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Thermal comfort Modeling in Hot and Dry Urban Squares

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Abstract

Thermal adaptation plays critical roles in users' ability to assess thermal environments. Previous studies have rarely addressed the effects of demographics on outdoor thermal comfort. This study investigated thermal comfort at two city squares regarding thermal environment and the visitors' demographics. In addition to physical measurement and questionnaire survey, a non-linear model was employed. A common thermal index i.e. predicted mean vote (PMV) was trained and tested using neural network auto regressive (NN-ARX). The attained statistical indicators of the MAE and the RMSE were 1.28 and 0.71. The findings showed the superiority of the NN-ARX for thermal comfort prediction.

Keywords: Outdoor thermal comfort; Soft cpmputing; Hot and dry climate; Demographics

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1. Introduction

It is believed that outdoor thermal environment affect residents' thermal sensations (TSs) in open urban areas; thus, it can play a significant role in utilization of these places. Urban space utilization is a gauge for estimation success of a city (Kariminia, Sh Ahmad, Ibrahim, & Omar, 2010). Having said that, urban spaces such as squares are exposed to extreme weather conditions, particularly due to climatic change and global warming phenomena (Kariminia, Ahmad, & Hashim, 2012; Kariminia, Ahmad, Hashim, & Ismail, 2013). Indeed, open urban spaces (i.e. plazas or squares) are vulnerable to extreme weather conditions. Thus, designers and planers consider it essential to prepare more attractive outdoor spaces, which can be better utilized by the residents (Kariminia, Ahmad, Omar, & Ibrahim, 2011).

The micro-climatic condition is a key parameter that influences the level of user's perception and attraction to outdoor settings (Kariminia & Ahmad, 2013). In addition, the pedestrians of these places are directly exposed to outdoor environment. Their perceptions are also influenced by the immediate micro-climatic conditions that they experience outdoor. Previous studies have identified a strong relationship between the outdoor and indoor TSs (Kariminia, Ahmad, & Saberi, 2015). Hence, engineers and designers need to consider the outdoor thermal conditions, which in turn influence the energy management of buildings.

In the previous research works, the influence of individual demographics on the indoor thermal comfort have been properly documented (Nagashima et al., 2002). Nevertheless, there is lack of investigation on the outdoor thermal comfort of users. For example, an indoor field study performed by Nakano, Tanabe, and Kimura (2002) showed a considerably higher neutrality temperature of the Japanese female group compared to the non-Japanese male subjects. (Karjalainen, 2007) performed quantitative surveys, both in offices and houses reported that males were more pleased and less sensitive in both hot and cold conditions. Indraganti and Rao (2010) studied the effect of gender, age, tenure and economic condition on thermal sensations of apartment inhabitants (n = 100) in India. It was found higher discomfort in those with better economic situation. Furthermore, the owners fortified people to take on adaptations; therefore, the tenants exhibited higher thermal sensitivity to the conditions.

Several investigations have been carried out to assess the influence of canyon structure (Ali-Toudert & Mayer, 2007), shading (Lin, Matzarakis, & Hwang, 2010) and vegetation (Shashua-Bar & Hoffman, 2000) on thermal comfort in different climatic zones (Soebarto & Bennetts, 2014; Taleghani, Kleerekoper, Tenpierik, & van den Dobbelsteen, 2015). Nevertheless, the existing literature has rarely addressed the urban squares, particularly in the Middle East (Kariminia, Sh Ahmad, & Ibrahim, 2013). Although, it is evident that public TSs vary with demographic parameters, their effects are not well documented in the literature.

The study aimed to apply the NN-ARX model to explore the effects of micro-climatic parameters and demographics on the visitors' outdoor thermal comfort. In this regards, we employed the NN-ARX model to evaluate subjects' TS.

2. Research methods

2.1. Case studies

Two urban squares located in Isfahan in the central part of Iran were selected for this case study. Isfahan is a historical city situated at 32°37' N and 51°41' E, 1590 m above the sea level. In terms of climate, this city experiences cold winters, hot summers and low annual humidity. Based on the long-term measurements for the period of 1951 to 2012, the Iranian Meteorological Organization (IMO) reported the maximum 28.9 °C and minimum 3.7 °C of monthly average temperatures for Isfahan. The month of January had the lowest air temperature (T_a) equal to –19.4 °C, while the month of July achieved the highest temperature of 43 °C. In the same period of measurement, an average relative humidity (RH) was observed in the range of 25%-60%. To achieve higher reliability in the results, the summer was considered as the peak uncomfortable condition to gather data and perform analysis.

The first site of this case study, Naghsh e Jahan Square, is a large open area surrounded by long low elevated buildings, with a gap along two streets on the east and west sides. The ground floors of the buildings are mostly occupied by retail spaces, whereas the first floor loggias are used as the service rooms. In terms of geometry, the square is almost symmetrical and four tall buildings are located at four sides. The sides of the square are covered by two rows of small evergreen bushes. The ground surface is mainly covered with stone and grass. On the other hand, Jolfa as the second case study is a small neighbourhood square that is used for a range of daily activities such as, shopping, visit, relaxing, cultural events and networking. Besides, a large number of residents use it as a shortcut to pass through to the adjacent neighbourhoods. There are linear porches all around and a raised platform at the centre. The lateral tall deciduous and short evergreen trees are the vegetation within the square. The square is enclosed by single-story shops with brick facades under a symmetrical form and is paved with concrete blocks. Motorized vehicles cannot access the main part of the square; however; a narrow passage exists at the southern area.

2.2. Physical monitoring

The field measurements were taken between 12 and 24 July 2014 (8 days in Naghsh e Jahan and 5 days in Jolfa). The portable HOBO data-logging mini weather station, including psychrometer, thermometer, and omni-directional anemometer, was used to record wind speed (W_s), T_a, average RH, globe temperature (T_g), and solar radiation (R_s) from 10 am to 6 pm at 10-minute interval. The company calibrated the sensors the week proceeding to the start of the field experiment.

A handy 38-mm black globe thermometer was used to record the T_g. The equipment was positioned 1.5 m above the ground level using tripods at four pre-selected points in the squares at different times. This could be helpful in understanding effects of changing environmental situations on the visitors' thermal comfort across the square. In Naghshe-Jahan Square, the 1st point was situated on top of an platform (80 cm height) near the entrance porch of Sheikh Lotfollah Mosque, shielded with albedo stone 1 m away from the façade. This area was under shade of the mosque for two hours in the morning during the fieldwork period. The second point was located within the vicinity of the bushes. The 3rd point was adjacent to the fountain and pool at the central part, and the last point was in the middle of a wide pathway, far from any environmental element. The four locations were labeled as P1-P4, respectively.

Four locations were similarly chosen in the Jolfa Square. The first point (P1) was located at the covered colonnade in the southern part. A fully shaded area under the arcade attached to square was allocated to the second point (P2). In order to determine the role of plants, the microclimatic parameters were also monitored at the north eastern corner of the square under the tall and relatively dense trees (P3) as the baseline conditions. Finally, P4 was situated in an open area in the center of the square. The data logger recorded data at a unit pre-selected point every day during the fieldwork. In fact, the fieldwork team only recorded the microclimatic situations of one of the pre-selected points during each day of the fieldwork in each square. The datasets were compared to the meteorological data obtained from the Isfahan meteorological station with WMO code 40800 and coordinates 32.47 N, 51.72 E, 1,550 m to ensure the accuracy and reliability of datasets. The distance of this station from Naghsh e Jahan Square and Jolfa Square is 8 and 10 km respectively.

2.3. Surveys

Structured interviews by questionnaire surveys were simultaneously carried out with the microclimatic measurements. The demographic information, the subjects' activity level and attire constituted the first section of the questionnaire. The respondents' preferences for the microclimatic parameters, overall comfort (OC) and TS were gathered on the ASHRAE scale (3, 7 and 5 points, respectively). The 3rd part questioned the reasons that brought the visitors to the square. Samples were selected randomly among the population attending the square.

2.4. Simulation by NN-ARX model

2.4.1. Input and output parameters

Computing modelling is a new method of perception analyses (Kariminia, Motamedi, Shamshirband, Petković, et al., 2015). As it was previously explained, this study evaluated the TS of subjects by deploying a non-linear model, known as NN-ARX, was employed. The inputs of the model were age group, gender, Tg, air temperature (Ta), RH, Rs, Ws, and Wind Direction (Wdir). The input data were gathered by questionnaire survey and fieldwork. The output of the model in this study was a common and useful thermal index i.e., PMV. This index was developed by

Fanger (1972) through extended and tightly-controlled laboratory experiments, based on the body energy balance model. This model integrates the T_a, W_s, radiant temperature, RH, clothing insulation and activity level. The PMV values were calculated by the RayMan model. The environmental and personal values obtained from the fieldworks in the model were inserted in the calculation, including the T_a, RH, W_s and the subjects' clothing and activities. The model's accuracy formerly ratified (Hwang, Lin, Cheng, & Lo, 2010), was verified once more in the current research, explained in Section 3.

2.4.2. NN-ARX with exogenous inputs

The artificial neural network) is an developing method. Lately, a combination of Autoregressive Extra Input (ARX) and artificial neural network (ANN) (NN-ARX) became popular in the field of control. Essentially, NN-ARX has a linear structure that can be defined as (Kariminia, Motamedi, Shamshirband, Piri, et al., 2015):

$$A(q)y(t) = B(q)u(t-n_k) + e(t) \tag{2}$$

, where $e(t)$ signifies the white noise, $u(t)$ represents a vector with all the inputs and $y(t)$ is the output. $B(q)$ and $A(q)$ are the polynomials relating to the time shift operator with the orders of and n_b and n_a, respectively. Also, n_k represents the time delay. Some researchers have used the structure of the NN-ARX. The expected value of $y(t)$, articulated by $\hat{y}(t\,|\,\theta)$, is:

$$\hat{y}(t\,|\,\theta) = f(u(t-n_k),\ldots,u(t-n_b-n_k+1)y(t-1),\ldots,y(t-n_a)) \tag{3}$$

, where $f()$ is the ANN's nonlinear mapping, and θ represents the parameters of model.

This step does not deal with the experimental phase similar to the working principle of the System Identification Toolbox from the MathWorks, Inc. Proper sampling frequency should be used to obtain the experimental data. The obtained data describes the underlying system during operation:

$$Z^N = \{[u(t), y(t)] | t = 1 \ldots, N\} \tag{4}$$

, where $y(t)$ is the measured output signal, $u(t)$ represents the control signal and t is instant number for sampling. Here, $u(t)$ and $y(t)$ are vectors that have more than one input and/or output.

3. Results and discussions

In followings, we present the experimental results of this study and the results of NR-ARX methodology.

3.1. Experimental results

Figures 1 and 2 display some of the microclimatic data recorded on the first day of the fieldwork in both squares. It is clear that throughout the day, T_a shows a steady pattern of increase until around 17:30 pm, while the RH decreases from morning to evening. Typically, the wind speed is very low in Isfahan city all year round. Based on the data presented in Fig. 2, the wind speed reaches to the highest value of 1.1 m/s, while in most of the day time it is approximately close to zero.

Prior to calculation of the thermal comfort index, to evaluate the accuracy of measurement procedure, the recorded data by the data logger at the squares were compared to those obtained from the Isfahan meteorological stations as the nearest meteorological station. Explicitly, values of the measured and modelled T_{mrt} for both squares were compared. For calculating T_{mrt} from the recorded parameters, this study applied Eq.1:

$$Tmrt = \left[(Tg + 273.15)^4 + \frac{1.1 \times 10^8 Ws^{0.6}}{\varepsilon\, D^{0.4}} \times (Tg - Ta)\right]^{0.25} - 273.15 \tag{1}$$

For this validation, T_{mrt} was chosen for two reasons. Firstly, it integrates T_a, W_s and R_s that can be easily measured and modelled. Secondly, it is the most important thermal factor under the sunlight and in summer (Kariminia, Ahmad, et al., 2015). Figure 3 shows the correlation between values of the T_{mrt} measured in the two squares and those obtained. The similar trends and values, small discrepancies and in total strong correlation (R^2 = 0.92, support the accuracy of the applied model.

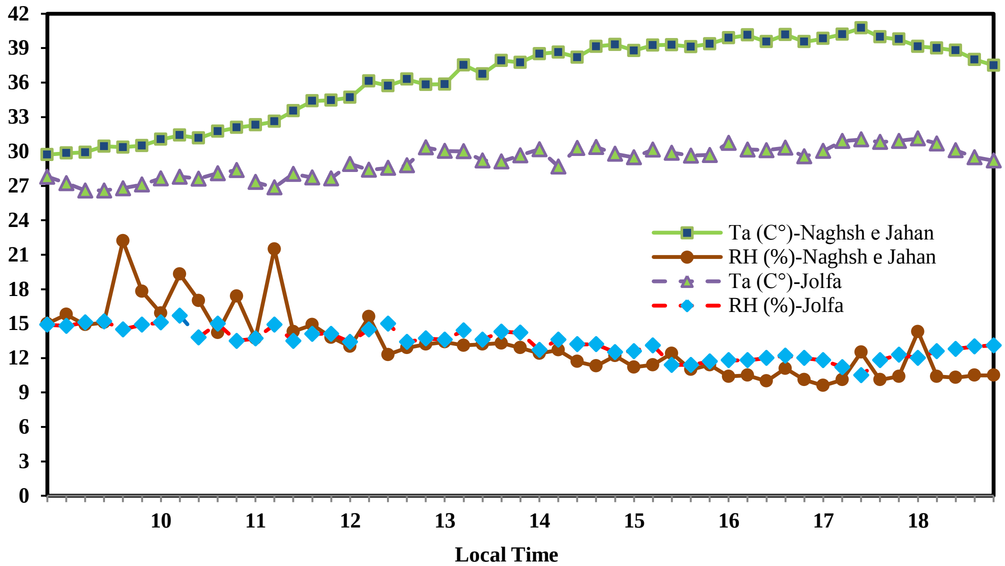

Fig. 1 Values of Ta and RH recorded on 12 July in Naghsh e Jahan & 19 July in Jolfa

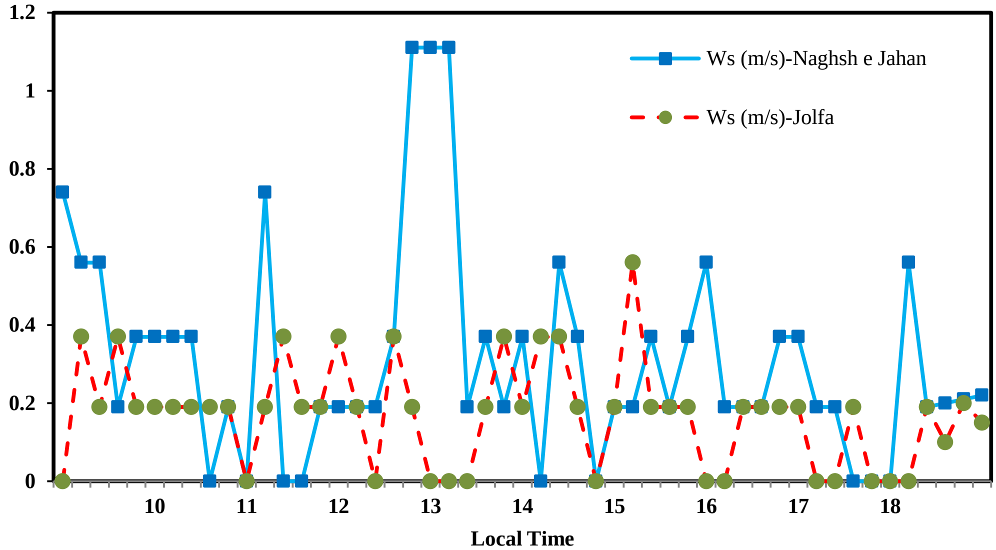

Fig. 2 Values of Ws recorded on 12 July in Naghsh e Jahan & 19 July in Jolfa

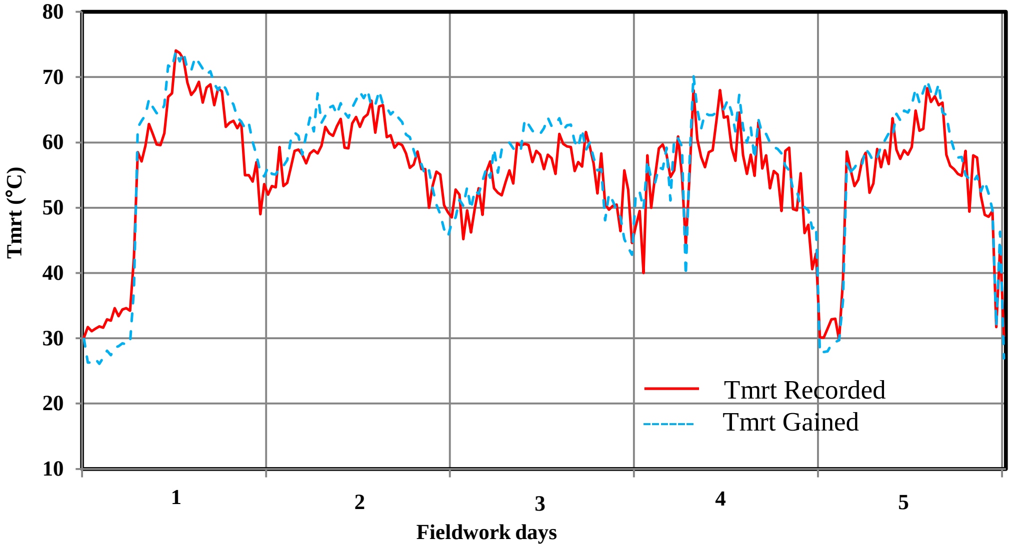

Fig. 3 The T_{mrt} obtained in five days of fieldwork in Jolfa Square (20-24 July) compared to the meteorological data of the nearby station

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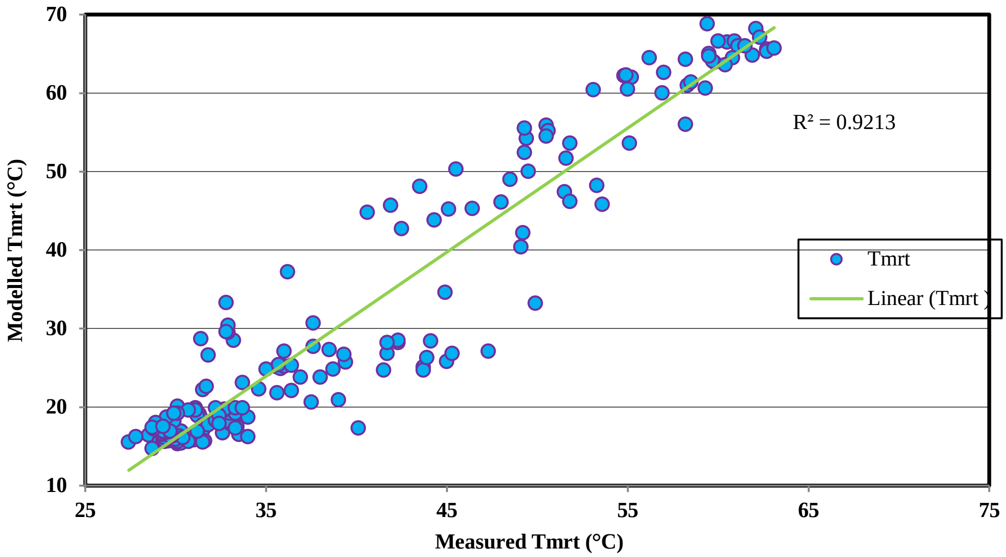
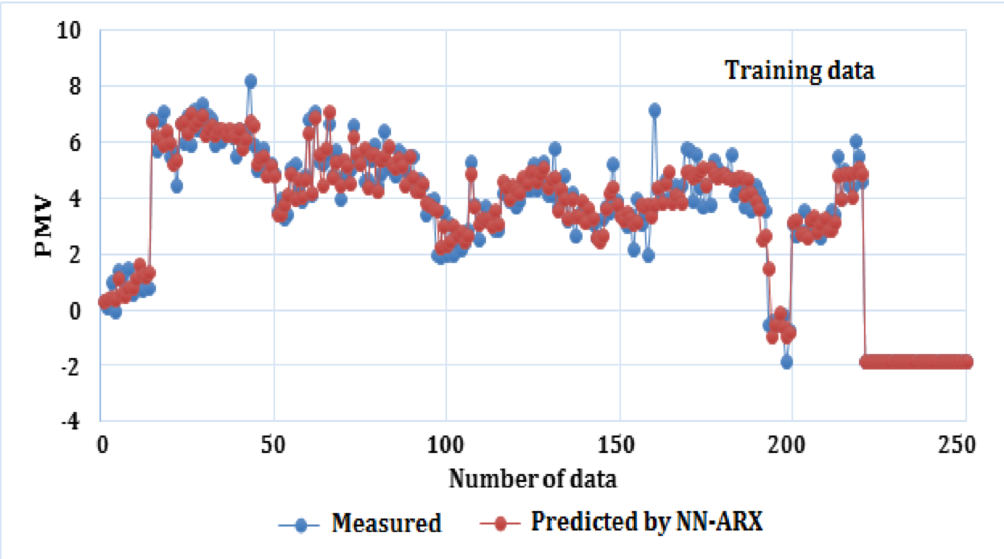
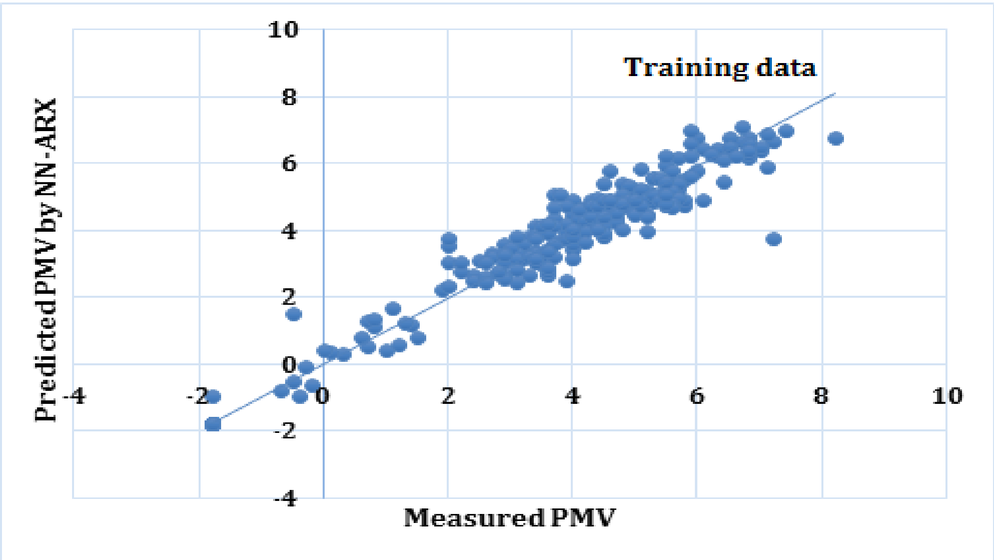


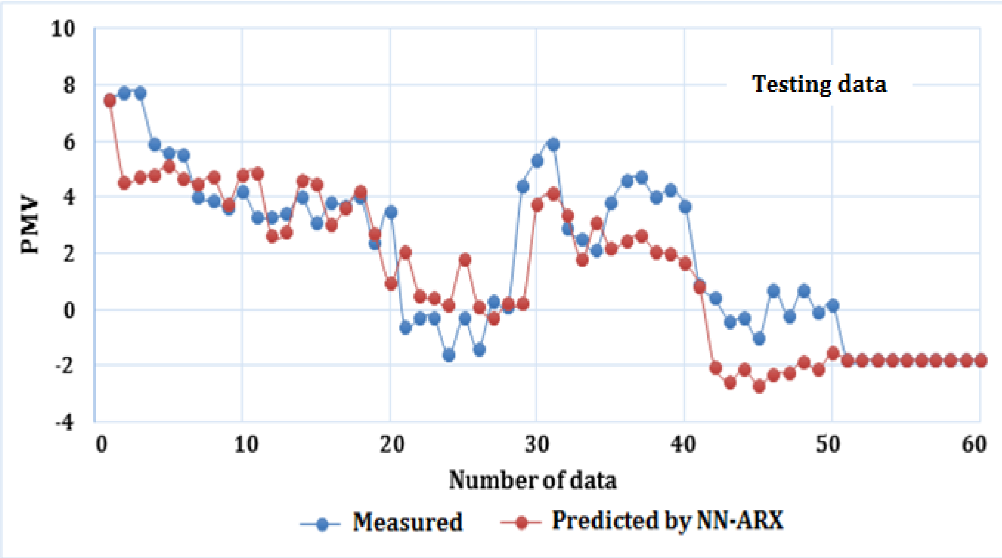
Fig. 4 Correlation between the modelled and the measured T_{mrt} during the whole fieldworks in the both squares

4.2. Results of NN-ARX prediction model

In this study, a comprehensive examination was carried out based on the given inputs in order to make regression and choose a set of optimal inputs combination. The most influential input of the outset for the estimation of output was recognised and determined. The primary aim was to predict a common useful index, namely the PMV. The predictions were conducted via the developed NN-ARX model. The achieved predictions for the output index were compared to the actual values in Figure 5 for both training and testing data. According to this figure, it is observed that the precisions of the predicted values by NN-ARX model are quite favourable. In fact, the predicted values can follow the actual values with very good accuracy. It is also noticed that further precision is attained for the training phase compared to the testing phase. The same numbers of training and testing data were utilized; however, for the scatter plots presented, the number of points seems to be limited compared to other scatter plots, because the values of some points are similar. One can note that some points show strong differences between the observed and predicted values. It can be attributed to the measurement data, calibration of measurement data and overtraining of the proposed models.







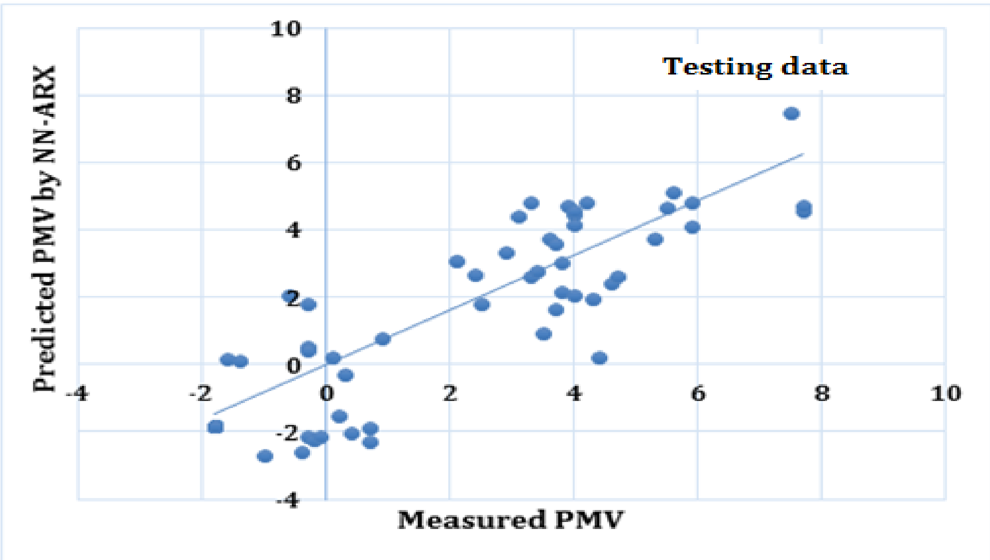


Fig. 5 Comparisons between the measured PMV and the predicted values by NN-ARX for the training and testing phases.

4. Conclusion

The Artificial intelligence models are considered as highly capable techniques for predicting the unknown parameters. In this research work, a nonlinear model (NN-ARX) was employed for identifying its suitability to estimate the effect on the visitor's TSs. A systematic approach using the NN-ARX model was followed to choose the main leading parameters for predicting the thermal comfort of visitors in 2 squares in Iran. A portable data collection mini weather station was employed to log the T_a, T_g, RH, W_s and R_s from 10 am to 6 pm at 10-minute intervals from 12th to 24th July, 2014. Simultaneously, a questionnaire survey was used to find the TSs of visitors. For this study, a common useful index i.e., the PMV was used to evaluate the interviewees' TSs.

The process had many stages to find a subgroup of overall logged parameters, showing good prognostic ability. A comprehensive search was performed on the given inputs to choose a set of optimal input combination, and to make regression. Afterwards, these values were used to determine useful index of the subjects; PMV. It was found that T_a and R_s were the most effective parameters on the thermal perception, and can be considered as accurate predictors. The attained statistical indicators of the MAE and the RMSE were 1.28 and 0.71.
The accuracy of NN-ARX was verified. Based on the results of both training and testing phases, the NN-ARX model provides a good prediction capability for thermal comfort. In total, due to their accuracy, soft computing models can be widely used in thermal comfort and similar behaviour studies. Polling into deeper problems of visitors is recommended for future research to attain further reliability.

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