

Low-energy cooling of a medicine warehouse in a hot humid climate

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ABSTRACT

The present research was aimed at the definition of a design hypothesis for the construction of a pharmaceutical warehouse in a hot humid area of southern Sudan. The candidate hypotheses were based on an existing prefabricated single-storey pitched-roof steel structural systems 18 m long and 9 m wide and had to be constructible at a low cost and using local materials. At climatic level, the goal was that daily d.b. temperatures not exceeding 27-28 °C were reached by passive of very low-energy means, which was not easy to achieve in the given conditions. A construction hypothesis was made by the author adopting the following solutions: a) masonry for the walls, insulated from the outside and protected by rainscreens; b) a heavy concrete floor insulated from the outside and suspended upon a ventilated cavity; c) a ventilated and insulated metal-sheet pitched roof. Three passive cooling strategies based of the described solution have been tested by the author through the use of the ESP-r software tool: the first exploiting nightly stack effect ventilation, the second based on forced night-only fan ventilation, and the third based on night top-down ventilation activated by roof radiant cooling. The second and third hypotheses have been found to meet the thermal requirement and the second one was at last selected, because it seemed to guarantee lower construction costs and be less dependent from weather conditions.

1. INTRODUCTION

The present research was aimed at the definition of a design hypothesis fit for the construction of a small pharmaceutical warehouse in the hot humid climate of southern Sudan. The candidate design hypotheses made use of an existing prefabricated single-storey pitched-roof hot-rolled steel structural systems 18 m long and 9 m wide with a double pitched roof and had to be constructible at a low cost and using locally available materials.

At climatic level, the design goal was to obtain daily d.b. temperatures not exceeding 27-28 °C by passive of very low-energy means.

2. CONSIDERATION DERIVING FROM CLIMATE AND USE TYPE

The town which the construction was aimed to was Bor, near Juba, in southern Sudan.

The climate in Bor is very close to that of Juba, about which more weather data are available. The weather in Juba is characterized by high temperatures in both the October-March period and the April-September period, with the first rather hotter and the second more humid and rainy.

The highest mean monthly maximum d.b. temperatures are about 31.5 °C in March and 27 °C in July, August and September. The lowest mean monthly minima are about 3 to 4 °C lower than the maxima, producing very small daily temperature excursions.

The extremes of relative humidity mean maxima and minima are found in August (93% in the morning and

60% in the evening) and February (53% in the morning and 21% in the evening).

The average daily wind speed is usually about 3 to 4 m/s, mainly present through the day, with calm nights and a (weakly) dominant wind direction is from east.

Periodically the weather is characterized by rainy wind storm.

The main challenges deriving from the climate are due to its high temperatures, its small thermal excursions and its high relative humidity in the rainy season, which makes difficult the exploitation of evaporative cooling strategies.

For what medicines are concerned, the high d.b. temperatures are the main issue, while the high relative humidities and the latent heat of air are a minor concern if the medicines envelopes are effectively sealed.

The use type of the building makes particularly important that the temperatures are stable.

The above unusual conditions has suggested the following considerations. The building:

- 1) had to be high-mass, even with the rather small thermal excursions in question, to exploit at least the small thermal excursion usable for night mass cooling;
- 2) had to be highly insulated, both to maximize the effectiveness of night flushing by daily closing of the envelope and to lower as much as possible the cooling loads when additional cooling by active means has to be used;
- 3) should exploit wind night ventilation when possible, therefore requiring wide surfaces of high-thermal-resistance operable doors or windows;
- 4) may exploit night stack effect ventilation;
- 5) could not exploit day ventilation due to the facts that the ambient temperatures during the day are higher than the maximum temperatures that could be tolerated by medicines and that the medicines cannot loose sensible heat.
- 5) may exploit indirect evaporative cooling, but

should not exploit direct evaporative cooling, in order not to increase the humidity levels in the room;

- 6) may exploit radiant night cooling to the sky with no counterindications;
- 7) should be heavily shaded, with shading devices not hindering ventilation;
- 8) its facades and roof should be vented, due to the high levels of daily solar radiation;
- 9) ground heat exchange could not be passively pursued, due to the fact that local ground temperatures are likely to be very high, being about the level of the mean annual ambient temperature of the place, that is indeed about 27 °C.

3. DESIGN HYPOTHESES

The above considerations led the author to the definition of a base design hypothesis allowing to implement several cooling strategies. The construction hypothesis was based on the adoption of:

- a) masonry for the walls, insulated from the outside and protected by rainscreens. The solution which has been proposed is to apply wooden cavities filled with loose straw outside the masonry and to protect them by a white painted vented wooden rainscreen;
- b) a heavy concrete floor insulated from the outside and suspended upon a fully ventilated cavity. This is a common local solution, due to the very high humidity levels of the clay soil;
- c) a ventilated and insulated metal-sheet-covered pitched roof, operable from the inside for night ventilation and conceived to screen the rain even when in open position;
- d) operable, wide, full-facade-height highly thermally insulated door and roof vents. These should allow for cross ventilation and air extraction from the ridge when the wind is present and for stack effect ventilation when the wind is low or absent.

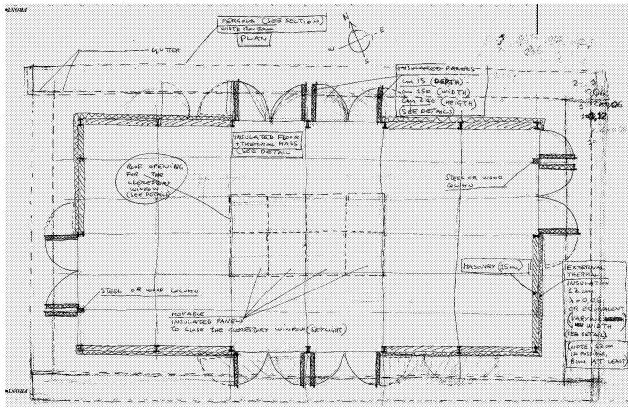


Figure 1. Sketch of the building plan.

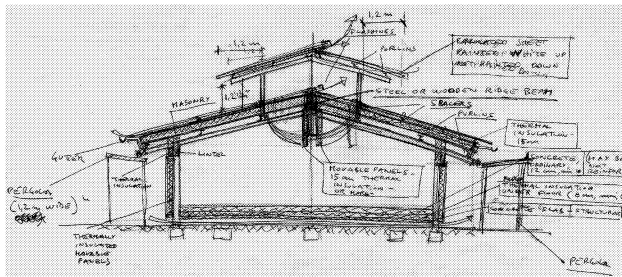


Figure 2. Sketch of the transversal section.

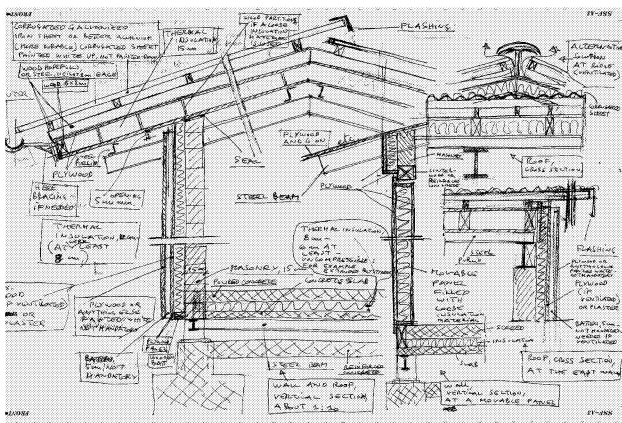


Figure 3. Detailed sketches of transversal sections.

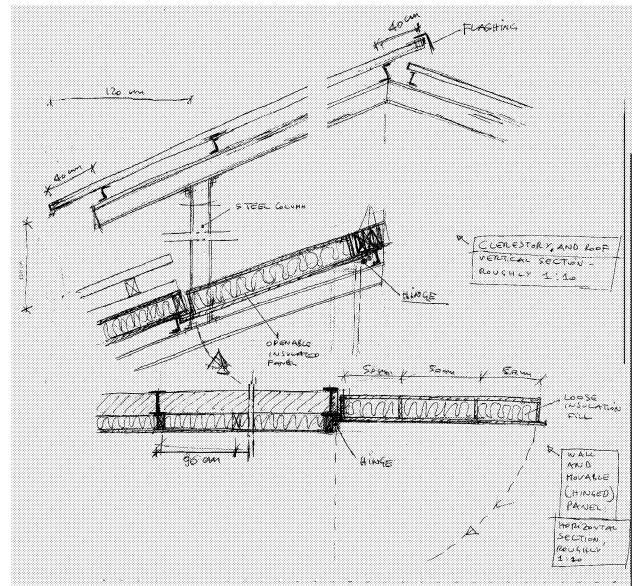


Figure 4. Detailed sketches of transversal (top) and horizontal (bottom) sections.

4. SIMULATION MODELS AND RESULTS

Three passive cooling strategies based on the described common construction solution have been tested through ESP-r by the author: one (a, base case) exploiting the stack effect for night-only ventilation, another (b, actively vented case) based on forced night-only fan ventilation (20 ach), and a third (c, radiant cooling case) based on night-only, top-down ventilation activated by roof radiant cooling thanks to an inverted pitch of the roof.

Moreover, a case implying a thicker insulation layer and a thicker thermal mass (d), a case implying a thicker insulation layer, a thicker thermal mass and active ventilation (e) and a case without thermal insulation and actively vented (f) were tested.

The ventilated facades and roofs and the ventilated floor have been modeled as separated fully vented thermal zones in ESP-r and the upper and lower zone of the room were modeled as distinct zones separated by a virtual surface, to take into account the effect of air thermal stratification. This was important since the medicines were probably to be stocked in the lower zone, so that the upper space of the room could reach higher temperatures with no undesirable effect.

The hypotheses were simulated by the author implying no internal gains, no transparent envelope surface, the presence of a light-color, horizontal, wind-permeable

shading device two meters deep at the height of the eaves, and the activation of (natural or forced) night ventilation from 11 p.m. to 8 a.m.

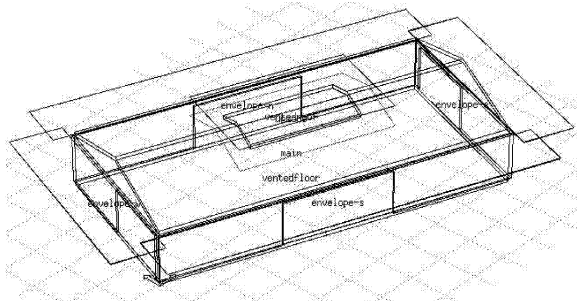


Figure 5. The base case thermal model as edited in ESP-r.

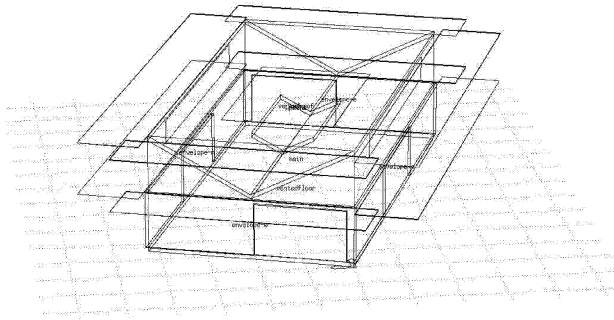


Figure 6. Night radiant cooling thermal model as edited in ESP-r.

Hourly weather data for south Sudan were not available to the author so the weather data of the northern part of Kenya – town of Lodwar – were used for the thermal simulation, being the most similar to the cities in south Sudan among the available ones.

This makes the obtained results useful as indications about the possible situation that could be encountered in south Sudan, but not identical to those that could be obtained with local data, due to the differences between the two considered climates (mainly the higher daily temperature swings, the higher temperature maxima and the somewhat lower relative humidity seasonal values in Lodwar, Kenya).

All the three base design hypotheses (a, b, c) have shown to perform well: but not enough

well in the first case (a): the ventilation rate obtained by stack effect has shown to be not effective enough to provide the required night flushing.

Due to the difficult climate conditions, all the parts of the building system had indeed, in general, to perform to the maximum degree of effectiveness for the temperature objectives to be met.

Both the second and third of the described hypotheses have instead been found to meet the thermal requirements; but the second one was selected at last over the third, both because it seemed to guarantee lower construction costs and its results seemed to be less weather-dependent and because functionality and its simulation model was far more robust than that regarding the third hypotheses, which effectiveness was dependent from the fact that transparent barriers constituted by PVC foils were able to avoid that radiant cooled air on the roof be washed by night breezes, without hindering long wave radiation to the sky.

Moreover, in case (b) a great difference has not been found between the temperatures obtained with 20 ach and 10 ach, which makes likely ventilation to be activated by cheap machinery.

The ameliorative hypotheses (d) and (e) have shown to perform rather better than respectively hypotheses (a) and (b), but not probably *so* much better to justify their higher construction costs, while the non-insulated, actively ventilated case (f) has shown an unsatisfactory performance due to the fact that its envelope thermal resistance is too poor for the building to profit during the day from the “coolth” collected at night.

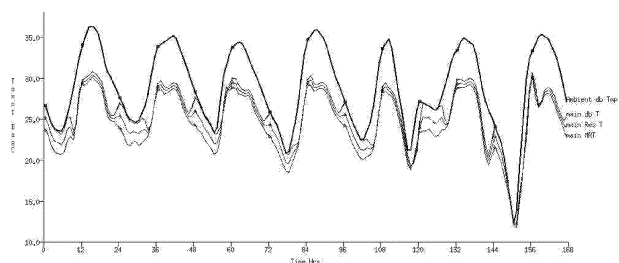


Figure 7. Base case (a). Ambient temperature (thickest line) and air d.b., mean radiant and resultant temperatures in the lower zones of the room. 9-15th of January. The highs exceed 30 °C.

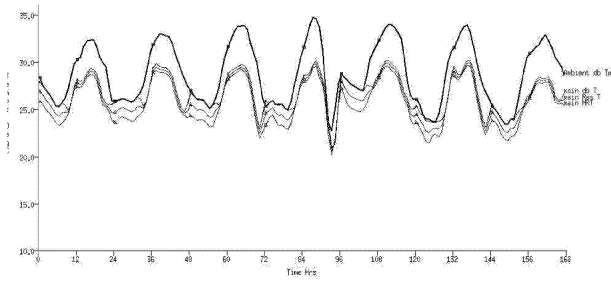


Figure 8. Base case (a). Ambient temperature (thickest line) and air d.b., mean radiant and resultant temperatures in the lower zones of the room. 9-15th of July.

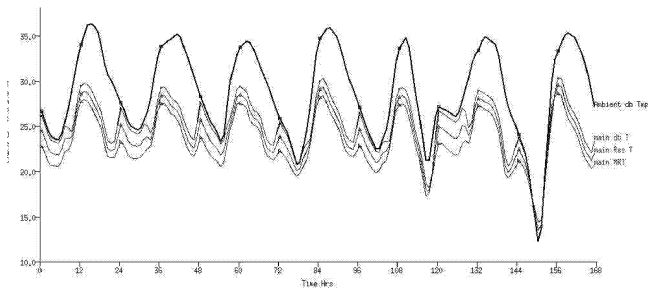


Figure 9. Actively vented case (b). Ambient temperature (thickest line) and air d.b., mean radiant and resultant temperatures in the lower zones of the room. 9-15th of January.

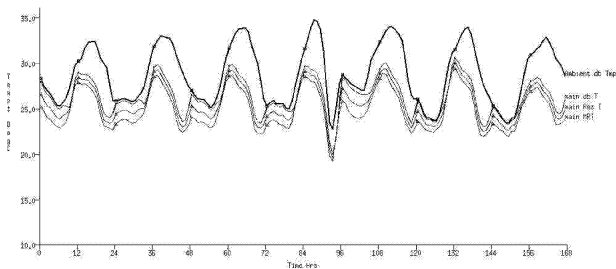


Figure 10. Actively vented case (b). Ambient temperature (thickest line) and air d.b., mean radiant and resultant temperatures in the lower zones of the room. 9-15th of July.

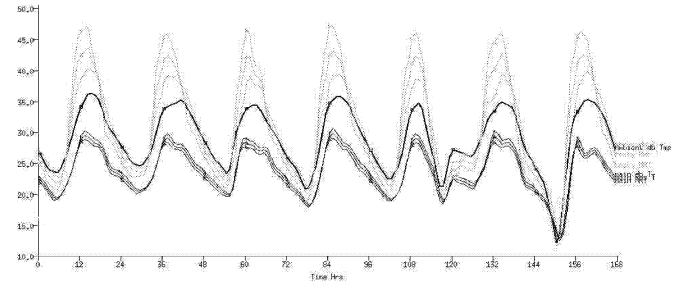


Figure 11. Radiant night cooling case (c). Ambient temperature (thickest line); air d.b., mean radiant and resultant temperatures in the lower zone of the room (blue lines); air d.b., mean radiant and resultant temperatures in the vented roof cavity (beige lines). 9-15th of January. The highs are kept below 30 °C.

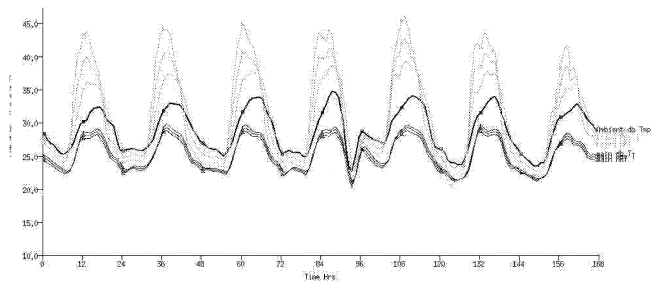


Figure 12. Radiant night cooling case (c). Ambient temperature (thickest line); air d.b., mean radiant and resultant temperatures in the lower zone of the room (blue lines); air d.b., mean radiant and resultant temperatures in the vented roof cavity (beige lines). 9-15th of July.

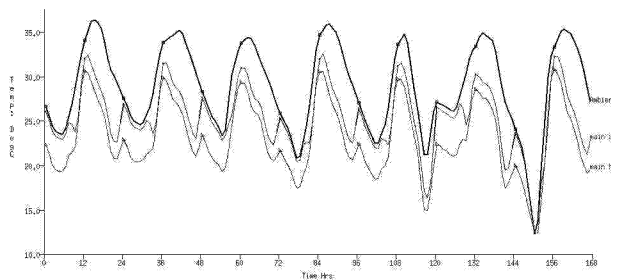


Figure 13. Uninsulated and actively vented case (f). Ambient temperature (thickest line) and air d.b., mean radiant and resultant temperatures in the lower zones of the room. 9-15th of July. Without additional thermal insulation the active night ventilation is clearly not enough to avoid that temperatures exceed 30 °C.

A hypothesis of radiant and indirect evaporative cooling by a concrete slab roof pond were found encouraging

following the simplified criteria described in Givoni (Givoni 1994), but they have not been tested in ESP-r due to the uncertainty found by the author about the passive system model to apply. Furthermore, this solution has been discarded due to the reported difficulty of constructing it in an affordable and reliable manner in the given conditions. This hypothesis implied the shading of the roof pond during the day with a wide textile canopy to be fixed to a suitable structure and its removal at night.

Also an hypothesis of wetting the soil under the vented floor with water during the day has been found promising following the criteria reported by Givoni (Givoni 1994), but even this solution has not been tested in ESP-r, for the same reason of the previous one. Another reason for this is that this solution implied that the floor should not be insulated in order to exploit the passive thermal coupling with the cooled soil surface beneath, while the author felt that it was important to have the floor insulated under a very deep high density concrete screed (as tested in cases a, b, c, d, e) in order to make night mass ventilation effective and in order to keep cooling loads low in case of need of active cooling.

5. CONCLUSIONS

The considered environmental condition made difficult to cool a medicine warehouse by completely passive strategies.

Given (a) the need of stable internal temperatures (b) the absence of internal gains and (c) the hotness of the air during the day, the simulations have shown that night mass flushing should be the base cooling strategy to exploit, better if coupled with other suitable strategies. But for it to be effective, a high thermal insulation of the building envelope is required, which is also essential to allow for additional active cooling under extreme thermal circumstances. Moreover, for night flushing to be effective enough (“enough” that, in the specific case means: at its highest level) active ventilation is very advisable.

Other cooling strategies may be very promising or interesting in the given conditions. Those are night radiation to the sky from a concave ventilated roof or from a shaded roof pond (radiant cooling is coupled, in this case, with indirect evaporative cooling) or evaporative cooling of the vented wetted ground below grade.

These last solutions are particularly complex and would deserve further simulation tests.

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