Indoor temperature predictions in an energy efficient solar house

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Abstract. This paper presents results of long term temperature monitoring in an energy efficient solar house at the University of Fort Hare, South Africa. Measured data was stored by a datalogger every 10 minutes. Formulas for predicting the daily indoor maximum, average and minimum temperatures were developed on the basis of outdoor climatic parameters. Passive solar housing aims to raise and lower indoor temperatures in winter and summer respectively. As a result, analysis of the data and development of predictive formulas of indoor temperature were done separately on part of the winter and summer seasons. The models were then validated against measurements taken in different time periods. Results indicated that indoor maximum, average and minimum temperatures can be predicted on the basis of outdoor temperature. Prediction of maximum indoor temperature was improved by incorporating daily solar irradiance in the formula. It was also revealed that indoor temperatures are affected by outdoor temperatures of the previous three days.

1. Introduction

Desirable thermal performance of energy efficient solar housing is based on two objectives: raising the indoor temperatures in winter using solar radiation as the principal heating source and lowering indoor temperatures in summer through natural ventilation and minimising solar gains [1]. Indoor temperature is influenced by the outdoor weather patterns, thermal absorption, thermal capacity of the house envelope and thermal mass, and presence/absence of heat sources. Human activity also influences the indoor thermal behaviour. Together with wind speed and relative humidity, indoor temperature is often used to determine thermal comfort [2]. The energy efficient solar house was built at the University of Fort Hare and its thermal performance has been monitored since 2009.

The majority of national meteorological stations measure and keep records of daily maximum, minimum and average temperatures among other climatic factors. This data is often published through public media and is made available to researchers and interested parties. This article analyses the influence of outdoor weather factors on indoor temperatures. Measured outdoor weather data was used to develop formulae for predicting indoor maximum, minimum and average temperatures. The objective of the exercise was to develop formulae that use the least amount of measured outdoor data which give a reasonable description of indoor temperatures.

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2. Measurements

Outdoor and indoor temperature and relative humidity were measured by a HMP50 probe. Global solar irradiance and wind speed were measured by a Li-Cor pyranometer and wind sentry set respectively. Data acquisition was made using a CR1000 datalogger which recorded average values every ten minutes. Measurements were done throughout the winter and summer seasons of 2009 and 2010.

3. Indoor temperature sensitivity to outdoor weather

Linear regression was used to analyze the relationship between indoor temperature and each of the measured outdoor variables. For example, the measured outdoor ambient temperature was plotted against the indoor temperature. The best fit linear regression correlation for June 2009 is shown in figure 1. It was observed that both indoor and outdoor temperatures do not exceed 27.00°C while the outdoor temperature gets to subzero values. The outdoor temperature range was 29.24°C (varying from -2.46°C to 26.78°C) while the indoor range was 20.05°C, that is 46% lower.

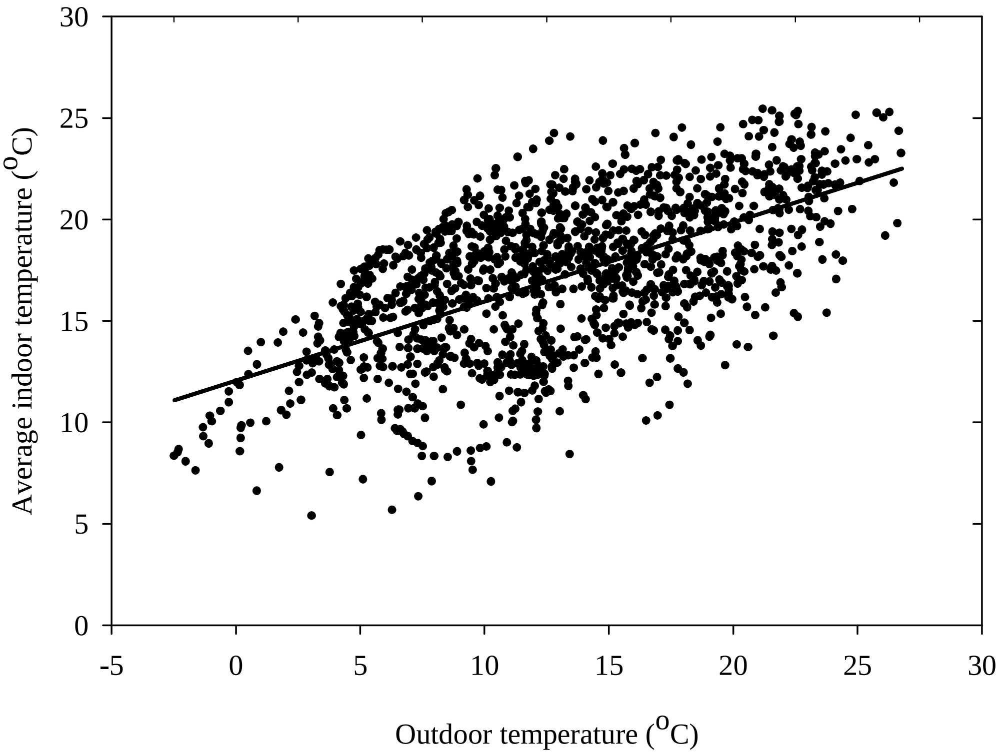

Figure 1. Correlation of indoor and outdoor temperature for June.

The correlation relationship between indoor and outdoor temperature was found be:

$$T_{in} = 0.39T_{out} + 12.06 \qquad R^2 = 0.37 \tag{1}$$

The relationship has a correlation coefficient $R = 0.61$ and a coefficient of determination $R^2 = 0.37$. This means that only 37% of the variation of indoor temperature about its mean can be explained using outdoor temperature. This correlation is weak, implying that T_{out} cannot individually be used to predict T_{in}. Other parameters account for the 63% deficit.

The indoor temperature (T_{in}) was also plotted against outdoor relative humidity (RH_{out}), wind speed (W_s), and solar irradiance (G). The results are summarized in table 1.

Table 1. Correlations of indoor temperature with outdoor variables

Y-variable	X-variable	R^2	Comment
T_{in}	RH_{out}	0.10	No correlation
T_{in}	W_s	0.03	No correlation
T_{in}	G	0.06	No correlation

It was observed that individual climatic factors cannot independently predict indoor temperature. Combinations of independent climatic factors and the previous day(s) climatic conditions have to be used to model indoor temperature.

4. Indoor maximum, minimum and average temperature predictions

The energy efficient solar house was designed to perform differently in summer and in winter. It follows that the analysis and development of predictive formulae of indoor temperatures was done separately for the summer and winter periods. The measured data for each period was divided into two sub-groups. The first was used to generate the predictive formulae and the second dataset of the subgroup was used for validation as independent data.

Scatter and regression plots of indoor temperatures as dependant variables against outdoor temperatures were performed. Kruger and Givoni [3] and Ogoli [4] reported that indoor climate is influenced by that day's weather conditions and the weather conditions of the previous days. With the first day of the dataset taken to be day *n*, the outdoor temperatures were lagged by one (*n-1*), two (*n-2*) and three (*n-3*) days. The procedure involved analyzing the coefficient of determination R^2, the p-value and standard error of each indoor parameter plotted against various outdoor variables. The R^2 values greater than 0.5 were deemed to signify a valid linear relationship and a p-value less than 0.05 was considered to be statistically significant. Variables which gave correlation relations which were statistically insignificant were neglected. Correlations for $T_{o\text{-}max,\ n\text{-}3}$ and $T_{o\text{-}min,\ n\text{-}3}$ and lower, gave p-values which were statistically insignificant and R^2 values which were trivial. The relationship between indoor temperature and the moving average (*mav*) outdoor temperature of the previous days was also investigated.

The indoor temperature formulae generated for the winter period were:

$$T_{in\_\max,\,n} = 0.63T_{o\_\max,\,n} + 0.051T_{o\_\max,\,n-1} + 0.19T_{o\_mav} + 0.29G + 3.76 \quad (2)$$

where T_o is the outdoor temperature
T_{in} is the indoor temperature
max is maximum
min is minimum, and
mav is moving average.

The correlation coefficient for the generation period was 0.87 and for the validation period was 0.80.

$$T_{in\_ave,\,n} = 0.28T_{o\_\max,\,n} + 0.14T_{o\_\max,\,n-1} + 0.05T_{o\_\max,\,n-2} + 0.15T_{o\_\min,\,n} + 0.23T_{o\_mav} + 3.60 \quad (3)$$

The correlation coefficient for the generation period was 0.90 and for the validation period was 0.80.

$$T_{in-\min,\,n} = 0.20T_{o-\max,\,n-1} + 0.01T_{o-\max,\,n-2} + 0.51T_{o-\min,\,n} + 0.13T_{o-\min,n-1} + 0.11T_{o-mav} + 2.83 \quad (4)$$

The correlation coefficient for the generation period was 0.87 and for the validation period was 0.80.

For the three formulae generated in winter, the indoor maximum temperature is the only one which appears to be influenced by the daily solar irradiance. The daily indoor minimum temperatures are not affected by the outdoor maximum temperature of the same day. The minima cannot be physically affected by the maxima which were observed to occur about seven hours later. Minimum temperatures generally occurred just after sunrise in winter. Figure 2 and figure 3 show the measured and computed indoor maximum and minimum temperatures during the winter and summer seasons respectively. Equipment failure caused data loss in the period 12 to 19 July.

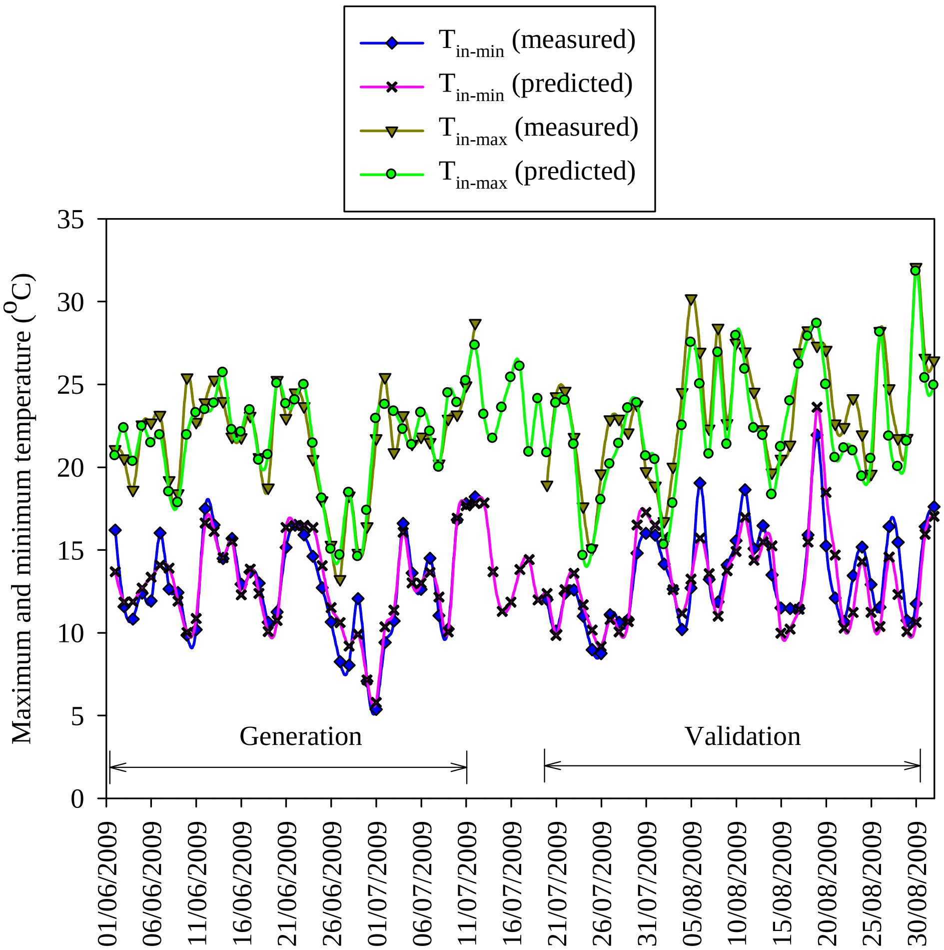

Figure 2. Measured and predicted indoor minimum and maximum temperatures in winter.

The indoor temperature formulae generated for the summer period were:

$$T_{in-\max,\,n} = 0.47T_{o-\max,\,n} + 0.23T_{o-\max,\,n-1} + 0.19T_{o-mav} + 0.19G + 6.37 \qquad (5)$$

The correlation coefficient for the generation period was 0.91 and for the validation period was 0.80.

$$T_{in-ave,\,n} = 0.26T_{o-\max,\,n} + 0.29T_{o-\max,\,n-1} + 0.16T_{o-\min,\,n} + 0.14T_{o-mav} + 0.13G + 5.79 \qquad (6)$$

The correlation coefficient for the generation period was 0.94 and for the validation period was 0.91.

$$T_{in-\min,\,n} = 0.37T_{o-\max,\,n-1} + 0.05T_{o-\max,\,n-2} + 0.37T_{o-\min,\,n} + 0.13T_{o-mav} + 3.77 \qquad (7)$$

The correlation coefficient for the generation period was 0.92 and for the validation period was 0.87.

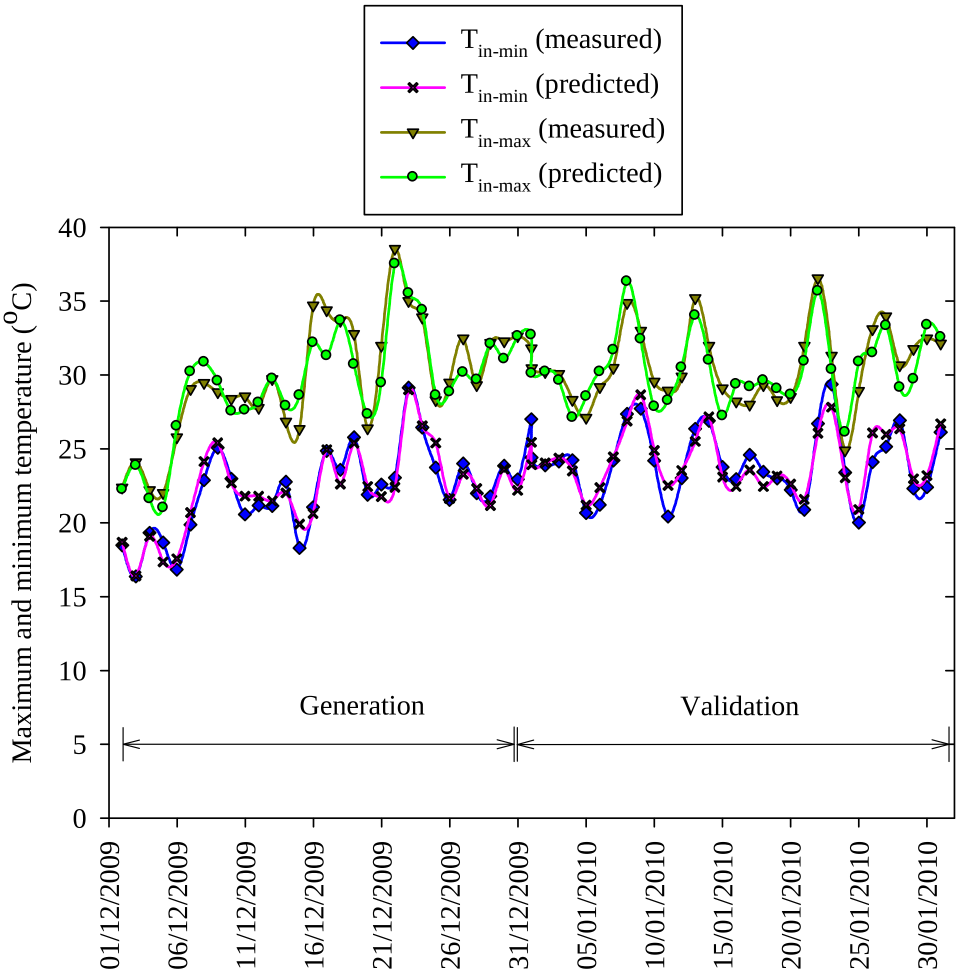

Figure 3. Measured and predicted indoor minimum and maximum temperatures in summer.

The relationship between the average indoor temperature and predicted average temperature is shown graphically in the scatter plot of figure 4 in the winter season.

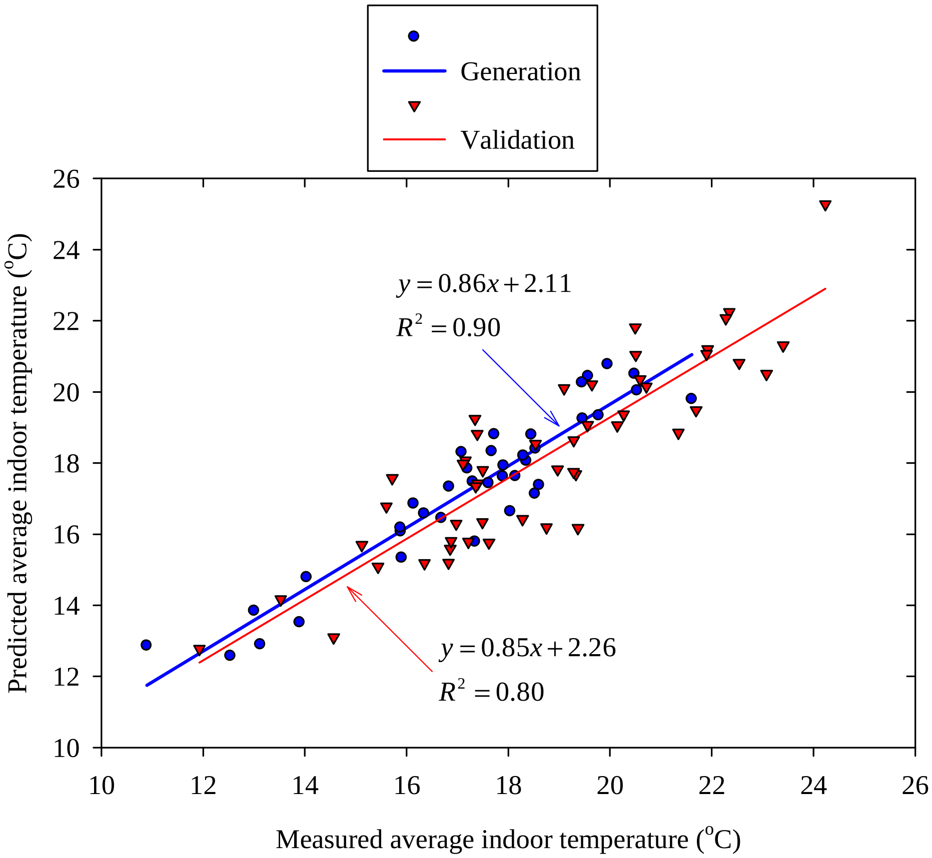

Figure 4. Scatter plot of indoor measured and predicted average temperatures.

Indoor temperatures have been shown to respond directly to outdoor climatic conditions. This can be attributed to the fact that the solar house does not have heating, ventilation and air conditioning equipment. Outdoor temperature has been proven to be a parameter that can serve as a basis for indoor temperature predictions for this type of buildings. In addition, the amount of climatic data required in these formulae is only a fraction of that required to run simulations and computerized models.

5. Conclusion

The developed models have maximum temperatures recorded two days earlier and a three day moving average parameters. Correlations with moving averages with *n* greater than four gave R^2 values which were trivial. Thus, the thermal mass retains heat received extending to the third previous day. Records of outdoor temperature can be used as a basis for predicting indoor maximum, minimum and average temperature. However, it is envisaged that the developed formulae can be improved by including the thermo-physical properties of the building components.

6. References

[1] Givoni B 1998. *Climate considerations in building and urban design* (John Wiley & Sons Inc.)

[2] De Dear R and Brager G S 2002. Thermal comfort in naturally ventilated buildings: revisions to the ASHRAE Standard 55 *Energy and buildings* **34** 549-561.

[3] Kruger E and Givoni B 2008. Thermal monitoring and indoor temperature predictions in a passive building in an arid environment *Building and environment* **43** 1792-1804.

[4] Ogoli D M 2003. Predicting indoor temperatures in closed buildings with high thermal mass *Energy and buildings* **35** 851-862.