Prediction of indoor air temperature for assessment of people's thermal stress

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Abstract. Climate change is expected to increase the frequency and intensity of extreme weather events. Individualized and timely advice on how to cope with thermal stress is therefore needed to encourage protective strategies and reduce morbidity and even mortality among vulnerable populations. Such advice can be based on integration of human thermal models, weather forecasts and individual user characteristics. The current study focused on development of an algorithm to predict indoor air temperature and assess indoor thermal exposure with incomplete knowledge of the actual thermal conditions. The algorithm provides discrete predictions of temperature through a decision tree classification with six simple building descriptors and three parameters harvested from weather forecast services. The data used to train and test the algorithm was obtained from field measurements in seven Danish households and from building simulations considering three different climate regions ranging from temperate to hot and humid. The approach was able to correctly predict approximately 68% of the most frequent temperature levels. The findings suggest that it is possible to develop a simple method that predicts indoor air temperature with reasonable accuracy.

1. Introduction

Climate change projections point at increased frequency and intensity of extreme weather events in the future. Individualized and timely advice on how to cope with thermal stress is needed to encourage protective strategies and reduce morbidity and even mortality among vulnerable populations. Outdoors, thermal stress in hot or cold exposures can be evaluated with local weather forecasts and personal information on clothing and activity. Indoors, prediction of people's thermal stress requires knowledge of the indoor air temperature, or better, operative temperature, which is the result of a complex and dynamic building heat balance including external and internal heat gains, ventilation and building properties. The current study focused on development of an algorithm for simplified prediction of indoor air temperature to assess people's indoor thermal exposure with incomplete knowledge of the actual thermal conditions. The algorithm is now implemented in a mobile application that translates thermal stress into coping strategies at individual level.

2. Materials and methods

In the mobile application ClimApp (http://www.lth.se/climapp) evaluation of thermal exposure indoors will rely on calculation of the Predicted Mean Vote index [1]. The calculation is based on local weather data and simple building descriptors that are used to predict the indoor temperature. Other input parameters required to calculate PMV are the mean radiant temperature, air humidity, mean air velocity, clothing insulation and metabolic rate. These five parameters are estimated based on season, geographical location and input provided by the user.

The performance of a decision tree model to predict air temperatures was tested with data collected in field studies carried out in Denmark [2,3]. In addition, a building simulation model was used to evaluate how generalizable the framework was in predicting indoor temperature in different climates. Indoor environment parameters (temperature, relative humidity and CO_2 concentration), outdoor climate, and parameters related with occupant behaviour were monitored across different seasons. Altogether, the prediction relied on eight inputs: three parameters related with the outdoor climate (outdoor temperature, outdoor relative humidity and solar irradiation), three building-related parameters (floor area, number of occupants and construction year) and two parameters related with occupant behaviour (thermostat setting and window opening). The CO_2 concentration was used to evaluate occupancy.

Measured and simulated temperatures were divided into seven discrete categories that each spanned an interval of ±1ºC. Thus, the outcome of the prediction was a temperature interval in which the predicted air temperature would be included. As the method developed in this study should be implemented in a smartphone app, it was essential that it was as simple and reliable as possible. A C4.5 decision tree algorithm was used to predict air temperature. A decision tree is an algorithm that makes predictions by calculating the probability of an outcome, based on the attributes that influence it. The C4.5 decision tree was implemented in Java using WEKA [4].

3. Results and Discussion

Figure 1 shows that the F1-score, which is a measure of the prediction accuracy, differed between locations. Overall, the performance of the algortihm was lower when predicting the simulation data than the real data. For the simulated results, the F1-score was the highest in Athens, compared to the results using the data from Copenhagen and Abu Dhabi. Also, the prediction performance decreased when some of the attributes used as input were omitted from the algorithm. The absence of solar radiation, outdoor temperature and number of occupants decreased the performance with data for Athens and Copenhagen. Only the omission of outdoor relative humidity and solar radiation negatively affected the performance when using the data for Abu Dhabi. The maximum prediction performance was 68% with the most frequent air temperatures in Athens, whereas it was more modest at 50% in Copenhagen and Abu Dhabi.

The distribution of the air temperatures in the testing data set was within a broader range for Athens (from 16ºC to 38ºC) and at a higher level for Abu Dhabi (from 24ºC to 38ºC) than for Copenhagen (16ºC to 30ºC). The highest performance was achieved when predicting the most common air temperature classifications, which corresponded to temperatures between 16ºC and 30ºC. Hence, the method requires that the air temperatures used to train the algorithm data are distributed as evenly as possible across a broad range of temperatures. This maximizes the performance of the method under diverse climate conditions. Testing and improvement of the methodology thus requires comparison of comprehensive sets of measurements and predictions in a wide range of climatic conditions, geographical locations, building properties and user behaviours. In the app, an option is now included that allows the user to evaluate the correctness of the predicted temperature. If the predicted temperature is in agreement with the user's percoption of the actual temperature, the prediction and the corresponding input data will be added to the training data set, enabling continuous adatation of the decision tree algorithm that is updated on a daily basis.

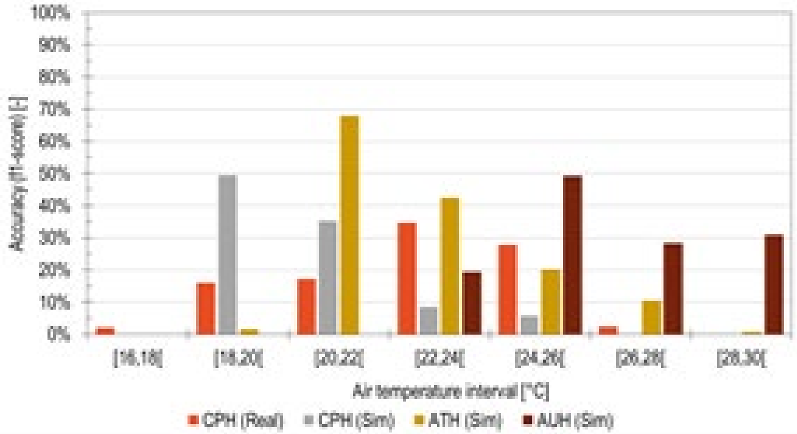

Figure 1: F1-score for data measured in Danish dwellings (CPH (Real)) and simulated for dwellings in Denmark (CPH (sim)), Athens (ATH (sim)), and Abu Dhabi (AUH (sim))

4. Conclusions

This study tested the validity of a method to predict indoor air temperature based on weather data and simple building and behaviour descriptors. The method was able to predict correctly approximately 68% of the most frequent temperature levels. Solar irradiation, outdoor temperature and number of occupants were most important and increased the accuracy of the predictions, whereas building related parameters (construction year and floor area) only had a minor influence on the prediction performance. The data used to train the algorithm was dominated by measurements and simulations representing temperate to cold climate conditions where heating of buildings is typical for conditioning of indoor environments. The accuracy of the temperature prediction may be improved with additional data from climate zones with a higher cooling need.

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