COOLING IN HOUSING IN SOUTHERN EUROPE WITHOUT CHILLERS.

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ABSTRACT

COOLHOUSE demonstrates the use of passive cooling techniques in southern regions of Europe which are aimed at giving comfortable summer conditions in domestic scale buildings without using mechanical cooling systems. The project focussed on three sites, a private development of houses for sale in south west Portugal, an old people's home in south France and a community centre in mid Italy. All are new buildings and were designed to provide cool internal conditions by passive means such as using solar shading and thermal mass, with the addition in all three cases of ground cooling pipes. This combination of measures was designed, constructed and monitored as part of the project. The ground pipe systems used PVC pipes buried 2-3 metres below ground with air drawn through using electric fans. The results demonstrate that the whole package of measures is successful in providing summer comfort. There is also benefits to the heating of the buildings in winter if the preheated air is used. The project concludes that there are no architectural difficulties in buried pipe system or providing and using internal thermal mass and that the COOLHOUSE package of measures could be replicated in different building types across all southern Europe.

KEYWORDS

Passive, cooling, thermal mass, ground cooling, adobe construction.

BACKGROUND

COOLHOUSE was a European Commission supported Energie Demonstration project which ran for four years from 2000. The project aimed to test the viability of alternatives to air conditioning using passive and low energy construction, cooling and ventilating techniques in Mediterranean and coastal climates and to demonstrate that such strategies can be practical and provide comfortable internal conditions for the occupants. One objective of the Coolhouse project was to reduce the energy demand and the environmental impact of the developments. Another was to provide economic and environmental arguments to justify the cost of the systems and to design and construct ground cooling systems that are easy to replicate at reasonable cost.

The design phase aimed to examine several natural ventilation and cooling strategies, including passive architecture, wind catchers, wind towers, ground pipes, and rock stores. However, the concept of ground cooling systems was common to all three sites. The Coolhouse project finally aimed at the construction, monitoring and publicity of the architectural integration of ground cooling systems with passive architecture in new domestic type developments.

DESCRIPTION OF THE TEST SITES

Three sites were finally included in COOLHOUSE. A new housing development in south west Portugal (Alma Verde), a nursing home in southern France (Frejus) and a community centre in central Italy (Aler Pavia). The developers in each country worked in partnership with energy consultants to achieve the project aims.

A fourth housing site, in Crete was included in the original contract, but was never built. The design work on the project was carried out in 2000 by the University of Athens but no further action was taken by the Contractor ElGreco.

The three sites are different in both location and building type and use and the details of the components and systems finally incorporated into the buildings varies greatly. Each site used its own designers and consultants, though all sites and installations were discussed between the design teams at the regular six monthly meetings. This variety also demonstrates that design of passive cooling systems can take on a number of different forms and the results demonstrate that each can be successful.

There is a general level of innovation in all the buildings which is that they are all designed to optimise the use of the local climate. The majority of new construction in hot countries is not designed to work with the climate and produce sustainable buildings, but rather ignores natural and passive design and, building to current regulations produces buildings that need heating in winter and cooling in summer to make them acceptable to occupants. This is very energy inefficient and very different from the COOLHOUSE building design.

The main technological innovation in all three projects is the use of buried pipes to cool external air and draw this into the buildings to provide cooling. This innovation avoids or at least reduces, the need for conventional active cooling using electrically driven compressor systems. The initial design studies showed that fans were necessary to draw the air through the buried pipes and this uses electricity, though considerable less than air-conditioning systems. It is also thought that buried pipes require less maintenance that air-conditioning systems and certainly have a much longer life.

Site in Portugal

Alma Verde is a 35.3 hectare new residential community with numerous public and private amenities located in the unspoiled western Algarve 8km west of Lagos, Portugal, some 25km east of the tip of Europe. When site design started the first house to be built on the site were the set of 6 detached houses and it was decided to use these to demonstrate the COOLHOUSE principles. Design of the houses and cooling systems started in 2000 and the whole concept of passive cooling, together with the ground cooling systems was developed on a comprehensive basis.

The general design of the houses was passive with external wall insulation, solar shading and internal thermal mass, including adobe internal walls. For the ground cooling, standard PVCu drainage pipework was used for the ground pipes, with the widest readily and economically available diameter being 160mm. With this duct size taken into account, computational analysis showed that a duct air speed of 4m/s running through two ground tubes of 25m length each would achieve an air temperature reduction of 8ºC at the ground tube outlets. This equates to 2500W of cooling energy. Further, computational fluid dynamic analysis showed internal air temperature reductions of 3ºC compared with outside temperatures, which under most circumstances is considered sufficient for thermal comfort.

It also became clear that direct wind power alone would not be adequate to achieve these duct velocities, and that fan assistance would be required. Also, with wind power only, the system would not operate on still days and these are the days when cooling would be most required. Again, analysis showed a separation between pipes of 2m allows heat dissipation and avoids the cumulative build-up of heat from both pipes that would occur if they were closer together. Unavoidable 90º bends in the ground tube layout are formed from two 45º pipe sections to reduce the air resistance encountered with short radius 90º bends, as long radius bends were unavailable locally. Periodic cleaning of the ground tubes is catered for by installing the tubes with a fall from start to end of about 1: 60. This allows jet washing from the intake end of the tubes to the low point at the other end, where a sump enables a temporary pump to remove cleaning fluid.

Site in France

“L’Aubier de Cybelle” is a 80 beds care home for elderly people, which has been built in Fréjus, Southern France. It has been designed to response to high quality standard, in terms of comfort and environmental issues at all levels, inside the building, locally and globally, and to be the very first “green” nursing home available in the south of France, using in particular bioclimatic and passive cooling design. Because of the particularly climatic conditions in Fréjus and the appropriate choice of land, the building is largely open towards the south, allowing the best use of natural conditions for passive heating and cooling, and natural light. The building, on two levels, covers a total surface of 3950 m2.

All the technical systems have been adopted to reach summer comfort without having to install centralized air-conditioning. These include insulation, solar shading, daylighting, thermal mass, natural ventilation, planting and ground cooling. Among these solutions, the most innovative is a ground cooling system for the dining room area of 380m^2, for which a grid of 11 pipes each of 0,2m diameter has been buried 2m under the ground covering an area of 400m2 outside the building. Solar water heating and passive solar gain are also included in the building.

Site in Italy

The Pietrasana neighbourhood, Vigevano, Italy, is an area of existing social housing undergoing refurbishment. The district consists of 220 dwellings located in 10 buildings. The central courtyard area has been completely re-designed and a new community centre built. The centre, which is the “COOLHOUSE” building, named “CircoLab”, is a multi-functional facility with corporate, conference, recreational, cultural and community functions. The minimisation of the running and maintenance costs was of prime importance in the “CircoLab” design. A mechanical ventilation system connected to air solar collectors during the winter season and to the ground cooling duct during summer, provides a reduction of the heating and cooling costs, and an improvement in comfort of users.

The building is a “concrete box”, cut by two internal glazed patios along the longest walls, and completely greened by creepers. The visual connection with neighbourhood is given by a large window on the East side, in front of the central courtyard, while a door on the S/E corner which provides the access.

The cooling of the building is provided by connecting the system for the mechanical ventilation with a ground cooling system, of which the core is made of a PVC pipe, diameter 0,4 m, 40 m long buried 4 m under the ground level, taking the outdoor air from a shaded area at the opposite side of the courtyard. An air-to-air heat exchanger provides the connection between the ground pipe and the ventilation system, avoiding any possible air pollution problems. At night, the building is cooled taking the air directly from the roof, when the outdoor temperature falls below the internal one, giving the ground cooling system time to re-charge.

During wintertime, the mechanical ventilation system is connected to a set of glazed air solar collectors of about 36 m^2, placed on the CircoLab flat roof, which provide pre-heating of the inlet air.

RESULTS

Portugal

The monitoring at Alma Verde shows how effective the ground was 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 +DT i.e. heat removed from the incoming air was 11°C and the maximum -DT was 8°C i.e. heat added to cold external air (during winter months or during the evening). For house 56 the maximum +DT was 12°C and the maximum -DT was 8°C.

The temperature of the air leaving the ground pipes varied from 26^0C in August to 15^0C in winter, only one or two degrees different to the temperature of the ground itself. The system achieves the equivalent cooling of fresh ventilation air at a 95% reduction in energy and CO_2 emissions, compared with air conditioning. Useful ventilation pre-heat gains are also available in winter mode. An unexpected benefit from the Alma Verde Coolhouse system when combined with the use of adobe blockwork and vapour permeable external wall construction, is that it is very effective in making significant reductions in internal relative humidity compared to external conditions. Monitoring shows these reductions to be 25% of RH and occasionally up to 30% reductions were recorded.

France

At the nursing home in Frejus, the ground cooling system was monitored during in June and delivered an initial cooling power of 14 kW at 2m^3/s air flow-rate and of 9.5kW at 1m^3/s air flow-rate, which corresponded to expectations. In tests in July and August, cooling power values of typically 5 kW were observed after one to three days of uninterrupted use.

The measured cooling power values are probably lower than values under operational conditions as the soil was backfilled above the pipes in summer conditions of high temperature and low humidity, just before the monitoring started.

Ground temperatures were measured over six months and shown to rise by typically 1 to 2°C per month until the end of August, when decline sets in. At a depth of 2m, earth temperatures ranged between 13 and 28°C.

Based on these results, a one-dimensional finite element simulation calculation predicts annual yields of 2.2 MWh for cooling, 6.7 MWh for heating and an equivalent ventilation coefficient of performance of 16.

Italy

At Vigevano in Italy, monitoring of the whole installation showed that the peak cooling power was 3.2kW with a peak temperature difference 5.0^0C. However the average cooling power was only 0.8kW and the average temperature difference of the air entering the building below external air temperature was 2.9°C. In this particular installation, the earth pipe cooling power seemed too small to overcome solar heating of the duct and heat exchanger located on the roof. In future applications, it is concluded that cooled air should not be brought into the air outside the building in order to keep all the cooling potential inside the building.

The winter monitoring has shown the amount of heating energy generated by the solar panels and the overall building performance, with the solar panels giving 15% of the heating supply, more that 12 000kWh per year.

CONCLUSIONS

COOLHOUSE confirms that several straightforward construction measures are important in providing summer comfort, including solar shading, thermal mass, insulation etc. and that ground cooling pipes can also contribute. Ground cooling pipes work best if they are used in a simple way e.g. air pulled slowly through and used directly as cooled ventilation air. Then they can deliver air at at least 10^0C below outside air temperatures at peak times. At night if the air is cold it can be drawn through to help cool the ground ready for the next day. The pipes can be used only for peak times of the day or for longer periods and also for preheated ventilation air in winter. They can make active air conditioning unnecessary but cannot supply the same blasts of cold air, they work in a slower way and will work best if there is a pre-planned strategy for their use. Ground cooling pipes supply coolth over long periods of time but at a low rate, which is almost the opposite of active chillers. This is very important in understanding and designing a good ground cooling system.

The experience in the community centre in Italy is more difficult, as the ground pipe cool air passes through a heat exchanger first and is integrated mechanically into the heating and ventilating system of the building. The benefits of ground cooling are more difficult to identify and it seems that the particular use strategy was not best suited to the pipe system installed.

We conclude that ground pipe systems work best where the building itself is passively designed to minimise the need for cooling and then a ground cooling system will lop off the peaks of temperature. This generally gives a very comfortable internal environment.

The costs of ground cooling obviously vary with the size but are not expensive, a price per house of about 7500euro was quoted at Alma Verde and a rough estimated payback was 10 years, due to avoided electricity running cost of chillers. From an environmental point of view the energy savings are large at around 5000 tonnes of CO_2 per year per house. This is a very significant conclusion for European energy consumption.

A study on Regional Suitability of the technologies concludes that all technologies are widely applicable across southern Europe where cooling is needed, and could become useful in more northern areas as global warming spreads its effects.

Design of passive cooling measures, including ground pipe systems is not difficult and methods are described in a report on calculation methods used in the project. Computer modelling and calculation methods are available and are tried and tested. The integration of the passive measures into the architecture of a building are not likely to cause any major difficulties, is the conclusion of the Architecture and Passive Design report, but they must be carefully considered from the start of the design process.

Overall it is concluded that occupants like the passive systems but there remains the question as to whether individuals will actually buy in. The Marketability of Passively Cooled Housing report concludes that although passive cooling is low on the list of priorities of prospective purchasers it does have some marketing benefits and has been used as such at Alma Verde (the only private development for sale in COOLHOUSE). The report also indicates that a significant number of purchasers will opt for the optional “COOLHOUSE” system, if offered to them at the current price.