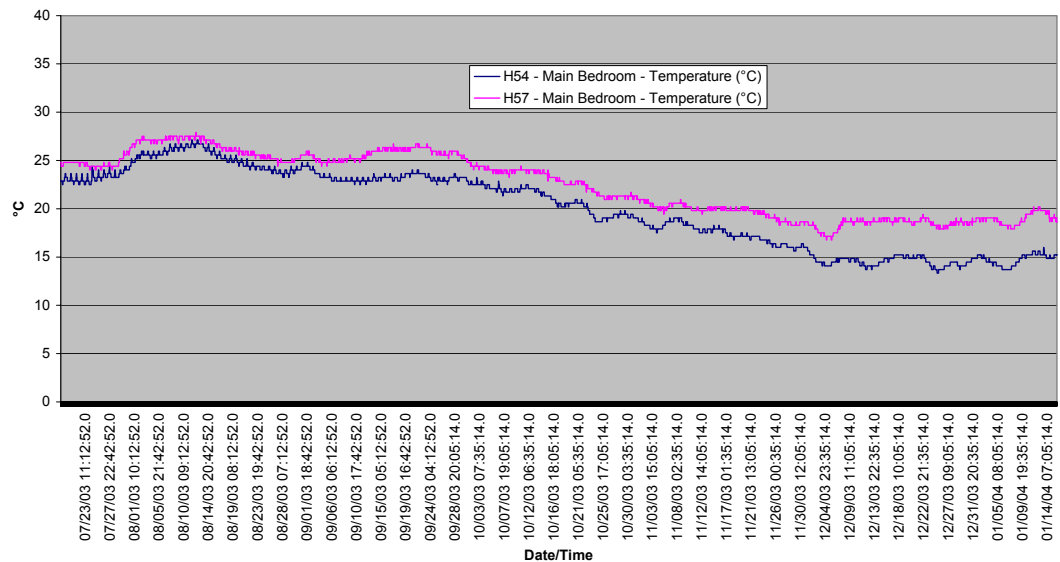
House 54 Main Bedroom against House 56 Main Bedroom



The main reason that the room temperatures are not lower within house 54 is probably because the internal doors through the dwellings during the monitoring period were always open and the windows and external doors were closed.

This is not particularly realistic of how the villas would be treated had they been occupied i.e. people close the bedroom doors at night and have windows open to allow fresh air into the bedroom (after a mosquito net had been installed). Therefore, it is a more telling comparison to compare house 54 bedroom temperature with house 57 (the occupied villa without ground tubes supplying the bedroom) to see the difference that the Coolhouse ground tube makes to the overall temperature.

House 54 Main Bedroom against House 57 Main Bedroom



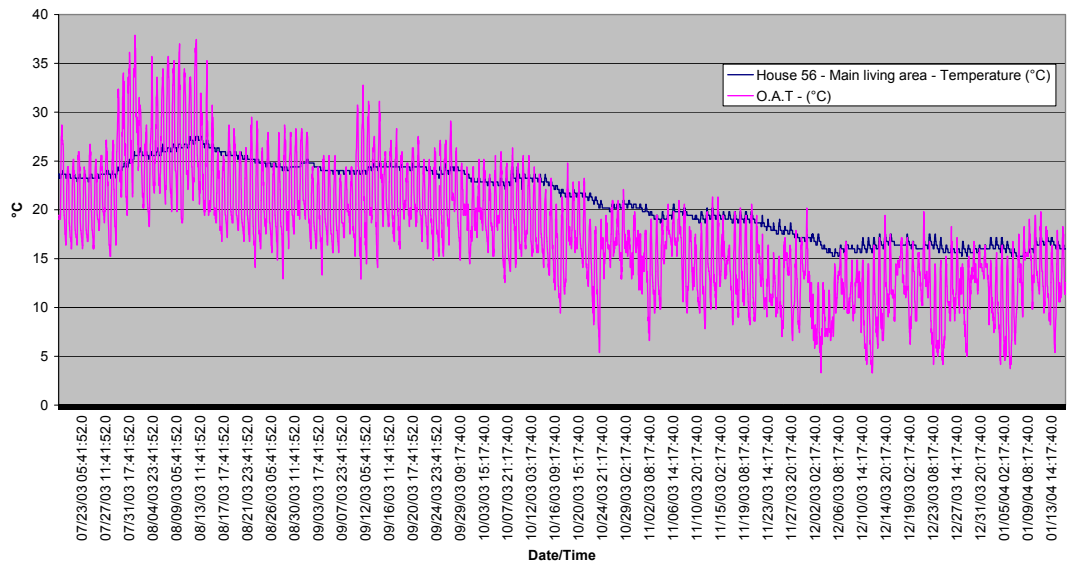
As can be seen from this comparison the occupation of the villa raises temperatures within the dwelling and the ground tubes do make a substantial impact on reducing this temperature. Indeed, during the questionnaire that was completed during the monitoring program the residents of house 57 replied to the question 'Any other comments' they stated that:

'They would like the Coolhouse system to work in the master bedroom, at present they cannot have the window open during the night because insects come into the room, they have a fly screen on order for the last two years but it has still not arrived! They feel that a Coolhouse vent in the bedroom would allow them to have fresh air during the night as well as keeping them cool.'

House number 53, which was not monitored during this program but does use of the Coolhouse system, replied to the same question; *'The system could be usefully extended to cover more rooms in the house.'*

7 House 56

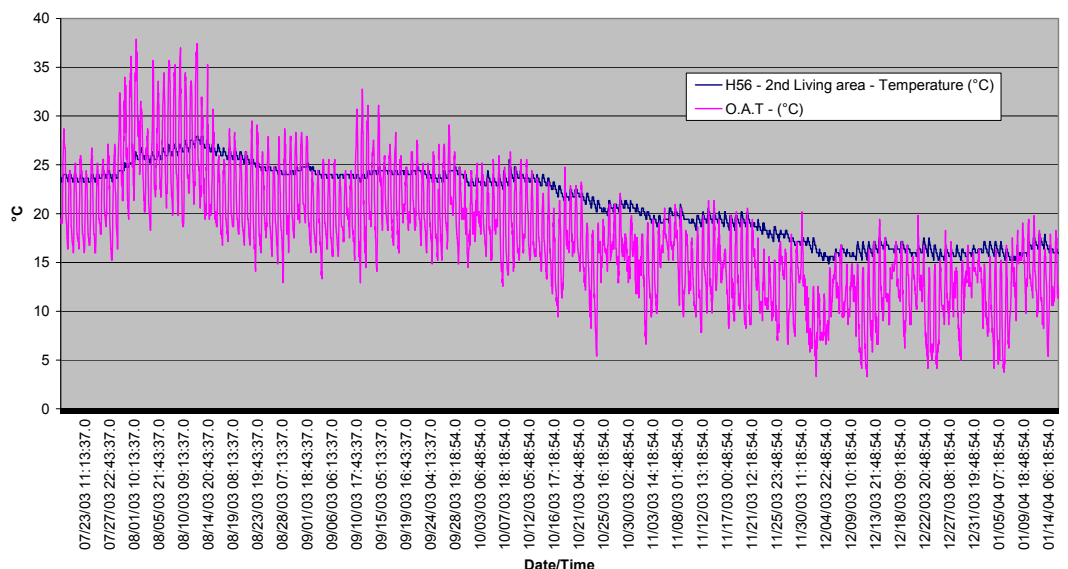
House 56 - Living room area temperature against O.A.T.



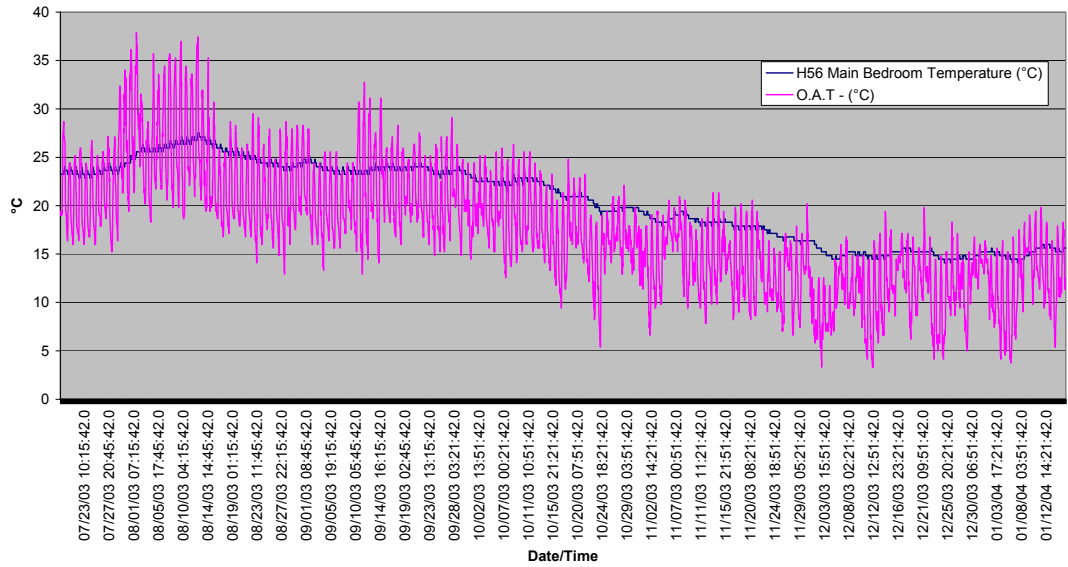
The graph above shows the main living area of house number 56 against O.A.T. As with house 54 the graph shows that the troughs and peaks associated with the fluctuating O.A.T are stabilised within the house and relatively consistent temperatures are achieved. This is ideal for villas in this area of Portugal where the temperature range between Summer and Winter can be very great. Conventional Portuguese villas, built with fired clay bricks and very little internal or external insulation, can suffer from very hot internal conditions during summer but very cold conditions during winter. These internal conditions in turn lead to condensation, mould growth and unpleasant living conditions.

The next two graphs show the conditions in the second living area and the master bedroom (without ground tubes).

House 56 Second Living Area - Temp v OAT



House 56 Bedroom temp v OAT

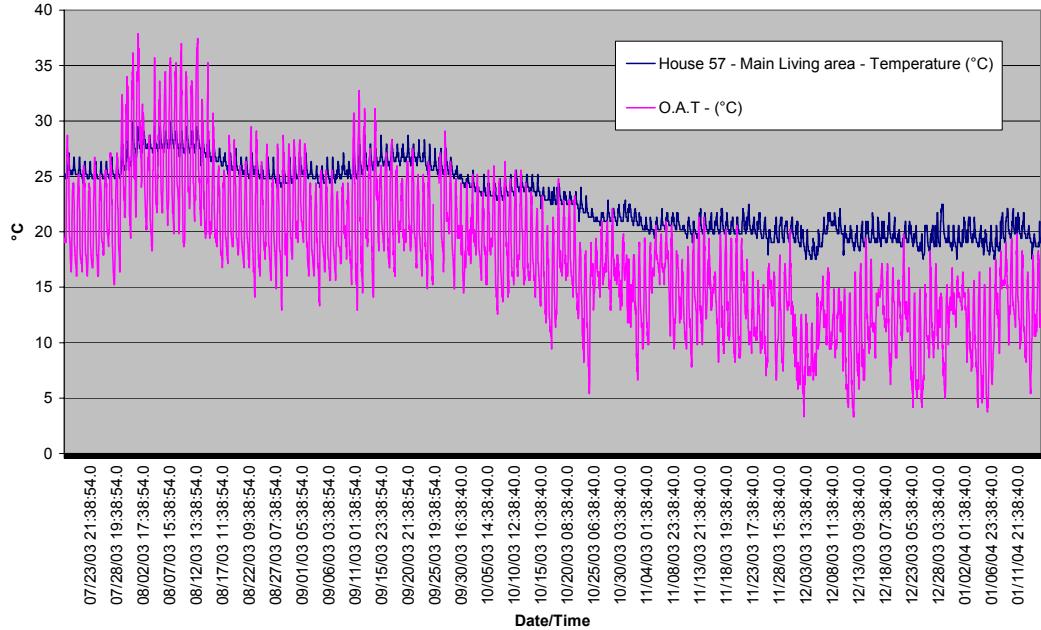


It is interesting that the temperature line within the bedroom is a lot less fluctuating than that in the two living areas, this is shown by the temperature line being clearer and comprising of a greater number of flatter peaks. This suggests that the lack of ground tube cooling vents allows the conditions to be more stable and that the ground tubes do not provide that much cooling (compare and contrast the internal temperatures with the living areas and the bedroom area). However, as stated above for House 54 this is not a fair conclusion to make as it does not take into account the fact that the houses are unoccupied and the bedroom comparison graphs between 54 and 57 should be viewed to get a more accurate picture of the affects of the Coolth provided by the ground tubes.

8 House 57

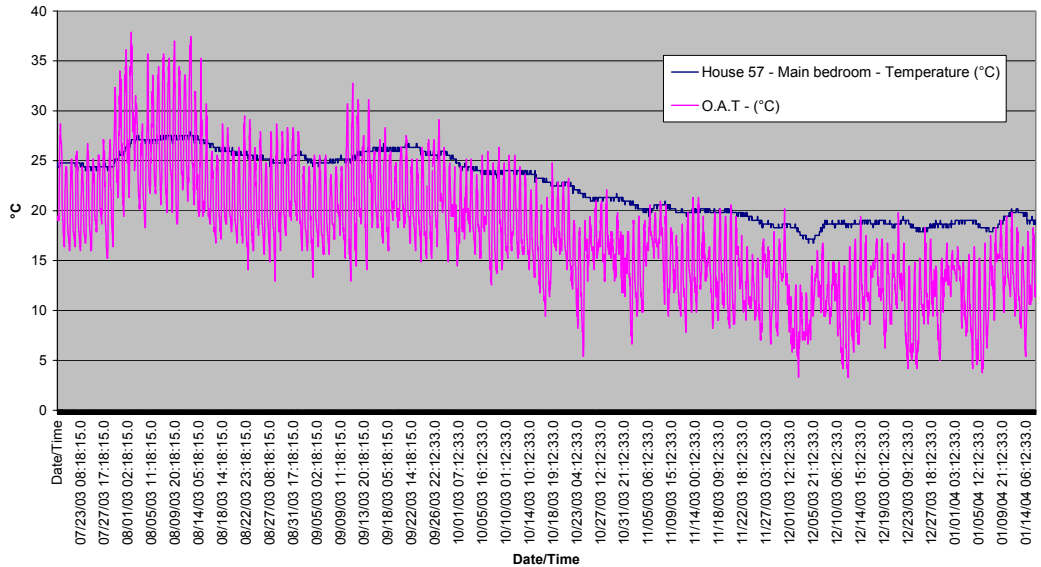
Although the graphs for the occupied house number 57 have already been viewed as a comparison for the previous two houses they can be seen in isolation below.

House 57 - Main living area against O.A.T.



These graphs are interesting in that they show the consistency of the internal temperatures achieved throughout the year even with human interaction.

House 57 - Master bedroom temperature against O.A.T.



Throughout the monitoring period the ΔT (the maximum temperature minus the minimum temperature) for the internal temperatures is 12°C in the main living area and 11°C in the bedroom, when these are compared to the outside ΔT of 35°C for the same period the thermal stability of the building is highlighted.

As with house 56 the figures for the internal temperatures in the bedroom seem to fluctuate less than the figures for the living area. These fluctuations are probably due to the way in which the living area is used i.e. the large doors leading to the garden being opened during summer days, the use of appliances i.e. cooker, television etc that provide heat during the evening, the occupiers spending the majority of their time in this area (a retired couple lived in the house) whereas there were no secondary heat sources in the bedroom (except the heat given off by them whilst sleeping).

However, even with these heat sources the closeness of the two ΔT figures shows the level of coolth provided by the Ground tubes and show how affective they are at dragging internal temperatures down within the treated areas which otherwise could increase uncontrollably due to the level of insulation within the building.

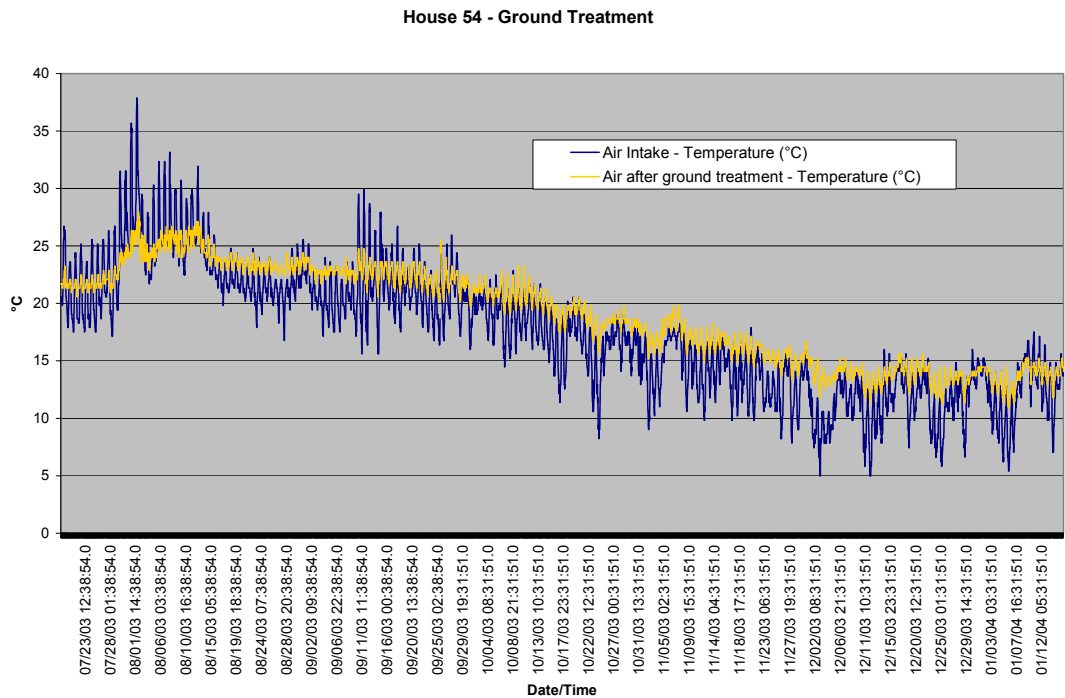
9 Air temperatures before and after ground tube treatment – houses 54 & 56

In previous sections the data produced has shown the internal temperatures of the houses, this data, although very interesting, does not show the ground tubes activity as any temperature behaviour could be solely down to the build qualities of the dwellings.

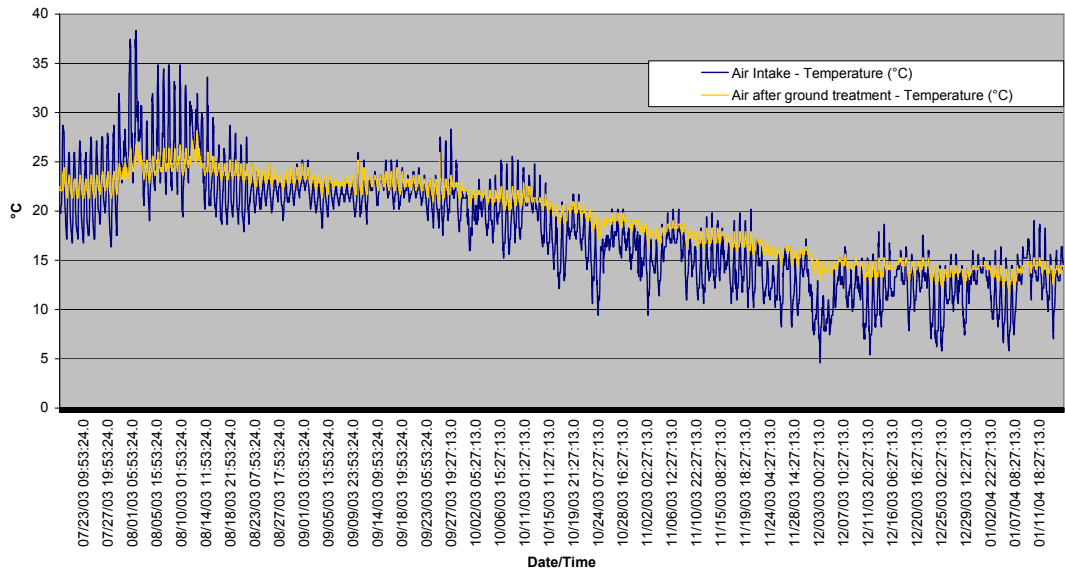
As such, this section will concentrate solely on the ground tube treatment of an 'air parcel'. This component of the Coolhouse project was monitored by installing loggers at the air intake and the air extract of a ground tube and the level of heat taken up, or emitted, by the ground mass was monitored.

Air is taken into the ground tubes at a highly insulated 'cupboard' on the North face of each dwelling, air is pulled in from outside through an insect prevention wire mesh. The 'parcel' of air enters the ground tubes and is pulled through the length of the underground tubes by a fan located at the other end of the pipe work. The extract logger was located after the air parcel had been through the ground tube but before it reached the fan from where it would go into the plenum and into the house. Only houses 54 and 56 were monitored, it was felt that it would be excessive and could cause inconvenience to the residents of house 56 if their ground tube performance was also monitored.

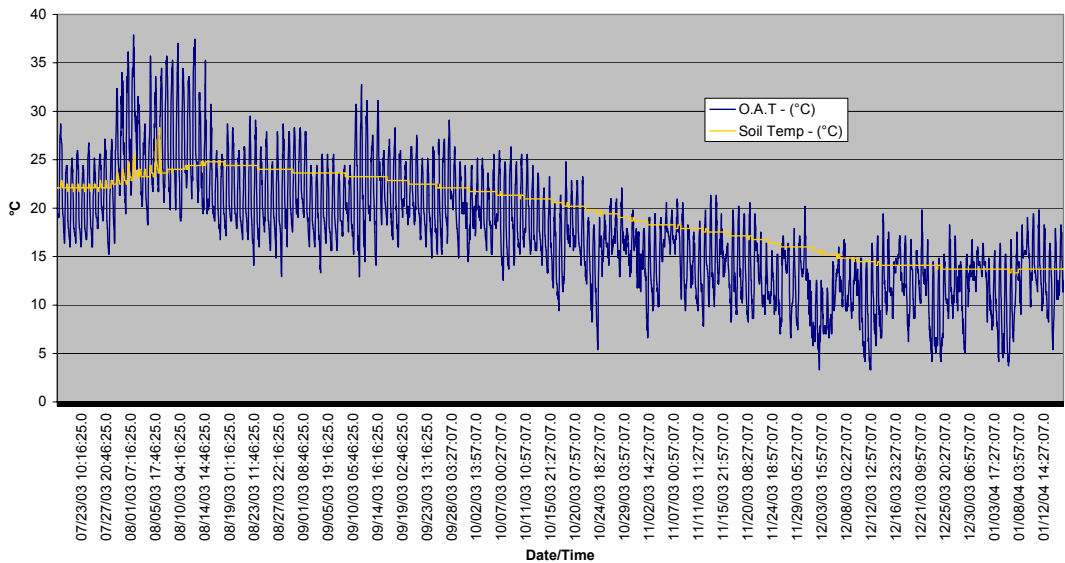
The graphs below show the air temperature at the air intake and compares this with the temperature at the extract, due to the amount of information present on these graphs the O.A.T. is presented separately along with the soil temperature to give an indication of how the ground storage medium reacts at different times of the year.



House 56 - Ground Treatment



OAT and Soil Temperature



There are two interesting factors to consider within these graphs, the first is how similar the two extract temperatures are. Although this may have been expected because the two building were very close to each other and the external temperature were the same, the soil conditions that the ground tubes were buried under may have been different, as was the vegetation planted over the garden areas. It was thought that this may affect the performance of the heat sink, however, it would appear not to have affected its performance. This may prove to be a greater factor elsewhere within the development and may prove to be a limiting factor to using the technique elsewhere in Europe.

The second and more important factor to consider is how effective the ground is at removing the peaks and troughs of the external air during hot weather and adding heat to the incoming air during cooler weather.

- Throughout the monitoring period for house 54 the maximum $+\Delta T$ i.e. heat removed from the incoming air was 11°C and the maximum $-\Delta T$ was 8°C i.e. heat added to cold external air (during winter months or during the evening).
- Throughout the monitoring period for house 56 the maximum $+\Delta T$ was 12°C and the maximum $-\Delta T$ was 8°C .

This addition and subtraction of heat energy shows how effective the ground tubes are and helps to explain the consistency and stability of the internal temperature of the Coolhouse villas.

The graph above that shows the relationship between the soil temperature and the O.A.T is interesting as it shows how rapidly the soil temperature reacts to a rise or fall in O.A.T. Research at the beginning of this project stated that the baseline temperature for the soil will be the same as the average external temperature throughout the year, in this area of Portugal this is 14°C .

The relationship between the two is important as it is expected that when the incoming air is losing heat to the soil heat sink i.e. from an area of greater heat energy to less heat energy this heat will be stored and then used when the energy relationship is reversed, i.e. heating air that is less than the baseline. Normally, this reversal would expect to be done within every diurnal cycle to provide a constant input temperature over 24 hours. However, during the summer when night temperatures are greater than the baseline figure the heat removed builds up within the ground heat sink causing a reduction in efficiency of the system for the next day i.e. night time purging of the heat sink is not occurring.

Within this monitoring project this lack of purging seems to be occurring for 34% of the time as the heat sink was increasing in temperature. However, this was only at the start of the project, it was during the summer months and the heat sink started from a very hot start (reasons for this can be found in Section 4.2). As the external temperatures started to decrease the soil temperature also decreased until the temperature of 14°C that was originally predicted was achieved.

Due to the size of the soil heat sink it cannot be determined if the temperature will increase again next summer to the levels seen during this monitoring period or whether now that a baseline has been achieved and there is no further external interference in the structure of the heat sink the system will now become self sustaining on a diurnal/season cycle.

10 Fan Activity

The table below shows the kWh consumption of the fans found in houses 54, 56 and 57.

Coolhouse Fan Electricity Consumption

House number	kWh consumed during monitoring period	kgs CO ₂ produced during monitoring period	Cost - €
54 – Living area	505	217	51
54 – Bedroom area	505	217	51
56	627	270	63
57	245	105	25
Total	1882	809	190

Assuming:

- A factor of 0.43 for kWh to kgs CO₂ – standard factor in UK but this is dependent upon a countries electricity production breakdown, this data is not available for Portugal.
- A cost of €0.10 per unit of kWh – based on Portuguese cost of electricity for standard domestic usage.

Within the 'conventional' air conditioning industry there is a standard method used that takes into account floor area, percentage glazing, North/South alignment etc to produce a kW figure required for split unit air conditioning. This has been used to produce the following table.

Split Unit Electricity Consumption

House number	kW rating of required split unit.	kWh consumed during monitoring period	kgs CO ₂ produced during monitoring period	Cost - €
54 – Living Area	15.1	10,948	4707	1,095
54 – Bedroom area	4.5	1,634	702	163
56	13	10,816	4,651	1,082
57	9	11,952	5,139	1,195
Total	41.6	35,350	15,199	3,535

It must be highlighted that unlike the Coolhouse system that is a passive system split units outputs are thermostatically controlled. This means that whereas the Coolhouse fans would operate for the entire period of time they have been programmed i.e. ten hours to provide a constant supply of coolth. A split unit would operate until it achieved its setpoint, at which point it would either switch off until required again or reduce its output to maintain its environment as closely to the setpoint as required. Therefore, using knowledge based on experience an assumption has to be made regarding the kWh consumed by a split unit to produce the same environmental conditions as those experienced by the Coolhouse system. These assumptions are included in the table above and are as follows.

House Number	Number of hours Coolhouse operates daily.	Number of hours a split unit would operate.	Number of hours Coolhouse operated over the monitoring period.	Number of hours a split unit would have operated over the monitoring period.
54 – Living Area	10.5	4	1,904	725
54 – Bedroom area	10.5	2	1,904	363
56	15	5	2,495	832
57	16	5	4,248	1,328

Therefore, based on the four separate areas (i.e. three houses but one with two systems) it can be determined that the Coolhouse system is capable of making the following savings per

cooling season if installed in houses in hot climates where otherwise conventional air conditioning system would be used.

	kWh	kgs CO₂	Cost €
With Coolhouse	1,882	809	190
With Conventional Air Conditioning	35,350	15,199	3,535
Savings created by using Coolhouse system during the monitoring period.	33,468	14,390	3,345

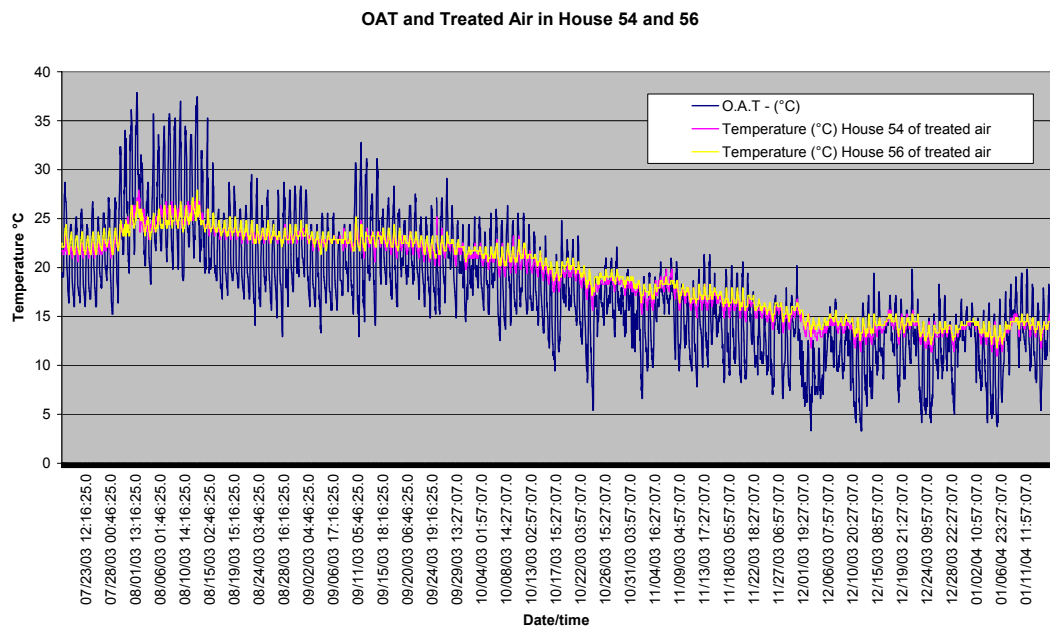
Therefore, if a Coolhouse system costs €7,500 to install per dwelling (from the Alma Verde marketing report produced by John Tranmer) and there are four systems installed, the total installation costs for the buildings monitored is €30,000. Therefore, if Coolhouse systems were installed in preference to conventional split units then the unit would have a payback period of just under 9 years for these dwellings cooling use alone. Obviously if no cooling system was installed then the system is an additional cost to the annual running of the property but is a very small cost for the amount of cooling energy that is provided.

11 Calculations Regarding Coolth Engine

Looking at the data for house 54 and 56 the following table can be produced to show the average monthly temperature of the delivered air in relation to the average monthly OAT over the monitoring period.

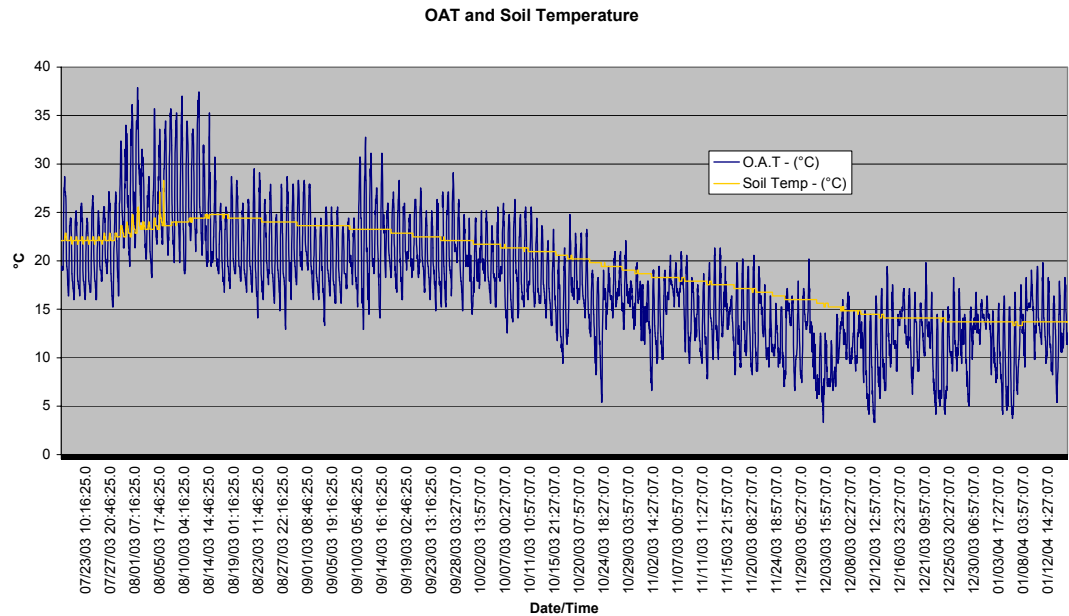
	Average treated temperature for House 54	Average treated temperature for House 56	Average OAT
July 2003	23	23	23
August 2003	25	24	24
September 2003	23	23	23
October 2003	18	18	18
November 2003	16	17	17
December 2003	14	14	14
January 2003	14	14	14

This table suggest that the delivered air is the same temperature (+/- 1°C) as the OAT, as such it suggests that the ground treatment is not very effective at producing cool air. However, it should be remembered that the figures shown are average daily figures presented on a month-by-month basis. It does not show the delivered temperature in relation to OAT at a given point, this information is shown in the graph below.



This graph shows that relying on data given in the table, as an indication of the performance of the ground heat sink, would be a mistake as it shows how the ground treated air in both building 54 and 56 follows the trend of the OAT but removes the peaks and troughs associated with day and night temperatures. Of particular interest is how high external temperatures do not immediately affect the treated air temperature; this proves that the average figures shown in the table do not reflect the daily performance of the tubes.

The graph below (also shown in Section 9) shows the relationship between the OAT and the ground temperature.



This graph shows that the soil temperature relates to the overall trend of the OAT, albeit with a much slower rate of change. It was discussed during the original monitoring program whether the soil mass should have been monitored in greater detail i.e. with one soil temperature probe next to the ground tube, another one a metre away from the ground tube, another one a further meter away from the tube etc. This would enable the heat dispersion affect of the soil to be monitored and see on what scale the heat from the ground tube affects the underground system.

However, it was decided that this level of monitoring would only be specific to one location due to the unique combinations of soil types and as such would not have a transferable benefit for sites elsewhere. There has been previous research into heat transfer within soil at depths, which is why the original modelling work stated that the ground pipes should be two or more metres deep.

If the monitoring program was over a longer period of time it would be interesting to see if the ground temperature followed external temperature on a yearly/seasonal cycle as is suggested by the graph above. If this trend did not appear then it would be imagined that a base temperature would develop, which is what the original modelling programme stated.

One reason why this base level might not have been achieved is because the ground tubes have not experienced an entire years temperature range i.e. charging the ground with heat during the summer period and coolth during the winter period. Therefore, all the embodied heat introduced into the ground during the excavation of the ground tubes and by one cooling season activity may not have had a chance to counteract upon by the winter operation of the system.

The average level of cooling that can be delivered by the Coolhouse ground tube system was originally calculated as being 2.5 kW, however, the monitoring program showed that in reality the delivered cooling varied according to ΔT (i.e. the temperature between air being taken into the ground tube matrix and the air being expelled at the other end). The results from the monitoring are as follows:

ΔT	KW Cooling
12	58
6	29
1	4.8

These results show that the amount of coolth available does depend upon the outside air temperate with the higher the ΔT the higher the potential coolth. However, this monitoring does not show how sustainable this cooling potential is as periods of ΔT being 12°C are few and far between and rarely last longer than two hours i.e. from 13:00 to 15:00 during August. Therefore, it would be considered prudent that the lowest figure give in the table above is used during the assessment of cooling potential.

Furthermore it should be remembered that this figure is solely applicable to the unique conditions of this site and that a full modelling assessment of a site prior to any development will give a useful figure of potential coolth.

12 Using the Ground Cooling System

One factor that will affect the efficiency of the Coolhouse system is the manner it is used, i.e. if the system was used throughout the day and night would this cause a decrease in the effectiveness of the system?

A number of conclusions can be made as to the most efficient method of using the ground cooling system; but these will require the system to be used for a number of years to determine whether they are always correct.

The monitoring of inlet air temperatures from the ground cooling system and internal temperatures in the houses, showed minimal variation related to the different patterns of usage. This implies that the system is very robust, that there is considerable cooling capacity in the system which is not quickly exhausted. The ground temperatures appears to rise and fall roughly in line with average outdoor temperatures, but this change is gradual and not apparently subject to significant influence from the effects of warm air being drawn through.

However the system is used, its main advantage of smoothing out the extremes of temperature occurring externally, will always be achieved.

It is thought that the ground tubes will provide the most cooling if operated from the middle of the day throughout the afternoon and continue until the early hours of the following morning. This will allow the colder night air to 'recharge' the heat sink with coolth allowing it to be at a lower temperature the following day. Although this might seem to be counter to the data produced during the modelling that the heat sink effect of the ground can be seen as being infinite it is assumed that this purging action would make the cooling more dynamic, making it more efficient.

However this long period of use of the system will use more fan energy and there is no evidence from the monitoring that night purging of the ground is necessary, the thermal mass of the ground may be enough in itself to provide the necessary cooling for the next day.

The conclusion is that the combination of the well designed and constructed buildings with considerable internal thermal mass, and the ground cooling system, allow several different modes of operation which will all provide adequate internal comfort conditions in summer.

13 Conclusions

Using the data obtained over this monitoring period the Coolhouse system seems to be very effective at producing stable internal temperatures throughout the heating and cooling season.

Internal temperatures reflect outside air conditions but the Coolhouse ground heat sinks appear to remove the peaks and troughs associated with external conditions. This means that internal temperatures are not completely incongruous with outside conditions that can happen with conventional air-conditioning units, this produces more pleasant living conditions.

The different temperatures between peak O.A.T. and internal temperatures range from 11°C reduction, i.e. cooling, to 12°C addition, i.e. heating. However, these figures are slightly meaningless unless the graphs that plot the relationship between OAT and internal air temps are studied.

It is hard to determine where the affects of the ground tube system start and where the thermal mass of the building start, however, the Coolhouse system as a whole entity seems to work very well together.

The use of the Coolhouse system will produce far less CO₂ through electricity consumption than an equivalent system using conventional air conditioning. Although this figure depends upon usage it is thought to be in the region of 809 kg CO₂ per cooling season as opposed to the 15,199 kg CO₂ that would be produced using split units.

Residents of the Coolhouse villas are very happy with the building quality, the sustainability aspect, and the anticipated low running costs of the dwellings. It is concluded that residents may operate the ground cooling system in a number of different ways, such as long or short periods, night purging, etc. and still achieve very acceptable internal temperatures.

The Coolhouse project can be seen to have achieved its original aims of providing high quality, comfortable dwellings that do not consume large amounts of energy to provide these conditions, therefore reducing the environmental impact of the dwellings and allowing the residents to increase the sustainability of their lives.