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Performance analyses of the D'aDif Pavilion

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Abstract

All over the world, during the past as well as today, different kinds of buildings in different climate zones use the envelope, and in particular way the cover, to operate on the inner thermal and visual comfort. Vernacular tradition shows that textile skins allow creating adaptive envelopes that integrate principles of active control. This paper presents the results of the optimization design process of an adaptive umbrella configured in a double covering system for a small temporal pavilion. The pavilion is characterized by a small inner space with changeable dimensions and an adaptive enclosure. Materials like coated fabrics as well as lightweight structures like aluminum frames are combined together and used in an innovative architectural solution. Due to the transient nature of the analyzed building, the great challenge is to guarantee an adequate level of inner thermal comfort all over the year and in different climate zones and conditions. The research starts from the assumption that membranes combined with lightweight structures provide some special properties to temporal small buildings, like easy transportability and installation. The umbrella, used in a double roof consisting of three different textile layers, define an active responsive covering directly controlled by users in order to obtain shading and air flow permeability depending on the seasons and the environmental conditions. The computerized analysis has been carried out by means of the software package Energy Plus which allowed the simulation of a wide range of alternatives for the external envelope (cover, materials, layers, air gaps etc.) and the comparison of the performance in several climatic conditions to respond to user's requirements.

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Keywords: Temporary architecture ; active envelope ; multi-layer system ; textile roof ; Energy Plus ; Thermal Performance

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1. Introduction

Temporary buildings have always been present in architecture, but today they are enriched by new characteristics and potential. Originally linked to nomadism and because of the few possibilities in the use of materials and technologies, temporary buildings were used to live in. Today they host exhibitions, conferences and events in general.

The flexibility of contemporary society and the speed with which people and knowledge have to deal with, must necessarily be supported by appropriate architectural solutions: adaptive, removable, lightweight and easily transportable. In designing phase it is necessary to choose materials and technologies in relation to the durability of the building and to keep in mind the possibility of changing the use of the construction. Temporary and contemporary pavilions become more and more architectural, functional and complex objects of renewed artistic value. In fact, the quality of temporary architecture is also determined by its aesthetic impact: pavilions summarize in themselves the above mentioned requirements and today the best architects of our time work in their design [1].

The temporary and mobile nature of these pavilions implies a choice of lightweight materials, economical and as environmentally friendly as possible. Coated fabrics meet these requirements [2] [3].

The greatest challenge is to be able to guarantee an adequate level of environmental comfort despite their low thermal mass and their high solar gains due to their transparency. Furthermore, to ensure a good level of comfort in the different conditions of use of the building, coated fabrics allow to design with a good degree of adaptability and flexibility [1].

Membranes are a viable solution that applied to the D'aDif Pavilion have been analyzed in this work.

2. D'Adif Pavillion

The pavilion has been designed for the city of Perugia on the occasion of a competition organized by the City Government (2015, October) with the aim of realizing a temporary structure to host market-exhibitions in the city center. The project uses contemporary languages not only from an aesthetic point of view, but in the technologically innovative usage of materials related to the pavilion's tradition (wood, membranes, steel and aluminum).

2.1. The project

The Pavilion plan base is an irregular pentagon with approximately 5m² surface and 3m height. The main characteristic of the pavilion is the adaptive envelope that ensures the inner environmental comfort in several climatic conditions and user's requirements.

The structure is a steel frame of scaffolding pipe on adjustable bases and it is easily mounted, dismantled and reassembled. The vertical closures of the four equal sides of the pentagon (1,8m) are modular wooden panels (fiberboard). These panels, linked to the scaffolding pipe structure through pins and magnets, can rotate around the lower or higher horizontal scaffolding pipe generating planes used as benches, counters or shade elements.

The wooden door (fiberboard) is on the only different side of the pentagon (1,61m).

Table 1. Wooden panels properties

Material	Thickness (mm)	Thermal-physical properties				
		U value (W/m^2K)	Specific heat capacity (J/KgK)	Density (Kg/m^3)	Long wave emissivity	Conductivity (W/mK)
Fiberboard	50	0,997	1000	300	0,9	0,06

The modular raised floor is sustained by the same adjustable bases that support both the steel frames and the umbrella. This solution can not be applied in case of the use of the land as floor.

2.2. The active textile roof

The roof is the main climate regulator component and consists of three membrane layers alternated with air gaps. The external two layers, Polyester fabrics coated with PVC, are supported by a free-standing umbrella system. In this way, the outer cover system can easily be kept open or closed by users in function of the

boundary conditions. The third inner layer consists of a roller blinds system of triangular shape. Fixed to the top horizontal scaffolding pipe and hooked on the umbrella's tube, the blinds are easily extendible to user discretion.

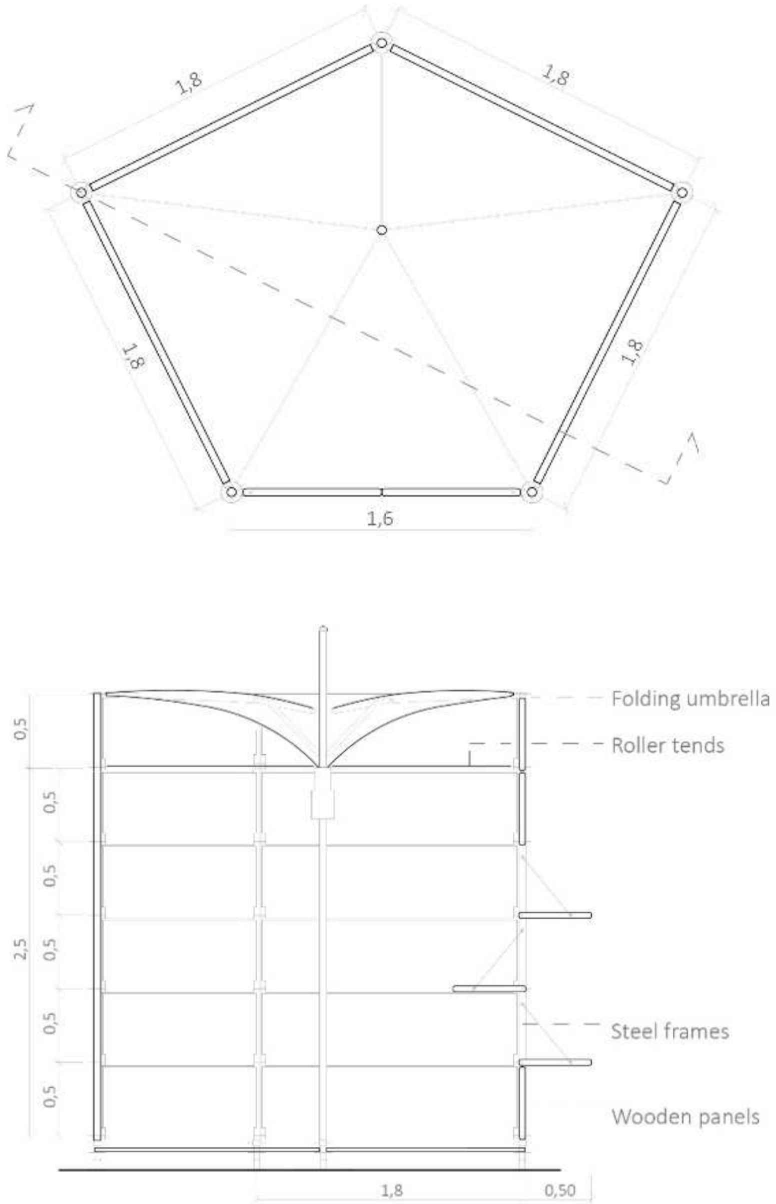

Fig. 1. D'aDif Pavilion: plan and section.

2.3. Polyester fabrics coated with PVC for temporary applications

The design of temporary pavilions is focused on lightweight materials and efficient structural solutions which minimise the waste of resources and reduce the cost of transportation. In addition, due to the expected short life span, it is preferable to use recyclable materials or materials characterised by a reduced amount of embodied energy. Coated fabrics and foils are an efficacious alternative to more traditional materials and they are characterised by several advantages in terms of technical and environmental aspects, level of comfort and safety.

Polyester is the most used fibre for architectural fabrics since the early 1960s due to the reduced price, good mechanical performance and the expected lifespan. The progressive degradation due to UV rays and the behaviour in case of fire can be easily improved with an adequate coating. The fibres are quite flexible and are very common for temporary and seasonal structures. Thanks to new technologies, coated fabrics based on polyester fibres, are now recyclable [2].

For this projects has been considered the polyvinylchloride (PVC) coating. PVC (polyvinylchloride) is generally used in combination with additional additives and top-coatings to improve the fire behaviour, the expected lifespan, the self-cleaning properties and the colour stability. It can be easily painted or printed and it can reach a life span of more than 20 years [1].

3. Analyses of the D'aDif Pavillion

This paper aims to analyse the inner thermal comfort of the pavilion in several configurations of the adaptive roof carried out through dynamic simulations in the climate context of Perugia, an Italian city located in the inner central part of the country.

In the simulations the indoor volume is a single thermal zone and some simplifications are adopted: the model simplifies the umbrella's curved surface to plane but maintains the same envelope area of the design. Then the paper is focused on the issues related to the summer period because of the translucent characteristics of the membranes and their high solar gains. Finally the membrane is built in the model starting from a generic single glass and changing its optical and thermal properties in order to allow the program to consider the relevant solar gains of the translucent material. The characteristics of the membrane included in the design have been extracted from the literature [4] [5].

The envelope thermal-physical properties are given as inputs to the software. The simulation is carried out by means of the software package Energy Plus using a dynamic model in Design Builder. There are numerous graphical interfaces for Energy Plus software, of which the most comprehensive is Design Builder. The typical use of Design Builder allows the possibility to model various options and rapidly analyze the thermo-physical state of the building.

Table 2. Textile properties used as inputs

Material	Thickness (mm)	Typical optical properties (%)				Core conductivity (W/mK)
		Light transmission	Solar transmittance	Solar reflectance	Long wave emissivity	
PVC/polyester	0,6 (single layer)	12	10	75	86	0,19
	1,2 (double layer)	8	4	77	86	0,19

3.1. Mathematical Models for Predicting Thermal Comfort

Many researchers have been exploring ways to predict the thermal sensation of people in their environment based on the personal, environmental and physiological variables that influence thermal comfort. From the research done, some mathematical models that simulate occupants' thermal response to their environment have been developed. Most thermal comfort prediction models use a seven or nine point thermal sensation scale.

Table 3. Nine point thermal sensation scale

Nine point scale	Thermal sensation
4	Very hot
3	Hot
2	Warm
1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold
-4	Very cold

The most notable models have been developed by P.O. Fanger (the Fanger Comfort Model), the J. B. Pierce Foundation (the Pierce Two-Node Model), and researchers at Kansas State University (the KSU Two-Node Model).

Fanger's Comfort model was the first one developed. The mathematical model developed by P.O. Fanger is probably the most well known of the three models and is the easiest to use because it has been put in both chart and graph form [6].

3.2. Simulations _ step 1

The first step of the optimization process aims to define the advantages of using a textile covering compared to more traditional roofing systems.

If the pavilion is covered by a traditional and fixed roof system (glass or wood), while the walling panels can rotate creating breaks in the walls and allowing the natural ventilation inside, this kind of building should still be considered a complex temporary construction because of its adaptable and flexible envelope. It means that a traditional, fixed roof can't by itself guarantee an adequate level of inner thermal comfort. At the same time the comparison between the thermal transmittance value of the wooden panels, the glass and the membrane did not have a relevant impact on the winter behaviour, while their optical characteristics are crucial to investigate the summer comfort. The first simulations allow the analysis of the different behaviour of the pavilion in the three typical configurations described above and shown in the diagram below. The following comfort-related output is shown above: Daylighting Factor; Internal operative temperature (the mean of the internal air and radiant temperatures); Fanger PMV (Fanger Predicted Mean Vote calculated according to ISO 7730); Discomfort hours_all clothing (the time when the combination of zone humidity ratio and operative temperature is not in the ASHRAE 55-2004 summer or winter clothes region).

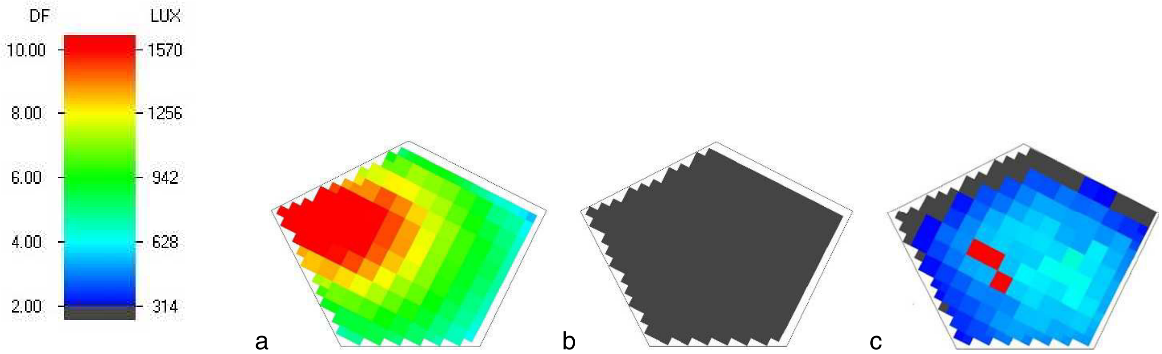

Fig. 2. Daylighting factor calculated at 21/09/2013 09:00 AM: (a) glass roof; (b) wooden roof; (c) coated fabric roof.

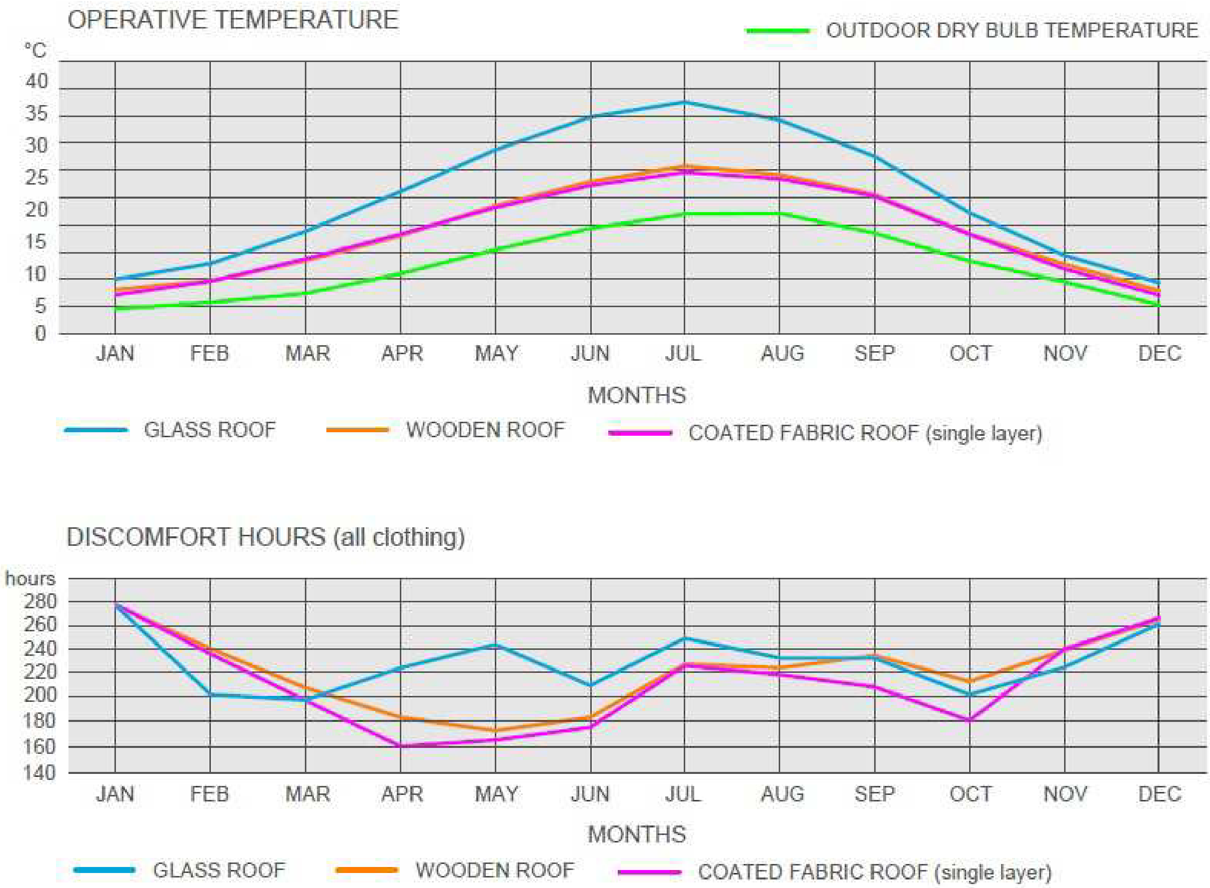

Fig. 3. Comfort analysis_step1

Fig. 4. Fanger index_step1

The firsts analysis show that in summer there is a huge numbers of discomfort hours due to the transparency of the glass that generates the great problem of overheating. The wooden roof and the coated fabric roof have quite the same thermal performance, but as expected the first one generates a daylighting discomfort while the membrane allows a good level of natural light in the pavilion.

3.3. Simulations_step 2

In this second step, the simulations concern the usage of an adaptive cover consisting in three layers of membranes in place of the single membrane roof tested in the previous simulation. Five different configurations have been simulated and compared in the diagram below.

Fig. 5. Discomfort hours_step2

3.4. Simulations_step 3

The optimization design process permits the best usage of the adaptive cover depending on the seasonal climate changing. The umbrella, designed in order to optimize the performance of the Pavilion, allows obtain the best thermal comfort in each period of the year in which the structure is used.

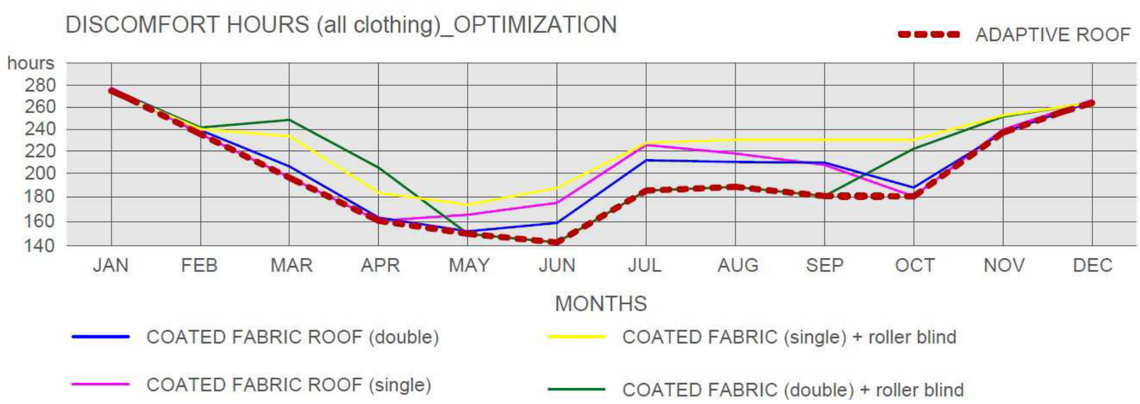

Fig. 6. Optimization design process

4. Conclusion

From the simulations which were made it is possible to verify how a flexible and adaptive covering is the ideal solution for the coverage of temporary spaces and how it can greatly affect the level of the inner thermal comfort. Furthermore, the use of coated fabrics allows the possibility to modify the envelope of the pavilion even during the usage of the structure to optimize the performance depending on the boundary conditions. In case of seasonal usage it is instead possible to utilize the best solution according to the period in which the structure is used.

Although this work concerns the great problem of overheating in summer periods, the results do not exclude the possibility to optimize the winter behavior through the conscious usage of the ventilation in the air gap between the membranes.

The suggested method permits the control of the functioning of the pavilion, bettering it already from the designing phase with visible saving in consumption (installation of air conditioning in summer) and a more responsible way of designing with regard to the environment.

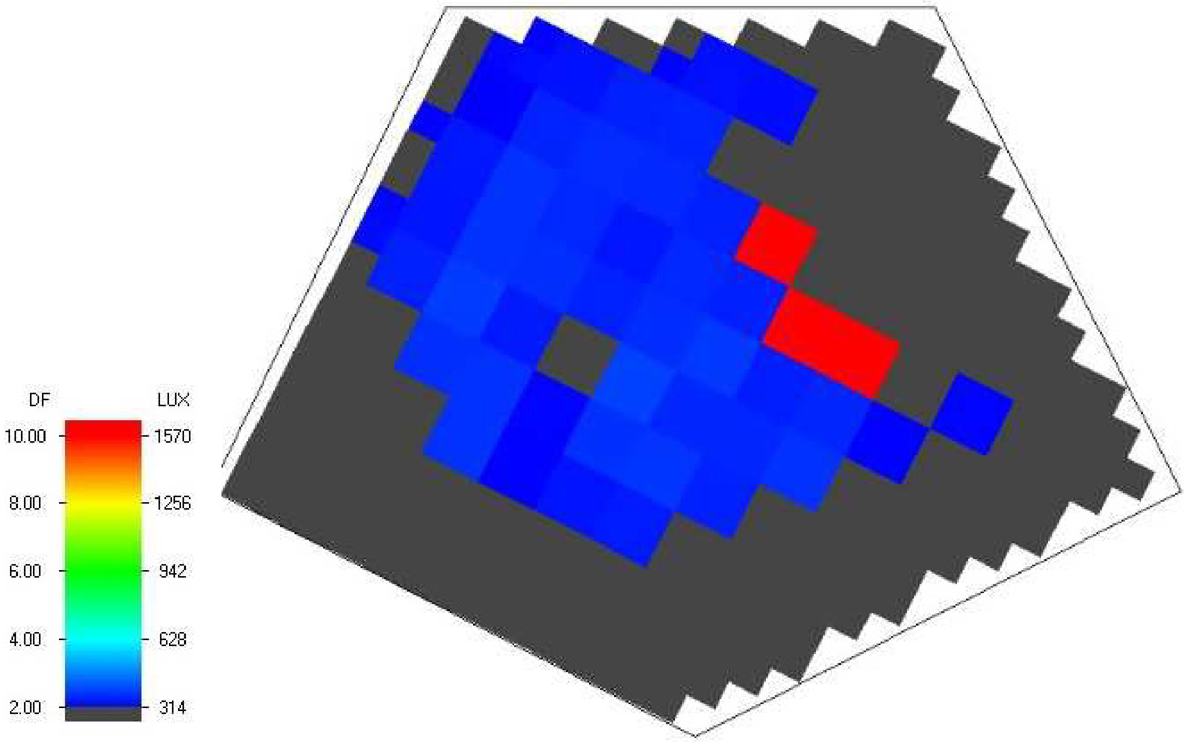

Fig. 7. Daylighting factor calculated at 21/09/2013 09:00 AM: coated fabric roof (double) and blinds.

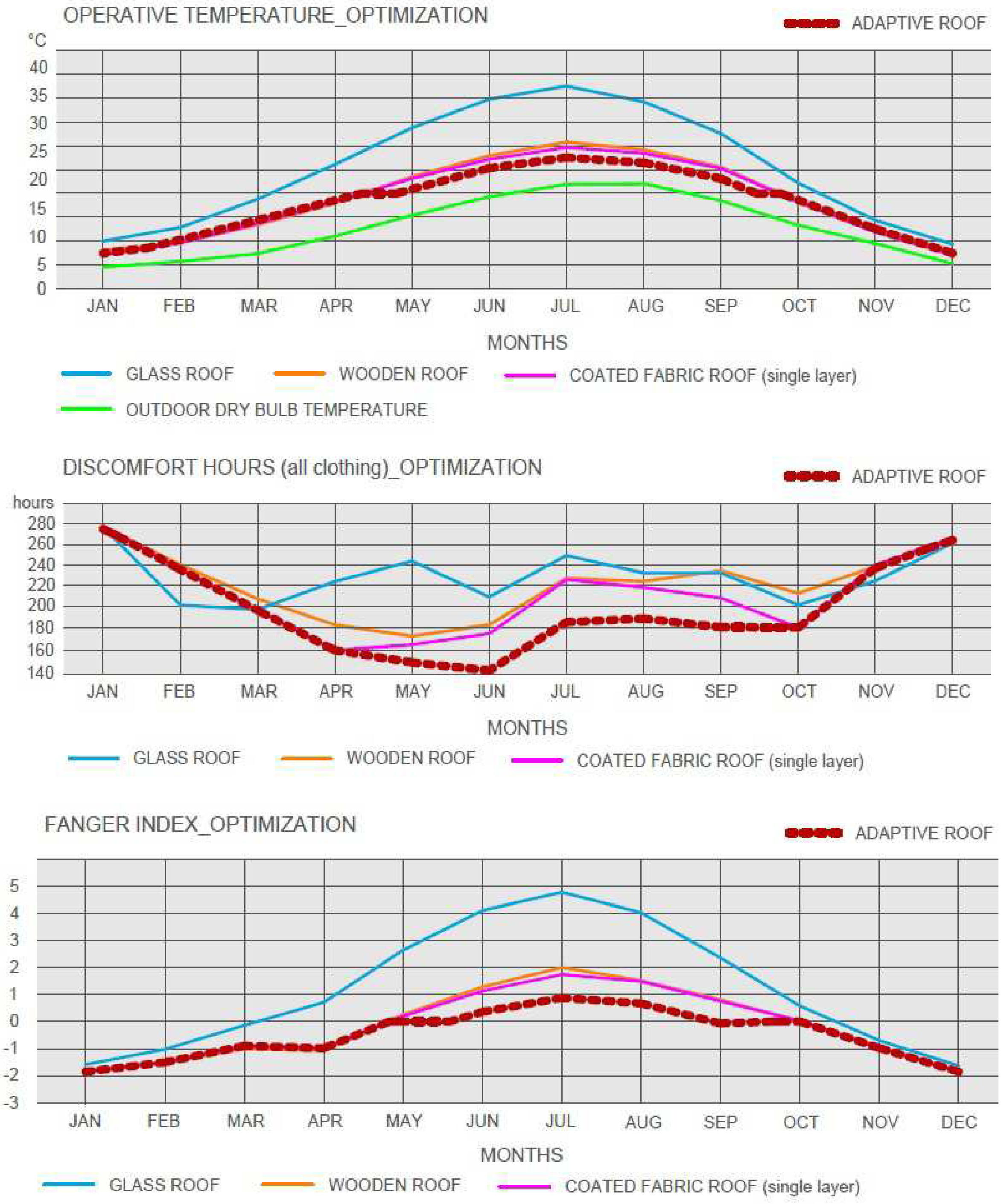

Fig. 8. Comfort analysis with the adaptive roof.

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