Solar XXI building: proof of concept or a concept to be proved?

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ABSTRACT: Solar XXI building is a prototype of low energy office building where passive and active solar strategies have been applied to reduce the use of energy for heating, cooling and lighting, combining also an extensive photovoltaic façade for electricity production.
Solar XXI was built in 2006 and is considered a high efficient building, close to a net zero energy building (NZEB), because the difference between the energy consumed and that produced is 1/10th of the energy consumed by a standard new office building. Its design includes a large number of energy efficiency concepts, such as a high insulated envelope, south sun exposure, windows shading, ground cooling or stratification and cross ventilation.
The windows solar gains and the effectiveness of shading devices were proved correlating solar radiation, external and indoor air temperatures. It was also verified that ground cooled air has a temperature close to that theoretical expected.

1 INTRODUCTION

Solar XXI building is a prototype of low energy office building located in Lisbon (38º46'N, 9º11'W) where passive and active solar strategies have been applied to reduce the use of energy for heating, cooling and lighting, combining also an extensive photovoltaic (PV) façade for electricity production (Rodrigues et al. 2008).

Lisbon climate is characterized by monthly average temperatures that swing between 10.6ºC for the coldest month (January) and 22.6ºC for the hottest (August). During summer solar radiation is high, more than 6.5 kWh/m^2 per day, and maximum average air temperature is around 28ºC; however extreme values, air temperatures higher than 35ºC, can be observed during a sequence of days. Winter is less severe because the average minimum temperature is between 8 and 10ºC and precipitation days are not frequent.

Solar XXI was built in 2006 and it has been intensively monitored ever since (Gonçalves et al. 2008). It is considered a high efficient building, close to a net zero energy building (NZEB), because the difference between the energy consumed and that produced is 1/10th of the energy consumed by a standard office building. Solar XXI building design includes a large number of energy efficient concepts, such as a high insulated envelope, south sun exposure, windows shading, ground cooling or stratification and cross ventilation.

Considering that Solar XXI's design is based on the concept of integrating passive solar strategies for heating and cooling in a single building, in this paper, such integration is explored and analyzed in order to assess if the results obtained so far constitute a proof-of-concept, or else further research is required to improve it.

2 SOLAR BUILDING CONCEPTS

2.1 *Direct gain*

Direct gain concept, applied in solar buildings, consists of enlarging windows area in south façade so that winter solar energy is easily collected during the daytime hours. In cooling season these windows should be properly shaded. This strategy includes the minimization of windows area in the east, west and north façades to the strictly necessary in terms of natural lightning proposes.

In the Solar XXI building, offices are south oriented and have large windows providing heat and natural light to these rooms during heating season. South façade is totally covered by windows and PV panels by equivalent proportions (Figure 1). Each window area is 4.4 m^2 and the glazing system area (without frame) is 3.6 m^2 corresponding to 22% of room floor area.

Figure 1. Direct gain and PV panels in south façade of Solar XXI building.

The remaining rooms located in the north part of the building, such as laboratories, auditoriums, bathrooms and occasional offices, constitute the building buffer zone.

During winter sunny days, the total amount of energy collected by each direct gain system (window) is about 35 MJ. Because floor is a light element in terms of thermal inertia, a small part of that energy is stored in built elements and the remaining part causes an increase of the sensible temperature during day time hours which is a desirable behavior for an office building.

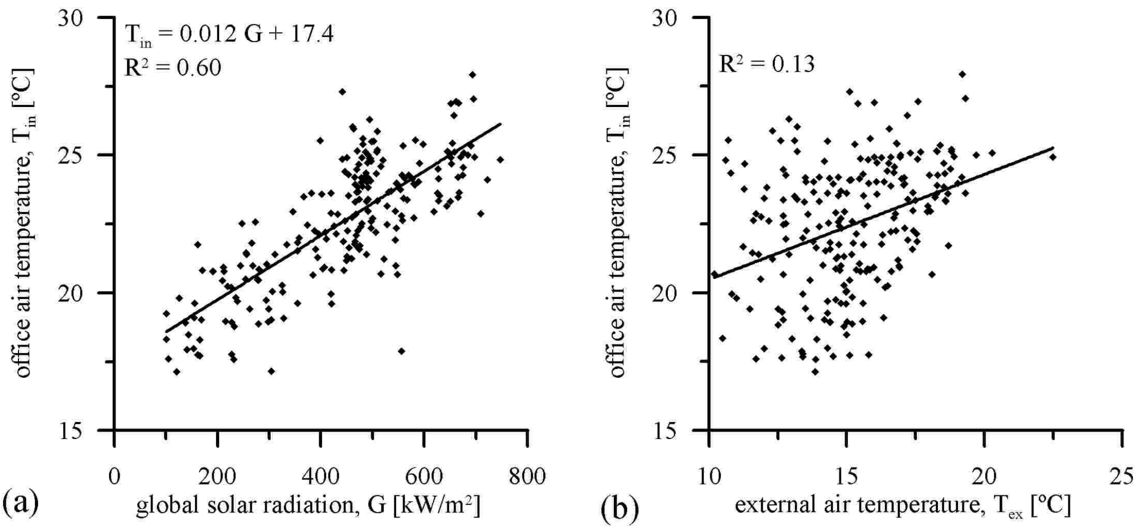

Figure 2. From December to February of 2007, 2008 and 2009, linear correlation of measured daily maximum values of (a) global solar radiation and office air temperature and (b) external and office air temperatures.

During a three-year monitoring period (2007-2009), from December to February, daily maximum values of office air temperature are plotted against daily maximum global solar radiation (Fig. 2a) and external air temperature (Fig. 2b). The results show that, when compared to external air temperature, global solar radiation is correlated with the office air temperature and solar gains through window office contribute to an increase of office air temperature of 1.2ºC for each 100 kW/m^2 of daily maximum global solar radiation.

2.2 *Thermal insulation*

In solar buildings, thermal insulation elements are fundamental because they reduce thermal exchanges by conduction trough external envelope. This preventive strategy is useful in winter season by blocking heat (solar gains, internal gains due to occupation and boiler produced) from leaving or, in summer season, from penetrating.

Brick walls are externally insulated by 0.06 m of expanded polystyrene, the roof is externally insulated with 0.10 m of expanded and extruded polystyrene (0.05+0.05 m) and the ground floor is perimeterly insulated by 0.10 m of expanded polystyrene. Thermal bridges are reduced in spite of the position of insulation elements. Double glazing is also used in order to reduce thermal losses by windows.

Considering all this elements, a global U-value of 1670 WK^{-1} is estimated for Solar XXI building. The compactness of Solar XXI building, expressed by a shape factor of 0.33 m^{-1}, is also an important characteristic to prevent thermal losses.

2.3 *Shading elements*

During summer season, in spite of natural light requirements, windows shading is very important for preventing excessive solar gains. Preferably shading elements should be externally positioned, but different façades require different types of shading elements.

In this building, south windows have moving external blinds, manually operated. Windows in other façades are shaded by internal and light roller shades. Some of them, including roof skylight, do not have any type of shading device.

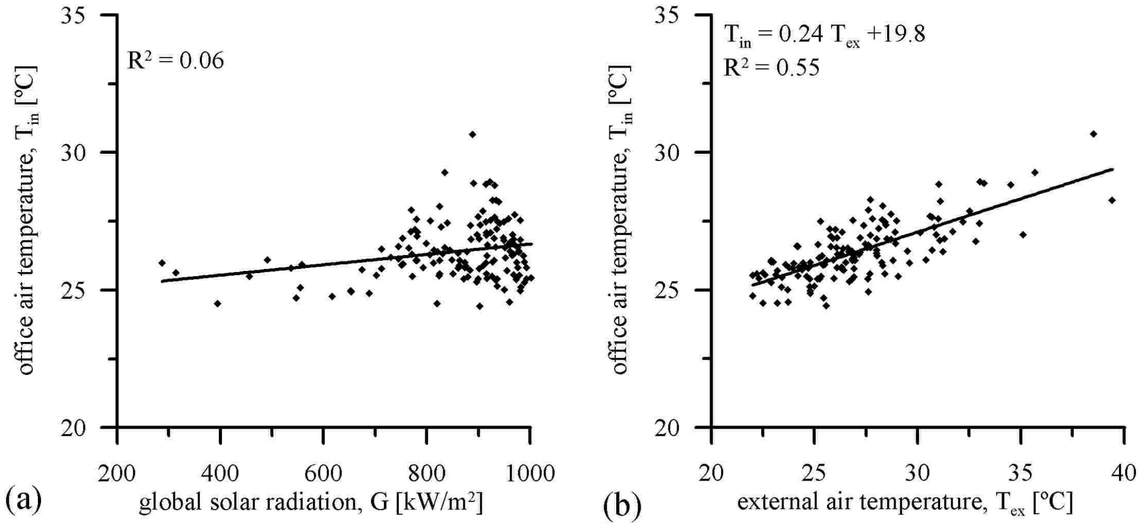

Figure 3. From July to September of 2007 and 2008, linear correlation of measured daily maximum values of (a) global solar radiation and office air temperature and (b) external and office air temperatures.

In summer season, unlike winter, room temperature is more sensitive to the external temperature than to solar radiation as Figure 3 shows. In fact, external air temperature is the parameter most correlated with office air temperature (R^2 = 0.55). The fact that room temperature is better correlated with external temperature than to solar radiation shows that other phenomena besides solar gains, such as heat conduction and infiltration of external air, are dominant in the energy balance. It is also noteworthy that these results show that south windows position conjugated with shading devices are sufficiently efficient for neutralizing the summer solar radiation.

2.4 *Ground cooling*

No air conditioning system is used in Solar XXI building; however, for hot summer days, buildings users can “turn on” the ground cooling system making use of the ground high thermal inertia. This system consists of two concrete pipes for each office room with a diameter of 0.30 m and a fan which insufflates air into the office. The air is collected 15 m from the building, travels at a depth of 4.6 m and is finally fanned into the office room after crossing the pipes circuit; the fan flow rate is 200 m^3/h.

Ground temperature throughout the year varies from 13 to 19ºC; ground is therefore an excellent cooling source during summer season. Using the theoretical formulation of Hollmuller (2003), for the summer period of Lisbon’s climate, with an average maximum external temperature of 28.9ºC, it is estimated an average maximum temperature for the air exiting the ground cooling pipe system (air insufflated into the room) of 21.5ºC, representing a decrease of 7.4ºC. However, as Figure 4 shows, this difference increases with external air temperature, therefore, in hot days with a external air temperature of 30ºC, the air crossing the ground pipes can be insufflated into the room at 22ºC.

The comparison of model results with experimental data is compromised by the intermittent use of the ground cooling system. However, for the period where fans are turned on (some afternoon hours during five summer days), the air is insufflated into the room at a temperature close to the expected by Hollmuller’s theoretical formulation, as shown in Figure 4, where the temperature difference between external and insufflated air is plotted against daily maximum air temperature.

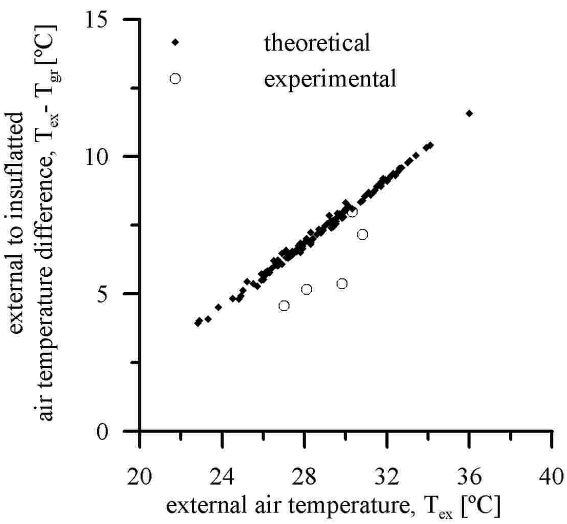

Figure 4. Difference between daily maximum external air temperature and calculated daily maximum temperature of the air exiting the ground cooling system against daily maximum external air temperature using a four month period of Lisbon climate (theoretical) and some monitoring days (experimental).

2.5 *Stratification*

In the middle of the building, there is a three-floor atrium with the double function of natural lighting and air exhausting for circulation areas. As the atrium communicates with the office room, the air is naturally exhausted from the lower to the upper floor as well as from the office to the circulation areas. During summer, skylights opening cause the hot air exhaustion from the building.

An air temperature gradient is expected in the atrium, with higher temperatures in the upper floors. During summer and winter periods, the three floors air temperatures were measured and differences between floors are presented in Figure 5, taking as reference the ground floor.

In the first and second floors the gradient is always positive for both seasons. During winter, the air temperature in the first floor is 1 or 2ºC higher than the ground floor. In the second floor the gradient is higher, with differences around 2 and 4ºC. For both floors, during night period, differences are smaller and less than 1ºC (not observed in Figure 5).

During summer, despite some few exceptions where differences are very small, the temperature gradient observed has values close to those measured in winter. Therefore, from these results it can be concluded that stratification of the air inside the atrium is verified for both periods with a large intensity during daytime period.

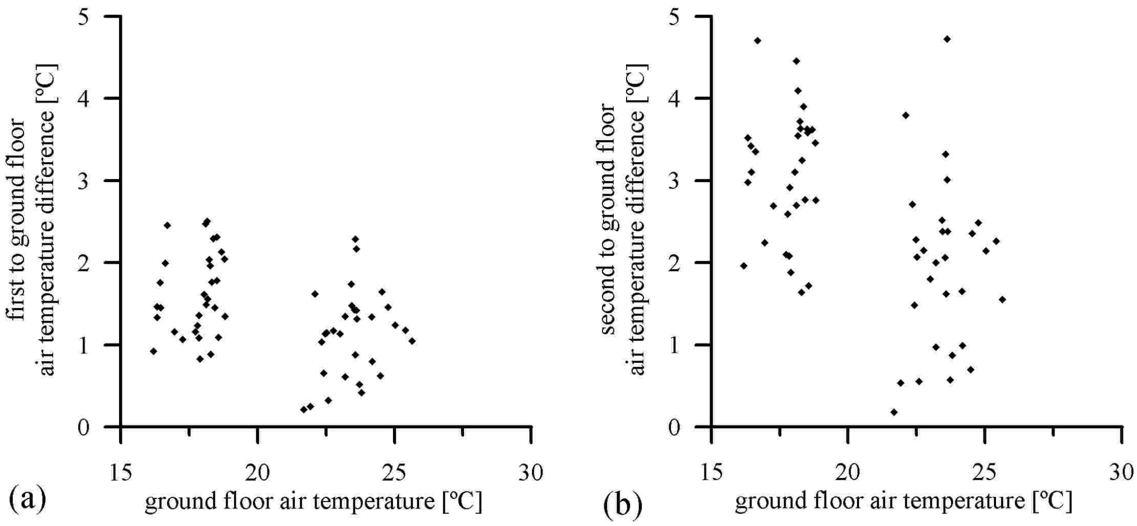

Figure 5. Daily maximum air temperature differences between (a) first and ground floors and (b) second and ground floors.

3 ENERGY CONSUMPTION

3.1 *Final energy use*

Solar XXI uses natural gas for heating and electricity for office equipments and lightning. Estimations based on inquiry and simulations indicate that 69% is used in office equipments (computers, printers, photocopiers and fax machines), 19% in lightning and 13% for heating (natural gas boiler). These percentages refer to primary energy use. It is important to emphasize that lighting use would be much higher in a standard office building without natural lighting strategies. In fact, besides some darker days or late hours, south offices and indoor circulations rarely need electric lighting. Photovoltaic panels integrated in the south façade and parking areas produce about 12 MWh/year which is about 67% of the primary energy and 70% of total electricity used in the building.

The above figures result on an energy efficient index (IEE in Portuguese legislation) of 2.5 kgoe/(m^2.year) which is about 1/10th the total use of energy of a standard new office building. Solar XXI is therefore a high energy-efficient building close to a net zero energy building (NZEB), because of the very small difference between the energy consumed and that produced.

4 FINAL REMARKS

Solar XXI building is occupied since the beginning of 2006. The three year utilization and monitoring made possible to make a first proof of the concepts which sustain the building design. South façade is equally divided into direct gain systems and photovoltaic panels for electricity production. The windows of the office rooms contribute with solar gains during winter sunny days, as the correlation between solar radiation and indoor air temperature showed. The effectiveness of shading devices is also proved by the correlation between external and indoor air temperature, instead of solar radiation.

Besides the small amount of monitoring days where ground cooling system worked, it was verified that the air insufflated into the room has a temperature close to the theoretical predicted by Hollmuller's (2003) model.

In terms of energy balance, this building is an example of a low energy building, consuming about 1/10th of a standard new office building, according to Portuguese legislation.

Future monitoring should be orientated for the ground cooling functioning in order to have a more accurate assessment of its effectiveness on removing heat from the offices, as well as the optimized schedules.

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