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Energy cost models for air supported sports hall in cold climates considering energy efficiency

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ABSTRACT

The aim of the study was to develop models for energy planning for an air supported sports hall by analyzing different energy efficiency possibilities. This is a very specific building type suitable for sport activities in cold climates. The observed hall was operated when outdoor temperature was under 5 °C, while the most common measured indoor air temperature was 8 °C during the year. Neither indoor nor outdoor temperature influenced the overpressure. Based on the measurements, the specific annually heating energy use was 75 kWh/m^2. The results showed that improvement in the hall insulation would not give a significant effect on the heating use. The analysis of energy efficiency measures showed that air recirculation has the greatest effect on total energy use and the air recirculation could give an energy saving of 27% when 50% of the indoor air was recirculated. The results might be used to calculate heating energy demand for different operation scenarios in the air supported halls. The results give a simple tool to size the heating coil in the AHU and for energy planning for similar halls. The study gave very specific and unique data on energy use in sport halls in cold climate.

1. Introduction

Air supported hall is a specific construction where overpressure in the hall has to be kept to maintain the hall height. A sport hall is usually built with a plastic cover and insulation. This type of construction may be used for sport facilities in the cold climates to afford a long training season for outdoor sports such as football, golf, running, or some other activities. In addition to these sport activities, the sport hall could be used for some other activities such as social gathering, a temporary cinema, or military training. These other activities usually requires a higher indoor temperature in the hall than for the sport activities. The air supported hall can afford to people in the cold climates to train outdoor sports all over the year. However, there is a few references on the energy use or operation of these sport facilities. A similar problem regarding insufficient information and lack of consistent data about building energy use in general is pointed out in [1].

Energy use in sports halls can be very different from ordinary buildings such as residential or office buildings. The Norwegian statistics show that the total specific annual energy use in offices and commercial buildings may vary from 200 to 250 kWh/m^2 [2], where the exterior wall U-value might be from 0.18 to 0.5 W/m^{2}K. Energy use in sport facilities may be influenced by many factors that are not directly technical parameters. Therefore, it may not be acceptable to use the basic assumptions of building energy use for these sport buildings. For example, operation time and type of activities may have great influence on energy use in the sport halls. Therefore, it is important to analyze energy use in the sport halls for a proper analysis.

Sport halls in Greece use less than 100 kWh/m^2 per year [3]. However, climate is much warmer in Greece than Norway and it might cause that the sport halls in Greece have much lower heating demand and higher cooling demand. Therefore, it could be concluded that a higher energy use might be expected in the sport halls located in Norway. In the research work of the Centre for Sport Facilities and Technology [4], energy use in the swimming pools in Norway is analyzed. Swimming halls are a very different building type than the air supported sport hall, but their energy use could give a theoretical maximum on energy use in the sport facilities. They found out that the swimming halls may use from 2000 up to 7000 kWh/m^{2}ws (water surface) [5]. In the work of Nord and Sjøthun, it was found that two Norwegian sport halls built in 1967 and 2003 have the specific total annual energy use of 1600 and 230 kWh/m^2, respectively. Both examples show possibility to

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decrease energy use by 30% [6]. An air supported sport hall in Trondheim consists of three handball courts and occupied 2718 m^2 [7]. This hall is covered with two-layer cover with insulation which gives U-value of 3.05 W/m^2K [8]. The indoor temperature in this hall is maintained at the minimum of 16 °C. The total annual district heating use was 583 324 kWh in 2012. Monthly distribution of the district heating use and monthly average outdoor temperatures are given in Fig. 1. Based on the presented facts, the total annual specific heating use was 215 kWh/m^2, while the average annual outdoor temperature was 5 °C.

To decrease energy use in the air supported construction, air recirculation might be a good energy efficiency measure. Air recirculation can be calculated in terms of the proportion of return air in the total supplied air flow. Proportions of recirculated air as high as 80–90% are common in North America, whereas, in Finland, they are usually between 30 and 70% [9]. To get an acceptable living environment, a minimum ventilation rate of 0.5 h^{-1} is recommended in Finland and other EU countries [10]. For example, 70% recirculated air accompanied by an adequate intake of outdoor air can be used without causing adverse effects [9]. Another study also reported that the potential energy saving of 8.3–28.3% may be achieved with acceptable indoor air quality (IAQ) by increasing recirculated air [11]. One recent study developed a local demand control ventilation solution, which may save 40–50% supply air in the system by using recirculated air [12]. Table 1 gives a summary of energy saving potentials and consequences on IAQ and indoor environment quality (IEQ) by using recirculated air or return air in buildings.

The above information found in the literature and examples together with the data collected from the observed hall in Mo i Rana, Norway, were useful information to calibrate the simulation model.

To enable easy energy planning, renting, and design, it is necessary to have available tools and methods for energy use prediction based on the driving variables. In that way, a building operator or building owner could budget the energy cost and plan building activities. For example, principle component analysis is used to identify important variables of energy use in low energy office building. In this study the outdoor temperature and heating system operation parameters are identified as important and may be used to describe heating energy use [13]. In the work of Hens, simple linear regressions between daily or monthly heating use and outdoor temperature show good fitting results reliable for a further analysis [14]. In this study, linear regression was used to derive simple tool for energy planning and hall design.

The aim of the study was to analyze different energy efficiency possibilities for the air supported sport hall in Mo i Rana, North Norway. Further, the aim was to analyze possibilities to achieve a higher and more stable hall temperature. The study also estimated energy use when the hall would operate longer and the hall temperature would be higher. Total annually and daily energy use were also calculated considering sensitivity of the results. In addition, the real time indoor environment and energy measurements were analyzed in this study. More than one year of the detail operation data were analyzed in this study. All these data were combined to give suggestions for heat supply sizing and energy planning for the air supported sport hall. Since the air supported hall is a typical construction, the results of this study could be treated as general and could be used in for other similar constructions.

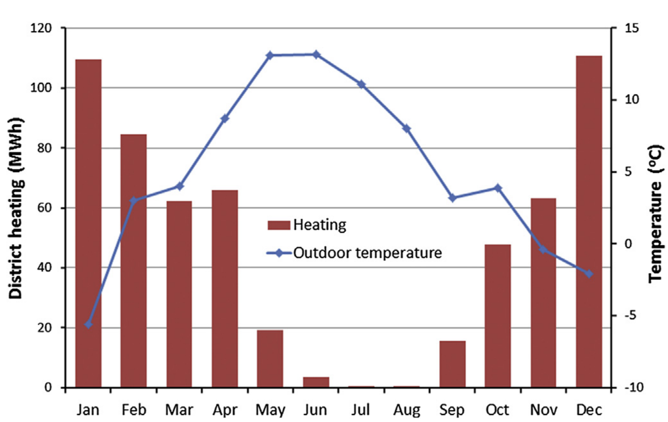

Fig. 1. District heating use in the air supported sport hall in Trondheim, Norway.

2. Methods

To analyze energy use in the air supported sport hall, documentation from the observed hall, together with the real-time measurements, and simulation were used. *EnergyPlus* was used as a simulation tool. The real-time measurements and documentation were used to calibrate the simulation model. *EnergyPlus* is based on the most popular features and capabilities of BLAST and DOE-2, it includes many innovative simulation capabilities such as time steps of less than an hour, modular systems, and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, and photovoltaic systems. EnergyPlus has been verified and used for many studies related to energy use.

Modeling of pressure level is based on simplified equations for pressure drop and pressure differences. Nevertheless, the results can still show trends for the pressure level in a hall. These results for pressure levels are not equal to the real hall measurement, but can be still used as guide values to show trends.

The model calibration was performed by using data from the hall documentation and by introducing several operation scenarios.

3. Air supported sport hall

3.1. Sport hall description

In this Section basic information about the hall, the hall operation, and the hall construction are given. Importance and meaning of this information for the simulation model and the analysis are also briefly explained in the text.

Figs. 2 and 3 show two photos of the air supported sport hall, which is a full-scale football court and has a ground area of 120 × 95 m. The highest point of the roof is at 28 m above the floor. The hall can be considered as one of the biggest in Europe of this type [8]. The hall has been used for football, golf, and different training activities of the pupils. The stands can receive 650 people. The floor consists of sand and artificial grass over the sand. In addition to the football court, the hall contains changing and storage room. With changing room is meant all the rooms used for changing such as showering and meeting rooms. Changing room, storage, and other rooms occupied an area of 75 × 12 m. Therefore, an area of 11 400 m^2 was used for the further simulation and result presentation, where the changing room takes 900 m^2.

3.2. Energy service system description

The air supported sport hall is connected to the district heating network in Mo i Rana with a heat exchanger of 580 kW. Originally a bigger heat exchanger of 1300 kW was planned. The idea was that 1050 kW would be used for heating of the hall and 250 kW for heating of the changing rooms. The hall is warmed up with the ventilation air that was blown directly into the hall. The air is warmed up by a heating coil. Air handling unit (AHU) has one fan