A TRANSIENT TWO ZONE MODEL FOR THERMAL STRATIFICATION IN DISPLACEMENT VENTILATED TOOMS

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SUMMARY

Displacement ventilation (DV) has gained renewed interest in Norway, especially in high performance buildings. The fact that DV can remove contaminants and excess heat significantly more efficient than conventional mixing ventilation, leads to lower air flow rates and hence less demand for heating, cooling and fan energy. In this paper models for vertical temperature gradients in displacement ventilated rooms are proposed. The model is based on a two zone approach, assuming a lower clean and cool zone and a upper polluted and warm zone.

Results from the model have been extensively compared to and validated against measured data from DV rooms. An inter-model comparison against other commonly used thermal stratification models has also been conducted. The two zone model predictions compare very well with the measured empirical data, both for stationary cases and transient cases. The two zone model also predicts better than the three other simplified models used for intermodel comparison in this paper.

Keywords: Displacement ventilation, ventilation efficiency, stratification, validation, two-zone model.

1 INTRODUCTION

Displacement ventilation is an efficient system for removing surplus heat and contaminants. Experience from realized and closely monitored plus energy buildings with DV solutions also shows that the solution works in practice (Dokka et.al., 2015), to achieve both good indoor climate and high energy performance.

To design accurate and good DV solutions it is necessary to predict the thermal comfort, the heating and cooling load and energy use during various conditions (e.g. winter, summer, fall and spring). With simulation tools and models different design solutions/options can be evaluated at a very low cost. In this paper models for vertical temperature gradients in displacement ventilated rooms are proposed. The model is based on a two zone approach, assuming a lower clean and cool zone and a upper polluted and warm zone. The proposed models can be used for design of displacement ventilation and evaluation of ventilation efficiency. They can also be implemented in transient building simulation tools. The two zone model is described and mathematically deduced in (Dokka, 2000). The two zone model is in this paper compared to other simplified models and also empirical experiments.

2 METHODS

For verification of the proposed two zone model both comparison against other simplified models (intermodel comparison) and comparison with measured data (empirical validation) has been conducted.

2.1 Intermodel comparison

Three different models for prediction of temperature stratification in displacement ventilated rooms under steady conditions have been chosen for the inter-model comparison. They are:

- the "rule of thumb" model proposed by Skistad (Skistad, 1994)
- the simplified model by Mundt (Mundt, 1996), where the floor temperature is deduced from the specific ventilation air flow
- the simplified model by Nielsen (Nielsen, 1996), where the floor temperature is deduced from the Archimedes number.

2.2 Empirical validation

Empirical data sets (measured data) for validation and comparison of the models have been taken from the literature on displacement ventilation. There exist a lot of experimental investigations on temperature stratification in displacement ventilated rooms. Many of them, however, ignore, or fail to report, important parameters that influence thermal stratification. The cases chosen for validation of the models have detailed temperature measurements and most of the data needed for prediction.

Data sets for the empirical validation and inter-model comparison of the steady state thermal model have been taken from Mattson (Mattson, 1999): two offices and two classroom cases. Li et.al.(Li, 1992&1993): two office cases. Brohus & Nielsen (Brohus, 1996): one meeting room case. These rooms differ in size from 15 m² to 60 m² and in ceiling height from 2.5 m to 4.2 m. The heat load varies from 8 W/m² to 48 W/m², and the specific air flow rates are in the range: 1.38 l/sm² to 3.16 l/sm². This conditions are fairly representative for rooms in office and educational buildings. In addition a transient (time dependent) cases from Mattson (1999) have been used to verify the transient solution of the proposed two-zone model. See Dokka (2000) for more details.

2.3 Compared quantities

To compare the models with measurements and the other three simplified models, the following three temperatures are compared: #1. The average temperature in the occupied zone, which in all cases is set to 1.2 meters above the floor, assuming seated activities. #2. The temperature in the non-occupied zone (above 1.2 meters). #3.The air temperature at floor level (10 cm above the floor)

In addition, the following indices are compared:

- the temperature effectiveness in the occupation zone, defined as the difference in extract- and supply temperature divided by the difference in temperature in the occupied zone and the supply temperature.
- the normalized floor temperature, defined as the difference in floor temperature and supply temperature divided by the difference in extract- and supply temperature.
- the mean temperature gradient, defined as the difference between the temperature in the upper polluted zone and the temperature in the lower clean zone, divided by half the ceiling height.

3 RESULTS AND DISCUSSION

3.1 Comparison of temperatures

Figure 1 to 3 shows the compared temperatures in the occupied zone, the non-occupied zone and the floor temperature. In all 21 cases (3 x 7) the difference between the measured temperature and the prediction with the two-zone model is within 1 K, which is a reasonable demand for accuracy if the model should be used for design. The prediction with the model of Skistad is less good, where 8 cases is above 1K different from the measured value. The prediction with the model of Mundt is also less good, where 10 cases is above 1K different from the measured value. The model of Nielsen is somewhat better with 7 cases above 1K different from the measured value.

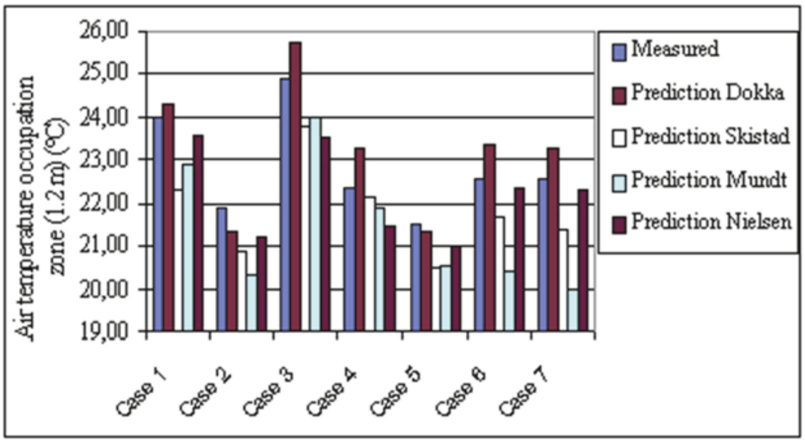

Figure 1. Average temperature in the occupied zone (1.2 m high).

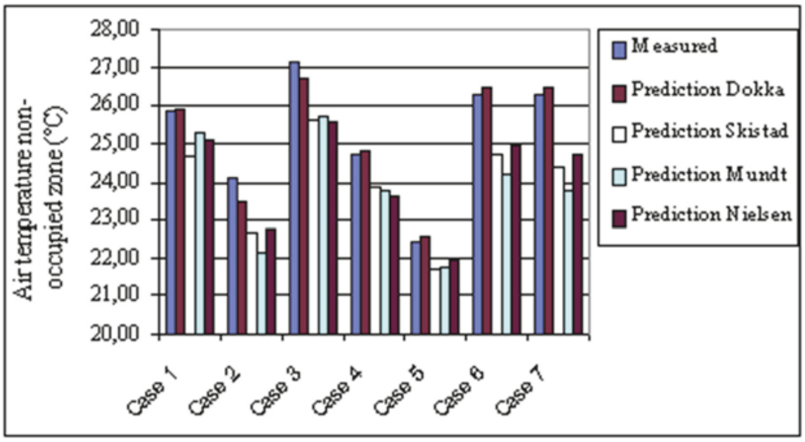

Figure 2. Average temperature in the non-occupied zone (above 1.2 m).

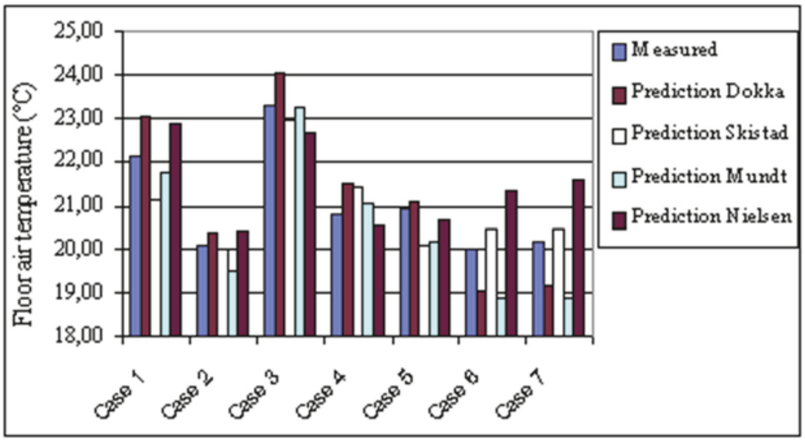

Figure 3. Floor air temperature (0.1 m above floor).

3.2 Comparison of temperature indices

Figures 3 to 6 shows the compared temperature effectiveness, the normalised floor temperature and the mean temperature gradient. The difference between the measured temperature effectiveness and the prediction with the two-zone model is reasonable good for all cases. The prediction with the three other models is less good, especially the models of Skistad and Mundt predicts more than double the temperature effectiveness compared to the measured for several cases.

The difference between the measured normalised floor temperature and the prediction from the three models is generally small and there is not much difference between the three. The same goes for the linear temperature gradient where the predictions is generally good, with a small exception of the model of Nielsen which underpredicts for case 6 and 7.

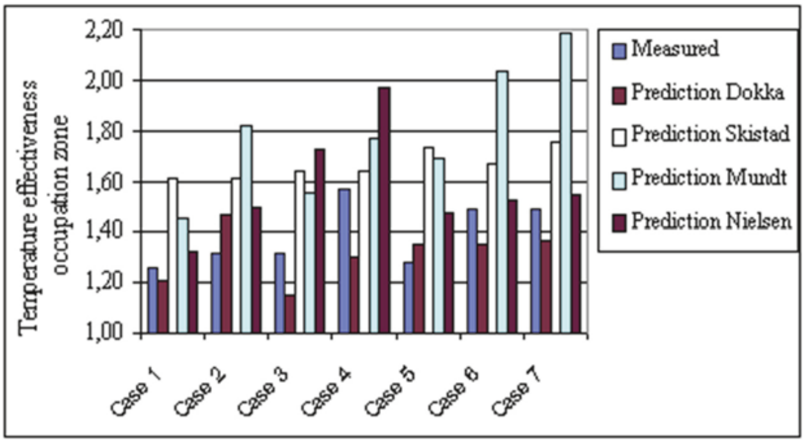

Figure 4. Temperature effectiveness occupation zone (1.2 m high).

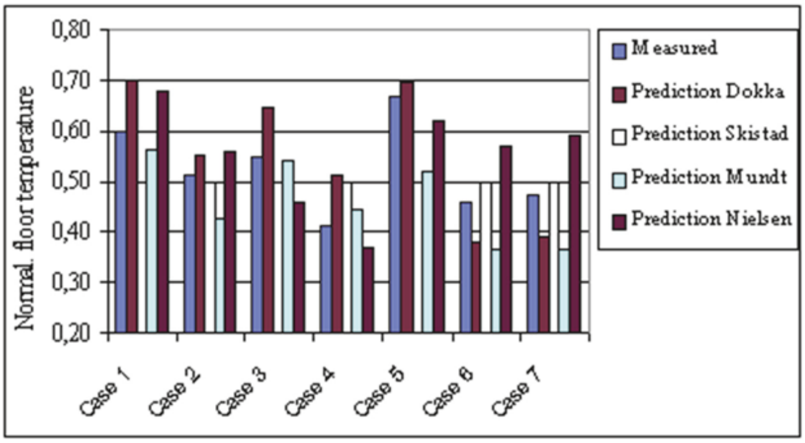

Figure 5. Normalised floor temperature.

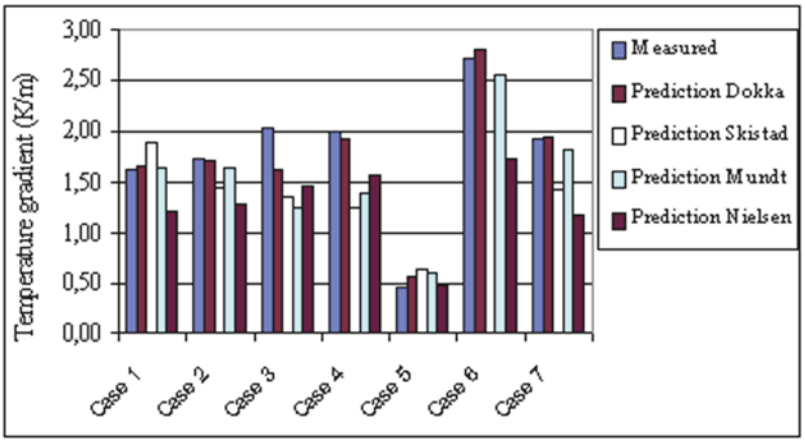

Figure 6. Linear temperature gradient in the room.

3.4 Comparison transient cases

Figure 7 and 8 shows the comparison of the measured temperature during an 18 hour transient experiment in a class room (Mattson, 1999) compared to the predicted temperatures from the transient two-zone model. The predicted transient temperature curve follows the measured ones very closely, both in the extract and in the occupied zone.

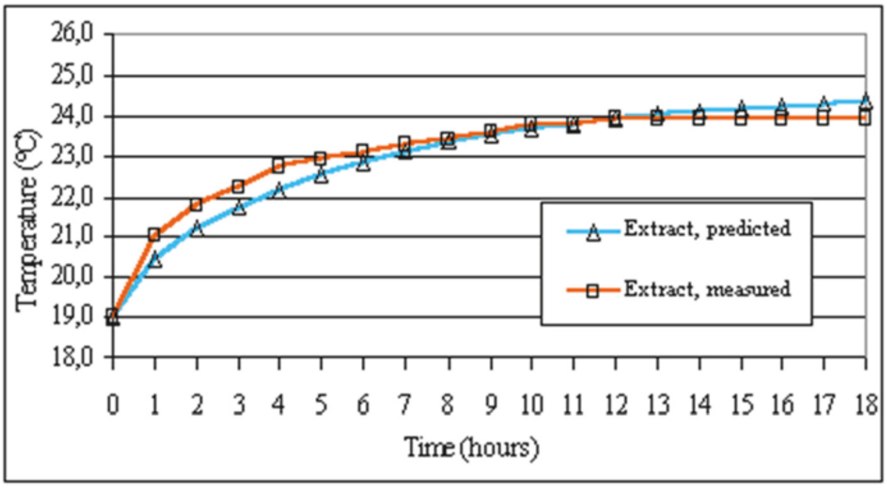

Figure 7. Comparison of measured and predicted temperature in the extract.

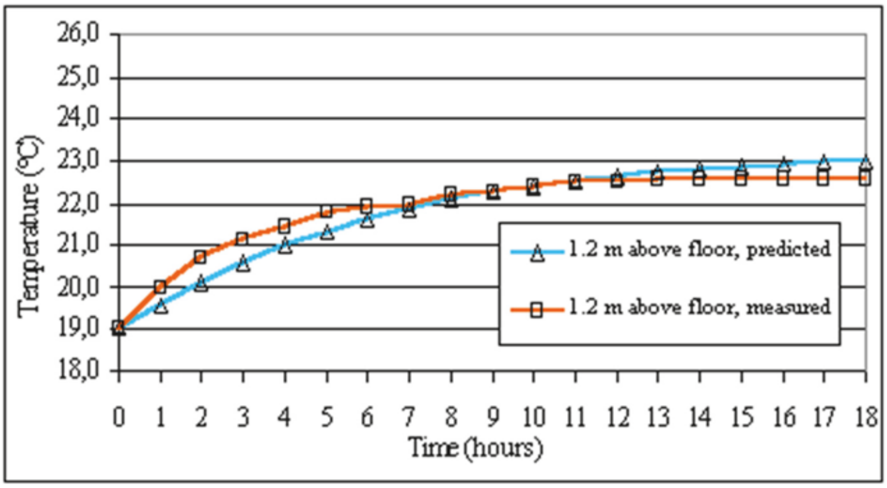

Figure 8. Comparison of measured and predicted temperature 1.2 meter above the floor in the classroom.

5 CONCLUSIONS

The following conclusions can be drawn from the experimental validation and from the inter-model comparison:

- The presented two-zone model is predicting well for all the seven cases and the three compared temperatures, and also the three compared indices. The validity of the steady state thermal model can therefore be regarded as good for rooms similar to those tested here (small to medium large rooms).
- The predictions of the proposed two zone model are closer to the experimental data than the predictions using the models of Skistad , Mundt and Nielsen. However, the two zone model is slightly more complex than the three other models, but can be defended by its better predictive capability.
- The transient thermal two-zone model is in very good concordance with experimental data. However, the model should be compared to more transient cases before a final conclusion can be drawn about the validity of the model.

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