EINDHOVEN UNIVERSITY OF TECHNOLOGY

Applied design of an energy-efficient multi-layered membrane sheltering system

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XXVI IAHS - Applied design of an energy-efficient multi-layered membrane sheltering system for climate-control of semi-permanent shelters for disaster relief.

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Abstract
Within the research group of Product Development a low cost semi-permanent building system is developed with passive climate control for dairy cattle. The system proved to be successful and two new applications were found for the system; 1) an emergency community shelter and 2) a pig breading stable.
Both new applications require a stable and comfortable indoor climate. To achieve such a indoor climate, a thermally active roofing system is developed to active acclimatize the inside conditions.

1. Introduction

Within the Department of Architecture of the Eindhoven University of Technology, a low cost arched construction has been developed in order to function as a stable for dairy cattle. This so called *arched stable* was created by ir. Roel Gijsbers within the SlimBouwen® approach and enthusiastically introduced as a pilot in October of 2006 in Dieteren in The Netherlands [1,2]. It proved that a rather slim and low cost construction, covered with a double layered membrane can be installed within a relative short period and offer the inhabitants a large amount of comfort.

Fig 1. Pilot project arched cattle stable in Dieteren
(The Netherlands)

The basis of the construction exists of steel truss elements with a triangular cross section that can span a width of 30 to 40 meters. The length can vary from 20 meters to any desired size by adding more arched segments to the construction. The arcs are fixated in concrete base elements which are subsequently moored within the ground. In between the arcs beams are shored for cross directional stability.

In between two successive arcs, a double layered membrane is placed in order to form a natural insulation and create a ventilation system that can be regulated.

Fig 2. Detail of the roof, the truss structure and the upper and lower foil

The arched stable produced new and valuable information on an large span arched construction, availability and usage of different membranes, ventilation within a double layered skin and a general impression of the atmosphere within a membrane covered space. For these results it was chosen to be translated for the use for other purposes.

Benefits of the arched stable roof compared to a ordinary stable roof:
- 30% cheaper
- 50% less weight
- less material
- shorter building period
- sectional
- better indoor climate because of:
    - more daylight
    - more stable indoor climate

Most functions, for humans as well as for animal housing like pigs, demand a higher thermal comfort then dairy cattle. To make the ached shelter suitable for these functions which are demanding high indoor comfort, the membrane roofing system has to be further developed into a system for active climate control. A newly introduced goal for this development, other than the passive climate control, is energy efficiency. Consequently, the building has to be conditioned with a minimum of building services.

2. Case study

A case study is introduced to set the boundary conditions for the development of the active climate control of a multilayered, energy efficient membrane roofing system.
The case study consists of a family shelter for emergency situations. This sector is in need of building solutions which are zero energy, thermally conditioned, durable, flexible, low cost, and most important, one hundred percent reliable. Single layered or non-insulated tents and other forms of easy-to-install lodging are often used in the case of direct aid and relief after

calamities and wars. In an emergency situation there is a limited amount of energy available for conditioning of the housing. Therefore, the building climate has to be controlled without or with a minimum input of energy.

In extreme climate conditions, the energy and indoor climate demands for human beings are high. A stable climate of approximately 15°C to 25°C has to be realized the whole year round, regardless of outside climate conditions. Furthermore, the application demands a high level of indoor lighting (min. 200 Lux) ,a high ventilation rate and a low infiltration rate.

The façade/roof fulfils two basis functions in this case. The first is weather resistance as building envelope and the second one is a system for energy efficient climate control. To make high thermal comfort by the system possible, the solution is sought in a thin and light weight highly insulating building envelope, by combining multiple layers of membranes filled with nanogel for thermal insulation. Nanogel is a product from the aerospace industry and is the best thermal insulating material known yet. A 30 mm layer will be used between the inner and outer membrane. In addition, tests are carried out to use the gap between the insulation layers for heat recovery by large laminar counter flows, which will provide an energy efficient pre-heating of incoming air. Calculations prove that the principle is efficient in consideration of the boundary conditions.

The next step in the development is to fine tune the transparent parts of the shelter shell and to fit the ventilation system for the selected purposes. The systems was tested on a small scale before scaling it up to real-time applications.

2.1 Emergency community shelter

The aim of the research was to develop a community shelter for emergency situations. Tents and other forms of easy-to-install lodging are often used in the case of direct aid and relief after calamities and wars. In an emergency situation there is a limited amount of energy available for conditioning of the building. Therefore, the building climate has to be controlled without the input of energy [3]. The community shelter is a newly introduced concept and is developed in association with a large humanitarian organization.
The reliability of the system is one of the most important properties by developing of a shelter. The system must be 100% proof and put up by refugees. The system must be transportable within a sea container and when needed transferred to smaller trucks or pickups. The shelter has to resist a wind load up to ca 120km/h. The shelter must be able to provide adequate indoor climate at extreme outside conditions (-10 °C).

2.2 Boundary conditions

The application demands a stable indoor temperature of ca 20°C and a high level of indoor lighting (min. 200 lux) for varying outside conditions. Furthermore an adequate ventilation rate is neccesary. The ventilation rate inside in an emergency shelter is high compared to normal dwellings (see Table 1).

Table 1: Comfort conditions for humans, pigs and cows

Condition	Humans Insulated	Cattle Not Insulated
Comf. temp.	20°C	5 till 15°C
Ventilation min.	$3{,}2 m^3/h/m^2$	natural

Ventilation max.	$35m^3/h/m^2$	natural
Air speed max.	0,2 m/s	0,25m/s
Humidity	40-60%	60-80%

3. Climate control

To understand the development of this active climate control system the effect of the existing roof will be explained, followed by:
- an insulated version and
- the heat recovery roof.

3.1 Existing roof (non-insulated)

The double layered roof consisted of an outer layer of 55% open windbreak mesh which breaks the wind, but more important it keeps a part of the sun radiation and heat out of the space underneath it. When the sun heats the air underneath this mesh, it can get out because of the buoyancy induced flow and the air movement because of wind by wind speed over 3m/s.

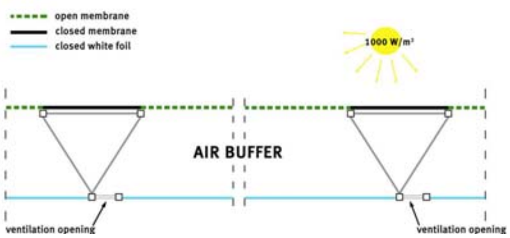

Fig 3. Detail of the roof, on top a windbreak mesh and below a semi transparent foil

An inner layer of a white foil keeps most of the rain outside. Underneath the truss elements there are small gaps for ventilation purpose. The white foil also reduces direct light into space.

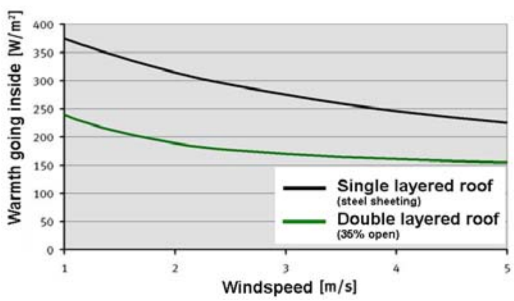

Fig 4. Radiation to the inside by 1000W/m2 sun load

In comparison with a normal steel plated roof (sheet of corrugated iron) with no insulation there's less radiation towards the inner space (see Fig. 4.). . The maximum temperature of the outer material is also less, 85°C by steel plating and 65°C by the windbreak mesh.

The walls of the construction are made out of the same material as the outer layer of the roof, the windbreak mesh. Therefore the inner space is ventilated and there's less wind inside.

3.2 Insulation roof

One of the advantages of the arched stable roof is the enormous amount of light that gets in and gives the inhabitants a day and night rhythm.

By adding normal insulation like glass wool to the lay up of the roof, the effect of light in the space is cancelled out. For some purposes that isn't a problem, in that situation a layer of aerogel can be added to the lay up. The insulation value of this aerogel is 3 times higher than normal insulation (λ=0,012W/mK), therefore the thickness of the construction can be reduced.

In situations where daylight is needed, for instance shelters, a layer or cushion of air can be added simply by tightening an extra layer of foil to the construction. Of course this extra foil needs to be air tide applied, so the air in between stands still. Secondly it's important that the two foils are not to far from each other and not to close (20~60mm).

3.3 Heat recovery roof

At places where there's lack of energy or the demands of the use of energy are set high like the cases introduced before, heating up and ventilating big indoor spaces is a problem. Accordingly, the roof can fulfil two functions in this case. The first is weather resistance as building envelope and the second one is integrated energy efficient climate control. Because a certain amount of ventilation is needed by emergency shelters and pig stables and this air must be fresh, the air has to come from outside. The outside temperature is most of the time below the inside temperature, so heating is necessary. Therefore this concept is thought out.

3.3.1 The concept

The concept of the roof consists of combining the existing roof and a heat recovery unit. To make active climate control by the roofing system possible, the solution is sought in combining multiple layers of semi-transparent membranes.

To preserve the indoor climate multiply layers can be formed to cushions filled with standing air for insulation. Underneath of the insulation layers (Fig.5. (1)) heat recovery by large turbulent counter flows will provide an energy efficient pre-heating of indoor air.

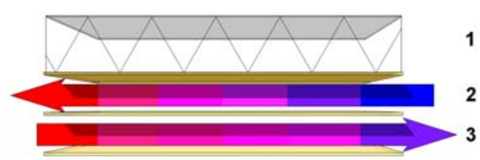

Fig 5. Concept lay up; insulation layer (1), outdoor air (2), indoor air (3) (windbreak mesh on top not displayed)

Extra layers, of for instance foil can be added to the roof so the flows can be created (Fig.5. (2,3)). By adding a small and energy efficient ventilator these flows can be put in motion.

3.3.2 Calculation

A physical modelling is set up from a wide angle perspective. The calculation model will be specified by using simplified cells (see Figure 6). In this calculation the influents of temperature, transition coefficient, air speed and specific measurements are used.

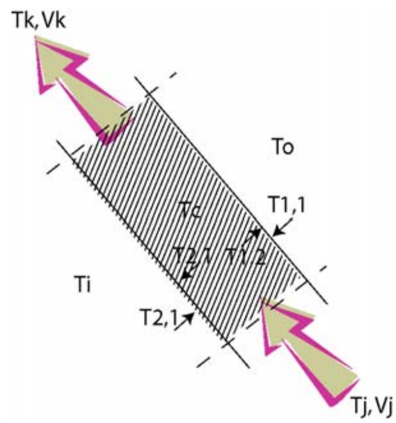

Fig 6. Calculation model with simplified cells

In this calculation, is in contrast with a heat recovery unit, just one layer of flow and counter flow calculated. That isn't a problem because the whole roof can be used.
Calculations prove that the principle is efficient in consideration of the boundary conditions.

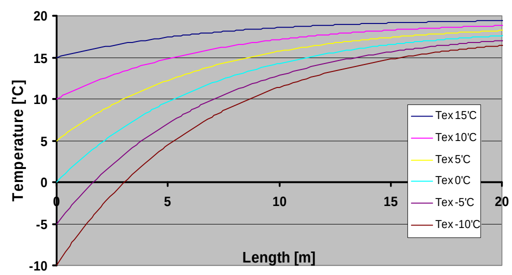

Fig 7. Calculation result by different outdoor temperatures

After finding the right basic measurements and needed values, the model gives information about usable materials and airspeeds that are useful.

3.3.3 Materialization

After calculation, the earlier suggested use of foils as the channel walls seems to be a problem. The distance between the foils must be around 30mm, when the air creates under pressure, the foils will collapse to each other. By adding a triple wall semi transparent polycarbonate sheet with channel from around 26mm high to the isolation layer, the problem is solved.

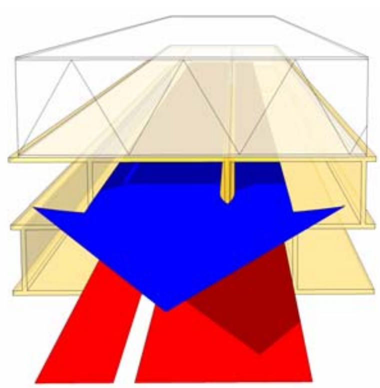

Fig 8. Final lay up of the heat recovery roof

(windbreak mesh on top not displayed)

The daylight advantages as mentioned before are kept with the use of a insulation layer filled with air and the heat recovery sheet realized with transparent polycarbonate sheets.

3.4 New developments: Low cost high volume heat recovery unit

When outside temperatures reach far below zero the heat recovery roof can not provided a comfortable indoor air temperature. Because of the high ventilation capacity (approx. 30.000m^3/h) needed in emergency shelters and big stables a special heat recovery unit is needed. Regular heat recovery units are made of aluminium and therefore very expensive. To solve this problem a low cost high volume heat recovery unit made out of foil is developed at present within the chair of Product Development.

4. Conclusion

Now that designing and calculation is finished, in November an insulated arched building based on the arched stable with an insulated roof is build. This stable will be monitored so that in the future designs can be refined and newer models can be adjusted.

At this moment a scale test of the emergency shelter is in preparation, after testing there are plans to start a pilot model for 1:1 model tests in association with an international aid organization.
Not only technical and financial aspects are reviewed also the logistic part will be looked over.

The end conclusion is that these types of energy efficient buildings good alternatives are for a specific market segment (farmers and emergency relief) with regards to energy use, building costs, environment pollution and international completion compared to traditional buildings. And therefore hopefully urge on to innovative thinking about buildings in relation to durability, weight and energy efficiency.

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