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Downdraught assessment during design: Experimental and numerical evaluation of a rule of thumb

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ABSTRACT

Large glass façades are popular architectural features in building design nowadays. However, these façades can result in interior downdraught during periods with low outdoor temperatures. A rule of thumb exists to assess the downdraught risk, based on window height and window temperature [1]. In this paper the validity of this rule of thumb is evaluated by an experimental and a numerical study.

In the experimental part ten healthy male subjects (age 20–26 year) are exposed to two different downdraught conditions in a controlled climate chamber. Experimental results are also used to validate the numerical models. In the numerical (Computational Fluid Dynamics) part a parameter study has been performed to assess the influence of window height and window surface temperature beyond the range tested in the climate chamber. In addition, different floor temperatures have been investigated to evaluate the effect of floor heating as a possible design option to prevent downdraught.

Based on both experimental and numerical results the existing rule of thumb is shown to be conservative. Furthermore, the numerical results reveal that an increased floor temperature (i.e. floor heating) can increase the downdraught risk. Therefore, it is recommended to modify the rule of thumb by incorporating the floor temperature as a parameter.

1. Introduction

Glazed façades and atria are popular architectural building design features. These features are regarded as beneficial measures in terms of daylight. However, these façades may cause comfort related problems due to downdraught. In case of downdraught the air layer close to a cold surface (i.e. window) is cooled, which causes this layer to flow downwards due to buoyant forces. In this paper the term 'downdraught' is used for this type of buoyancy driven flows.

If the cold air flow is not compensated for by an upstream air flow, the cold air can penetrate into the living zone [2]. Until ten years ago downdraught related problems were mainly solved by placing heating appliances underneath glazed façades and large windows. With the improvement of the thermal performance of windows and window systems since, additional heating appliances may not be necessary anymore [3–7]. However, in current building practice often a cautious approach is taken. Therefore, radiators, convectors or floor heating systems are installed beneath windows while they might not be required with respect to downdraught.

According to Huizenga et al. [4] two aspects are important regarding a glazed façade in relation to thermal comfort: cold radiant asymmetry and draught. Radiant asymmetry is influenced by the surface temperature of the window, posture and position of the subject and human factors like clothing level and metabolism. Draught is affected by the air velocity, turbulence intensity and air temperature.

Several numerical and experimental studies have been conducted to improve understanding of the flow principle and the effect of several solutions to prevent downdraught. Heiselberg, among others, concluded that windows up to 2.5 m height do not cause downdraught related problems in case of well-insulated glazing systems (expressed by a maximum temperature difference between the room air and the window surface of 2.5 °C) with the occupied zone starting at 0.6 m from the window [2].

To assess the risk of downdraught in the design phase several rules of thumb are available. Olesen, among others, defined a rule of thumb that allows assessment of the maximum window height (h in m) in combination with the U-value of the glazing (U_{glass} in W/m^{2}K) with given constraints on the maximum accepted air velocity (v_{air} in

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m/s) in the living area (Equation (1)) [1]. If a lower maximum accepted air velocity is considered, equation (2) can be applied [8].

$$U_{glass} * h \leq 4.7 \text{ W/m K} \quad v_{air;max} = 0.18 \text{ m/s} \tag{1}$$

$$U_{glass} * h \leq 3.2 \text{ W/m K} \quad v_{air;max} = 0.15 \text{ m/s} \tag{2}$$

The numerical and experimental studies from which the rule of thumb has been derived, show some limitations: – Only draught is taken into account, while according to Huizenga et al. [4] radiation also has a significant influence on thermal comfort related to downdraught; – The results are not validated in experiments with human subjects; – In most studies the window height is limited to two or 3 m, while it is expected that frequently installed higher windows cause more problems related to thermal comfort.

As this particular rule of thumb is still applied in practice, the question is to what extent it is able to predict the downdraught risk correctly. As the rule of thumb also does not address contemporary counteracting design solutions, the query arises whether low-temperature heating systems (e.g. floor heating) are able to prevent downdraught.

Following the above, the objective of this study is to validate the presented rule of thumb in an experimental study with human subjects and evaluate its applicability for high windows and configurations with floor heating.

The research method applied experiments with human volunteers in a climate chamber and numerical modelling with Computational Fluid Dynamics (CFD) to evaluate alternative configurations. The experiments with the human volunteers were designed *a priori*. Since, the configuration of the climate chamber did not allowed an evaluation of the downdraught risk with respect to the window height, a numerical study was performed to analyse the effects of the window height. The numerical model is validated against experimental results obtained under the same conditions as the subjects were exposed to.

First, the experimental facility (Section 2) is described. In this facility both subject experiments and measurements to validate the numerical model have been conducted. Description and results of the subject experiments are presented and discussed in Section 3. CFD model details and verification are described in Section 4. In Section 5 the variant study to investigate different downdraught configurations is presented and discussed. In Section 6 conclusions from the experimental and numerical study are discussed with respect to the objective of the study. The paper ends with conclusions and implications for building practice and topics for future work (Section 7).

2. Experimental facility

Both the experiments with human subjects and the experiments for validation of the CFD model were carried out in a climate chamber (thermophysiological test room, Fig. 1). The test room is situated at the laboratory of the unit Building Physics and Services of the department of the Built Environment at the Eindhoven University of Technology. The dimensions of the room are similar to a standard office room: 3.6 × 5.4 × 2.7 m^3 (W × L × H). The test room is constructed of a well-insulated chamber (wall thickness is 100 mm). In this chamber the temperature of each surface can be controlled individually in the range of 11–35 °C [9]. Cooling of these panels is possible through a connection to an aquifer system and ranges between 10 and 17 °C. For heating, a boiler in combination with a supplementary electrical heater for fine-tuning the supplied water temperature is applied. The total temperature range of the supplied water is 11–35 °C.

The air was conditioned by an air-handling unit (Verhulst); the ventilation rate was 150 m^3/h. Supply was through a slit (0.01 m

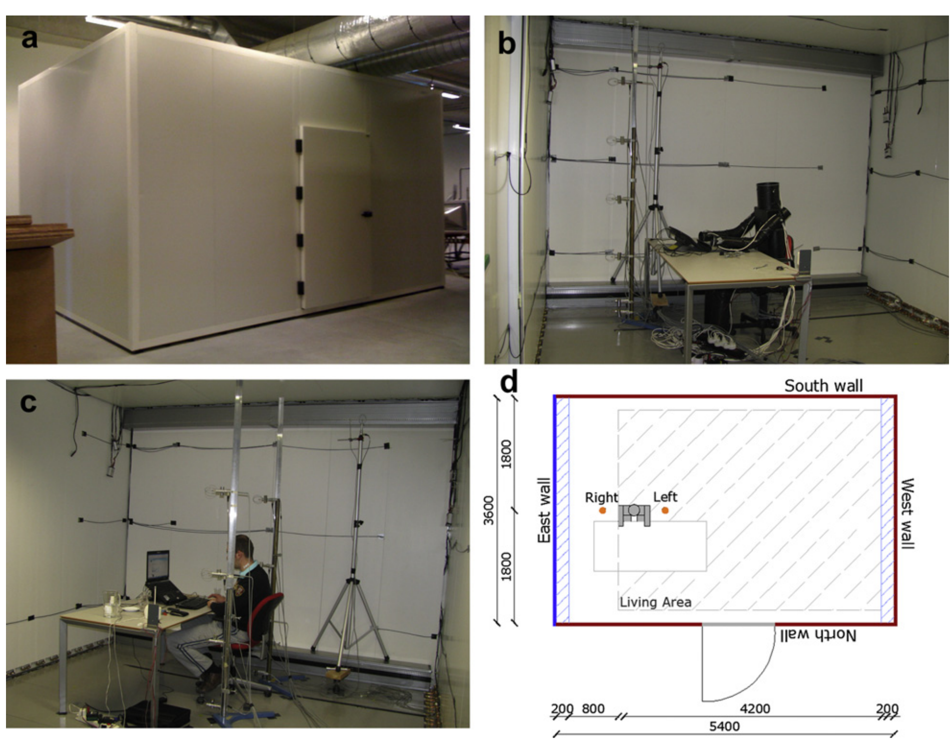

Fig. 1. (a) Thermophysiological test room; (b) thermal manikin in experimental set-up; (c) test subject in experimental set-up; (d) floor plan where the orange dots indicate the measurement stands, the grey hatched surface represents the living area, the blue hatched surfaces represent the plenum boxes and the blue wall indicates the cold wall. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).