An accurate model to design displacement ventilation in office rooms

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Thermal comfort estimation and airflow rate calculation for displacement ventilation (DV) directly depends on indoor temperature prediction. Inaccurate estimation can result in 2–3 °C temperature difference compared to the target design values, which could lead to poor thermal comfort in the occupied zone. The paper presents a more accurate model to design DV.

Keywords: Displacement ventilation, temperature gradient, simplified model, internal heat loads, mixing height

Modelling of displacement ventilation

First implemented in industrial buildings displacement ventilation (DV) has gained extensive use in commercial buildings. In DV systems, cool air is supplied into the occupied zone of the room near the floor at low velocity and then entrained by buoyant plumes over any warm objects. As a result, a two-layer room air temperature profile, stratified and mixed, is developed. Ideally, the cleaner outdoor air movements utilised by thermal plumes transport heat and pollutants to the layer above the occupied zone. The transition level between a mixed upper layer and stratified layer is called mixing height. Controlling the mixing height position is one of the most challenging tasks in DV system design.

Since in office buildings cooling requirements are important, the temperature-based design method is applied in this case. An accurate temperature gradient calculation is essential for DV system design, since it directly relates to the calculation of supply air flow rate. Several simplified nodal models were developed in order to estimate the temperature stratification in rooms with displacement ventilation. Five models with different approaches were chosen to be analysed and compared with the proposed one: the Mundt (Mundt, 1996), the Nielsen (Nielsen, 2003), the Rees (Rees, 2001), the Mateus (Mateus et al, 2015) and Nwe nodal model (Lastovets, 2018). Some of the models are already implemented in the various building simulation programmes The Mundt and the Mateus et al. models are implemented in EnergyPlus and the Mundt model is also available e.g. in IDA ICE. However, validation and development of the calculation methods have been based mainly on measurement using low ceiling height (below 3 m), while displacement ventilation is usually applied for high-ceiling rooms. Also, the previous studies have not covered typical head loads and office layout that exist in office buildings. As a result, the calculation methods based on these studies are not able to correctly predict the occupied zone temperature (Kosonen et al., 2016). It leads to poor thermal comfort and inadequate sizing of the ventilation system. In the paper, the main factors affecting the temperature gradient in office rooms with DV are presented and analysed based on the experimental results.

Effect of the ceiling height

The test setup to analyse the DV performance in the room (20.8 m² floor area and room heights of 5.12 m and 3.33 m) with different flow elements is shown in (**Figure 1**).

The case with the lower height was organized so that the whole ceiling was moved down together with the exhaust diffuser, heated foils and light units. The internal heat loads consist of heated cylinders representing persons, heated cube-shaped boxes representing computers, heated foils on wall, floor and ceiling representing solar load on window at different levels and fluorescent lighting units. The temperature profiles are measured from four locations (P1-P4 in **Figure 2**) at ten heights with calibrated PT100 sensors (accuracy ± 0.2 °C). Surface temperatures were measured with Testo 830-TI-infrared thermometer (accuracy ± 0.1 °C). Supply and exhaust air flows were measured with air flow rate measurement device MSD 100, that was calibrated with an orifice plate to reach the accuracy ±3%.

The measured data of the temperature gradient for the typical indoor heat loads were compared with the calculation results of the selected simplified nodal models: the Mundt, the Nielsen, the Mateus, the Rees and New nodal model. The results of the corresponding measurements and calculations are presented at the **Figure 2**.

In the cases with low level loads, heat sources the major part the gradient exists in the occupied zone regardless of the room height. The influence of the room height on the vertical temperature difference is essential in the cases with high-level heat loads, when the temperature

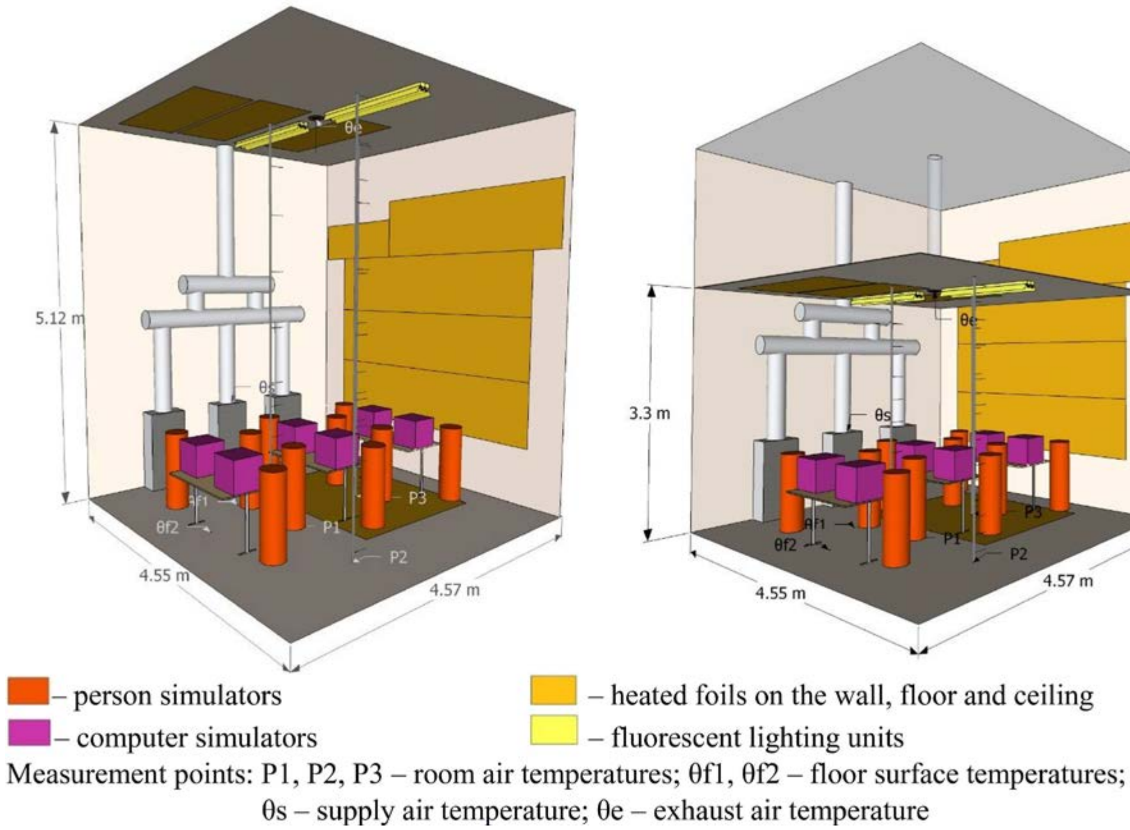

Figure 1. Measurement setup to study the effect of different room heights and heat loads.

tends to stratify over the mixing level. However, for the cases with only vertical heated surfaces, air flow rate is more influential on the temperature gradient in the rooms with different heights

Effect of office layout

In addition, the model was validated with the experimental results published by Arens (Arens, 2000) for open-plan and cubicle-style office arrangements.

The test room layout is shown in the **Figure 3**. The open-plan office case was measured with the partitions dividing the workplace, whereas the cubicle-style office includes them. The supply air is delivered from two opposing air diffusers, whereas the exhaust grille is located overhead at height of 5 m. The internal heat loads were modelled by

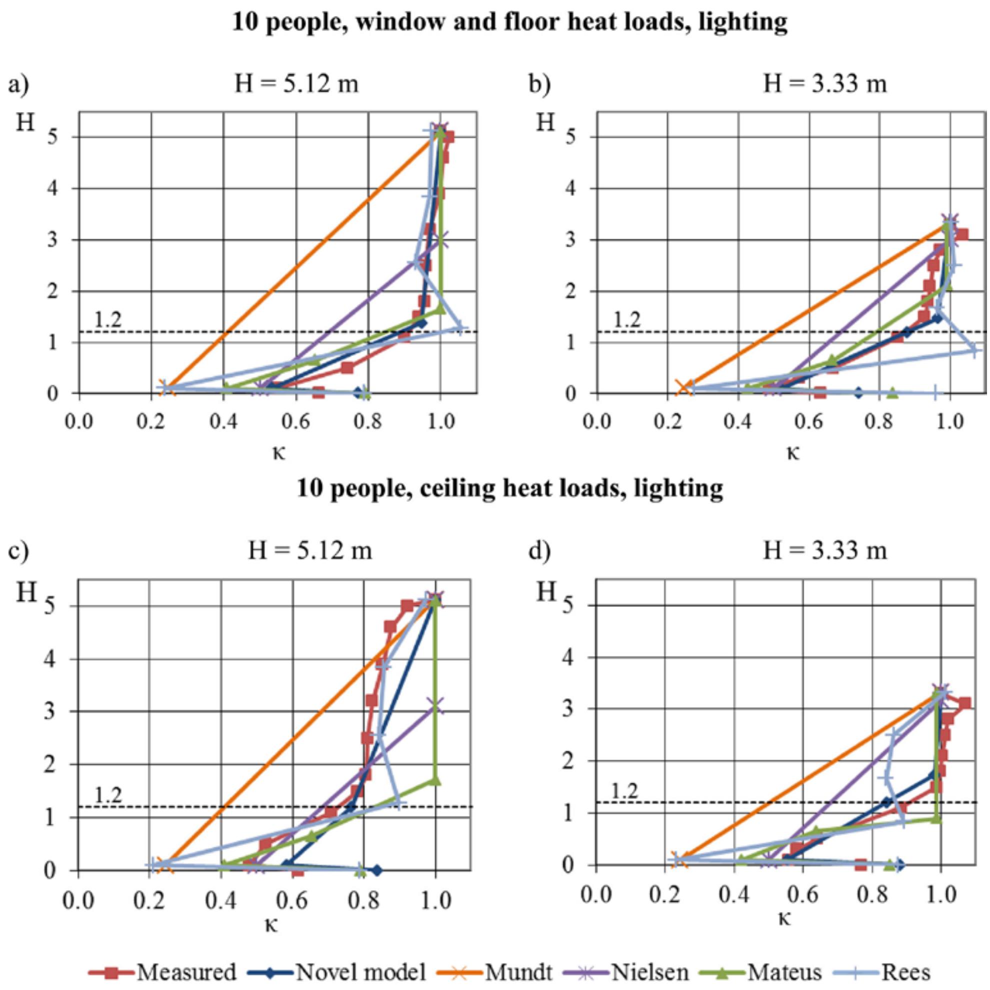

Figure 2. Measured and modelled temperature gradients for the rooms with different heights and heat loads.

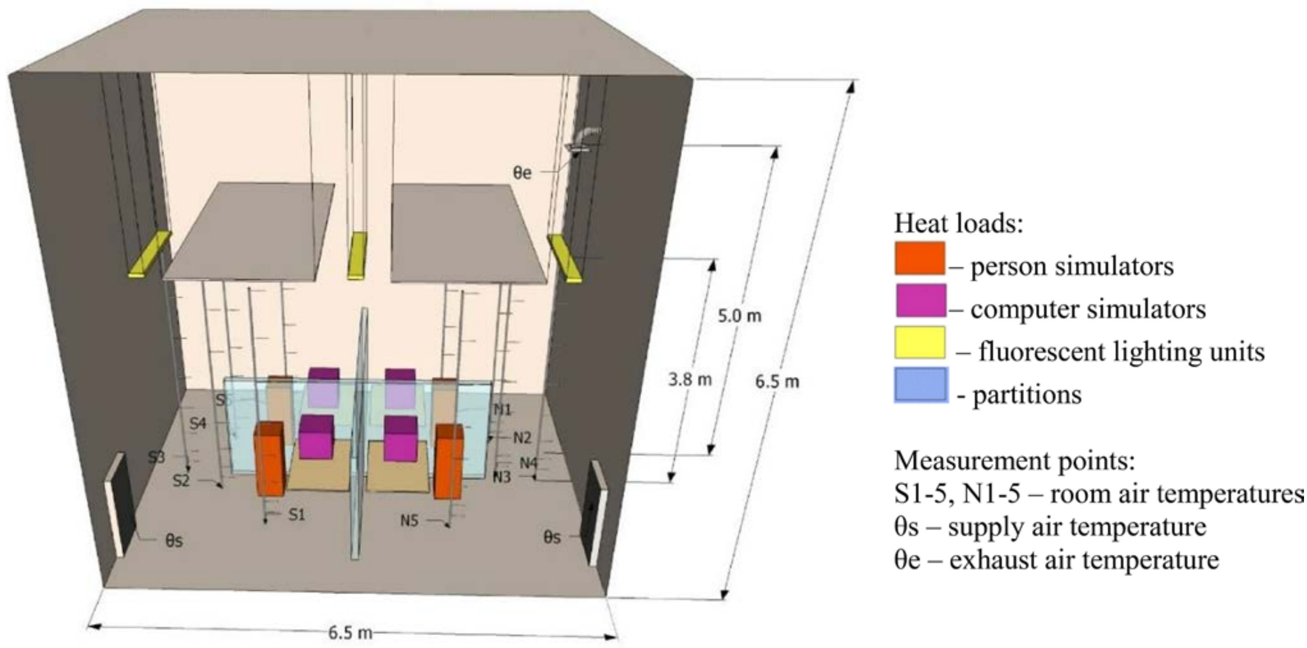

Figure 3. Measurement setup to study the effect of different room heights and heat loads.

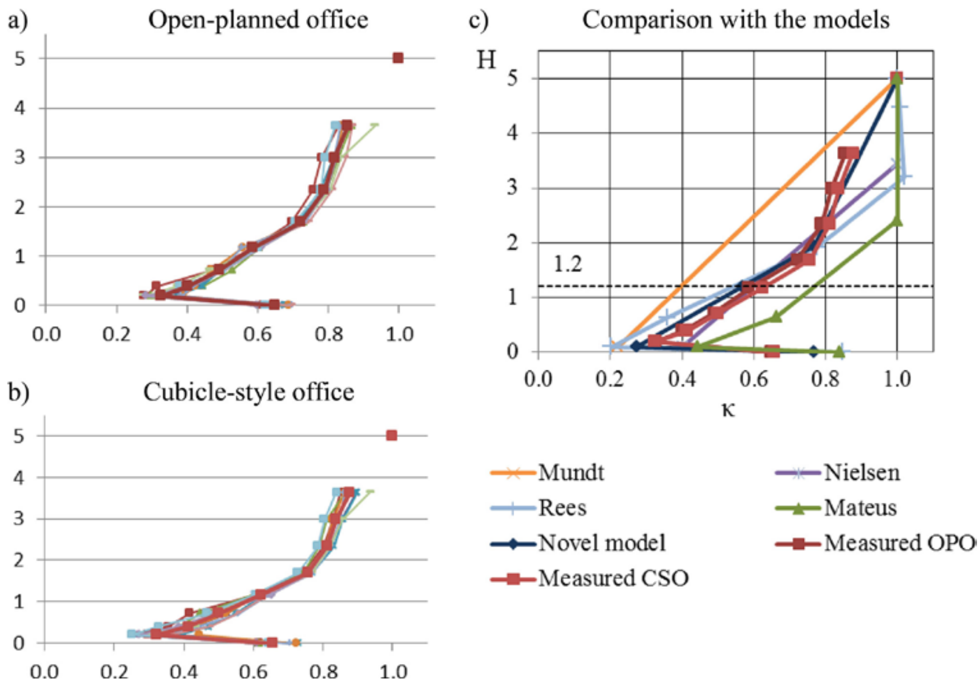

Figure 4. Measured and modelled temperature gradients in different place of the room.

rectangular person and computer simulators and 3 rows of lighting units. The room height is 6.5 m, whereas the fluorescent lighting fixtures were located 3.8 m above the floor. Air temperature measurements were conducted with 0.6 mm diameter copper-constantan thermocouples with a ± 0.2 °C accuracy at each of the ten positions indicated during each test.

An arrangement of office layout has some effect of the thermal stratification in rooms with DV (**Figure 4**). Despite the fact that the vertical temperature gradients tend to be similar throughout the room, the office furniture that prevents even air distribution increases unevenness of temperature stratification in low zone of the room.

Conclusions

In the present study, five simplified nodal models are analysed and validated with the experimental results in two measurement setups. In addition, the effect of the room heights and locations of the indoor heat sources were studied for the typical office environment. The experiments demonstrate that displacement ventilation provides even temperature gradient throughout the simulated office room spaces. The influence of the room height on the vertical temperature gradient is significant in the cases with high-level heat loads. The new nodal model demonstrates an accurate calculation of the vertical temperature difference for the typical heat loads office layouts. ■

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