Science, Engineering & Education, 5, (1), 2020, 15-18

Thermodynamic Processes at Air-supported Structures for Indoor Sports

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Received 04 September 2020, Accepted 30 October 2020

ABSTRACT

Thermodynamic processes occurring in air-supported structures for indoor sports are considered. Possible variations of the parameters of the indoor air depending on the climatic conditions, technical features and operations of the constructions are analyzed. The knowing of these processes is important for the proper sizing of the heating and ventilation installations and for the adjustment of the system for their automatic regulation.

Keywords: air-supported domes, ideal gases, thermodynamics, infiltration, ventilation, air conditioning, automation and control.

INTRODUCTION

The air-supported structures, also known as a domes or baloons, are suited to cover areas for indoor sports as soccer fields, large swimming pools, tennis and multisport facilities where large clear-span space is necessary [1, 2]. They can be wholly, partially, or roof-only air supported. The wholly air-inflated structure is a lower cost alternative to the traditional building. It can be mobile and semi-permanent as the domes can be taken down and set up every season. The initial costs are considerably lower in comparison to the traditional construction and the operating costs can be smaller as well due to simplicity of the design. The structures are made by fabric membranes, anchored to the ground around their perimeter, without needs of supporting beams or columns. The dome access points include revolving doors, pedestrian airlocks for barrier free access, and vehicle airlocks for maintenance and lift equipment. The grounding of the membrane is an important issue, requiring a high level of engineering and design to guarantee the sealing and safety of the dome.

A slightly higher air pressure inside the dome in comparison to the local meteorological pressure supports the entire structure. It is maintained by continuous fresh air input into the structure to compensate the leakages. This airflow is regulated by the automation system in order to keep nearly constant difference between the outdoor

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and indoor pressure, controlled by a differential pressure gauge.

The aim of this study is to discuss the thermodynamical processes and dependencies, whose knowledge is important for the proper adjustment of the automatic control of the heating and ventilation of the air supported domes for sports at the tempered climate.

Requirements for the thermodynamic parameters of the indoor air

According to [3] the optimal temperature and relative humidity of the indoor air in covered places for sport (halls) are in the ranges 14 - 16ºC and 30 - 60 %, respectively. The optimal air velocity is 0.3 - 0.4 m s^{-1}. The Bulgarian regulation [4] imposes more précised parameters for covered sport halls in universities and schools: temperatures of 18ºC at the winter, 22 - 27ºC in the summer and a minimum of 60 $m^3 h^{-1}$ fresh air per person.

The indoor gauge pressure has to be enough to compensate the gravity force of the membrane and the wind forces. The higher pressure increases the resistance of the envelope on the wing load. Therefore, at a given mass of the envelope the required gauge pressure is a function of the wind speed. It is recommended to be 50 % of the dynamic wind pressure [5]. The snow load due to snow covers in the winter seasons also has to be taken into account. A gauge pressure of 250 Pa in the indoor space is enough to compensate the loads, mention above according to [5].

The air is accepted as an ideal gas at the mentioned conditions above. The mass of the indoor air in the dome m is computed by Clapeyron - Mendeleev equation:

$$pV = mR_{air}\mathrm{T} \quad (1)$$

$$m = \frac{pV}{R_{air}\mathrm{T}} \quad (2)$$

where p - absolute pressure, Pa; V - volume of the indoor space, m^3; T - absolute temperature, K, R_{air} - 287 J $kg^{-1}K^{-1}$ - specific gas constant of the air.

For example at an air supported dome, covering three tennis courts (Fig. 1) with a volume of 10424 m^3 the mass of the air is 12512.5 kg at

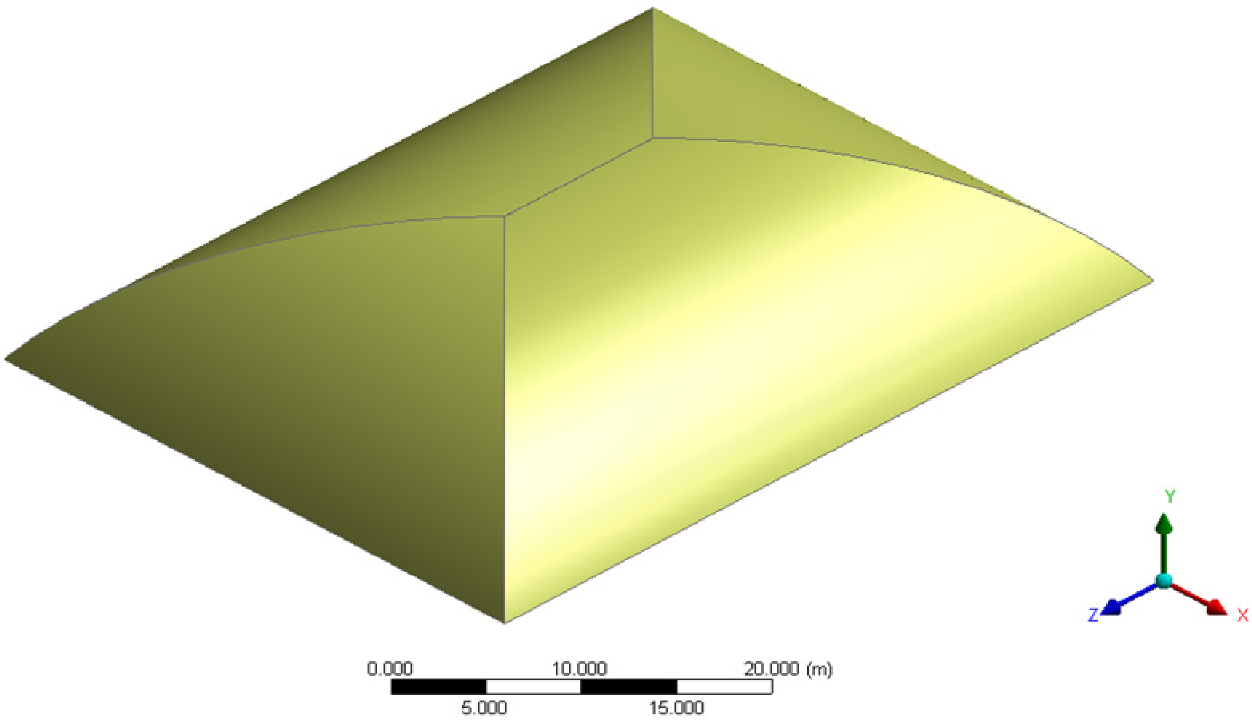

Fig. 1. Air supported dome with height 10 m, length 48 m and width 37 m.

atmospheric pressure 1 bar, gauge pressure 250 Pa and temperature of 18ºC (291 K). The air mass in the dome varies inversely proportional to the change in temperature, but this process is insignificant.

Inflation and operation of the air-supported structures

The temperature and the pressure in the air-supported domes are maintained by ventilation –heating units. The ventilation system can ensure 100 % fresh air, if it is necessary. For economical aspect, a recirculation of the return air is maintained. The supply airflow is consisted of recirculating and fresh air that is enough to compensate the leakage and to ensure the necessary fresh air according to the number of the people in the dome. The temperature and the pressure are kept in ranges, programed in advance in the system for automation control.

According to [5, 6] the blower capacity of the ventilation unit should be designed to allow:

• a compensation of the maximal air leakage at the base, around the doors and through the vents. The experience indicates that the leakage losses at a gouge pressure 250 Pa in the dome can reach 57 $m^3 h^{-1}$ per linear meter of base perimeter, 340 $m^3 h^{-1}$ per door assembly, and 43891 x A $m^3 h^{-1}$ for vents where A is the total vent area in square meters;

• a fresh airflow of at least 60 $m^3 h^{-1}$ per person according to [4];

• a satisfactory initial inflation time specified by the design requirements.

It is recommended the blowers be capable of providing at least twice the calculated airflow.

For example, the expected flow of the air leakage at the balloon on Fig. 1 is about 14500 $m^3 h^{-1}$. The necessary fresh air is 720 $m^3 h^{-1}$ at 12 person in the balloon (4 persons per court). So a blower with a capacity of 30000 $m^3 h^{-1}$ will inflate the balloon for 0.35 hours (10424 m^3/30000 $m^3 h^{-1}$ = 0.347 h) and can ensure enough fresh air for the people.

An emergency automatic power system - an auxiliary engine-generator set capable of powering the blower continuously for 4 hour or a supplementary blower powered by an internal combustion engine is required to ensure the inflation pressure in a case of electrical supply interruption [6].

The capacity of the heating installation of the dome is designed to work satisfactory at the hardest climatic parameters of the region by a thermal balance according to [6 - 9]. The higher is the thermal resistance of the dome envelope, the smaller is the energy input for the heating. The thermal accumulation ability of the air is relatively low - small amounts of input or output heats can cause temperature changes. During the exploitation of the dome, there are fluctuations of the indoor temperature. Such processes can be caused by climate changes and thermal loses through the dome envelopes. It is important to know how the temperature change of the air influences on the indoor pressure in order to proper setting of the temperature range, which is kept by the automation system. Gay-Lussac's law at constant volume of the balloon gives this dependency:

$$\frac{p_1}{T_1} = \frac{p_2}{T_2} = const. \quad (3)$$

The internal pressure is decreased at indoor temperature drop at chilly time. The volume of the balloon is constant until the indoor pressure reach the outdoor one. As the internal pressure drops below this limit, the balloon begins to fall in the absence of air supply. The rate of that process also depends on the leakage air flow.

For example, if the indoor pressure and temperature are 100250 Pa and 291 K (18 ºC), respectively, and the outdoor pressure is 1 bar (100 000Pa), a drop of the internal temperature of 1 K will cause zero gauge pressure (absolute indoor pressure of 100000 Pa).

$$\frac{p_1}{T_1} = \frac{p_2}{T_2} \quad => T_2 = \frac{p_2 T_1}{p_1} = \frac{100000.291}{100250} = 290 \text{ K}$$

(1K temperature drop)

If the temperature continues to decrease at absence of fresh air supply the volume of the balloon will start do decrease. Therefore, the set limits in which the indoor temperature and pressure are maintained are very important. This is especially important for the temperature - its variation has to be as small, as possible (below 2 K). The pressure range can be higher. For example maintaining of 250 Pa ± 10 % or range of 225 - 275 Pa by the differential pressure switch is a good solution. The smaller is the range of maintained pressure, the smaller are the fluctuations of the fresh airflow and indoor temperature. The advanced systems for inverter based fan speed control allow the adjustment of such smoot operation of the heating-ventilation system.

The positions of the sensors are also important, as stratifications of the temperature and the pressure exist due to the relatively high dome heights. The modeling and numerical simulation of the thermal and fluid flow processes in the air domes are successful approach for solution of such problems.

CONCLUSIONS

The wholly air supported domes are mobile and suitable for fast covering and discovering of sport facilities. However, their safety operation and the ensuring of thermal comfort in the indoor space require continuous work of the heating-ventilation units and emergency backup electrical generators working on liquid or gas fuel.

The energy consumption for the operation depends on the thermal resistance of the envelopes, the sealing of the structure and the efficiency of the heaters and the blowers. Such thermal insulated domes and efficient equipment require relatively high initial investments. Therefore, the profitability of the installations depends on the daily occupation of the dome for sport activities.

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