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Thermal monitoring and indoor temperature predictions in a passive solar building in an arid environment

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Abstract

In this paper, results of a long-term temperature monitoring in a passive solar house, located at the Sede-Boqer Campus of the Ben-Gurion University, in the Negev region of Israel are presented. Local latitude is 30.8°N and the elevation is approximately 480 m above sea level. The climate of the region is characterized by strong daily and seasonal thermal fluctuations, dry air and clear skies with intense solar radiation. The monitored building consists of a two storey, passive solar house and belongs to a student dormitory complex located at the Sede-Boqer Campus. Formulae were developed, based on part of the whole monitoring period, representing the measured daily indoor maximum, average and minimum temperatures. The formulae were then validated against measurements taken independently in different time periods. In managing the building, the main objective in the winter was to bring up the indoor temperature by direct and indirect solar gains while in the summer it was to keep the temperature down. Therefore, analysis of the data and development of predictive formulas of the indoor temperatures were done separately for the winter and for the summer. Measured data of each season were then divided into two sub-periods, the first one used to generate formulas based on measured data (generation) and the second for testing the predictability of the formulas by independent data (validation). In general, a fairly good agreement was verified between onsite measurements and results of the formulae, with regard to daily indoor maximum, average and minimum temperatures. The issue of using outdoor temperatures measured in the adjacent street canyon instead of those registered at the local meteorological site for evaluating the building's cooling demand is also addressed in the paper. The developed formulae were here used for estimating the building's thermal and energy performance in summer, taking into account: (1) solely climatic data from the meteorological station; (2) climatic data from the meteorological station, except for outdoor ambient temperature, which was monitored adjacent to building. Results indicated that the calculation of the building's energy demand for air-conditioning based on temperature data collected at the meteorological station would yield half of the cooling degree-days externally and about two-thirds of that internally, as compared to adopting measured canyon temperatures for such calculations.

Keywords: Thermal monitoring; Solar passive house; Indoor temperature predictions

1. Introduction

According to climatic design, for arid locations, it is advised to build with a great amount of thermal mass, taking advantage of solar gains in winter, so that daytime heat is stored within the building and its fabric for the nighttime period, when temperatures drop. Thermal mass is also of great benefit in summer, allowing daily fluctuations of outdoor temperatures to be smoothened, so that a more stable pattern of the indoor conditions is created. Givoni [1] suggests for hot-dry regions buildings with high-mass walls and roof and the use of openable glazing, combined with insulated shutters, in order to promote ventilation in the hours when outdoor temperature drops down. In regions with cold winters, both the minimization of solar gains in summer and maximal solar

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utilization in winter should be regarded as main objectives and openings should be designed accordingly.

In this paper, we present the results of a long-term monitoring of a passive solar house, located at Sede Boqer, Negev Desert, in Israel. Considering that a ‘‘passive house requires active users’’, the house was operated in a climate-responsible manner throughout the seasons. This paper shows summarized results of such measurements, also presenting formulae, which were developed for predicting indoor air temperatures in the monitored building. As these formulae are based on climatic data, commonly registered at meteorological stations, the issue of adopting site-specific outdoor temperatures instead of those gathered at the meteorological station for evaluating comfort and cooling demand is also addressed in this paper. Evaluations of a given building's energy demand for air conditioning tend to consider climatic data from the local meteorological station, not necessarily close to the spot where the building will be sited. Oke [2] discusses the importance of locating meteorological locations within the city and the difficulties that sometimes arise when selecting reliable climatic data, which actually represent the urban microclimate. The formulae were here used for estimating the building's thermal and energy performance in summer, taking into account: (1) solely climatic data from the meteorological station; (2) climatic data from the meteorological station, except for outdoor ambient temperature, which was recorded outside the building.

2. Local climate

The monitored building is located at the Sede-Boqer Campus of the Ben-Gurion University, in the Negev region of Israel. Local latitude is 30.8°N and the elevation is approximately 480 m above sea level. The climate of the region is characterized by strong daily and seasonal thermal fluctuations, dry air and clear skies with intense solar radiation. In summer, average daily maximum temperature is 32 °C and average daily minimum is 17 °C. Global radiation averages 7.7 kW h/m^2/day during June and July. In winter, days are typically sunny and have an average daily maximum temperature of 14.9 °C and a minimum of 3.8 °C. Prevailing winds blow in summer from the northwest and are consistently strong in the late afternoon and in the evening, according to Bitan and Rubin [3] and Etzion et al. [4].

2.1. Thermal comfort conditions for Sede boqer

In this study, the adaptive approach originally proposed by Nicol and Humphreys [5] was used for establishing ideal operative temperatures in the building. The adaptive approach goes under the assumption that ‘‘if a change occurs such as produce discomfort, people reach in ways which tend to restore their comfort’’. Brager and De Dear [6] showed that the adaptive comfort standard (ACS), proposed to ASHRAE Standard 55 has a great energy-saving potential. Conventional standards define thermal comfort within narrow limits, therefore making it difficult for non-residential buildings to function without any mechanical assistance, even in relatively mild climatic conditions. Since the present project is related to the need of energy conservation in buildings, the adaptive approach was adopted.

Table 1
Adaptive comfort ambient temperature range for Sede Boqer—2006

Month	$T_{a,out}$	T_{comf}	Lower limit (90% acceptability)	Upper limit (90% acceptability)
Jan	10.1	20.9	18.4	23.4
Feb	12.0	21.5	19.0	24.0
Mar	14.5	22.3	19.8	24.8
Apr	17.5	23.2	20.7	25.7
May	20.4	24.1	21.6	26.6
Jun	23.9	25.2	22.7	27.7
Jul	24.58	25.4	22.9	27.9
Aug	26.0	25.9	23.4	28.4

For naturally ventilated buildings, ASHRAE Standard 55 suggests an alternative for the PMV-based method for establishing a comfort zone. Optimum comfort temperature T_{comf} is therefore calculated based on the monthly mean ambient temperature $T_{a,out}$ [7]:

$$T_{comf} = 0.31T_{a,out} + 17.8. \tag{1}$$

The comfort range for 90% acceptability is of 5 °C and for 80% acceptability is of 7 °C.

For the year 2006, when measurements in the building were carried out, comfort ranges are as presented in Table 1.

3. Long-term temperature monitoring in a passive house at Sede Boqer

Within a post-doctoral research framework, a series of indoor temperature measurements was undertaken in a passive solar house during the months of January–August 2006. The building consists of a family-apartment unit and belongs to a student dormitory complex located at the Sede-Boqer Campus. The overall floor area of the building is 55 m^2. Openings have mainly a south-facing exposure, such that the window-to-wall ratio (WWR: net glazing area to gross exterior wall area) of the north façade is only 0.05 and in the south façade 0.14. Double-glazed doors were used in the lower floor. Except for two small windows in the lavatory and in the bathroom (net glazed area of about 0.3 m^2), swing/tilt windows were used throughout (in the kitchen and in both bedrooms) and all windows include insect screens. Fig. 1 shows the plans of both floors of the two-storey building.

As for the building materials used, the building envelope (poured concrete) is covered by an insulation material, commercialized locally as Rondopan. This insulation layer