Natural Ventilation through Buried Pipes in a Small School in Viamão (Brazil)

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ABSTRACT: the ground usage as inertial mass for thermal buildings conditioning, such as the Italians cellars, is an old practice. However, its use as heat exchanger with buried pipes for natural indoor ventilation is quite recent. The system uses pipes with variable extensions and diameter buried between 0.5m and 1.5m deep. The air flows trough the pipes from the outside to the inside by a natural way: convection or wind effects – pressure and depression zones. Although it's already a bioclimatic architecture system, there are few conclusive studies about its real effectiveness. The objective of this paper is to investigate the benefits of natural ventilation through buried pipes in a building located in the south of Brazil. Method: A prototype building and a buried pipe system have been built and measured during a period in the summer of 2005-2006 in Porto Alegre, Brazil (30º 01'59"S, 51º13'48"W). The influence of the pipes diameter, inclination and orientation has been studied. Results: The system is efficient for thermal building conditioning and air renovation. At small depths, the ground presents a more steady temperature than the air, close to the annual average temperature (19,5ºC at Porto Alegre), cooling the air in hot days warming it in cold nights – a similar effect is expected on a yearly period.

Keywords: buried pipes, natural ventilation, passive cooling.

1. INTRODUCTION

The use of the geothermal energy retraces to the most ancient populations, mainly in the regions where the telluric heat reaches the surface or in the severe climate places [1, 2, 3, 4] and was maintained in different times of history and different parts of the world. Underground houses in villages and communities were also built in the Mediterranean region [5] and its applications in the modern days have been described in many papers [2]. It has been applied in buildings aimed at recreational and therapeutical uses and constitutes a good example of environmental sustainability. [6].

In Modern Ages, the use of the vapour coming from thermal sources, for the production of chemicals based on the boric acid, in the region of Larderello (Italy), today known as Boraciferous, is started. Through the years, the process evolved, changed and the vapors sources started being used to generate electric energy [6]. During the 20th century, however, the high availability and low price of fossils fuels and the lack of knowledge of its harmful impacts to the environment little help in the development of alternative and more sustainable sources of energy. Until the 70´s, when the oil crisis first was felt, the technology related to geothermal energy was barely known and it was restricted to its uses in restricted areas. After the economical and political shocks that emerged since then, the crisis made clear the fragility of the economic-energy system. This vision allied to the increasing environmental awareness brought about the necessary atmosphere to the arising attractiveness of clean technologies. Today, geothermal systems are an alternative to fossil fuel energy plants, nuclear fission and other unsustainable paths [6].

In the construction area, in the same period, the development of techniques to exchange heat with the ground in cold and temperate climate areas, together with its use for warming or cooling, was retaken and has started to attract the attention of building scientists, mostly with those dealing with energy issues [2]. Hazer [7] refers two strategies in use: the first one is the direct contact with the earth that requires embedding, partially or totally, a building and the second, is the indirect contact that involves the use of buried pipes where the interior air is forced to circulate or the exterior air passes through them before being flow into the construction.

The use of the ground by indirect contact is relatively recent and it is still not much in use even though its advantages are innumerable [8]. Systems supplying the cooling of 100% of the construction were reported by various researchers in the decade of 90 [2]. The technology can significantly reduce energy consumption in buildings and has often been used to cool greenhouses [9]. The system enables heat to be transferred from earth to the construction during the winter and the other way round during the summer. It can also provide hot water, humidity and air infiltration control [8].

The pipes are, most of the times, made of plastic, aluminum or concrete with a diameter between 10 and 20cm. In not too cold climates they are embedded at depths between 0.5m and 2.0m under the construction, in one or two horizontal lines, with a space between them of approximately 0.4m. Greenhouses using buried pipes have an annual consumption of energy reduced by 30-60%, when compared to the conventional greenhouses. The indoor temperature varies between 3ºC and 10ºC above the external temperature [9]. According to Hollmuller [10] it is necessary the occurrence of hot weather previously to cold, to be possible to have the preheating in the winter.

The study of the literature allows to conclude that the efficiency of the system of the buried pipes depends on the pipe's characteristics (material and diameter), on the configuration of the system (distance between axles, length, inclination, depth and velocity of circulation of the fluid) and on the ground's characteristics (thermal difusity, humidity and covering system). Santamouris et alli, [9] say that getting its correct size demands a deep knowledge on the daily and annual cycle of temperature of air and of the ground. The algorithms developed by the centers of research in Europe and in North America allow simulations of with an average error of 3.24% [11].

This work's approach is, however, an alternative system to the use of air pumping that intends to take advantage of natural resources, such as the wind speed and natural convection for the air circulation inside the pipes, what means, without any active system. According to Lengen [12], this demands that the system is developed linearly and that the construction presents an opening in the upper part. Although emerging with sustainable architecture, few conclusive studies are available on its effectiveness for improving the thermal performance of buildings, and on the factors that control the air circulation in the pipes. Some studies on the subject were developed in Costozza (Italy) and in La Pampas (Argentina) [13].

2. METHODOLOGY

This article has the objective of evaluating the thermal performance of a construction that uses natural ventilation provide by buried pipes as well as to determine the influential factors in the air circulating through the ducts in the absence of active systems.

2.1. Prototype description

During the year of 2005 a small school for handcraft work was built in Viamão, in Porto Alegre metropolitan area, in southern Brazil, as a result of a partnership between a private institution and UFRGS. This 45.0m² building, built in one single floor, has a central classroom, a small office room located in the east part of the building and the toilet/bathroom in the west part. The school – designed by NORIE post-graduate students – functions as a prototype for diverse studies on more sustainable techniques of construction.

The prototype was constructed against the natural slope of the existing plot, resulting in integration between the building and the topography. The walls were built with 40x25x15cm sandstone blocks, largely available in the area (figures 1 and 2).

It is worth pointing out some building design bioclimatic strategies, aimed at optimizing the passive thermal performance. Among them, solar orientation, with main façade facing the north. The larger windows are located in this façade, allowing the benefit of light and solar radiation during the cold season. The roof projection avoids the direct incidence of solar radiation in the entire wall during the summer. Small windows face the south side and allowing cross ventilation, when necessary. In the office, as well as in the toilet/bathroom, a solar chimney was designed to improve air circulation in the absence of wind speed or reduced natural convection (figure 3).

Figure 1: The school building being monitored.

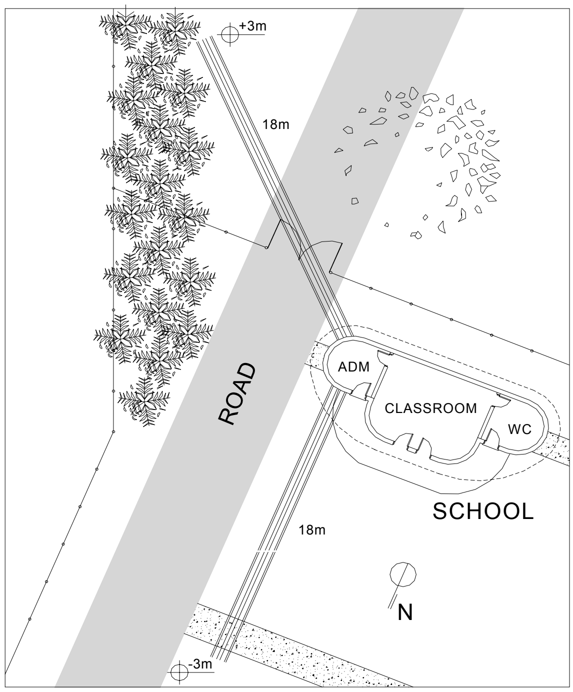


Figure 2: Plan.

A 20cm thick green roof, covering the building and the earth mass on its south side, in addition to the thick walls, determines the construction's big thermal mass, was intentionally designed to allow the evaluation of the influence of the passive buried pipe conditioning system. Its also worth mentioning that, according to the more sustainable strategies adopted in the project all the wood used in the prototype is of reforested woods (*eucalyptus*) that was planted, harvested, worked and protected with preservatives against termites inside the limits of the property, using local labor.

There are two indirect geothermal systems installed in the construction. The first one pumps water from a 200m³ cistern, located nearby, into the building with the help of hydraulic pumps, where a heat exchanger is used. The second one, which is the focus of this work, is installed in the office room (4.5m²). The set of buried pipes is intended to soften air temperature swings inside the building.

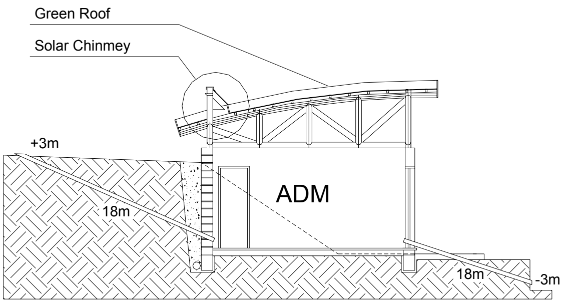


Figure 3: Section of the school.

Six pipes were used in this experiment: four Ø100mm, two Ø200mm. Taking advantage of the characteristics of the plot, they were split into two ascending and two descending pipes). The 18m long of recycled PVC pipes, have a variable depth (that goes from zero to three meters in both positions). The outdoor air that circulates in the ducts flows from the room into the ascending pipes through the basis of the south wall and into the descending pipes through the base of the north wall. The pipes can be closed with drain plugs, in such a way to be assessed independently.

2.2. Material and Method

The prototype was monitored from September 2005 to March 2006. Due to the great variability of probes, three types of data recording systems were used. The solar radiation data, as well wind speed (at 10m) and air velocity where air gets into the buried pipe) were collected using a controller plate CIO-DAS802/16 and recorded with a computer routine developed with software HPVEE 6.0.

The ground temperatures (measured in the depths of 5, 50, 100, 200 and 300cm), as well as the air temperatures in the interior of the pipes (1m of each extremity) and in the solar chimney (bottom and top, in the shade), were collected with thermometers NTC linked to TC-Clock900 controllers. Indoors, the air temperature and the relative humidity in the toilet were collected with the use of a thermal-hygrometer linked with TM-530Ri controllers. Both controllers stored the data using software Sitrad 4.0. This set of sensors, controllers and software are developed by the Full Gauge Controls® company.

The measurements of long wave radiation, air temperature and relative humidity, as well as the air velocity inside the pipes in the office area were made using the Indoor Climate Analyzer BABUC/A, developed by the Laboratori di Strumentazione Industriale (LSI). The equipment was kept in the center of the room, on a tripod, with the sensors at the height of 1.10m approximately and with the hot wire anemometer positioned in mouth of the pipes.

The study that follows corresponds to nine days of measurements, when each pipe was monitored independently, and intends to determine the factors that had an influence in the flow of the air inside the pipes. The values of solar radiation and wind speed were collected each 10 seconds with averages recorded each 12 minutes, together with the values of the air temperature and relative humidity. It is important to say that the construction was monitored without occupation, with the internal and external doors kept closed and without any internal heat source (except the equipment of measurement).

2.3. Data treatment.

Spread sheets with the compilation of the external and the internal data of the three monitoring systems were generated using the software Microsoft Excel®. The construction's thermal performance was evaluated considering the thermal comfort range suggested by Givoni [15] for tropical climates in developing countries, (between 18ºC and 29ºC) and the internal humidity varying between 4g/kg and 17g/kg (summer) not exceeding the limit of 80%. For comfort, the air velocity in the pipes should not exceed 1.5m/s and has provide an air renewal of 21m³/h per person.

3. THE ANALYSIS OF RESULTS

3.1. Parameters of comfort

The monitored period was characterized by high values of solar radiation together with some cloudiness. The external wind speed presented a regular cyclical behavior during the day, with calmness predominating during the nighttime, with some highest values occurring during the day time. The average wind speed was of 0.8m/s presenting a maximum of 4.8m/s (figure 4).

Figure 5 shows that the outdoor air temperature was relatively high, varying 18ºC and 29.2ºC, reaching a maximum of 39.7ºC. The indoor measurements however, showed that the air temperature varied mostly between 21.8ºC and 25.7ºC with a maximum of 30.0ºC. Considering the monitored period of 218 hours, only 8 hours exceed Givoni´s comfort limit of 29ºC (3.7% of the cases).

The outdoor relative humidity varied quite a lot reaching more than 70% of variation during a single day (figure 6). Its average was 71.4%, with most of the values between 51.7% and 91.1%. Values of 100% of relative humidity, typical in the region can be seen in occasions, even without rain being registered during the monitoring period. In the room's interior the relative humidity was almost constant (varying between 76.9% and 85.2%, in the majority of the cases), but high, its average (81.1%) was above the comfort limit of 80%. This high humidity was observed even in the hottest day and could be attributed to the porosity of the construction walls and its contact with the ground, considering that the South walls are leaning against the sloping terrain. The combination of high humidity with high temperature and the lack of ventilation determine a thermal discomfort sensation.

The maximum outdoor air temperature was recorded at 14:48 while the indoor maximum was recorded at 18h48. This 4h delay is useful for constructions that use buried pipe ventilation by, because at the critical indoor air temperature the air that is being caught from the exterior has a more pleasant (lower) temperature.

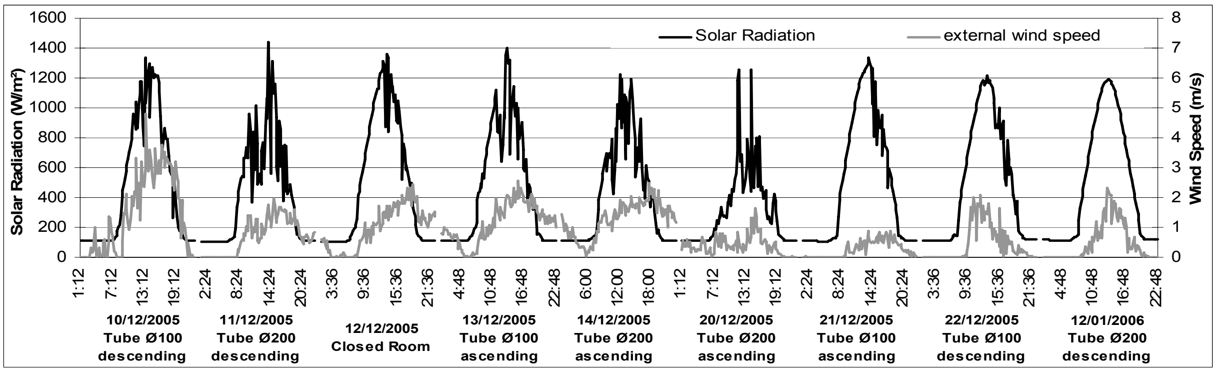


Figure 4: Solar radiation and external wind speed: Ascendant pipe

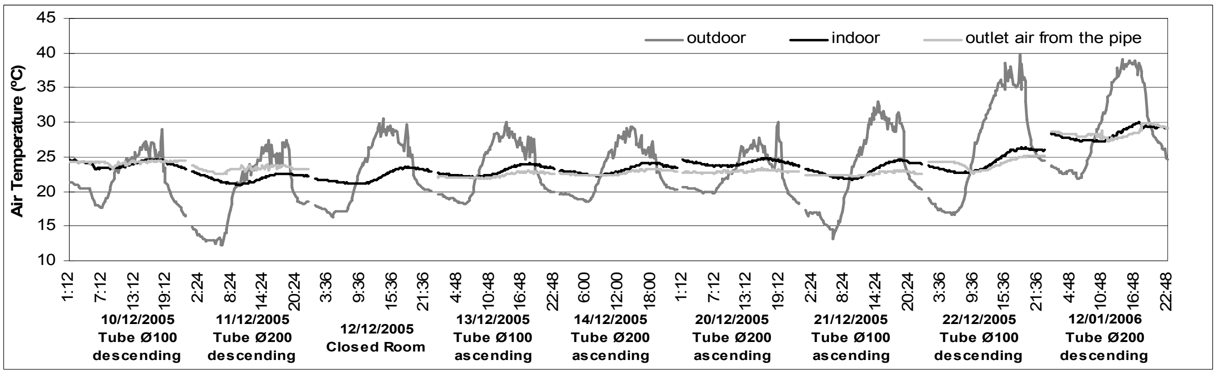


Figure 5: Outdoor and indoor air temperature (with and without ducts ventilation).

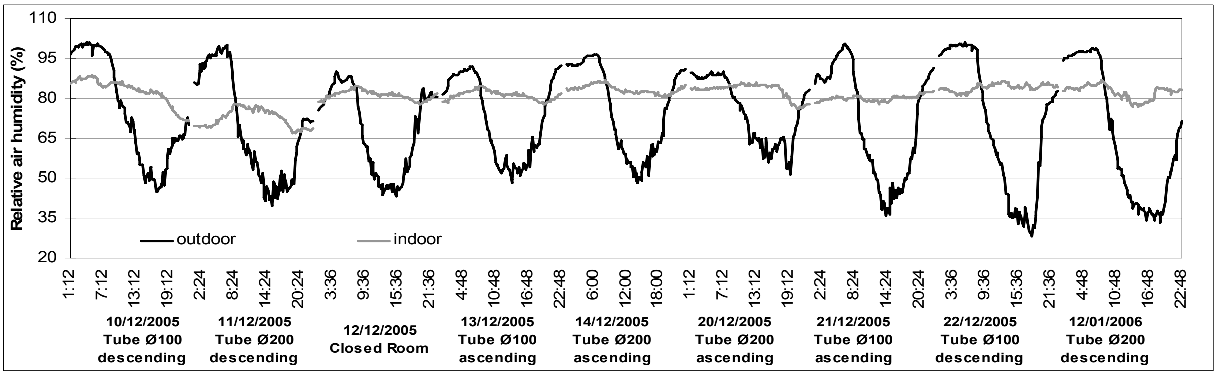


Figure 6: Outdoor and indoor relative humidity (with and without ducts ventilation).

The comparison between indoor and outdoor temperature, only, delay can be misleading, Table I shows the temperature variation in the pipes when the indoor temperature is lower and higher than the outdoors, respectively.

Table I: Temperature variation comparison.

	ΔT of the air in the internal and external extremeties of the tube. Tint < Text (ºC)	Tint < Text (ºC)
Lowest	-3.0	-6.9
Average	3.8	-1.9
Highest	11.8	2.2
average low	0.4	-3.7
average high	7.1	-0.1

By analyzing the table it is possible to conclude that the pipes function as if they were buffering the internal temperature. When the room temperature is lower than that outdoors, the air is warmed inside the ducts, raising 3.8ºC in average, while, in the opposite situation, it is cooled 1.9ºC in average. It is possible to conclude then, that in general, the ground cools air in the ducts during the day and it heats it during the night. Figure 5 shows that, in average, the air temperature, when leaving the pipe, presents a smaller thermal amplitude than that of the indoor air. This effect can be explained by the fact that the ground presents a much larger thermal mass if compared to the construction's and demonstrates that the heat exchange between the air and the ground is effective.

Lower average temperatures can be achieved with more deeply buried pipes [13].

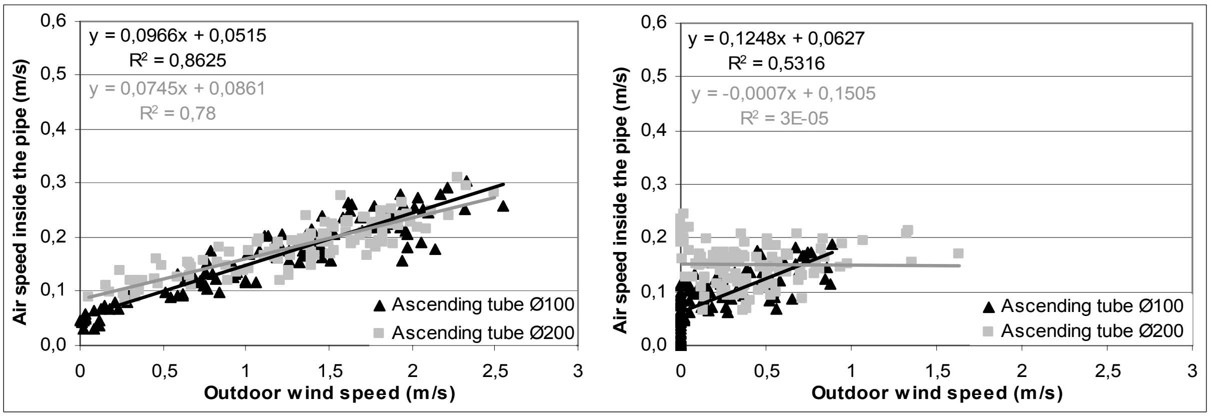
We can conclude, as result, that the pipes help to keep a steady temperature in the room, particularly in the case of Viamão, where the ground temperature is expected to swing around 19,5ºC, well inside the comfort zone. Considering that the relative humidity inside the room remains practically unchanged, while outdoors it shows large oscillations, it is possible to assume that the pipes do not contribute in a negative way to the air humidity. The air average velocity inside the pipes did not vary with the diameter or with time (night or day). It is possible to assume a general average of 0.22m/s for estimates of the air renewal in room. The pipes total area is of 0.095m² what results in 74.64m³/h of air, or in 5.52 renewals per hour, what is more than enough for the room's ventilation that will be occupied by only one user most of the time.

3.2. Variables with influence in the air circulation inside the tube

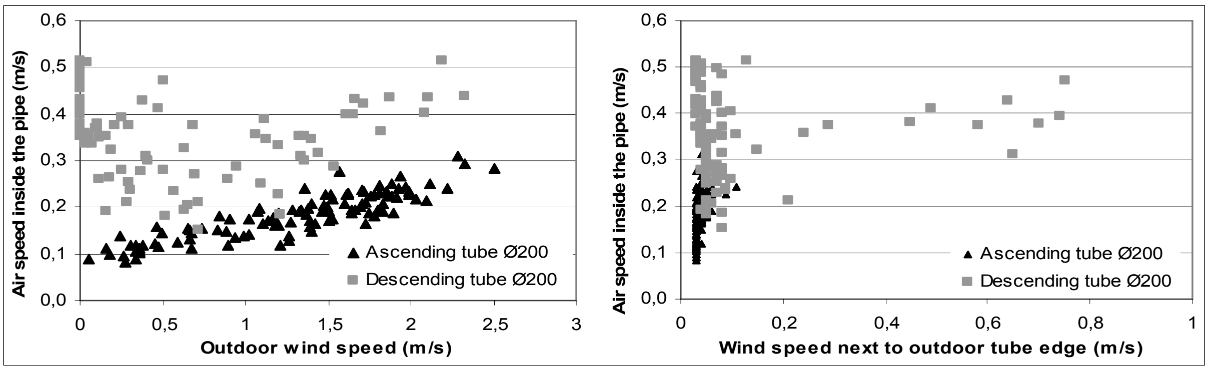
Figure 7 shows the results of the measurements air velocity in two pipes with different diameters, having the same inclination and position. It is possible to conclude that the variable that best explains the air circulation inside the tubes is the external wind speed, measured at 10m above the ground. This conclusion was made considering the value of R^2 found in the linear regression comparing it with the air velocity inside the pipe. It is also noticeable that the trend between the lines is similar, demonstrating that the pipes diameter has a small influence.

Figure 8, presents results on the same pipes, however in different days. It can be said that above referred direct relationship is valid only for days where the average wind speed is higher than 1.5m/s and there's no calmness occurrence. It demonstrates, also, that even in situations where the wind speed is less than 0.2m/s there is still air circulation in duct's interior, demonstrating that other factors are influencing the phenomenon.

The second variable studied was the wind speed closes the pipe's exterior end. Figure 9 shows that even having the same diameter and a similar wind speed, the ascending pipe presented higher and more dispersed results of average air velocity than in the descendant one. Checking these results with those of figure 10, we see that the extreme end of the ascending pipe is more exposed to the outdoor wind demonstrating that it acts significantly in the outflow of the duct.

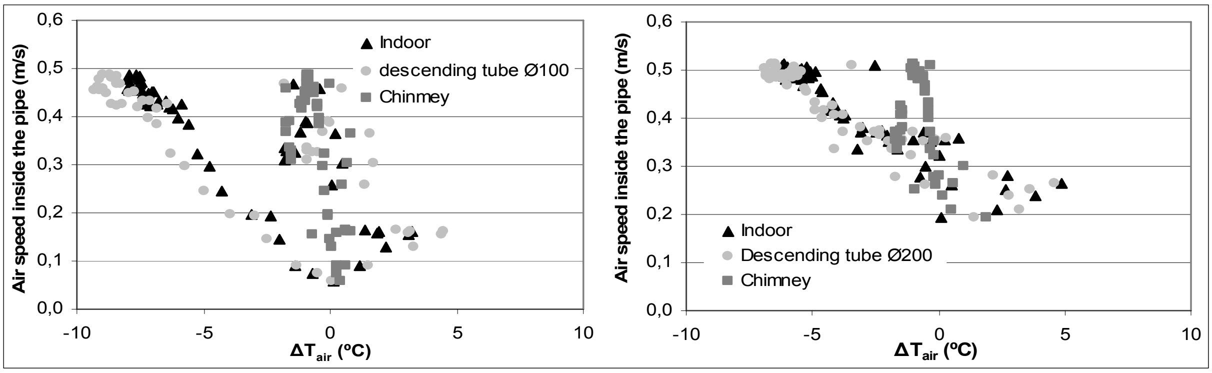


Figures 7 and 8: Relation between the wind speed and the air velocity inside the pipe



Figures 9 and 10: Relation between the wind speed and the air velocity inside the tubes for the same diameter, but with different inclination and a similar wind speed

The third variable studied was the differences of temperature in the interior of the (a) duct, (b) room and (c) chimney. In figures 11 and 12 we see that a trend of increasing the air velocity inside the pipe exists when the temperature's difference increases, and that demonstrates its influence. The larger dispersion of points for the negative values of temperature difference happens because the majority of the calmness moments were observed at night, when the indoor temperature is higher than that oudoors. This fact also explains why the temperature difference in the solar chimney demonstrated itself irrelevant.



Figures 11 and 12: Relation between the temperature difference and the air velocity inside the tube in different days, when wind in low (Va<0.5m/s e Vb<0.5m/s).

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