VENTILATIVE STRATEGIES FOR LOW-INCOME DWELLINGS

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ABSTRACT

Passive cooling devices for low-cost housing, where thermal comfort is usually not considered as an important variable of the design process are evaluated.

Low-cost dwellings, located in Rosario city, Argentina, with temperate-humid climate are presented. Their design is the result of the interaction of occupants' participation and experts' advice.

Passive cooling systems' efficiency for this climate is very low, due to the combination of high air temperatures and vapour pressure, which reduce convective cooling efficiency.

An alternative to ameliorate summer conditions could be to enhance airflow patterns through natural ventilation. A sequence of diurnal and nocturnal ventilative strategies is proposed to achieve thermal comfort.

Two ventilative systems have been installed: a duct located at the ridge of a pitched roof and an underground air-heat exchanger buried at depth foundations. Both are to operate depending on climate conditions.

Results of systems performance are compared with theoretical considerations.

KEYWORDS

Air flow pattern, comfort, ducts, natural ventilation, residential buildings.

INTRODUCTION

One portion of dwellings deficit is referred to people living in slums, usually characterised by illegal occupation of land in urban areas (Di Bernardo et al. 1992), caused by the effects of economical globalization which expulse low-income social sectors into marginality and defencelessness.

Some social policies tends to allow these people to achieve land property under affordable conditions, giving partially solution to illegal occupation of land.

In Argentina, mainly during the 80's, a considerable amount of public housing was built to satisfy the increasing demand, but not giving a correct solution to this problem, since occupants' way of life was not considered in the design process. Besides, a very low-level of building quality has increased functioning and maintenance costs, so difficult to afford for low-income people.

Another aspect for authorities involved in urban planning is referred to the final relocalization, usually developed in urban periphery, where infrastructure and services do not exist or have to be provided at high costs.

Autoconstruction is presented as an alternative practice to housing demand.

In most urban areas, a great portion of poor people build themselves their houses, without technical advice.

In this study case the decision arouse from the occupants of an area well connected to downtown. Organised in a cooperative, ... their informal neighbours into another with own identity. This was done under the basis that new houses should be in the same area where the previous ones were, built by inhabitants, assisted by professionals and in contact with earth, a deep tradition in our society.

Besides dwellings scarcity, other environmental problem arises. There exists little research on the evaluation of thermal comfort of low-income housing. Basically, it focuses on physical features such as infrastructure provision or degree of completion assessment, but does not consider occupants'higrothermal satisfaction as another variable to take into account in the design process (Mosconi 1994).

Thermal comfort is usually evaluated through theoretical analysis and complex tools, but post-occupational hygrothermal satisfaction is seldom object of interest for scientists. Though satisfaction concept involves economical, physical and cultural interrelation of variables (neighbourhood, relations, services, indoor and outdoor comfort), in this work it aims only to quantify the thermal performance of the ventilative systems under occupancy conditions.

While in developed countries people has become more sensitive to comfort and indoor air quality aspects, in developing ones, adaptation to local climate interacts with non-satisfied basic needs, such as food, education, health, clothing, etc.

Therefore, thermal indices, comfort zones and required flow rates, generated in industrialised countries should not be used as universal standards for developing countries (Fanger 1972). Generalised use of these standards may lead to incorrect estimation of buildings energy consumption for winter and summer. In this aspect, considerations as new limits of interior comfort zone and people acclimatization to local climate is usually ignored by standards'producers.
Givoni has evaluated the hot-humid climate of Colima, Mejico, and has demonstrated not considered in thermal assessments and comfort is obtained, though standards'use results.

About acclimatization, in developing countries, a new superior limit for the comfort zone is proposed: 32 C with air velocities of 2 m/s. (Givoni 1992).

In these countries, overheating problems cannot be solved with air-conditioning units due to elevated costs of electricity. Passive cooling techniques such as proper shading, envelope resistance, and low-energy systems can provide summer comfort at low-cost.

The study case proposes ventilative strategies assessment of a prototype belonging to a neighbourhood of 65 houses located in the south of Rosario city denominated "Cooperativa de Vivienda, Consumo y Crédito Saladillo Sur".

The linear characteristic pattern of the former railway track has enabled the location of two rows of dwellings, under the basis of intense and dense use of urban grid towards land economy and rationalization.

Houses with partition walls are in narrow and deep lots, in two storeys, with a total area of 56 m^2 each, with living-room, kitchenette, bathroom and two bedrooms, one of them with a front balcony, and a back courtyard of 26 m^2.

Building materials are: concrete blocks, 0.20 m width, concrete pitched roof, metallic side-mounted windows and doors.

Dwellings oriented NNE (north-noreast) are grouped in four units sectors, leaving small paths between them, for service entrance towards back courtyards, which can be used for recreation or production, agricultural or informal occupation. Compacity responds to envelope optimisation towards energy saving and comfortable interior conditions in winter and summer.

Figures 1, 2 and 3 show plan and section of the house, buried tube and ventilative duct system.

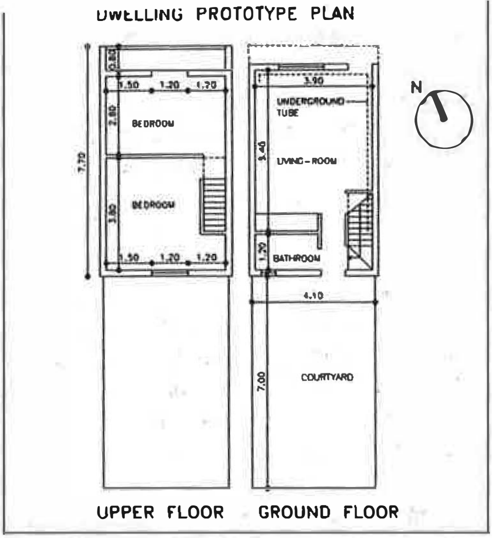

Figure 1

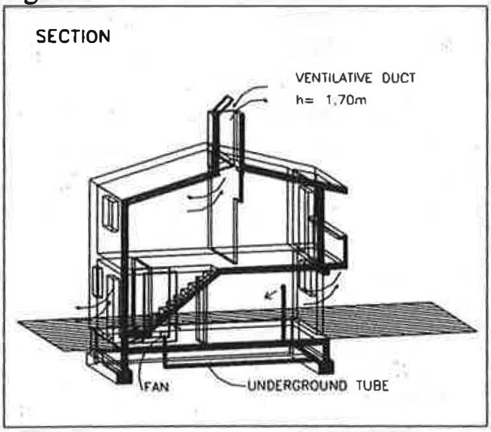

Figure 2

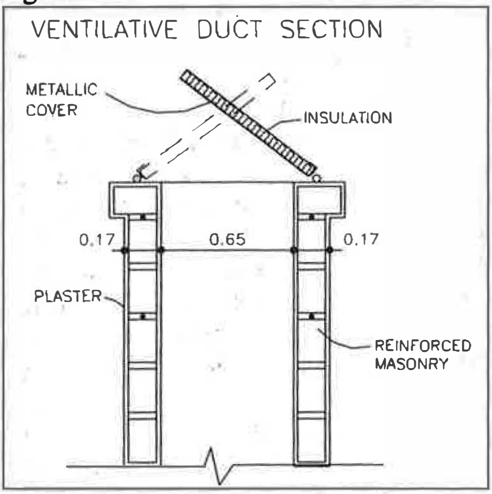

Figure 3

METHODS

Ventilative Strategies

Rural, urban or intraurban areas show climatic differences. They are owed to urban explosion' effects as well as changes in the urban structure and density. They modify urban canopy associated with different land-use patterns and proximity to open spaces (green, water or paved, etc.). That is why, a urban system can be approached from the determination of areas of relatively homogeneous thermal mass, taking into account land-use patterns.

This lead the authors to think about the "representativity" of climatic measurements obtained in meteorological stations and used arbitrarily for any topographical situation. Wind velocity on low-rise buildings is generally lower than data obtained at meteorological stations due to lower height, obstacles and terrain roughness.

Natural ventilation as passive cooling strategy for low-rise buildings is a subject of recent research, and is related with interior thermal comfort and energy saving (Lee et al. 1980).

Natural ventilation in buildings can be caused by pressure and temperature differences; either force may act alone or in conjunction, or in opposition to the other, depending upon atmospheric conditions and building design.

Basically, factors which influence air flow in low-rise dwellings are: shape factors and flow factors. First are related to building geometry and apertures exposed to wind forces (type and percentage of open area, location, and exterior devices). Flow factors are related with natural wind properties: velocity, direction and frequency.

In the last decade there has been an increasing interest on modelling airflow in buildings. Most models are based on steady-state conditions, then input data may vary between real systems and conceptual models.

Bernoulli equation is useful for flow rate evaluation in steady-state conditions, but when a great quantity of parameters prediction is a subject of a great complexity (Feustel 1992).

Airflow models, deal with the complexity between thermodynamics and flowdynamics in each enclosure of a multizone structure, which suppose a great number of data for different nodes.

In this case, airflow patterns is the consequence of vertical and horizontal aperture areas disposition, which induce natural ventilation, between upper and lower openings and apertures on one wall.

Average wind velocity profiles at different heights can be estimated with an exponential equation of simple application for any roughness type (Grosso 1992).

$$V(z)/V(zref) = (z/zref)^{\alpha} \qquad (1)$$

where $V(z)$ = wind velocity at height z from ground level (m/s)

$V(zref)$ = wind velocity at z ref (usually= 10 m)

z = height from ground level (m)

α = surface rugosity exponent

Optimisation of airflow to improve interior comfort in temperate climates has been based on a proposed sequence use of diurnal and nocturnal strategies under the basis of heat gain prevention and heat loss enhancement (Borda Díaz et al. 1987).

The objectives are: to focus on the evaluation of the underground tube and the air flowrate through the ventilative duct towards the rooms.

High temperature and vapour pressure do not allow high efficiency of isolate passive systems. That is why, complementation of different devices at day and night are suggested.

The proposed sequence, where comfort ventilation as physiological cooling is pursued, is the following:

1) ***diurnal strategies***: it refers to maximisation of envelope thermal resistance to avoid heat loads. It is combined with the use of an air-earth exchanger (diameter

built in galvanised steel used to recirculate interior air.

2) ***convective strategies***: when exterior air temperature is lower than interior air, optimisation of cross-ventilation from wind and thermal forces so as to promote skin perspiration and cooling of building mass is enhanced (Chandra 1983).

3) ***induced flowrate strategies***: to provide comfort at higher air temperatures, ventilative ducts generate flowrates through the interior, even with rather calm wind conditions.

The system proposed is an air duct built in concrete, of 1.70 m height, a square area of 0.5 m^2 located at the ridge of a pitched roof over the staircase with movable openings to capture leeward and windward air. The cover is operated manually and moves with hinges on sides in two positions.

Wind-towers like those used in hot arid regions of Iran, Iraq and Egypt pursue evaporative and convective cooling (Bahadori 1985).

The present system differs from Iranian wind towers, in the following characteristics: openable at will, reduced height, without partition walls inside and no evaporative cooling occurs.

Theoretical Considerations

Climatic Data

Temperate humid climate of Rosario city, (33 S, 60 W) Argentina, presents the following characteristics during summertime: high temperature and vapour pressure, which hinder the use of passive systems. The 38% of this period are critical days where interior conditioning systems for thermal comfort are required (Perone et al. 1985).

For comfort ventilation and energy consumption reduction, ventilative strategies imply air flow optimisation so as to improve sweating efficiency from occupants and cooling of building mass.

Table I shows climatic data for the overheated period and results of theoretical thermal analysis carried out for the prototype, based on the following assumptions:

- Interior temperature equal to 27 C between 10 a.m. and 8 p.m.
- exterior temperature lower in 2 C than interior temperature, between 9 p.m. and 9 a.m. when ventilation comfort is enhanced.

Summer Design Day February 21st.

Table I

Design Day	Humid	Sunny
Average Amb. Temp.	24.6 C	25.3 C
Horiz. Solar Rad.	21 MJ/m^2	27 MJ/m^2
Daily Heat Load	25 kWh	37 kWh
Hourly Peak Load	2.5 kWh (4 p.m.)	4.4 kWh (5 p.m.)

Hourly heat load was calculated with a simplified model for two Design Days (hot-humid and hot-sunny), which considers dynamic evolution of solar radiation and ambient temperature.

The ventilative assumptions for theoretical analysis were:

- oblique direction of wind,
- average velocity of wind obtained from equation (1) for suburban terrain,
- side-mounted casement windows without mosquito nets.
- effective window area as function of inlet and outlet areas

Required flow rate was estimated to compensate thermal load. Natural ventilation due to thermal and wind forces was calculated according to ASHRAE procedures (ASHRAE 1989). Combined and resultant flow rate was then calculated, demonstrating that nocturnal ventilation has a higher cooling potential than required, (e.g. for wind speed of 1.75 m/s, wind and thermal forces potential is in the order of 50 m^3/min).

Passive strategies are theoretically evaluated by means of the cool energy availability. The authors recognize the limitation of this analysis mainly because of the fluctuating nature and turbulence of wind, and consequently on pressure differences variation, which could be quantified more precisely with wind-tunnel tests.

A theoretical analysis and testing of an isolated underground heat exchanger in a previous research resulted in an average performance of 5% "production of cool energy" of a room heat load corresponding to 5 hours running. Then, a great number of buried ducts would be necessary to produce the required cool energy. This would mean high costs of excavation and tubes, therefore of difficult application in low-cost housing (Mosconi et al. 1986).

The following thermal balance equation for air convection pipe surface heat transfer was used:

$$m\, Cp\, (T_1 - T_2) = hc\, (2\pi R\, \Delta L)\, (Ta - Ts) \qquad (2)$$

where: m = mass flow rate
Cp = air specific heat
T_1 = inlet air temperature
T_2 = outlet air temperature
hc = convective heat transfer
ΔL = length of element
Ta = air temperature
Ts = pipe surface temperature

Additional considerations were:

- "black prairie" soil type for the microregion composed of sand, clay and loam.
- soil temperature profile at depth greater than 0.8m follows average annual temperature for the region.
- soil specific heat: 756 J/kgC
- soil is considered as a seminfinite solid.
- soil thermal conductivity varies between 3.3 kJ/hmC and 5.4 kJ/hmC.
- soil temperature varies between 21.6 and 23.3 C from November to March.
- soil humidity varies between 12% to 22% depending if it is insolated or in shade.

- soil specific weight varies between 1500 to 1800 kg/m^3.
- Convective air exchange coefficient varied between 10.8 kJ/hm^{2}C and 46.9 kJ/hm^{2}C for air velocities between 0.5 and 3 m/s.

Systems operation:

Buried tube:

The underground tube, 10 m long, with a centrifugal fan at one end, captures interior air, and on the other ejects fresh air into the room through a curve at 90°, elevated at 1 m above floor level.

Ventilative Duct:

Depending on wind direction, the cover may be opened to leeward or windward, allowing incoming air towards the ventilative duct or otherwise exhaust by suction effect.

If no wind is blowing and exterior temperature is lower than interior one an upwards force due to temperature difference occurs from lower openings to upper ones. Wind speeds for the microregion are in the order of 20 km/h, and prevailing direction fluctuate from N towards S, on the E quadrant.

RESULTS

Testing of the underground heat exchanger was performed during moderate hot-humid days. Indoor temperature dropped up to 4.5C by recirculation of interior air.

This would correspond to a production of "cool energy" up to 490 kJ, which represents approximately 5% of the hourly peak load for a hot-humid Design Day. Interior relative humidity of 75% and absolute humidity of 19 g/kg were obtained. Close to the exit of the pipe, a reduction in the air effective temperature was measured, (Tdb= 27.5 C, Twb= 24.5 C, ET= 23 C for 1m/s air velocity) but due to the high production of humidity by ocuppants' cooking habits, dry and wet bulb temperature remained almost constant. (See Figures 4 and 5).

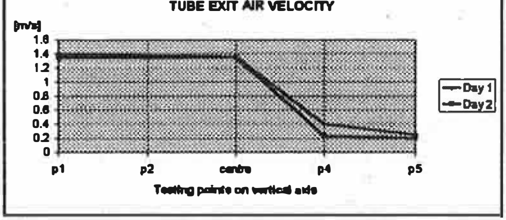

Figure 4

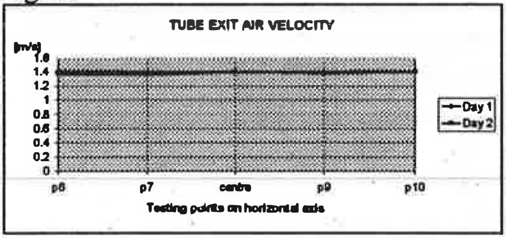

Figure 5

From the results obtained for the underground heat exchanger, earth potential as a cool sink diminishes with time. However, the advantages detected are that there is an intense use of ground and of its energy-saving potential.

Testing of the ventilative duct was performed during moderate temperate days. (See Table II).

The monitoring of the ventilative duct was performed with the following equipment: Weather Monitor Station Davis II and Anemometer TSI 1650.

Table II

	Day 1	Day 2
T Ext.	18 C	18 C
Dry Bulb Int. Temp.	21 C	19 C
Wet Bulb Interior Temp.	16 C	16 C
RH Internal		55%
RH External		57%
Wind Direction	South	Calm
Aver. Wind Velocity	6 km/h	Calm
Mass flow rate induced by the ventilative duct	0.63 kg/s (2268 kg/h)	0.38 kg/s (1361 kg/h)
Barometric pressure		1019 hPa

During the first monitoring, internal temperature remained constant in the upper and ground floor due to the intense flowrate by cross-ventilation induced by the pressure difference between opposite doors at ground level and windows at the upper floor.

The ventilative duct was virtually divided into 3 different horizontal sections: AA, BB, CC, from the bottom towards the top. From the testing, the authors assessed that average air velocity has remained almost constant in 5 reference points of the sections considered: Centre, N, E, S and W. (See Table III)

During day 1, the flowrate from the lower aperture (door facing the courtyard) towards the ventilative duct resulted in a wind suction force. In the upper floor at people standing level, interior air velocities were in the range of 0. 1-0.2 m/s.

During day 2, though internal-external temperature difference was small and wind calm conditions, an upwards flow occurred due to air density differences.

Nevertheless, when opposite doors at ground level were open, upwards flowrate was lower comparatively due to cross ventilation predominance.

Table III

Air velocity (m/s)					
Section	Centre	N	E	S	W
Day 1					
AA	2.5	1.6	1.5	1.6	1.7
BB	2.5	2.0	1.8	1.7	2.0
CC	1.1	1.5	0.7	0.8	0.7
Day 2					
AA	1.2	1.2	1.2	0.7	1.2

Pressure difference (ΔP) between external and internal air at the top of the ventilative duct is of particular interest to evaluate its operation. Pressure difference (ΔP) can be expressed as follows:

$$\Delta P = \Delta H\,(\rho e - \rho i) - Pw \qquad (3)$$

being:

ΔH = distance between lower apertures and upper exit

ρe = exterior air density

ρi = interior air density

and wind pressure is given by:

$$Pw = k\,v^2\,\rho/2g \qquad (4)$$

where:

k = pressure coefficient

v = wind speed

ρ = air density

g = gravity

First thermal term could produce an upwards flow as occurred during Day 1. Second wind term, explains enhancement of upwards flow for leeward opening conditions.

Another possibility is the downwards flow mode, for example, in isothermal conditions, a windward orientation of the cover could produce possitive values of Pw, according to local summer conditions, up to 0.6 kg/m^2.

This situation, (downwards flow), deserves further research since while in industrial buildings is not recommended for contamination reasons, in low-rise dwellings this effect may create significant effective temperature reduction.

DISCUSSION

The following aspects were noticed during testing:

- No disadvantages like dust, insects because the ventilative duct has a manual cover.
- Users'resistance to incorporate systems which differentiate with other houses.
- Difficulty on conciliating occupants' habits with ventilative strategies, due to the intense interaction between indoor and outdoor activities, then, theoretical analysis should be adjusted with empirical observation of people's behaviour.
- Theoretical consideration could not be totally confronted with measurements, mainly because long-time field monitoring for the buried tube and nocturnal ventilation would mean interference on occupants' privacy. The authors consider

that the first stage is fulfilled and that a new compaign will complete ventilative strategies' assessment.
- External window protections were not completely installed at the prototype, since autoconstruction rythm depend on people's economical possibilities.

ACKNOWLEDGEMENTS

Arch. J. A. Vazquez for his collaboration in the construction and systems monitoring. Dr. A. Cortés for his efforts in managing houses'construction and cooperative's enterprises. Prototype's occupants, Soto's family, for their kindness in permitting monitoring. Mr. A. Von Houten for the construction of the movable system of the ventilative duct.

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