Potential of inertial ventilation for passive cooling in Brazilian climates

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ABSTRACT

The objective of this study is to evaluate the potential of two inertial ventilation techniques (buried pipes and thermal phase-shifting) for passive cooling of buildings in Brazilian climates. Using EnergyPlus, a typical residential building was simulated in two locations (Sao Paulo and Florianopolis). Simulations consider 5 alternatives of passive cooling, combining different scenarios of controlled direct ventilation, buried pipes and thermal phase-shifting. Results show the potential of these techniques in free-floating as well as in air-conditioning mode.

1. INTRODUCTION/OBJECTIVE

In Brazil as well as in Europe, air conditioning has been a straightforward response to excess heat in buildings. This rapidly growing trend not only induces important electricity consumption but also sharpens the load profile at peak hours, becoming an issue as well for electricity companies as for building owners.

As an alternative response to air conditioning, proper conception of building envelope (use of solar protections and thermal insulation, control of glazed area, adaptation of structure mass, use of natural lighting) may help to keep the building within the comfort zone (in free-float mode) or to reduce expected cooling load (in air-conditioning mode).

Further reduction or suppression of air conditioning may be achieved by using passive or low-energy cooling techniques. Two of such techniques will be investigated here. Both use inertia for active storage of the meteorological day/night temperature oscillation, and may be classified as inertial ventilation techniques :

1) *Buried pipes*, which consist in forcing ambient air through the soil underneath or next to the building, so as to dampen the daily oscillation and to avoid temperature peaks during daytime. Although derivatives of it have been applied over centuries in more or less traditional forms, a modern revival of the technique has been manifest in Europe over the last decade, with construction and critical analysis of pilot and demonstration installations as well as production of simulation tools and thumb rules for engineers. In particular, it was shown that dampening of the daily oscillation can be achieved with barely 15-20 cm earth around the pipes, enabling for compact and cost-efficient systems (Hollmuller, 2002).
2) *Thermal phase-shifting*, a newly developed technique related to previously described air/earth heat-exchange, but based on recent discovery of a simple physical phenomenon, enabling to shift the temperature peak over time almost without dampening, so that the cold temperature peak of the night be available in the middle of the day. The air flow is now driven through a rock-bed type storage system of very precise dimension and with improved convective exchange. A series of such prototypes has been developed at the University of Geneva (Hollmuller et al., 2004), the most promising available system consisting of a 1 x 1 m square channel, 4.5 m long, filled with 1.5 cm thick terra-cotta plates hold 2 mm apart. Allowing for a 500 m^3/h airflow, it yields a 60% transmission of the 24h frequency shifted by 12 h.

Objective of this study is to evaluate the potential of these inertial ventilation techniques for passive cooling of buildings in Brazilian climates.

2. SIMULATED SYSTEMS

2.1. Climates

Since abovementioned cooling techniques depend on ambient daily average or minimum temperatures to be within the comfort zone, hot climatic regions from the Northern part of the country will not be considered here. The two cities we will focus on (Fig. 1) are Sao Paulo (17'000'000 inhab., 23°S, 60 km from coast) and Florianopolis (300'000 inhab., 27ºS, on the coast), with similar maxima (about 150 days reaching above 26°C), but somewhat distinct daily amplitudes (minima above 20°C during less than 10 days in Sao Paulo, against almost 90 days in Florianopolis).

2.2 Building

The building under consideration is a typical low-cost residential building for middle class revenue, as massively constructed all over the country. It consists of 4 floors on a ground area of 15 x 20 m, with 4 flats per floor. Each flat is divided in 3 thermal zones: living room (20 m^2), two bedrooms (24 m^2) and commons (33 m^2, without windows). General thermal and constructive characteristics are as follows:

- External walls (24 cm) are made of concrete blocks and mortar, with an overall U-value of 2.6 W/m^2 K and a capacity of 280 $kJ/K.m^2$.
- Window to floor ratio is 9.5% (16.7% without commons).

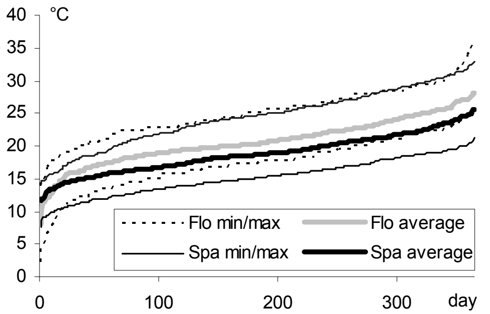

Figure 1: Classified daily temperatures (average and extremes) for Sao Paulo (Spa) and Florianopolis (Flo).

- Infiltration rate is 1.5 ach, 24/24h. This constant value is also maintained in the case of air conditioning, as well as with direct or inertial ventilation.
- Unlike for typical constructions of this type but as a preliminary cooling measure, fixed shading devices are supposed to cut off excessive solar gains (although for the sake of comparison a configuration without shading will also be considered).

2.3. Occupancy, comfort and HVAC setpoints

Occupancy is supposed to extend from mid afternoon to early morning, with a first period mainly in the living rooms (14 – 22h), followed by a period in the bedrooms (22 – 7h). Theses periods and zones will be used to determine the percentage of uncomfortable hours in free-floating mode.

Although air-conditioning is nowadays not yet affordable for population of such buildings, its generalization might give raise to very important energy consumption. Alternatively to the free-floating mode, we will hence also consider cooling and heating with individual fan coils in living and bedrooms. Upper and lower setpoints will be 18 and 24°C, as usual when such HVAC systems are available, but their use will be limited to same occupancy periods as before.

2.4. Direct and inertial ventilation

In comparison with the base case (only infiltration), the benefits of direct and inertial ventilation will be tested with each a 5 ach flowrate (9'760 m^3/h, for all the living and bedrooms). We therefore consider following systems:

1) *Buried pipes* of 20 cm diameter and 30 m length, with 50 cm inter-axial distance, each treating a 200 m^3/h airflow. So as to account for the total necessary flow, some 50 pipes need to be installed underneath the building, 12.5 m wide by 1 m deep (375 m^3 storage volume). Such a system allows for reasonable dampening of the daily amplitude (Fig. 2), with extreme values not exceeding 26°C.
2) *A thermal phase-shifting device*, basing on the prototype described above. So as to account for the total necessary airflow, the device would require four times less volume than the buried pipe system (2 x 3 x 15 m =

90 m^3), yielding a 12 h delay of the meteorological cooling peak (Fig. 2).

As for direct ventilation, inlet to the building will only be permitted if ventilation temperature is 1°C lower than zone temperature. Unlike direct ventilation, airflow through the storage system (buried pipes or phase-shifting device) has to be maintained 24/24h though, with a controller deciding whether outlet is to be conveyed to building (T_{out} + 1°C < $T_{building}$) or ejected to ambient again (T_{out} + 1°C > $T_{building}$). In latter case it may moreover be convenient to use direct ventilation in parallel to inertial ventilation. This is particularly evident for the phase-shifting device, for which the meteorological cooling peak thus gets available twice a day.

2.5. Simulation

The different possible configurations which arise from preceding considerations are listed in Table 1. They are simulated with Energy Plus software, with inertial ventilation temperature given by way of separated simulation with specific software (Hollmuller, 2002 and Hollmuller et al., 2005).

3. RESULTS

3.1. Operation on a typical summer week

In free-floating mode, analysis of mean bedroom temperatures over a typical summer week in Sao Paulo (Fig. 2) leads to following conclusions:

- Effect of shading device ("Base") is quite important, resulting in a building temperature with similar dynamic, but 1-2°C lower than in absence of shading ("NoShade"). Most important gain is during hottest hours, around 17h, building remaining below 28°C when ambient rises at 32°C.

Table 1: List of simulated configurations (each one in free-floating and air-conditioning mode)

Configuration	Ventilation source	Shading
NoShade	-	-
Base	-	yes
Vent	ambient	yes
Pipe	pipes	yes
VentPipe	min(pipes,ambient)	yes
Shift12h	phase-shifter	yes
VentShift12h	min(phase-shifter, ambient)	yes

- Direct night ventilation ("Vent") is a good strategy, enabling an additional 2°C gain during night. This gain however basically vanishes during daytime, inherent building inertia not being quite sufficient for storage of night cooling over 24h.
- In stand alone mode, buried pipes ("Pipe") are not a concluding alternative to direct night ventilation: because of dampening of the ambient amplitude, building temperature results somewhat warmer at night than with direct cooling gain during daytime. In compensation, is only possible during short overshoot periods (first 96h of selected week, when pipe outlet still is sufficiently fresh), but vanishes over longer periods (next 72h, when pipe outlet finally rises above building).
- Parallel use of buried pipes and direct cooling, which ever cooler ("VentPipe"), results in a slightly better option, keeping benefits of direct night cooling while enabling day cooling through pipes over certain periods.
- 12h phase-shifting ("Shift12h") results quite interesting over day time, but obviously needs to be run in parallel to direct cooling ("VentShift12h"), so as to directly benefit from night cooling peak.

3.2. Annual balance, free-floating mode

Preceding analysis is being confirmed on annual balance (Fig. 3), in terms of percentage of hours above 24, 26 and 28°C during occupancy of bedrooms and living rooms, both for Sao Paulo and Florianopolis:

- Again we note the important effect of simple measures like shading and direct night cooling, in latter case especially for night occupancy (bedrooms).
- In case of night occupancy (bedrooms), buried pipe systems in stand alone mode are worse than direct night cooling, and only a very slight thermal advantage appears in case of afternoon occupancy (living rooms). Use of buried pipe systems would need to be combined with direct ventilation, however for a quite relative thermal gain.
- Phase-shifting seems to be a more interesting option, enabling to keep maximum annual building temperature during occupancy be-

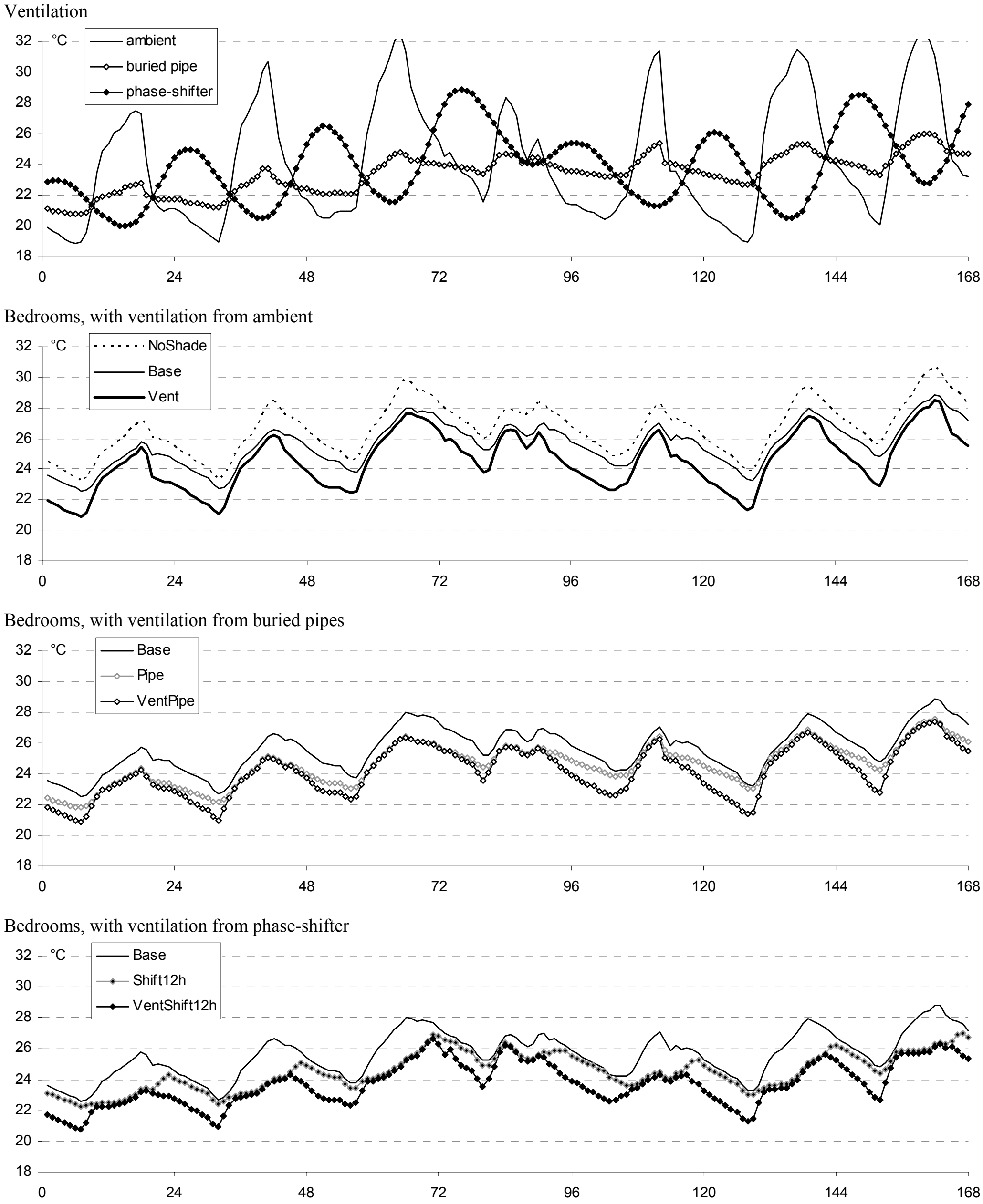

Figure 2: Sao Paulo, airflow and bedroom temperature for different ventilation strategies, hourly dynamic on one week (February 19th – 25th).

low 26°C (Sao Paulo), respectively 28°C (Florianopolis). Depending on occupancy period, such a system obviously needs to be coupled to direct night ventilation though.

- Maybe most important result is that proper treatment of building envelope and adequate use of direct ventilation are basically sufficient measures to keep building below 26°C

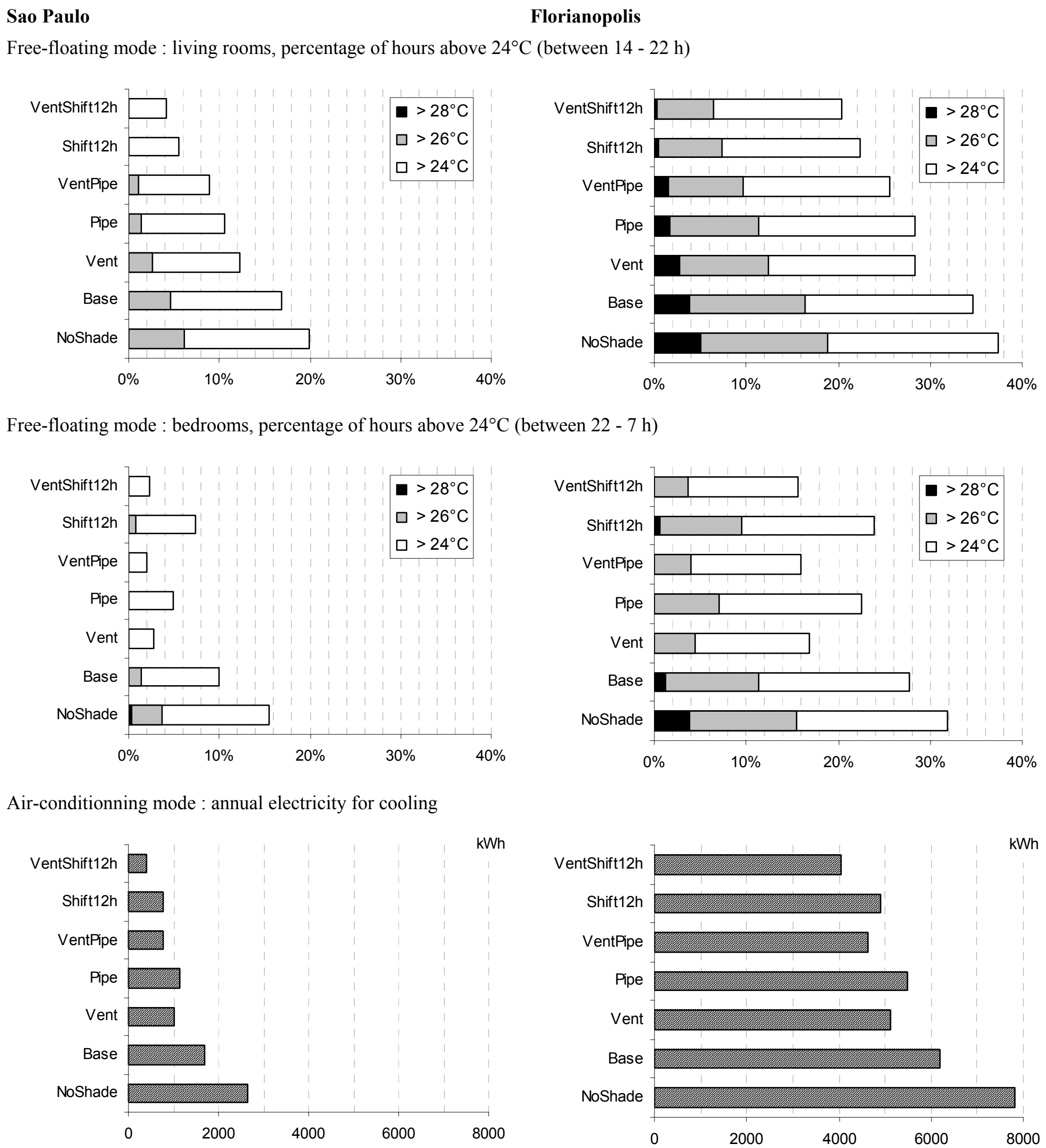

Figure 3: Simulation results for free-floating and air-conditioning mode, Sao Paulo and Florianopolis.

(SaoPaulo), respectively 28°C (Florianopolis) almost all year round.

3.3. Annual balance, air-conditioning mode

Similar conclusions for the air-conditioning mode, where use of 12h phase-shifting coupled to direct ventilation enables savings of the same order of magnitude as preliminary measures on building envelope.

4. CONCLUSIONS

Simulation of a typical residential building located in a mild Brazilian climate (Sao Paulo or Florianopolis) was undertaken, considering 5 alternatives of passive cooling techniques, with or without additional air-conditioning. Main conclusions are as follows:

- Importance of proper treatment of building envelope, in particular by use of shading devices, was underlined.
- Good potential of direct night ventilation was shown.
- With latter measures, air-conditioning is not necessary if building temperatures up to 26 or 28°C are accepted.
- As an additional measure, inertial ventilation, in particular phase-shifting, is particularly suited for day occupancy, but relatively unrelevant for additional gains over night.

Some important complementary aspects, which should yet be addressed, are:

- Evaluation of additional electricity for ventilation, which should stay much lower than for air-conditioning.
- Condensation/evaporation and other air quality problems within buried pipes or phase-shifting device.
- Constructive aspects such as air distribution within building.
- Economic aspects.

5. ACKNOWLEDGMENTS

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