CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 2

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Structures that Include a Semi-Outdoor Space: Part 2: Thermal Environment

Papachristou C.*, Foteinaki K., Kazanci O.B., Olesen B.W.

International Centre for Indoor Environment and Energy Department of Civil Engineering, Technical University of Denmark, Nils Koppels Alle, Building 402, Kgs. Lyngby, Denmark

*christinapmp@hotmail.com

Abstract

The thermal environment of buildings with a second "skin" and semi-outdoor space is examined in the present study. A literature review was conducted on similar structures and only a few studies were found focusing on the thermal environment. Two different building case studies were chosen with different building and shield geometry, different levels of insulation but same shield material; Dome of Visions (DoV) and EMBRACE. Both buildings were modelled in IDA ICE 4.6.2 simulation software in order to assess the thermal environment of the building and assess how long the semi outdoor space of each building can be used by the occupants. The study was based on weather data for Copenhagen. In addition to the simulations, physical measurements were performed in DoV to assess the thermal environment in the semi-outdoor space. Since existing standards are not applicable for semi-outdoor spaces, an alternative method was followed with adjustable clothing level and three different tolerance levels. The semi-outdoor area of both buildings was found to provide more than double the comfortable occupancy hours compared to outdoors and the semi outdoor spaces can be roughly used for 45% of the year. Finally, the semi-outdoor space's temperature in DoV was higher than the ambient throughout winter by at least 3ºC.

Keywords - semi-outdoor space, second skin, thermal environment, shield

1. Introduction

It is a worldwide goal to minimize the use of fossil fuels, and supply affordable energy to the future societies. Denmark, amongst other European countries, leads the effort and aims to become fossil free and use exclusively renewable energy by 2050 [1]. In order to accomplish this goal, it is crucial to look into the building sector, as the consumption of buildings, constitutes 40% of the total energy consumption [2]. Future Danish building regulations aim towards residential buildings consuming 20 kWh/m^2 annually while an existing building could have a consumption of 150 kWh/m^2 or more [3].

It is important to point out that energy savings in buildings should not be achieved at the expense of occupant thermal comfort. It is established that people in northern climates spent 90% of their time indoors [4], and the heating, ventilation and air-conditioning systems should create a satisfactory indoor environment. The goal for the

engineers of the present and the future is to design and construct buildings aesthetically pleasing, energy efficient with a healthy and comfortable indoor environment.

There have been several studies and extensive research on this subject. The present study studies an innovative design idea. Buildings covered with a second skin, so that a semi-outdoor space is created between the building itself and the skin. There are a few studies on buildings with a second skin like a dome. Lin and Zmeureanu [5], [6], [7] proved that a building in Montreal, Canada of 100 m^2 floor area and 4 m height in a transparent dome can experience a reduction in the heating load of 62%, while the cooling load increases significantly if no actions of natural ventilation or shading method are implemented. Moreover, Lyn and Zmeureanu showed that by improving the transmittance of the glazing of the dome or reducing the infiltration of the dome of the building, the heating load decreases further. Lyn and Zmeureanu created 3-D thermal and air flow (3D-TAF) models that were verified with Computational fluid dynamics (CFD) simulations, experimental measurements and simulation results. In the present study, two buildings built with a second skin were studied. The energy impact of this space was investigated and presented in another publication [8]. In the present paper, the indoor environment of the semi-outdoor space is analyzed and it is evaluated how long time this space can be comfortably occupied.

2. Methodology

The two buildings investigated are described in Foteinaki et al. [8] in detail. Fig. 1 shows the studied buildings.

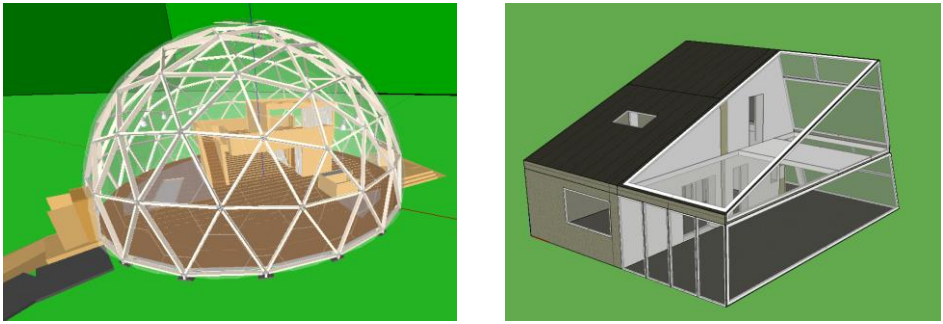

Figure 1: Sketches of buildings investigated. Dome of Visions (left) and EMBRACE (right)

In order to perform an indoor environment assessment, long term measurements were carried out in the Dome of Visions (DoV). The measurement period was from the 13th January until the 17th August 2015. The physical parameters measured were air temperature, operative/globe temperature and relative humidity in time intervals of 10 minutes for all the measured period.

The air and operative/globe temperature sensors used were developed by Simone et al. 2013 [9] and complied with ISO 7726 [10]. The air temperature sensor (Figure 2 A) consists of a radiation shield, thus avoiding the effect of thermal radiation, but it is open in both ends, allowing air flow around the sensor. The globe temperature was measured by a 4 cm diameter sensor (Figure 2 B), which at the heights 0.6 m and 1.1 m from the floor level is considered as operative temperature for sedentary and standing persons, respectively. Both types of sensors were calibrated for a temperature range of 18-28ºC. HOBO data loggers monitor relative humidity and air temperature (Figure 2 C) with built in sensors ranging between 10-90% with accuracy ±2.5% for relative humidity.

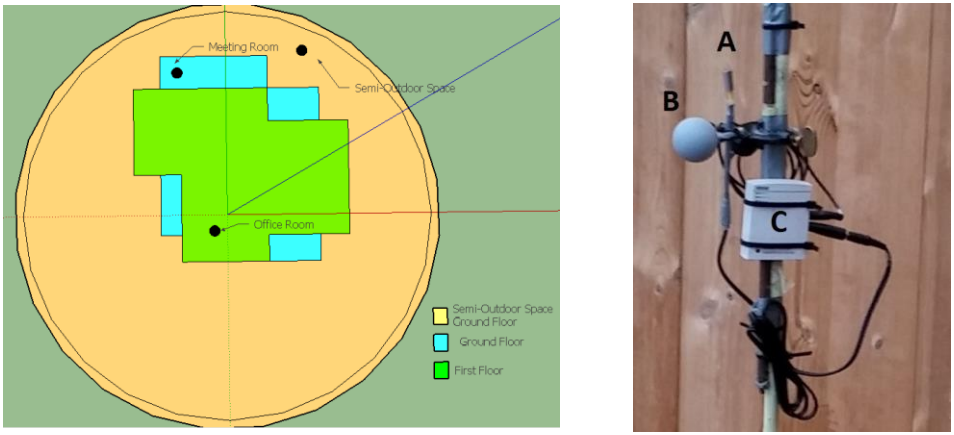

Figure 2: Measurement locations (left) and air temperature sensor (A), operative temperature sensor (B) and HOBO data logger (C) used in DoV (right)

Measurements were taken at three locations; the office room on the first floor, the meeting room on the ground floor and the semi-outdoor area. In every location a stand with four sets of sensors was placed, at heights of 0.1 m, 0.6 m, 1.1 m and 1.7 m from the floor level. These heights correspond to the feet, abdomen and head of a sedentary person and standing person according to DS/EN ISO 7726 [10].

The location of each stand was decided considering the description of the occupied zone according to EN/DS 13779 [11]. Since the requirements for the indoor environment should be guaranteed only within the occupied zone, the stands were placed within the dimensioning criteria of standard EN/DS 13779 [11] and as close as possible to a sitting position of an occupant. However, compensations had to be made considering the placement possibilities due to safety reasons (both for the occupants and for the sensors). Both buildings were built as residential buildings but Dome of Visions is being used as an office space in the first floor and as an exhibition space in the ground floor; thus there was no documentation of the occupancy throughout the measurement period.

One of the main advantages that a semi-outdoor space creates is that it could be used more often and for longer periods than an outside space, i.e. garden. It is an area that residents could enjoy being outdoors, but with more favorable conditions than the ambient and protected from rain, wind or snow. It could increase the living space of a house for a certain amount of time. In order to prove this and evaluate how valuable such a space could be for the occupants of the building, the thermal comfort in the semi-outdoor area of both EMBRACE and DoV was examined. The indicator used was the Predicted Mean Vote (PMV), which is a value that combines air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation [12] and can indicate the overall thermal comfort of an average occupant. When evaluating an indoor space there are standards established that define the acceptable values for the PMV. However, Bouyer proved that people's thermal sensation is more tolerant when being in a semi-outdoor area than when being indoors [13]. For example, it would be considered acceptable to wear an outdoor jacket during winter months in semi-outdoor space in order to feel comfortable.

Based on simulation models in IDA ICE 4.6.2 for both buildings, the implementation of flexible clothing insulation was decided in order to resemble this in the simulation model. For indoor spaces, based on the design criteria for different types of spaces, the basic assumption for clothing insulation is 0.5 clo during summer and 1.0 clo during winter. Since in the present study, a semi-outdoor space is evaluated, the clo value was set to be more flexible. According to ISO 7730 [14] and based on the clothing category of "daily wear clothing" the clothing levels of 0.3 clo and 1.5 clo were chosen, which correspond to:

- 0.3 clo: Panties, T-shirt, shorts, light socks, sandals
- 1.5 clo: Underwear with short sleeves and legs, shirt, trousers, vest, jacket, coat, socks, shoes.

The acceptable range for PMV values in a semi-outdoor area has not been documented yet. Initially, PMV values between $-0.7<PMV<0.7$ were used, which is the range defined as acceptable Category III in EN/DS 15251 [3] for indoor spaces. Since this range could be identified as conservative, two more cases were considered; $-1<PMV<1$ and $-1.5<PMV<1.5$.

In every simulation performed, the software automatically adjusts the clo value within the specified range according to the instant temperatures. So, the results from the simulation give instantaneous PMV values throughout the year having considered this clothing flexibility.

Based on the PMV values obtained for each month, the amount of hours that an occupant can comfortably use the semi-outdoor space was determined. For each month several possible schedules (time intervals) were investigated. The investigation started by assuming that it could be more possible to use the semi-outdoor space during warmer hours of each day, and based on trials and adjustments, the time interval that the semi-outdoor area could be used for each month was decided. In order to fulfil the requirements, each time interval should have at least 90% of these hours within the acceptable PMV range. Occupancy hours were considered 16 hours a day. Hours from midnight to 8:00 in the morning were not considered possible occupancy hours. The

scope of the investigation was to compare the use of the semi-outdoor space to that of an outdoor space (i.e. garden). Since PMV values are only applicable to indoor spaces, two temperature ranges were considered in order to resemble the different tolerance and clothing level of the occupants [15].
All simulations were conducted using the natural ventilation strategies that are actually implemented in both buildings. Dome of Visions is placed on a deck and the deck is not attached to the shield, so gaps are created. Moreover, there is a retractable piece of the roof. The gaps are open from May to September and the roof is operated by the occupants and it was simulated to be fully open during the cooling season and half opened during the transition months of March, April and October.
In EMBRACE, the natural ventilation strategy was implemented by opening two south ground floor windows and two north first floor windows during the cooling season (May-September) every day from 8-17 hours.

3. Results

In order to assess the thermal environment in the building of DoV and the semi-outdoor space, the measurements explained in methodology were conducted.
The operative temperature at 0.6 m height in the office space located on the first floor of the building is presented in Figure 3 and the operative temperature at 0.6m height of the semi outdoor area is presented in Figure 4 compared to the ambient.

In the office room, the operative temperature ranged from 8 to 44ºC with an average of 21ºC. It can be noted that there was overheating throughout the summer months, fluctuations throughout the measurement period and cold temperatures under 15ºC.

Regarding the office space in DoV and the time the measurements were conducted, 23% of the time it qualified as Category I of EN/DS 15251, 8% in Category II, 15% in Category III and 54% in the unacceptable Category IV.

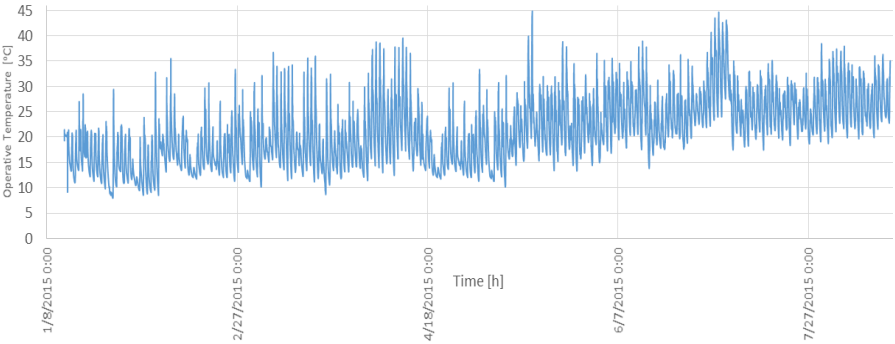

Figure 3: Operative Temperature of Office of Dome of Visions

Regarding the operative temperature of the semi-outdoor space, it was expected to not fall into the accepted categories since a semi outdoor area is not considered as an indoor space. The measurements showed that 65% of the time the thermal environment is in Category 4. However, when compared with the ambient temperature throughout the measurement period, the operative temperature of the semi-outdoor space was found higher by an average of 3°C as shown in Table 1. The temperature followed the trend of the outdoors rising from winter to summer months. Operative temperature ranged from 1 – during a very cold night when the ambient was -5°C -to 35°C. Overheating over 27°C is observed in the summer months (June-July-August).

Table 1: Average Temperatures during measurement period

Months	Average air temperature [°C]	
	Semi-outdoor space	Ambient
January	8.0	2.4
February	8.4	2.2
March	11.3	5.2
April	14.7	7.6
May	17.1	11.0
June	19.8	14.5
July	21.4	17.4
August	21.9	18.9

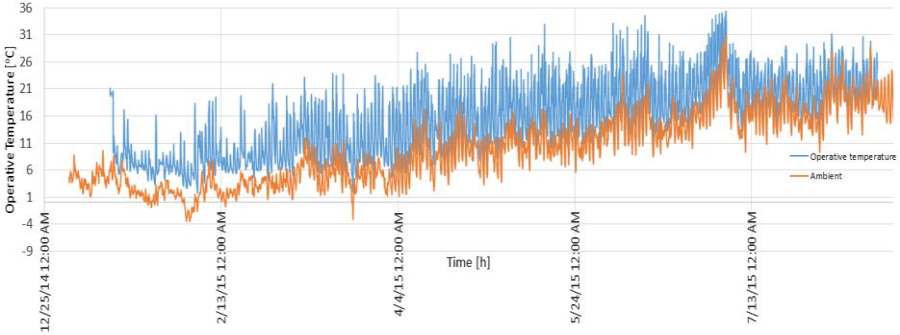

Figure 4: Operative Temperature of Semi-Outdoor Area of DoV and ambient

Since the semi outdoor space cannot be assessed based on existing standards, an alternative method was followed to investigate how long can the semi outdoor space be used without the occupants feeling uncomfortable. In Figures 5 and 6, the number of daily comfortable occupancy hours are presented ,throughout the year for Dome of Visions and EMBRACE's semi-outdoor space.

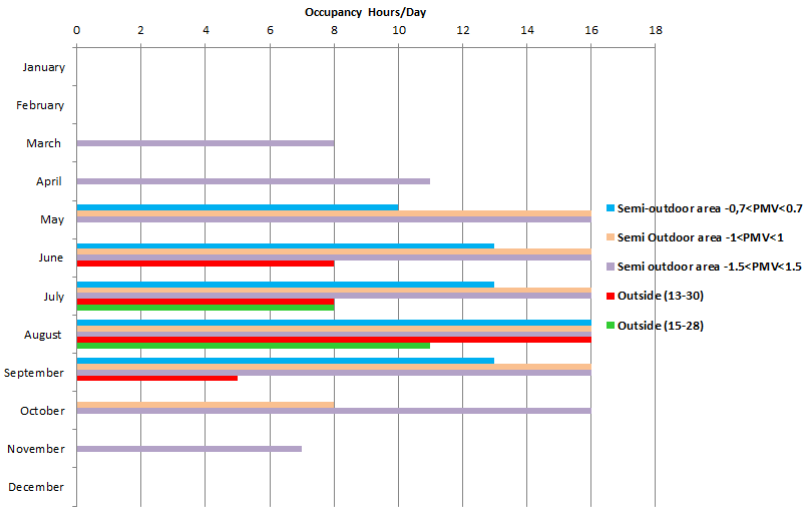

Figure 5: Occupancy Hours, Dome of Visions

As expected, by considering a wider PMV range -1.5<PMV<1.5, the comfortable hours of the semi-outdoor spaces in both buildings are increased. Considering a realistic PMV range of -1<PMV<1 and DoV's semi-outdoor space, it can be used for 6 months a year at least 8 hours a day. Throughout the cooling period (May-September) the area can be used for 16 hours a day which is considered as the maximum.

Considering an outdoor space and the wider range of temperature of 13-30°C, it can be noted that June-September can be considered occupancy months. However, the daily hours of comfort in these months for an outdoor space are less than those of the semi-outdoor space of DoV.

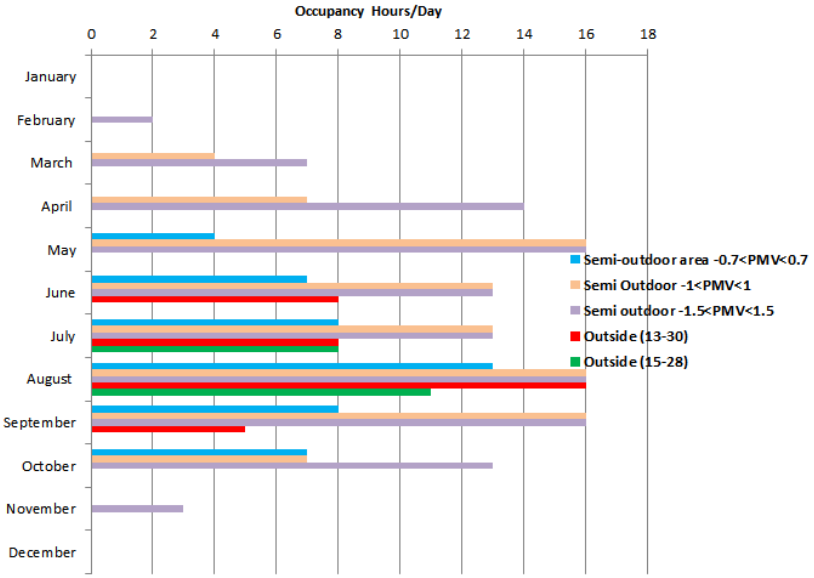

Figure 6: Occupancy Hours, EMBRACE

In EMRACE, the distribution of the comfortable occupancy hours is different. Its semi-outdoor area can be used for more months a year but fewer hours a day. This is mostly due to overheating. Considering the generally accepted PMV range of -1<PMV<1 in EMBRACE's semi-outdoor space, one can spend at least 7 hours a day from April until October, and considering the flexible PMV range of -1.5<PMV<1.5 only January and December are excluded as months with no comfortable occupancy.

4. Discussion

The present study was conducted in order to investigate the thermal environment in buildings with a second skin and semi-outdoor space. Regarding the measurements, it can be observed that for more than half the time of the measurements, the thermal environment is considered unacceptable in the office room. This is attributed to overheating during the summer months, insufficient ventilation and unoccupied hours during the transition months and unoccupied hours during winter. The HVAC system of Dome of Visions consists only of a heating system. There is no mechanical ventilation or air-conditioning system. All heating systems of Dome of Visions are operated by the occupants. There are no set-points or schedule, so only the occupants are in charge of opening operating and closing the radiators and floor heating system. So when a room is not occupied, no heating device is on and thus, several hours with lower temperatures than acceptable are observed both in the office room and the semi-

outdoor area. Regarding the semi-outdoor area, the temperature was found to be 3ºC higher throughout the measurement period, which was beneficial in the winter but caused overheating problems during the warmest summer months.
The natural ventilation strategies implemented in the models were the ones used in reality and the ventilation strategy in both buildings proved to be insufficient to avoid overheating. The semi-outdoor area of EMBRACE experienced overheating throughout the year including summer, while the semi-outdoor area of DoV experienced overheating problems in the transition periods of March and April while the gaps between the deck and the shield were closed and there was no natural ventilation but the solar radiation was high enough to raise the temperature above the comfortable limits. A different natural ventilation strategy in both buildings would have changed the results in a remarkable way. Shading should be considered or an advanced natural ventilation strategy should be implemented. The effects of short-wave solar radiation were not considered and it would be worthwhile to consider these effects in future studies. Even though the two buildings investigated have several differences both in construction and materials but also concerning the shield shape and attachment to the primary building, the total amount of hours considered comfortable for using the semi-outdoor spaces were found to be similar.
Considering the generally acceptable PMV range (-1<PMV<1), the results of the investigation were 2640 annual hours for the semi-outdoor space of DoV and occupancy hours from May to October and 2760 annual occupancy hours from March to October for EMBRACE. When considering possible occupancy hours the hours between 8:00-24:00, this corresponds to 45% of the whole year which compared to the 1100 hours annually that an outdoor space can be used, is more than doubled.

5. Conclusion

Through physical measurements in Dome of Visions and simulations of Dome of Visions and EMBRACE, the indoor space of the Dome of Visions was found to be for half the time of the measurement duration in the unacceptable category of EN/DS 15251, while the semi outdoor space was found to be 3°C warmer than the ambient in average throughout the measurement period.
Both of the semi outdoor spaces in the two buildings were found to offer more than double the amount of comfortable occupancy hours than an outdoor space throughout the year. Dome of Vision's semi-outdoor space can be used for at least 8 hours a day from May to October while EMBRACE's semi-outdoor space can be occupied from March until October for at least 4 hours every day.

References

[1] International Energy Agency. Energy Policies of IEA Countries-Denmark-A review, 2011. Paris, France.

[2] Website:. International energy agency, http://www.iea.org/aboutus/faqs/energyefficiency. 27/11/2014.

[3] Danish Standards. DS/EN 15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, 2007.

[4] B. W. Olesen and J. Seelen. Criteria for a comfortable indoor environment in buildings. Journal of Thermal Biology, 18(5):545–549, 1993.

[5] Y. Lin and R. Zmeureanu. Three-dimensional thermal and airflow (3d-taf) model of a dome-covered house in canada. Renewable Energy, 33(1):22–34, 2008.

[6] Y. L. Lin, W. Yang, and R. Zmeureanu. Solar performance of a dome-covered house. In Applied Mechanics and Materials, volume 704, pages 431–434. Trans Tech Publ, 2015

[7] Y. L. Lin, R. Zmeureanu. Mathematical model of the thermal performance of a domecovered house. The third international building physics conference, Concordia University, Montreal, Canada, 2006.

[8] K.Foteinaki, C.Papachristou, O.Kazanci and B. Olesen Structures with a Semi-Outdoor Space: Energy Performance. Submitted to 12th REHVA World Congress CLIMA 2016.

[9] A. Simone, B. W. Olesen, J. L. Stoops, and W. Watkins. Thermal comfort in commercial kitchens (rp-1469):procedure and physical measurements (part 1). 2013.

[10] Danish Standards. DS/EN ISO 7726, Ergonomics of the thermal environment - Instruments for measuring physical quantities, 2001.

[11] Danish Standards. DS/EN 13779, Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems, 2007.

[12] P. O. Fanger. Thermal comfort, 1972. McGraw-Hill Book Company.

[13] J. Bouyer, J. Vinet, P. Delpech, and S. Carre. Thermal comfort assessment in semioutdoor environments: Application to comfort study in stadia. Journal of Wind Engineering and Industrial Aerodynamics, 95(9):963–976, 2007.

[14] Danish Standards. DS/EN ISO 7730, Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, 2006.

[15] K.Foteinaki and C.Papachristou. Experimental and Theoretical Study of Indoor Environment and Energy Use in Houses with a Second "Skin" and Semi-outdoor Space, 2015