# Natural Ventilation and Ground Cooling to Improve Thermal Comfort Conditions of Workers in an Industrial Building

## Passive Cooling Techniques Applied in an Industrial Building

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*ABSTRACT: Natural ventilation is a suitable strategy to provide comfort conditions to building´s occupants. The objective of this research was to investigate the potential of natural ventilation strategies to provide comfort conditions of workers exposed to large heat gains sources from equipment and the building envelope. The case study is an industrial building located in a typical hot humid location in the city of Cali, Colombia, situated at 3° North latitude. The main internal gains come from the industrial process of copper casting that produces a mean radiant temperature over 40°C, and provokes a severe thermal stress to workers. This situation worsens with the prevailing high external temperatures of an average of 35°C or higher. Various cooling design alternatives were examined aimed at improving the ambient comfort conditions of the building personnel. These strategies included an earth conductive cooling system using buried earth tubes, which perform as Earth-to-Air Heat Exchanger (EAHX), natural ventilation devices, thermal insulation on the envelope, the relocation of the equipment and a more suitable architectural layout. Results showed that with the combined application of all the strategies, the operative temperature range was from 27°C to 29°C, and 60% relative humidity. Questionnaires of the workers hygrothermal perception were applied concurrently with the monitoring process of the indoor ambient conditions using the thermal sensation index. Therefore, the thermal comfort conditions of the workers building were improved whilst achieving an important reduction of energy consumption, which in turn contributes also to reduce the emission of greenhouse gasses to the environment.*

*Keywords: Natural Ventilation; Ground Cooling; Thermal Comfort; Hot Humid Regions*

## INTRODUCTION

The current high-energy consumption patterns in contemporary buildings and the adverse environmental effects that this situation provokes call for implementing corrective measures. The use of passive cooling techniques is a promising alternative to achieve comfort conditions for building´s occupants whilst reducing energy consumption for air conditioning (AC), as reported by previous studies [1, 2, 3, 4, 5, 6, 9]. By applying ambient energy sinks, such as air, water, earth and sky, excessive heat can be dissipated from buildings. A promising passive alternative is the use of earth, as it can serve as a heat source in the winter and/or as a heat sink in the summer. In winter, the soil temperature increases with increasing depth up to a certain distance and hence the earth can be used as an effective heat source.

On the other hand, in summer, the soil temperature decreases with increasing depth, and thus, the earth can be used as a heat sink Therefore, during the overheating event in any location, the utilization of earth as a heat sink can be a powerful strategy to remove unwanted heat from indoor architectural spaces.

Certainly, using ground for heat dissipation is a powerful strategy for cooling of buildings. This is due to the high soil thermal capacity and its temperature that at certain depth remains rather stable in most regions of the planet. Earth acts as an infinite heat sink providing nearly stable temperatures at relatively lower depths, then, the soil temperature virtually stabilizes as the average annual air temperature of a given region.

The use of buried earth tubes, acting as Earth-to-Air Heat Exchangers (EAHX) for pre-heating and pre-cooling of external fresh air, can be a promising and an effective alternative to reduce energy consumption for air conditioning (AC), whilst proving comfort conditions for building occupants [15]. The basic principle of the use of the high thermal capacity of the earth has been applied in traditional architecture since remote times. Certainly, earliest builders had to rely on natural energies to render the inside condition of the constructions relatively comfortable.

One remarkable example of the use of the high thermal capacity of the earth is found in the towns of Villa Eolia, and Villas de Costozza, 10 km south of Vicenza, Italy. During the Sixteenth century, earth was used for modulating the indoor conditions of buildings to provide comfortable conditions (Figure 1). A smart ventilative ground cooling systems was integrated in a group of six villas, mentioned in the remarkable classic work Four Books of Architecture, by the Renaissance architect Andrea Palladio, published in Venice in 1570 [14].

The construction system consisted of large underground sloped cavernas (called covoli), which served as coolness reservoirs. In the covoli, the air temperature remained almost constant throughout the year; this was due to the high thermal inertia of the ground above. Underground tunnels were connected to the villas to provide cooled air during the overheating season. The stacked effect assisted to promote exhausted air to be dissipated out of the upper rooms. It was hypothesized that the rooms of the villas had comfortable temperature conditions [14].

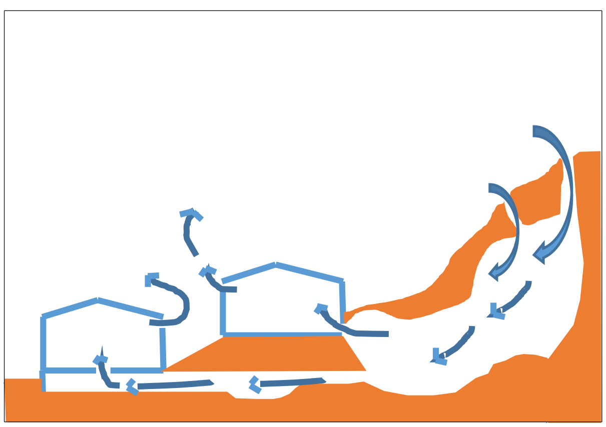

*Figure 1. Ground cooling ventilation schematic system of Costozza, Vicenza, Italy. Air flow patterns between covoli and villas*

Another very well-known example of utilization of earth in traditional construction is found in Cappadocia, Turkey. Cappadocia lies in eastern Anatolia, in the center of what is now Turkey.

This city has more than one hundred underground settlements. Some of them were used since the Bronze Age, used to be a settlement mostly during the Byzantine period, where the underground settlements were used for protection and religious purposes. In all the underground cities there are ventilation chimneys reaching place by place to a depth of 80 meters and until a source of underground waters. The chimneys were opened to provide the inhabitants ventilation and water. Studies conducted in some of these cities have shown that the indoor spaces are comfortable warm despite the harsh winters and remains cool in summer (Figures 2 and 3).

*Figure 2. Chimneys for promoting ventilation in the upper section of a typical Capadoccia underground city*

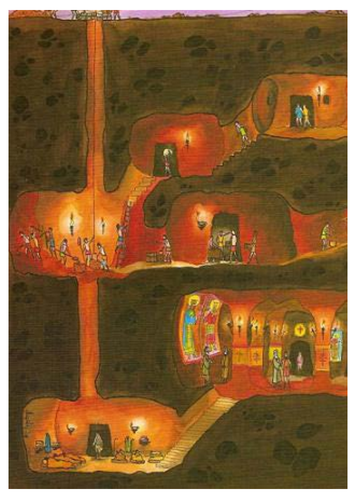

*Figure 3. Ventilation ducts for providing ventilation and underground cooling in a pictorical representation of a typical Capadoccia underground city*

## COMFORT MODELS APPLIED IN TROPICAL REGIONS

Comfort conditions in tropical regions have been intensively studied since 1960´s by Bedford [8]; Givoni 1976 [10]; Givoni 2007 [11]; Kukreja CP [12]), among other researchers. Recently, the adaptive model has been accepted as a convenient standard in the ASHRAE Standard 55-2010 [7], and it relates to the comfort sensation based on the perception and response of the occupants of a building relative to the differences of the external and internal temperatures.

## CASE STUDY BUILDING

The case study building selected for investigation in this research is and industrial building located in a typical hot humid region, in the city of Cali, Colombia, at 3° 25´14" north latitude; 76° 31´20" west longitude and 997 meters above sea level (Figure 4)

*Figure 4. External view of the case study industrial building*

## CLIMATE CONDITIONS

Köppen's climate classification defines Cali as a tropical savanna climate. Cali is located in a valley, surrounded by mountains. The annual average temperature is 23 °C, with a maximum annual average temperature of 31 °C and a minimum annual average temperature of 18 °C. Due to its proximity to the Equator, there are no major seasonal variations.

## OBJECTIVES AND METHODOLOGY OF THE RESEARCH

This research work proposes design guidelines suitable for industrial buildings in a typical tropical hot humid climate, under a high thermal stress condition, especially when workers have additional heat inputs coming from machinery at high temperatures operation process.

Two main criteria were considered in this research work:

1. The Graphic Comfort Zone Method as defined by the recent Standard ASHRAE 55-2010 [7] (Figure 5) , and the
2. Thermal Comfort Standard of Markus & Morris [13] (Figures 6 and 7), and the arguments from Bo. Adamson (1993) [1], based on the Discomfort Index (DISC), after A. P. Gagge. It predicts thermal discomfort using skin temperature and skin wittedness, using the following discomfort vote scales: Comfortable, slightly uncomfortable, very uncomfortable, and intolerable.

These criteria took into account a minimum and maximum comfort limits appropriate to examine the bioclimatic design strategies under a high thermal stress condition, such as the case study of this research work.

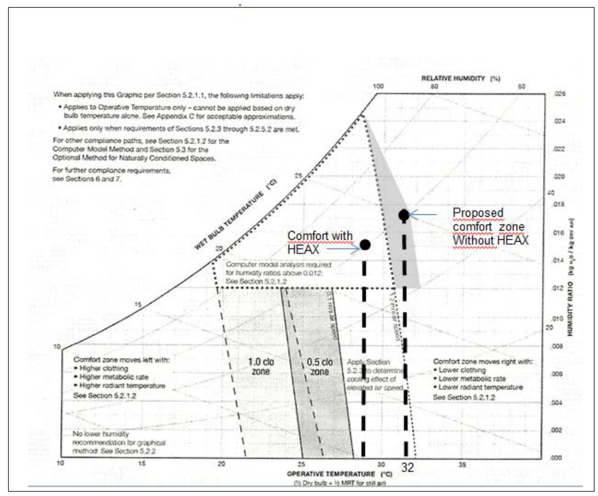


*Figure 5: The Graphic Comfort Zone Method as defined by the Standard AHRAE 55-2010. Applies only to Operative Temperature (to). It cannot be applied based on dry bulb temperature alone*

From Figure 5, the Operative Temperature (to) is defined as a uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual nonuniform environment. Some references also use the terms "Equivalent Temperature" or 'Effective Temperature' to describe the combined effects of convective and radiant heat transfer mechanisms.

$$to= \frac{((ta*hc)+(tmr*hr))}{hr+hc}$$

where,

ta = Ambient air temperature. Dry bulb temperature
hc = Convective heat transfer coefficient
tmr = Mean radiant temperature
hr = Linear radiative heat transfer coefficient

For occupants engaged in sedentary physical activities, from 1.0 metabolic rate (MET) to 1.3 MET, not in direct sunlight, and not exposed to air velocities greater than 0.20 m/s, it is acceptable to approximate this equation to the following:

$$to= \frac{ta+tmr}{2}$$

Thermal Comfort Standard of Markus & Morris [13]

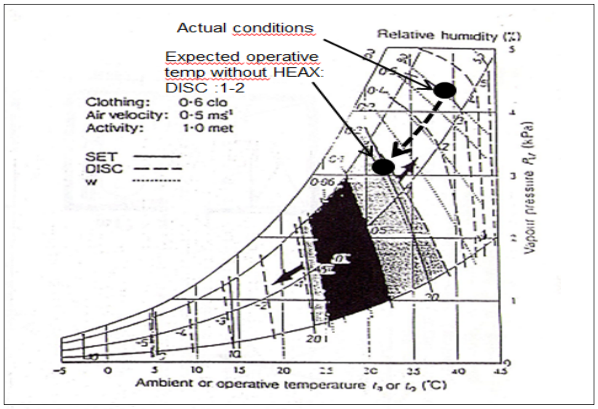


*Figure 6: Discomfort range without HEAX underground exchangers*

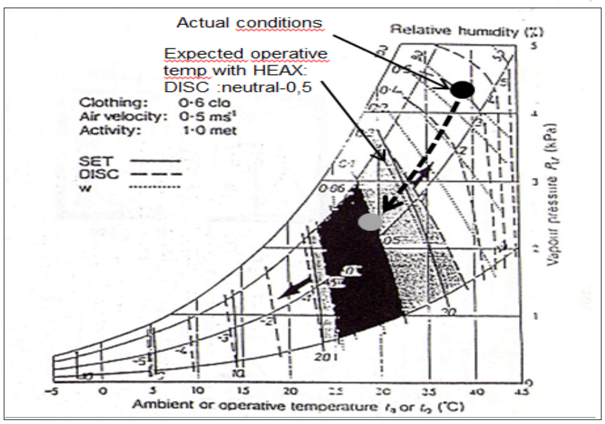


*Figure 7. Discomfort range with HEAX underground exchangers*

## SUSTAINABLE DESIGN STRATEGIES APPLIED IN THE CASE STUDY

The strategies implemented included:

**Natural Ventilation**: This strategy is based on the promotion of the maximum amount of air coming from de exterior. Louvers located at the bottom of the façade, allow external airflow to enter the space. A ventilated skylight located at the roof complements effective air movement into the space. Air motion and heat discharge is assure by the pressure and temperature differences between the outside and the inside of the building.

**Solar Control**: Shading devices were designed, built and integrated on the façade to provide a suitable control of heat gains coming from solar direct radiation. Translucent tiles and glazing with Solar Heat Gain Coefficient of 0.30 allow maximum solar control with suitable light gains from daylight available.

**Thermal insulation**: The building envelope of the industrial building included an external roof with high insulated white metal panels using an U value of 0,40 W/m2, and the external walls using an U value of 0,50 W/m2.

This configuration provided a suitable control from conductive external heat gains. Under the prevailing clear sky conditions of the location, the insulation effect of this combination on the external roof and wall reduced the internal temperature by 5K.

**Underground EAHX System**: With the application of this strategy integrated with the others above described the ambient internal temperatures monitored during current working conditions of the cooper boiling process (at typical temperatures of 40 °C) of the industrial building were below 30 °C.

## SIMULATION TOOLS APPLIED IN THE CASE STUDY

The methodology of this research included the application of two simulation tools, which provided useful information during the design process of the building:

- Computer Fluid Dynamic (CFD) computational simulation (Figures 8 and 9)
- Earth-to-Air Heat Exchangers (EAHX) computational simulation (Figures 10 and 11)

**CDF simulation results**:

Natural ventilation without EAHX underground exchangers:

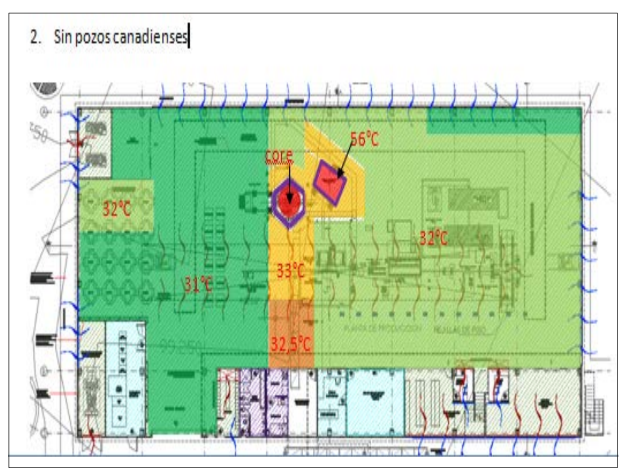


*Figure 8.Thermal zoning without EAHX underground pipes*

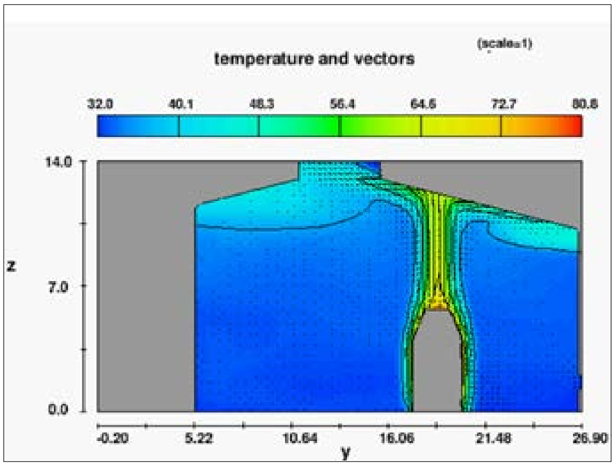


*Figure 9. CFD internal temperature range without EAHX buried pipes*

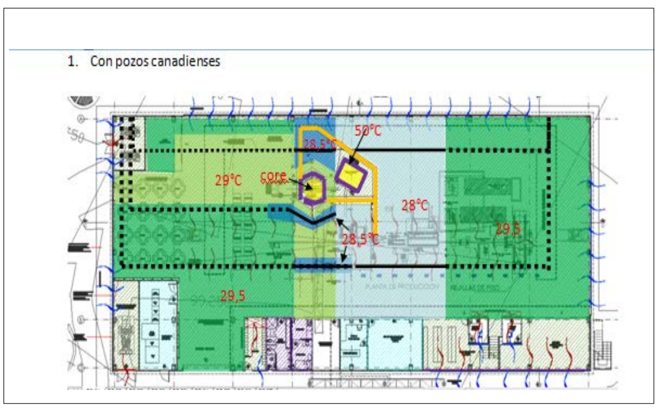


*Figure 10. Thermal zoning with EAHX buried Pipes*

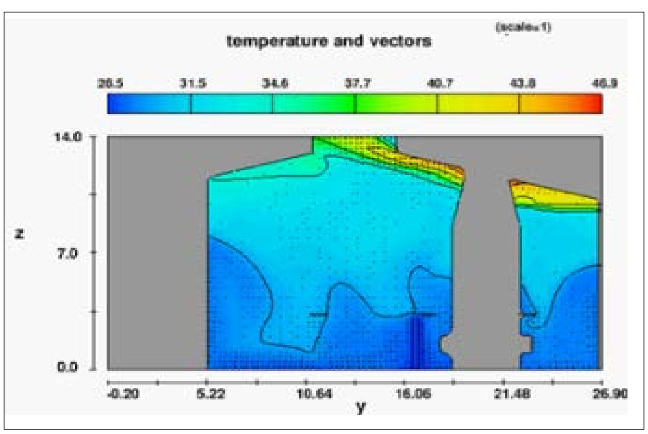


*Figure 11. CFD internal temperature range with EAHX buried Pipes*

## DISCUSSION OF RESULTS

Results of Simulations and Real Building Monitoring

The results of the simulations showed that with the implementation of natural ventilation, it is possible to achieve an average internal temperature of 31.5 °C. Integrating the strategy of EAHX buried pipes; the ambient internal temperatures recorded an average of 28.5 °C (Figures 8, 9, 10 and 11). These conditions demonstrated to be more suitable than previous ones shown in Figures 12 and 13). Interviews with workers were conducted concurrently with the monitoring of the actual ambient conditions in the building, using questionnaires to identify their hygrothermal perception. The ambient conditions in real building before implementing the bioclimatic design strategies plotted on psychometric diagram during critical overheating period are shown in Figure 11. These conditions showed thermal discomfort (DISC) using skin temperature and skin wittedness and stress sensation.

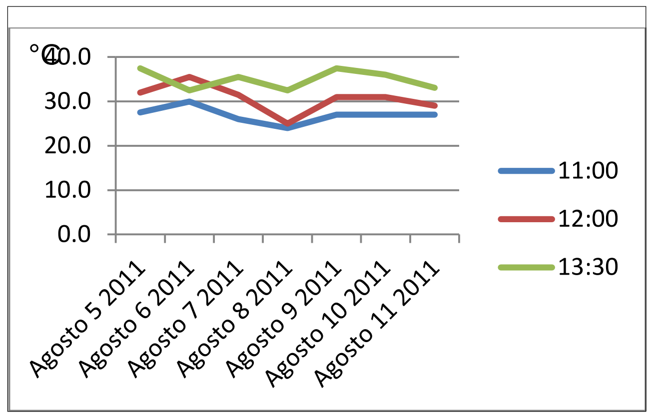


*Figure 12. Results of dry bulb temperatures monitoring in the interior of real building during critical overheating period*

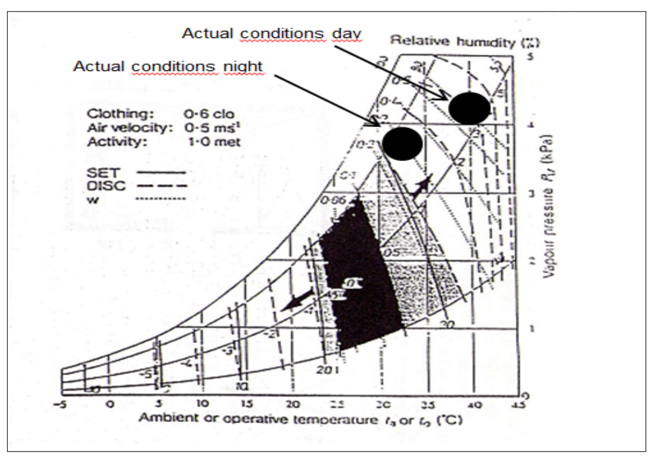


*Figure 13. Ambient conditions in real building before implementing the bioclimatic design strategies plotted on psychometric diagram during critical overheating period*

Figure 14 shows that the temperature reaching the interior is 26 °C. This means that 2.5K is lost through the blower distribution ducts and the mix of radiant heat coming from the industrial equipment of the building.

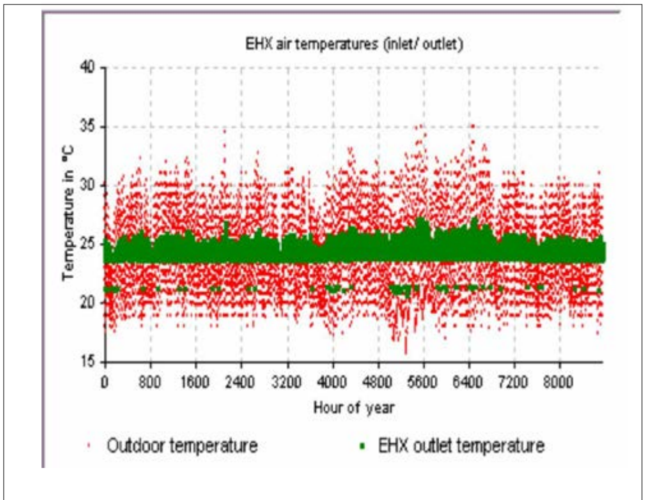


*Figure 14. EAHX simulation model for the buried pipes*

Therefore, the results of the simulations indicated that appropriate comfort conditions under an industrial activity, located at the tropics could be possible with the integration of various bioclimatic and sustainable design alternatives, such as the ones investigated in this research work (Figure 15).

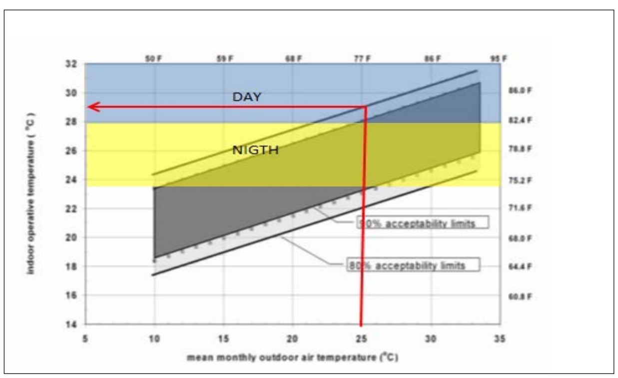


*Figure 15. Proposed operative temperatures according to the ASHRAE 55 -2010*

## CONCLUSIONS

The results of this research demonstrated that hygrothermal comfort under high thermal stress conditions of the occupants in a typical hot humid climate can be solved with the integration of different bioclimatic and sustainable low energy design strategies. The application of a “step by step” process during the design process in this work, based on a “degree per degree” simulation analysis, was confirmed to be a useful technique to analyse the thermal performance of the building in advance and to come up with suitable design alternatives. The proposed comfort ranges under critical stress conditions of the workers will be further revised in subsequent stages of this research, relative to the real hygrothermal comfort expectations. To sum up, the combined application of the strategies analysed and implemented in the real industrial building, significantly improved the workers comfort conditions, whilst reducing the energy consumption. Therefore, this integrated strategy, including the EAHX underground cooling will eventually contribute to reduce the emission of greenhouse gases to the atmosphere and to improve and preserve the global environment.

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