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Optimizing indoor climate conditions in a sports building located in Continental Europe

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Abstract

The present paper investigates the indoor climate conditions of a sports building in Michel Walter Stadium in Strasbourg during typical and extreme summer conditions. The thermal modeling of the building is conducted using the simulation tool Pleiades Comfie. Different design strategies were analyzed such as solar shadings, usage of vegetation, differentiated occupancy schedules and night ventilation, so as to deliver the highest possible energy efficiency results.

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Keywords: sports building; dynamic simulation;; indoor climate conditions;overheating

1. Introduction

In recent years, architects and engineers have become increasingly interested in building's thermal performance during summer conditions. This interest is orientated towards two aspects: reduction of energy consumption for air-conditioning purposes and minimization of indoor thermal discomfort. Within this context, the dynamic energy simulation and thermal modeling has become a compulsory process when designing new buildings in most European countries. The optimization of energy performance and indoor thermal conditions in buildings has been the objective of numerous studies worldwide; however, most of them focus on residential and office buildings and only a few deal with sports buildings, which accommodate distinctive activities, with special operational profiles and requirements.

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In this paper the indoor climate conditions of a sports building in Michel Walter stadium in Strasbourg is examined. The acquired information enables architects and engineers to take the right design decisions so as to achieve a high quality sustainable building.

2. Initial requirements

2.1. Building description

The building has a total surface of 896.7 m^2 and is divided into two parts with distinctive activities. In the first floor, there are three changing room, showers, first aid and storage spaces, while the second floor hosts two meeting halls for local sports clubs and two private offices for staff. The interior walls of the first floor are brick walls, whereas on the second floor, the interior concrete walls provide additional thermal mass. As the design of the building's envelope is crucial in terms of the interior thermal conditions' regulation and the minimization of space heating and cooling demand [1], special attention was paid to the envelope components in order to minimize the heat losses through the building's envelope. The heat transfer coefficients of the building's components vary from 0.13 to 0.18W/m^2/K; the windows are doubled glazed with aluminum thermal brake frame and a U-value of 1.40W/m^2/K.

2.2. Occupancy schedules and simulation parameters

The definition of detailed occupancy schedules for each thermal zone is of vital importance for the building's dynamic thermal modeling. Hence, high energy performance, significant reduction of energy consumption regarding mechanical ventilation, lighting and air-conditioning, can be achieved by occupancy based control systems [2]. In this study, the occupants' number of each zone and the operational profiles during three design periods were defined by Strasbourg's city authorities. (Table 1)

Table 1. Detailed occupancy schedules for the various building zones and maximum occupancy

Building zone	School year period	Winter period (15/12-15/03)	Holiday's period	Maximum number of occupants
first floor zones – changing rooms	Weekdays: 9:00 am to 12:00 and 17:00 pm to 21:30 pm Weekends :9:00 to 20:00 pm with a break interval from 12:00 to 14:00 pm.	Weekdays: 9:00 am to 12:00 and 17:00 pm to 20:00 pm Weekends: only on Saturday. 9:00am to 10.30am	Weekdays: 17:00 pm to 21:30 pm Weekends: only on Saturday, 9:00 am to 10:30 am	19
meeting halls	Weekdays: 14:00 pm to 21:30 pm Saturday: 14:00 pm to 21:30 pm Sunday: 9:00 am to 21:30 pm.	Weekdays: 14:00 pm to 21:30 pm Weekends: Unoccupied	Weekdays: 14:00 pm to 21:30 pm Weekends: Unoccupied	100
Offices	from Monday to Friday: 14:00 pm to 17:00 pm except holidays			2

In the meeting halls, a constant number of 45 and 90 people is assumed, during weekdays and weekends schedules respectively. Regarding other simulation parameters, thermostatic control during occupancy is set to maintain 21^{o}C and 19^{o}C in the changing rooms and second floor zones respectively while, in unoccupied periods, thermostat is set to 16^{o}C in all studied zones. Thermal bridges and ventilation rates for each zone are calculated according to the French Thermal regulation [3].The building is mechanically ventilated with a heat recovery efficiency of 85% while the system operates during occupancy time as well as 2 hours before the arrival and after the departure of the users. Infiltration rate is estimated to n50=0.76 vol/h while solar gains, internal heat gains regarding metabolic activity and appliances are also taken into consideration. Finally, lighting gains and other internal heat gains from appliances in the offices and meeting halls are estimated to 3W/m^2 and 7W/m^2 respectively.

3. Dynamic thermal modeling

The dynamic thermal simulation is carried out in order to propose design strategies that ensure suitable indoor thermal conditions during summertime. The simulation tool used for this study is the Pleiades-Comfie software developed by the Center of Energy and Processes of Mines-ParisTech, in collaboration with Izuba Energies [4]. The full 3D building model is constructed as shown in Figure 1(a). The simulation of the multi-zone building model (Figure 1(b)) is conducted for hourly time steps, including 8760 hours of analysis. The weather file is provided by Meteocalc, software that is integrated in Pleiades Comfie and allows generating hourly weather data from average monthly values. Two different series of simulations were run; for typical and extreme summer conditions with the weather file of the latter, being based on recorded data of the summer of 2003 which is considered as the most severe heat wave of the last decencies in Europe. During August 2003, temperatures higher than 35°C were recorded at more than 60% of weather stations in France while temperatures over 40°C were found at 15% of the stations, resulting in a dramatic increase of thermal stress and mortality [5].

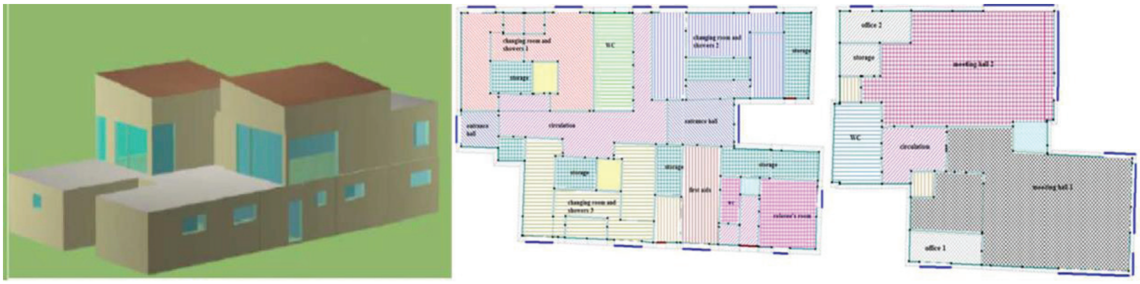

Fig. 1. (a) 3D building base case model; (b) first and second floor zoning

4. Results and discussion

The effect of four different design strategies on indoor air temperature is examined on an annual basis, in terms of the following parameters: The number of occupancy hours during which the zone indoor air temperature exceeds the maximum acceptable comfortable temperature of 27°C (NOC), which should not refer to more than 50h during a year [6] and the ratio of the occupancy time during which the internal zone temperature exceeds 27°C to the total occupancy period (POC), which needs to be lower than 10%. In case of heat wave summer conditions, the maximum acceptable comfortable temperature is set to 28°C. Both the above criteria need to be met so as to minimize the risk of thermal discomfort in the building. The NOC and POC values, for both typical and extreme summer conditions, are depicted in tables 2 and 3 respectively.

4.1. Indoor thermal environment assessment during typical summer conditions

The simulation focuses on the thermal zones of meeting halls, offices and changing rooms due to the importance of their occupancy schedules. The first simulation is conducted for the base case model with no opening shading system. It was found that the high inertia/thermal mass of the construction components maintain the heat longer during summer period. Thus, the indoor air temperature rises in all zones above 27°C for a non acceptable time period. Moreover, by means of solar gains, the latter proved to be rather high in the two meeting halls due to the large opening surfaces. The base case scenario results are not satisfactory and further methods for improving indoor thermal conditions will be investigated. Shading devices can lead to improved indoor climate conditions and lower electricity demand for air-conditioning [7, 8]. Indeed, the simulation of the second scenario, regarding the implementation of solar protection for all openings (VS scenario), proved to be very effective in terms of reducing discomfort duration. As depicted in table 2, POC is reduced by 42.83% and 55% at the meeting hall 1 and 2 respectively, while in the changing room, both criteria of NOC and POC values mentioned above are fulfilled. Shading devices also result in 119 and 139 less hours of discomfort within a year for offices 1 and 2 respectively. The results in Figure 2 also show the effectiveness of the vertical solar shading devices on the indoor thermal environment of the meeting hall 1. During the period 23 June – 9 September, the interior ambient temperature, for the BC scenario (red line), exceeds the upper limit for most of the time, with a maximum value of 33.2°C. For the VS scenario (green line), the ambient temperature exceeds 27°C during a smaller duration and the maximum ambient temperature was 2°C lower than the one of the BC.

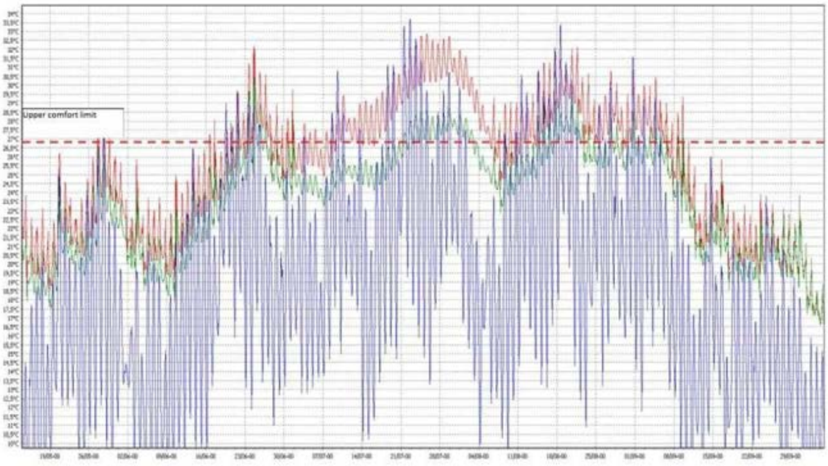

Fig. 2. Ambient temperature fluctuation in the meeting hall 1 during summer period (from May to September). The red line corresponds to the BC scenario, the green line corresponds to the VS scenario and the blue line represents the outdoor air temperature. Comfort upper limit is set to 27°C.

The second investigated strategy involves additional shading from deciduous trees with a height of 6.5 meters, placed around the building as well as natural ventilation (opening of windows) for the two offices (VEG scenario). The shading effect of the vegetation is simulated, using a specific transparency coefficient, defined by the simulation tool. Thus, during winter, the coefficient is equal to 0.9 indicating that solar radiation can pass through trees' leaves, whereas during summer, the coefficient value is set to 0.4, indicating that the foliage intercepts sunlight before reaching the building's envelope. Natural daytime ventilation of the offices takes place only during occupancy time and in case of an indoor air temperature higher than 2°C compared to the outdoor air temperature. Mechanical ventilation is operating even in the case of natural ventilation. It was proven that additional shading from trees and fresh air from natural ventilation can reduce by 69% and 57% the POC in office 1 and 2 respectively compared to the VS scenario. In this case, NOC were found to be lower by 35.1% and 30.6% for the meeting hall 1 and 2 respectively, compared to VS case, due to lower solar gains and convection phenomena due to natural ventilation in the offices. In the third scenario, the influence of occupancy patterns on the indoor thermal comfort conditions is studied (VO scenario). More specifically, an incompatibility may occur between the actual and simulated occupancy profiles due to the assumption of constant and simultaneous occupancy, which is often not realistic because of the stochastic nature of occupants [2]. Thus, the hypothesis that 45 people are constantly in each meeting hall can lead to an overestimation of the peak load. In this line of thought, the simulation showed that a reduction in the occupants' number by 50% would result in lower NOC by 36.2% and 55% for the meeting hall 1 and 2 respectively, compared to VS case, due to lower heat gains caused by the occupants' metabolic activity. The last scenario concerned nocturnal mechanical ventilation from 23:00 pm to 9:00 am, in the second floor zones and during summer period, only when the indoor air temperature in the meeting halls and offices exceeds the outdoor air temperature by 2°C (FC scenario). This measure had the most significant effect in terms of reducing overheating; in all the building zones the air temperature never exceeded the 27°C during summertime for more than 50h annually, complying with the two criteria set for this study. However, mechanical night ventilation may lead to increased electricity consumption due to the operation of fans and, thus, careful monitoring of operation schedules and energy consumption is required [9].

Table 2.Number of hours (NOC) during which interior temperature exceeds 27ºC for typical summer conditions and 28 ºC for heat wave conditions in the meeting halls, offices and changing room for the different scenarios.

	Typical summer conditions					Heat wave summer conditions		
Building zone	BC	VS	VEG	VO	FC	VS	VEG	FC
Meeting hall 1	201	94	61	60	50	379	297	31
Meeting hall 2	215	98	68	44	49	370	327	36
Office 1	219	100	16	31	39	247	174	30
Office 2	184	45	6	6	1	193	154	0
Changing room	100	21	9	17	3	164	142	0

Table 3. Ratio of the occupancy time during which the internal zone temperature exceeds 27ºC for typical summer conditions and 28ºC for heat wave conditions to the total occupancy period (POC) in the meeting halls, offices and changing room for the different scenarios

	Typical summer conditions					Heat wave summer conditions		
Building zone	BC	VS	VEG	VO	FC	VS	VEG	FC
Meeting hall 1	11.23%	6.42%	3.40%	3.57%	2.78%	21.19%	16.6%	1.72%
Meeting hall 2	12.02%	5.40%	3.79%	2.46%	3.30%	20.69	18.28%	2.00%
Office 1	14.10%	7.80%	2.37%	4.58%	2.47%	16.10%	11.05%	1.96%
Office 2	11.68%	2.10%	0.90%	0.90%	0.10%	12.24%	9.80%	0.04%
Changing room	4.70%	1.30%	0.41%	0.80%	0.14%	7.58%	6.57%	0.05%

4.2. Indoor thermal environment assessment during summer heat wave conditions

Further simulations to analyze the effect of three different design strategies during extreme summer conditions were carried out and the results are summarized in Tables 2 and 3. In order to investigate the worst case scenarios of thermal stress, only maximum occupancy schedules are simulated and the VO scenario is eliminated.

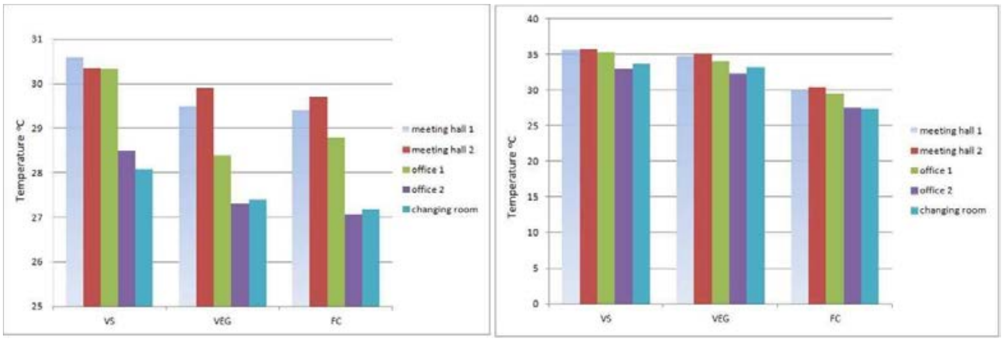

Fig. 3. Annual maximum indoor air temperatures in the different zones during typical and extreme summer conditions

Regarding VEG scenario, only additional shading from trees was taken into consideration while windows were kept closed during occupancy time as the outside air temperature was found to be always higher than the building zones indoor air temperature. Overall, the results show that little improvement on comfort duration was recorded after additional shading from trees foliage. POC values are lower by 22%, 12%, 31% and 20% for meeting hall 1, 2 and offices 1, 2 respectively compared to VS scenario but still, there is a high risk of thermal discomfort in all zones. However, the analysis indicated that the maximum improvement in indoor conditions of all zones is only achieved using mechanical night ventilation. Figure 3 rank the effect of different design strategies on maximum indoor air temperature during typical and extreme summer conditions respectively. Nocturnal ventilation results in a maximum reduction of 5.4-5.7^{o}C in the meeting halls and offices in case of heat wave while its effect is of lower significance during typical summer conditions where the air temperature is lower by 0.65-1.5^{o}C, compared to VS scenario.

5. Conclusion

In this paper, the indoor climate conditions of a sports building, during typical and extreme summer conditions are investigated. The design parameters such as increased insulation of the thermal envelope, high thermal mass of the building components, large openings that contribute to important solar heat gains, low thermal bridges and heat recovery from the mechanical ventilation system, result in a low annual heating energy demand. However the high inertia of the construction components and the airtight design maintain the heat longer during summer period. The analysis showed that despite the fact that the building is located in a continental Europe characterized by mild summer periods, there is still an important risk of indoor thermal discomfort in the building’s main zones, indicating thus the necessity of additional strategies towards the achievement of proper thermal conditions.

Shading devices should always be implemented as architectural elements due to their significant impact on improving internal thermal conditions. Additional shading from trees and natural ventilation can also ameliorate the indoor thermal environment of the building zones. However, during extreme canicular periods, there is no effectiveness to natural ventilation and thus, the opening of windows could even increase ambient zone temperatures. During heat waves it is very difficult to maintain satisfying thermal conditions and only additional strategies such as mechanical night ventilation contribute towards the achievement of comfortable indoor thermal environment but the risk of increased electricity consumption should not be neglected. Furthermore, occupancy profiles tend to overestimate peak internal thermal loads as they assume maximum occupancy simultaneously. Thus, a reduction in occupants’ number by 50% can result in acceptable thermal conditions due to lower internal heat gains by humans.

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