

GROUND COOLING OF VENTILATION AIR FOR ENERGY EFFICIENT HOUSE IN MALAYSIA: A CASE STUDY OF THE COOLTEK HOUSE

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Abstract

The paper presents an analysis of on-site measurements of the ground cooling air duct system of the energy efficient CoolTek house in Melaka, Malaysia. Measurements of temperature, humidity and CO₂ were undertaken indoors, outdoors and inside the ground cooling air duct system during two modes of operation. The first mode of operation was a fully passive mode where the ventilation was driven only by the thermal pull of the solar chimney. The second mode of operation was a hybrid mode where a small fan assisted the solar chimney in ventilating the building. Some improvements of the ground cooled air duct system are suggested on the basis of the analysis.

Keywords: Ground cooling of air, energy efficient tropic housing, CoolTek, solar chimney.

1. Introduction

Year 2004 saw the completion of the energy efficient CoolTek house in Melaka, Malaysia. The 200 m² house is air-conditioned 24-hours, yet, the daily air-conditioning consumption is only 8 kWh – or RM 1.8 in local currency. Insulation, shading, high performance glazing and air-tightness are among the energy efficient features employed in the CoolTek house. The focus of this paper, however, is on the workings of the ground cooled fresh air system for ventilation purposes. Ground cooling of inlet air is known from other climates – in particular in hot and dry climates with high diurnal temperature swings – but is not common in the hot and humid tropical Malaysia. Vernacular Malaysian architecture has high naturally ventilated pitched roof ceilings and big well shaded window openings to harness any breeze while not allowing entry of direct sunlight. In contrast, the CoolTek house has a flat (15° pitch) roof with low ceiling and is built very air tight. The only common design element is the wide eaves. The design strategy of the CoolTek house is possible due to the emergence of the air-conditioning technology and is intended to minimise its use. The paper investigates whether the ground cooling system of inlet air helps to increase the energy efficiency of the house.

2. Ground Cooled Ventilation System

The CoolTek house does not have any openable windows in the air-conditioned zone and all doors to the outside have double-seals to ensure air tightness of the building envelope. The darkest outdoor surface of the white coloured house is the red brick chimney, which deliberately has not been painted white in order to function as a solar chimney. The warm sun exposed surfaces of solar chimneys cause the air to rise due to the effect of thermal buoyancy, i.e. hot air rises. The air sucked out of the house by the solar chimney is to be replaced by air from the ground cooled ducts with floor level inlet openings in the living room, the corridor and the bedroom. The ground cooled air ducts are all connected to a sub-soil chamber with concrete rods penetrating into the ground. This chamber is again connected with an approximately 10 meter sub-soil duct with an opening below a shaded tree (Fig. 1). It is often fair to assume that the ground temperature equals the annual average ambient temperature, which in case of outdoor temperatures measured at the CoolTek house would be about 26.4°C.

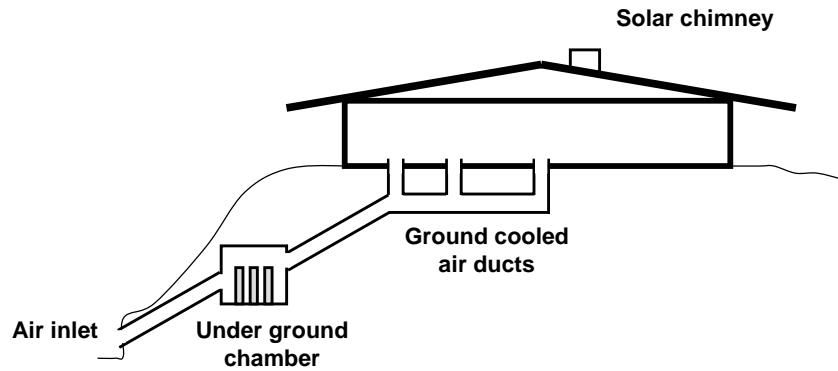


Fig.1 The ground cooled fresh air system of the CoolTek house

It is worth mentioning that the solar chimney is connected to the non-air-conditioned garage via the roof space. The garage, which is fitted with an automatic roller door with rubber seals, is not as air-tight as the remainder of the house and will therefore reduce the solar chimney pull on the air-conditioned spaces. The original design of the ventilation system relied solely on passive measure, i.e. the thermal suction of the solar chimney.

Apart from conditioning the air, the ground cooled air ducts were also intended to give a sound proof entry of fresh air to the house. Moreover, the under ground ducting system would also increase the air quality of the inlet air because dust and other particles would be able to settle out of the air before entering the house. Only the energy aspects of the ground cooled fresh air system will be investigated here.

3. Measurements

The performance of the ground cooled ventilation system was monitored with the use of several dataloggers measuring temperature, humidity and CO₂ levels. Only one CO₂ sensor was available, so it was shifted between the measurement locations. The instrumentation used was HOBO dataloggers that were set to log at 15-30 minute intervals; see Table 1 below.

Table 1. Measuring equipment

Instrument	Measurements	Accuracy	Logging interval
HOBO H08-004-02	a) Temperature b) Relative humidity	± 0.5°C ± 2.5%	15-30 min
HOBO U12-012	a) Temperature b) Relative humidity	± 0.35°C ± 2.5%	15-30 min
Telaire 7001	a) CO ₂	± 50 ppm	15-30 min

The measuring equipment was placed at three locations to monitor the temperature, humidity and CO₂ levels inside the house, outside the house and inside the ground cooled air ducts connecting the two. Since the CoolTek house is air-conditioned 24-hours the absolute humidity level of the air will be lower indoors than outdoors at all times. Similarly, the CO₂ level will be higher indoors than outdoors because of human occupation of the house. Continuous measurements of these values inside the cooled air duct would therefore give a good indication of the flow direction in the ground cooled air duct across the day. Some of the measurements were repeated one year later after the installation of a 35W auxiliary fan to the solar chimney had been installed at the exhaust from the living room to the solar chimney. The schedule of measurements is shown in Table 2 below.

Table 2. Schedule of measurements

Location	Measurements	Period	Logging interval	Fan operating	House electric consumption	Average outdoor temp.
A: Outdoors	a) Temperature b) Humidity	3 July – 12 August 2006	30 min	No	19.9 kWh / day	26.4°C
B: Inside the house (bedroom)	a) Temperature b) Humidity c) CO ₂	3 – 15 July 2006	30 min	No	20.4 kWh / day	26.6°C
C: Inside the house (computer room)	a) Temperature b) Humidity c) CO ₂	17 – 29 July 2006	30 min	No	20.1 kWh / day	26.5°C
D: Inside the ground cooled air duct (0.5 m below the floor)	a) Temperature b) Humidity c) CO ₂	31 July – 12 August 2006	30 min	No	19.1 kWh / day	26.0°C
E: Inside the ground cooled air duct (0.5 m below the floor)	a) Temperature b) Humidity c) CO ₂	19 May – 2 June 2007	15 min	No	-	-
F: Inside the ground cooled air duct (0.5 m below the floor)	a) Temperature b) Humidity c) CO ₂	3 – 6 June 2007	15 min	Yes	-	-

Table 2 shows that during the first batch of measurements in year 2006 the electricity consumption was virtually the same during each of the three 2-week periods (B – D) that the measuring equipment was shifted between the three locations. This indicates that the usage of the house was similar during these three periods, which the couple living in the house also could attest to. It can be observed that the slight variation in air-con consumption seems to match the slight variation in average outdoor temperature (Fig. 2).

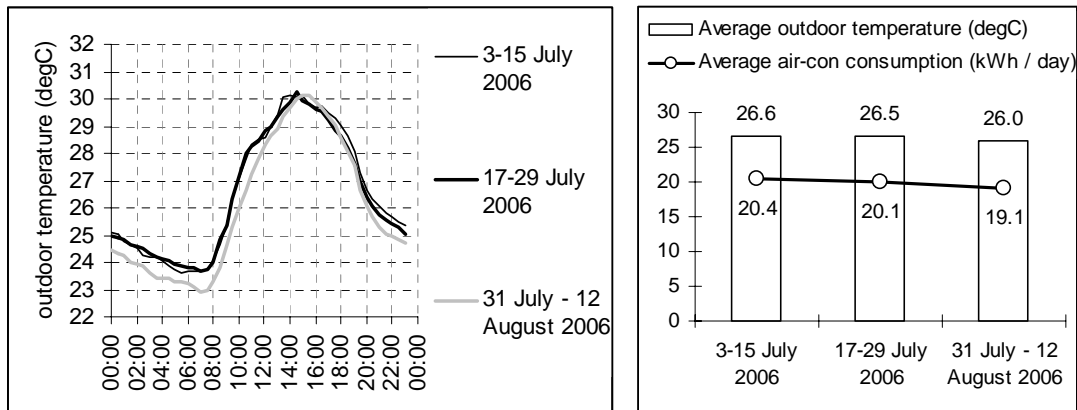


Fig. 2 Minimal variation in average temperature and air-con usage over three measuring periods

Fig. 2 shows that the variation in climate and house usage is minimal of the measurement periods B-D (Table 2), so it is fair to assume that the measured data for each of the periods can be compared to one another, as will be done in the following section.

4. Results of passively ventilated ground cooled air ducts

The measured variation in temperature, humidity and CO₂ level will now be analysed to evaluate the performance of the ground cooled air duct system when it is passively ventilated by the solar chimney.

4.1 Temperature measurements

The typical temperature profiles were measured to investigate at what hour of the day it will be advantageous to draw air through the ground cooled air duct in order to pre-cool inlet air to the CoolTek house. The average temperature curves are found in Fig. 3 below.

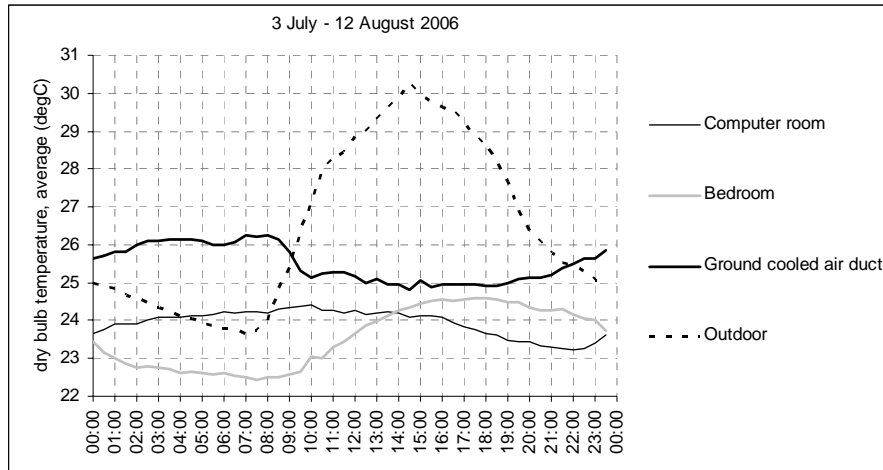


Fig. 3 Average daily temperature measurements (period A – D)

Fig. 3 shows that the indoor temperature, which is air-conditioned 24 hours with a set point of 24°C, is cooler than the outdoor temperature most of the time. The average outdoor temperature shoots up to about 30°C in the afternoon during which time it would be advantageous to draw air through the ground cooled air duct, which theoretically should have an air temperature of 26.4°C (i.e. the average ambient temperature). The average temperature measured in the ground cooled air duct is seen to vary between 25°C (day time) and 26°C (night time). If there was a steady flow of air through the ground cooled air duct to the indoor environment, one would expect the temperatures to be stable or to reflect the outdoor temperature variation, i.e. higher day time values than night time values. However, the opposite seems to be the case indicating either a smaller air flow or a reversed air flow in the ground cooled air duct during the day time.

4.2 CO₂ measurements

In order to determine the flow direction of air in the ground cooled air duct system it is useful to analyse the measured CO₂ levels, as they will differ from outdoor to indoors. The outdoor CO₂ level is expected to be more or less constant around 350 ppm whereas the indoor CO₂ level is expected to be higher indoor the house due to human respiration.

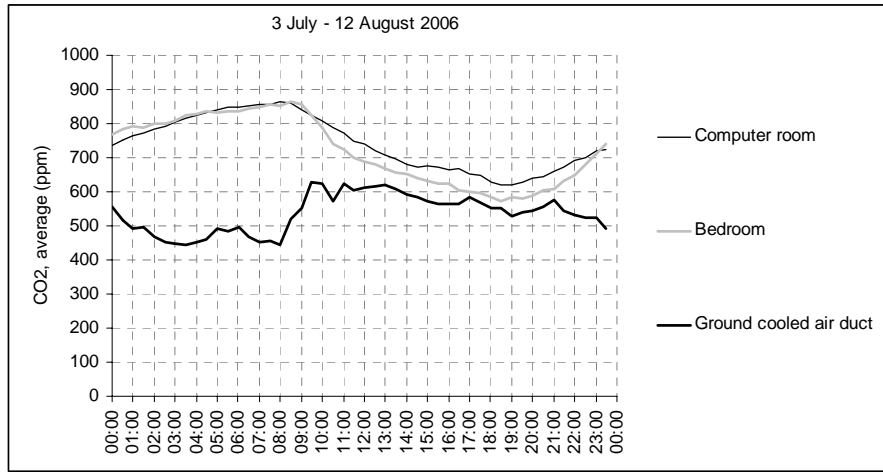


Fig.4 Average CO₂ measurements (B – D) in CoolTek house before installation of fan

Fig. 4 shows as expected that the ground cooled air duct has the lowest CO₂ level, as this is where the supply of fresh air to the house is supposed to occur. The difference in CO₂ levels is particularly high at night, where indoor CO₂ levels are about twice that measure in the ground cooled air duct. In the day time, however, the difference in CO₂ levels is smaller between the three measuring points. Interestingly, the CO₂ level of the ground cooled air duct is seen to increase about 100 ppm from night time levels indicating that the air flow in the pipe has decreased or perhaps reversed during the day time. The CO₂ readings also show that the CoolTek house is adequately ventilated for occupation by two persons as the CO₂ levels stay below the recommended 1000 ppm.

4.3 Absolute humidity measurements

The outdoor absolute humidity levels are more or less constant at 22 g/m³ air, whereas the 24 hour air-conditioned indoor environment of the CoolTek house has a humidity level of about half of that, namely 11.8 g/m³ air. In Fig. 5 below the average absolute humidity measurements are shown.

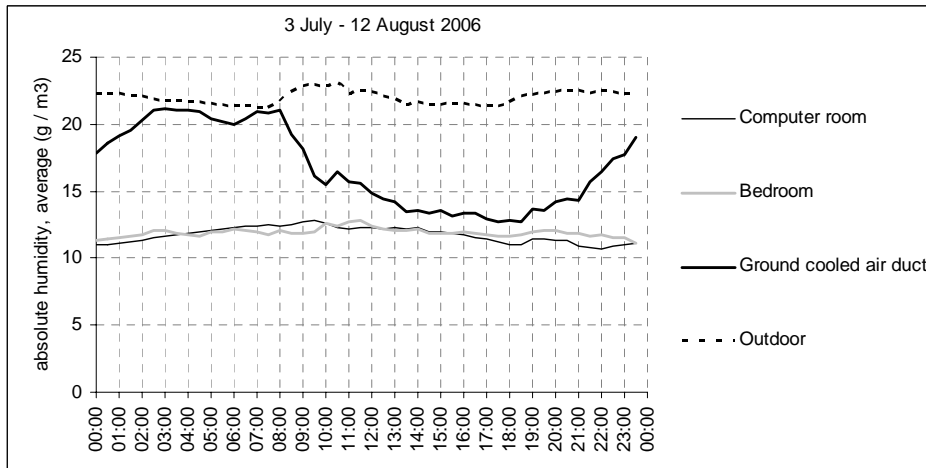


Fig. 5 Average absolute humidity measurements (A – D) in CoolTek house

Fig. 4 shows that the absolute humidity level measured in the ground cooled air duct nearly matches the outdoor level at night time and nearly matches the indoor level in the day time. This indicates that the origin of the air in the ground cooled air duct comes from outdoors in the night time and from indoors in the day time.

The above measurements of temperature, humidity and CO₂ levels all point to the same conclusion, namely that air flows through the ground cooled air duct pipe and into the house during night time and out of the

house during the night time. From a thermal buoyancy point of view this is understandable, because the 'thermal pull' delivered by the solar chimney simply is not strong enough to counteract the reverse buoyancy effect delivered by the air-conditioned and 'heavy' air (24°C) that drops out of the floor ventilation pipes and is being replaced by warm and 'light' outdoor air (30°C). Only at night when the temperature difference between indoor and outdoor air is 2°C or less does the air-flow reverse and fresh air enters through the ground cooled air duct and into the house (Fig. 6).

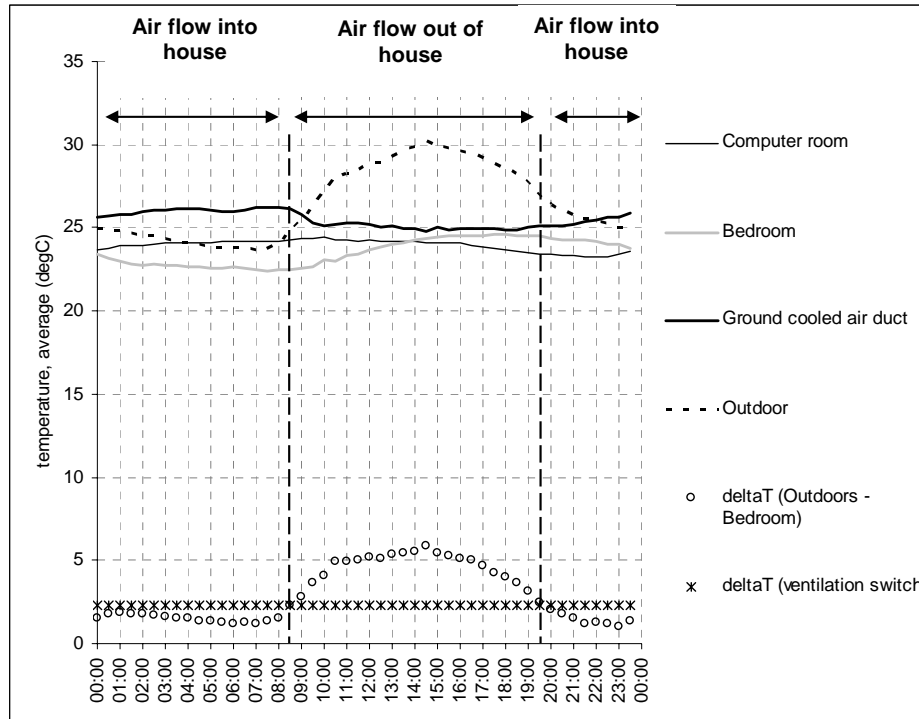


Fig. 6 Switching air flow directions in ground cooled air ducts of CoolTek house

Fig. 6 shows the switching of the air flow in the ground cooled air ducts at about 8:30 and about 19:30 o'clock. The reversal of flow is found to take place when the temperature difference between indoors (bedroom temperature) and outdoors equals 2°C. During the night (19:30 – 8:30) this temperature difference is less than 2°C and air flows from outdoors and into the house. During the day (8:30 – 19:30) the temperature difference is higher than 2°C and air flows from inside to outside. From an energy point of view the ground cooling system does not add to the energy efficiency of the house. On the contrary, when fresh air enters the house through the ground cooled ducts at night the air is 1-2°C warmer than if the air had come directly though the windows (Fig. 6). In the day time, cool air-conditioned air drops through the ground cooled ducts and is replace by outdoor air that penetrates the building envelope – some of which might come from the warm solar chimney. A mechanical fan was mounted as a result of the above findings to assist the solar chimney in driving inlet air through the ground cooled ventilation ducts.

5. Results of mechanically ventilated ground cooled air ducts

A small 35 Watt fan was mounted in the opening between the living room and the solar chimney. This auxiliary fan would assist the solar chimney, so that fresh air could be pulled through the ground cooled ducts in the day time. At the time of writing this paper only a few measured data with the fan in operation were available, as the fan was initially installed without any controls. After continuous operation of the fan for less than three days the occupants switch it off. They found that the fan over-ventilated the indoor space and introduced too much moist outdoor air. Thus, only one full day of continuous fan operation measurements (4 June) has been recorded; (Fig. 7)

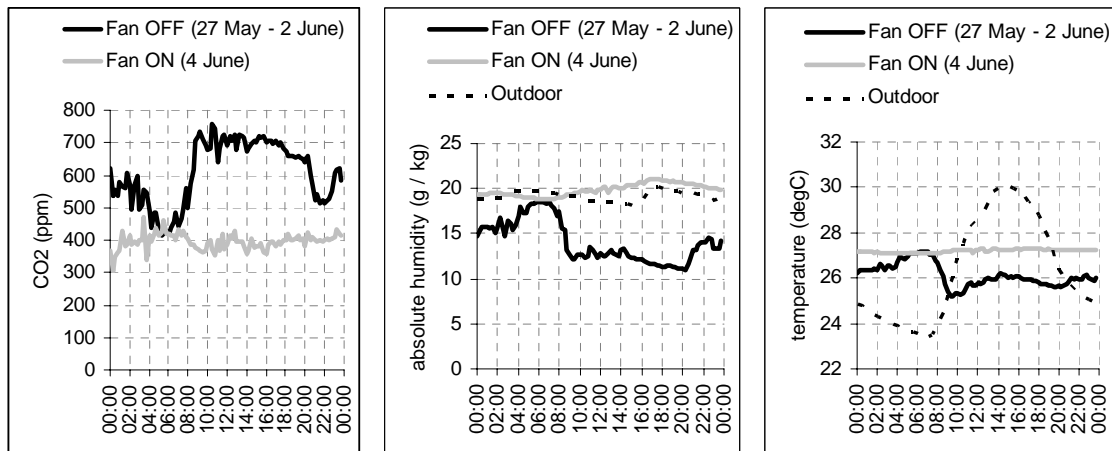


Fig.7 Temperature, humidity and CO₂ in ground cooled air duct with and without fan operation

Fig. 7 shows that the with the installed 35 Watt fan is strong enough to suck fresh air through the ground cooled duct during the day. A clear change in the measured parameters is observed. The CO₂ level is seen to be constantly low at around 400 ppm. The absolute humidity coming out of the ground cooled air duct is stable and is seen to attain slightly higher values than the outdoor levels during the day presumably because the warm outdoor air gets moisturised on its way through the moist ground chamber. The temperature is also seen to be stable around 27.2°C, which shows that the ground cooled air duct effectively can cool the up to 30°C outdoor air.

6. Conclusion

The ground cooled air duct system of the CoolTek house in Melaka, Malaysia, was analysed using continuous datalogging of temperature, humidity and CO₂ levels inside the house, outside the house and inside the ground cooled air ducts. Measurements were carried out during two modes of operation, namely when the house was passively ventilated by the solar chimney and when the house was actively ventilated by a small auxiliary fans mounted in the solar chimney.

When the CoolTek house only is ventilated by the solar chimney, the air flow in the ground cooled ducts was found to flow in opposite directions during the day and during the night. In the day time (8:30 – 19:30), outdoor air was not being cooled by the ground cooled duct, as air was flow from indoors to outdoors. Only at night did the flow reverse, when the outdoor temperature was less than 2°C warmer than the indoor temperature (24°C). At this time, however, it would mostly be cooler to get the fresh air directly through the window, as the ground cooled ducts heated the air 1-2°C before it entered the house.

When the CoolTek house is ventilated with an auxiliary fan in the solar chimney an air flow into the house through the ground cooled pipe can be ensured at all times. The ground cooled pipe was seen to deliver a constant 27.2°C air throughout the day even during the warmest time in the afternoon.

Based on the above findings it is recommended to operate the fan when the outdoor temperature exceeds 28°C. The fan should not over-ventilate the indoor space and could be controlled by a CO₂ sensor set to 1000 ppm. The adverse reverse air flow through ground cooling duct during the day time could be stopped by a damper. Alternatively, the outdoor air intake of the ground cooling system could be placed higher than the ceiling of the CoolTek house – an not at the bottom of a hill as is presently the case - to prevent that cool air-conditioned air 'drops' out of the house. It is generally concluded that the potential for ground cooled ventilation is relatively small in tropical Malaysia. The difference between the ground temperature and the outdoor peak temperature is not very great. In the case of the CoolTek ground cooling system the air was cooled to 27.2°C, which is not very much considering that peak day time temperatures typically only are 32°C. The bulk of the cooling lies in the latent load, i.e. dehumidification of air.