Low-Cost, Passively-Cooled Medicine Warehouses for Hot Climates:

A design and construction manual

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ABSTRACT: A manual for the construction and design of affordable, passively-cooled medicine warehouses in hot climates is here presented. The manual addresses specifically some design hypotheses aiming to be low-cost, easily buildable, easily maintainable and suitable to keep inside temperatures low enough to robustly allow for the preservation of medicines. In the document, some construction hypotheses are presented and investigated to verify if the given requirements are met. The thermal behaviour of the proposed solutions has been investigated with the aid of the ESP-r software tool. The manual has been made available for free on the web and has been licensed with a Creative Common license.
Keywords: medicines, warehouses, passive cooling

INTRODUCTION

A manual for the construction and design of low-cost passively-cooled medicine warehouses in hot climates is here presented. In the manual, general design requirements and specific design and construction solutions are proposed, along with explanations of the design choices and a study of the free-floating thermal performance of the considered buildings as verified through thermal simulations. The proposed models aim to be as affordable as possible, easily buildable, easily maintainable, and cool enough to robustly allow for the preservation of medicines. The document has been published through a Creative Common (attribution – non-commercial – share alike) license and is freely downloadable online (Brunetti 2008).

BACKGROUND

The topic of medicine conservation through passive cooling strategies in hot climates is a truly trans-disciplinary one. It involves at least the topics of passive cooling of buildings, medicine preservation, storage facilities design and appropriate building technology.

Most of the research literature about passive cooling techniques is aimed to human thermal comfort. The author has found no source explicitly related to the topic of passive cooling for medicine conservation. The existing literature is anyway essential for the study in question. Just reference to some outstanding sources of information (Givoni 1994, Cook 1989, Santamouris 1996) is here made.

Today the need of passively cooled storage facilities for medicines mainly regards people in developing areas or areas in emergencies in want to reduce dependency from external aid. The existing information here mainly stems from general studies about medical facilities in developing countries (Kleczkowsi and Pibouleau 1976-1985, Delrue and Mikho 1976) and from a great wealth of studies about appropriate technology for health facilities (among them, Hababou 1983, Rand et al. 2003) or emergency situations (among them, Davis and Lamber 1995), none of them directly dealing with passive cooling for medicines.

A great wealth of useful information is also available about strategies for the preservation of food or crops by passive means. This topic has much in common with the preservation of medicines, but it is not entirely coincident with it, mostly for the fact that for the preservation of food or crops the control of relative humidity is of primary importance, while for medicine preservation this is just important for non-packaged medicines, but not for plastic-packaged ones, which are today vastly prevalent. Two very interesting models are here the traditional yam barn used in western Africa (Wilson 1987, Knuth 1993) (Fig. 1) and the storehouse for fruits approved in 1983 as the standard type for farm-level storehouses by the Ministry of Construction of Korea (Kitinoja and Kader 1995) (Fig. 2).

But none of those two models appears to the author to be viable in the cases in question: the first of them because its cooling performance heavily relies on site features, and the second one because of its rather sophisticated building solutions.

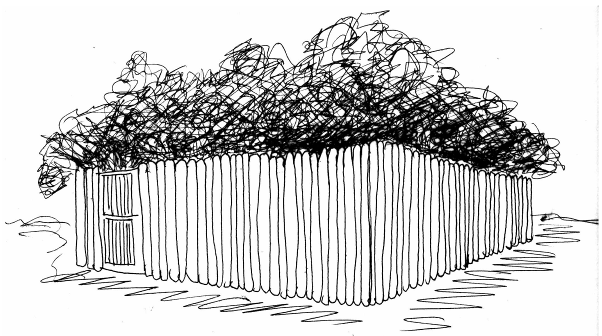

Figure 1: Traditional yam barn used in West Africa, obtained using live trees both for structural purposes and for shading and temperature control (redrawn from: Wilson 1987).

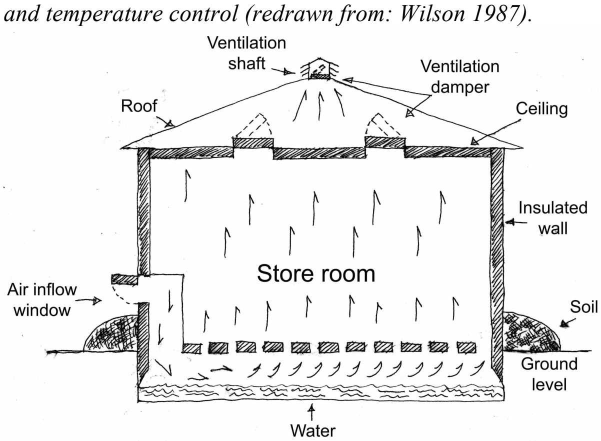

Figure 2: Model for farm-level storehouses by the Ministry of Construction of Korea, 1983 (redrawn from: Seung Koo Lee, 1994. From: Kitinoja and Kader 1995, section 7).

FEATURES COMMON TO MEDICINE WAREHOUSES FOR HOT-ARID AND HOT-HUMID CLIMATES

Medicine warehouses are characterized by peculiar utilization patterns setting them apart from most other building types. Their principal requirement is that room temperatures never gets higher than about 28 °C, for the sake of medicines conservation. Another peculiar feature is that they may be just artificially lit, having no need for daylight illumination: they may indeed be just sporadically lit.

With respect to the aim of preservation, modern medicines differ from traditional ones mainly for the fact that usually they are enveloped in airtight envelopes allowing for their preservation even in presence of high relative humidity.

In hot-arid climates, these features do not imply that design solutions required for medicines warehouses have to be very different from the ones required for habitations, since both situations can be dealt with high thermal mass and efficient night ventilation. But in hot-humid climates, these same features *do* imply that design solutions for medicines warehouses have to be different from the ones required for habitations. For habitations in hot-humid climates, indoor climate passive control is indeed usually based on comfort day-and-night ventilation, accepting that room temperatures follow rather closely the ambient air temperature. But the same strategy is not suitable to medicines warehouses, since this would cause room temperatures to be too high (often exceeding 30 °C) for medicines during the daytime.

This, in combination with the fact that in hot-humid climates medium dry-bulb temperatures are often less high than in hot-arid climates, makes the night mass-ventilation strategy (night flushing) of medicine warehouses also suitable for hot-humid climates.
There are therefore great similarities between design requirements for medicine warehouses for hot-arid and hot-humid climates. Clear distinctions between the two types of models mainly regard their basements and their relation with soil.

Generally, the passive indoor climate control of medicine warehouses may be pursued, like that of most building types, by adopting a combination of natural ventilation, direct and indirect evaporative cooling, radiative cooling towards the sky, and (direct, indirect or isolated) earth coupling. But, since the present study deals with the design and construction of low-cost medicine warehouses, mainly the passive cooling strategies that can be implemented at low-cost and with the least constructive difficulty - like ventilation cooling and, whenever possible, earth coupling - have been here taken into account. With respect to other possible passive cooling strategies, only the cheapest ones have been considered. Indirect evaporative cooling has for instance been just roughly taken into account with respect to the strategy of soil and/or roof wetting for hot-arid climates, but not with respect to the strategy of roof ponds of water pools exploitation; and radiative cooling has been taken into account with respect to the strategy of convective air collection from a concave sloping roof, but, again, not with respect to roof ponds exploitation.

Considering this, the following requirements have been identified by the author, and commented on in the manual, as the most important to be met for medicines warehouses.

1) Medicine warehouses have to have very little or – better - no glazed overtures (windows or doors) at all on the building envelope during the day, in order to keep solar gains as low as possible.

2) They have to be high-mass, to have a high thermal capacity. The placing of water containers in the central zone of the storing room is here a thermally efficient and cost-effective solution and is therefore essential.

3) They have to be thermally insulated on the external face of the envelope's thermal mass (walls or even roof in some cases), to reduce heat gain by conduction during the day. (Straw bales insulation is here, for instance, an interesting solution, when conceivable.)

4) They have to be passively ventilated by wind just when outside air temperatures are lower than inside air temperatures: this is not often the case during days in hot climates, but it is the typical situation during nights. During nights the storing room can and has to be ventilated, to allow for night flushing of the thermal mass. And in order to make cross-ventilation effective, the adjective construction elements (like doors, vents and windows) should be as wide as possible.

5) The building has to be stack-ventilated during days when the ambient temperature is higher than the inside air temperature and during nights. To encourage stack ventilation, the outlets should be placed as high as possible and the inlets should be placed as low as possible. Aerodynamic factors are not crucial for this kind of ventilation, because it implies slow air velocities. But they become crucial when stack ventilation has to be combined without conflicts with cross ventilation, which is a common situation. It is therefore mandatory that those stack ventilation systems are designed with an eye to cross-ventilation.

6) The building envelope at both walls and roof has to be completely shaded and this shading does not have to interfere with ventilation. This could be obtained for instance by the means of movable porches constituted by thick, white canvases (or by two-layer white canvases) placed horizontally at about the eaves level, supported by light wooden structures and detached enough from the roof not to hinder the passage of air to or from the building overtures. An alternative solution is that the walls are protected from solar radiation by a screen in a ventilated façade scheme, possibly low-e at the inside face and painted white on the outside, or by deep, porch-like horizontal projections supported by the walls. Such projections should be light, removable and in any case deep enough to be suitable to also screen a consistent amount of indirect solar radiation.

7) The medicine storing room should be high, to favour thermal stratification of air during the day, and the medicines should be placed in the lower, cooler zone of it.

8) The building may be assisted by active ventilation through small ventilation overtures (located at the room's lower and higher levels) coupled with fans. This may be necessary in extreme hot climates at times.

DIFFERENCES BETWEEN THE FEATURES OF MEDICINE WAREHOUSES FOR HOT-ARID AND HOT-HUMID CLIMATES

These differences in the view of the author are mainly the following.

1) In non-extreme hot-arid climates, the floor of the building should be built on soil as a concrete slab, while in extreme hot-arid climates the concrete slab may have to be thermally insulated underneath. In hot-humid climates, the concrete slab constituting the floor has instead to be elevated from soil in order to avoid soil humidity and reduce the risks of damages from floods (the height of the building upon soil should therefore be suitable to preserve the basement from water) and has to be insulated underneath.
In non-extreme hot-arid climates, the building can, and in most cases should, be partially built underground. In these cases, the thermal inertia of soil should be exploited, and therefore it should be avoided that the thermal insulation is placed between floor and soil, to allow for thermal coupling between them. In extreme climates, this thermal coupling may instead produce too hot temperatures in the storing room during the Fall, due to the soil's thermal lag.

2) In hot-arid climates, evaporative cooling may be exploited by wetting, at regular intervals, the shaded soil around the building and, if possible, under it (Givoni 2007). Even wetting of the roof may be effectively pursued if a suitable roof morphology is present. For the same reason, the building would greatly benefit from the presence of trees and shrubs around it (provided that they do not hinder ventilation) both because of their shade and because of their evapotranspiration effect.

3) Especially in hot-arid climates, an advantageous alternative to the ordinary gabled roof morphology may be constituted by a concave, V-shaped roof, lower at the ridge and open to the downflow of air at the centre when needed, to exploit air buoyancy coupled with radiant cooling of the roof (Fig. 4).

SPECIFIC DESIGN MODELS

Some specific design solutions have been proposed in the manual. Two types of buildings have mainly been dealt with, one entirely built with a light-frame wooden structure and the other with masonry walls coupled with a light-frame wooden structure for the roof.

The principal reference example of semi-permanent light-frame sanitary buildings that has been considered for the definition of the models is constituted by the light, modular wooden building presented in a guideline document of Mèdécins Sans Frontiers (De Bernardo and Isar 1998). The two groups of here proposed design solutions attempt to be not much more difficult to build than this reference building (their main additional construction difficulty here being constituted by efficient thermal insulation).

Following the cited example in the MSF document, all the here considered building models are 6 m wide and 13 m long in plan, plus or minus 2 m modules in length. The models, that may therefore be long 5, 7, 9, 11, 13, 15 or 17 m or so on, have to be elongated on the east-west axis to minimize internal heat gains.

The two considered buildings types (wooden and masonry) share the same shape and size and can both be coupled with two alternative roof morphologies, both allowing for stack ventilation: a traditional ventilated gabled roof with the ridge higher than the eaves and an elongated "ventilation lantern" on top of it (a); a V-shaped roof with the ridge lower than the eaves and ventilation vents aligned near its central axis (b).

From an operational point of view, the main difference between the two configurations is that the roof vents in the first case (a) have to be manually operated with the aid of a staircase or at a distance with a tool like a suitable operation stick, while in the latter (b) they are easier to control, since they are placed in the reach of a person without stairs and may be even put in place (closed) and removed (opened) without the aid of hinges.

From an energy point of view, in the second (b) configuration, the wall full-height ventilation overtures can be wider than in the first one (a), making likely that the effectiveness of cross ventilation (and, therefore, night flushing) is increased; but the first solution (a) is characterized by a greater compactness, favoring "coolth" conservation during the day.

The same should be noted for the choice of the proposed rather shallow building plan, which is less favorable to "coolth" conservation than a more compact one (requiring therefore a comparatively thicker thermal insulation), but is more favorable to cross-ventilation.

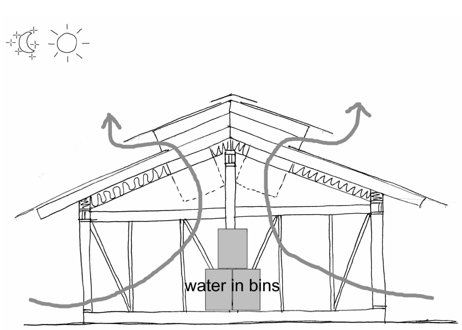

Figure 3: Stack ventilation in the ordinary gabled roof configuration.

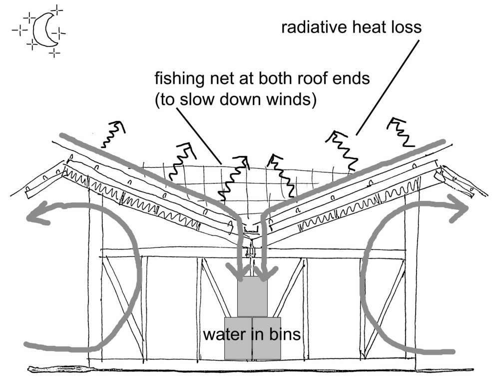

Figure 4: Cross and stack night ventilation in the V-shaped roof configuration.

For the wooden configurations, a platform-frame-like solution has been chosen with 1 m spaced rafters on centres.

Some solutions have been taken into account for the construction of roof and walls to allow for technological appropriateness depending from local conditions (availability of materials and components). The insulation material may for instance be constituted by loose fibres or by self-supporting panels and may or may not be enclosed by planks, sheets or panels, provided that the resulting walls are externally white and by some means effectively shaded.

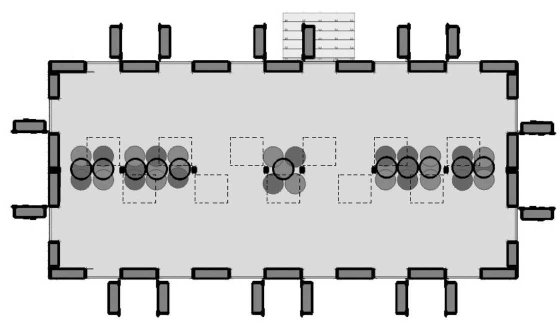

Figure 5: Plan of the wooden models.

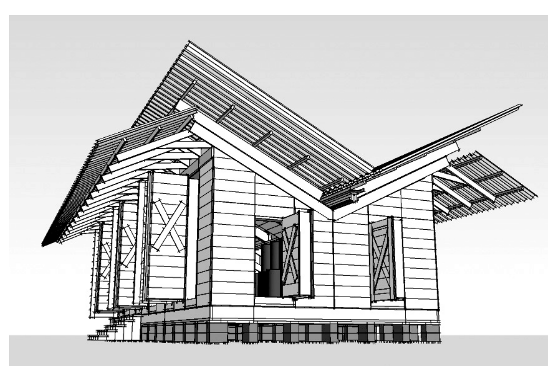

Figure 6: View of the V-shaped model.

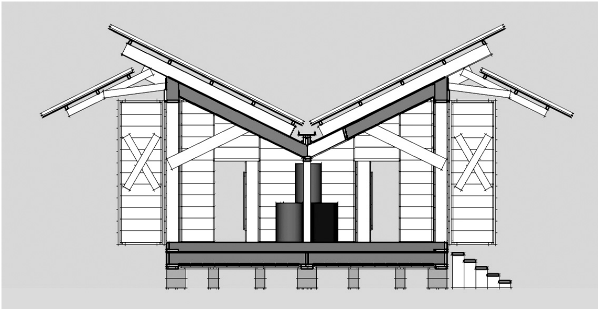

Figure 7: Transversal section of the V-shaped model.

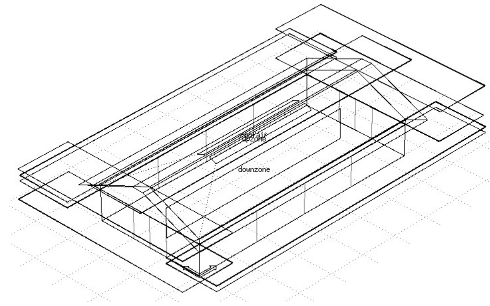

Figure 8: The considered ordinary gabled building model geometry, with solar shadings.

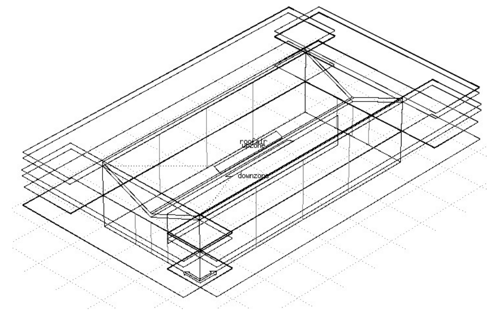

Figure 9: The considered V-shaped building model geometry, with solar shadings.

BIOCLIMATIC FEATURES OF THE PROPOSED SOLUTIONS

The passive temperature control of the considered building configurations is made possible by the daily operation of the architectural systems by the users.

In the ordinary gabled roof configuration, the exploitation of stack ventilation is made possible by the lower height of the doors with respect to the roof vents, while in the V-shaped configuration this is mainly made possible by the full height of the doors. Therefore, it is likely that this effect is stronger in the ordinary gabled roof case. On the other hand, the exploitation of radiative cooling from the roof, greater in hot-arid climates, is possible just in the V-shaped roof configuration. It is notorious that hot-humid climates, night radiative cooling is much lower than in hot-arid ones. Nevertheless, it is opinion of the author, supported by the simulation results, that even in this case radiative cooling might not have a negligible effect.

Plus, radiative cooling in the V-shaped configuration might be effectively combined with evaporative cooling by wetting the roof at night with small quantities of water taken by gravity (placing a water barrel on a structure at a higher level than the wall) or with an irrigation machine.

One further advantage of the V-shaped solution is that the radiating surface (roof) may be widened at will without increasing the room surface or volume.

The thermal behaviour of the considered thermal models has been analysed with respect to some reference climates: Cairo (Egypt); Jimma (Ethiopia); Asyut (Egypt); Luxor (Egypt); Aswan (Egypt), to represent hot-arid climates; Lodwar (Kenya) and Dhaka (Bangladesh) to take into account some particular cases of composite climates; Kuala-Lumpur (Malaysia); Hanoi (Viet-Nam); Bangkok (Thailand); Manila (Philippines); Managua (Nicaragua), Accra (Ghana) to represent hot-humid climates.

The simulation results show that all the considered building configurations perform reasonably well in all but the most extreme climates (worst of all, the very hot-arid climate of Aswan).

In all the considered non-extreme hot-arid climates, the models have shown to perform (slightly) better when uninsulated underneath.

The considered configurations have shown to perform less satisfactorily in hot-humid climates, due to the smaller effect of radiative cooling. Nonetheless, as explained, even in those climates night flushing has seemed to be a viable temperature control strategy for the considered kind of programmatically non-airtight warehouses.

To obtain better performance in hot-humid climates, both thermal mass and envelope insulation thickness have shown to have to be increased.

As expected, the results have also shown a (slightly) better performance of the masonry models over the light-frame ones. And they also have suggested that the V-shaped roof configuration performs slightly better than the ordinary gabled one - in spite of its larger envelope - even in hot-humid climates. But this might be due to the simulation models conception, and specifically to the fact that in them the downflow of air (deriving from night radiative cooling) though the roof void might have been less hindered by the wind than in real situations.

Last but not least, in all the models, as expected, the presence of thermal stratification of air in the room has appeared to be crucial for the obtainment of reasonably cool temperatures at medicines' level, in the lower zone of the room.

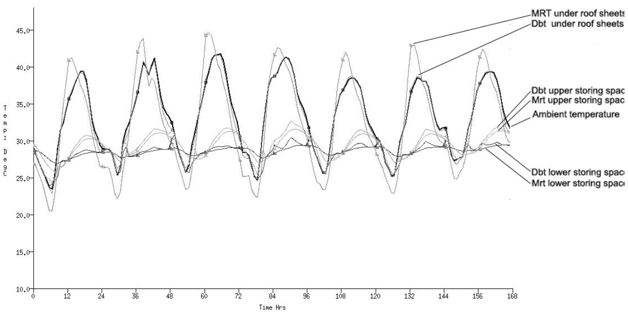

Figure 10: Air dry-bulb and mean radiant temperatures regarding the V-shaped configuration for the reference hot-arid climate of Luxor (Egypt), 1-7 July. The temperatures shown are those obtained in the lower part of the room, in the upper part of it and in the ventilated space under the roof sheets.

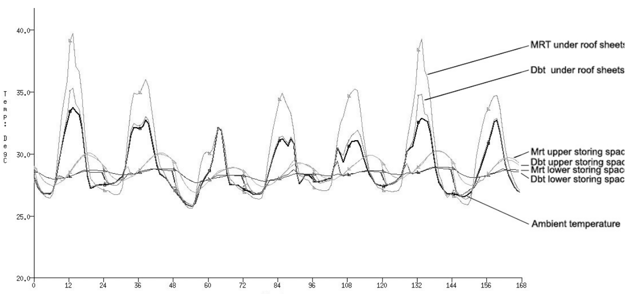

Figure 11: Air d.b. and mean radiant temperatures regarding the V-shaped configuration for the reference hot-humid climate of Hanoi (Viet-Nam), 1-7 July. The temperatures shown are those obtained in the lower part of the room, in the upper part of it and in the ventilated space under the roof sheets.

Typical results are shown in figures 9 and 10.

Figure 9 shows the temperatures obtained in the simulations regarding the V-shaped configuration for the reference climate of Luxor (Egypt) as an example of hot-arid climate. It can be noted that air temperatures in the roof ventilated space are well under ambient air temperatures. This suggests that the air under the roof sheets might be effectively used for night cooling.

Figure 10 shows the temperatures obtained in the simulations regarding the V-shaped configuration for the reference climate of Hanoi (Viet-Nam) as an example of hot-humid climate. It can be noted that air temperatures in the roof ventilated space are just slightly under ambient air temperatures. The air under the roof sheets might not therefore be very effectively used for night cooling.

CONCLUSION

The thermal simulations have shown that the proposed building configurations should be adequate to keep room temperatures low enough to ensure medicine conservation in all the considered climates but the extreme ones and that a rather broad spectrum of building solutions is available for the given purpose, at least in the case that the main here described requirements for the considered kind of building are respected.

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