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Measuring airflow in a gap-Prototyping an experimental setup and test measurements

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Introduction

The research department of Building Physics at TU Wien is currently trying to enhance numerical methods to quantify advective moisture transport in building components due to unwanted forced and natural convection.

Sarkany, Lewis, and Bednar [7] discussed the difficulties in simulating the advective moisture transport in gaps between and in between the insulation layer and other parts of the floor ceiling in a large-scale experimental setup of a cold attic. [6]. In regard to the validation of coupled models taking into account advective moisture transport Janssens [3] already pointed out:

> "Contrary to convection heat transfer, appropriate examples of this subject for the validation of heat, air and vapour transfer models are scarce in literature."

An error analysis of the influential parameters, the current state and forthcoming steps will be presented for discussion.

Main Objectives

The most prevalent questions the test measurements try to answer are the following:

1. Is the experimental setup fit to measure the volume flow-rate due to pressure differences in a gap?
2. Can this setup measure the influence of surface roughness on airflow within small gaps (approximately 2 mm wide) in building components, even when operating under laminar flow conditions?

Experimental Setup

The experimental setup consists of two insulation panels, where a 2 to 5 mm wide gap is created by a suspension, which also allows manipulation of the gap size, Figure 1.

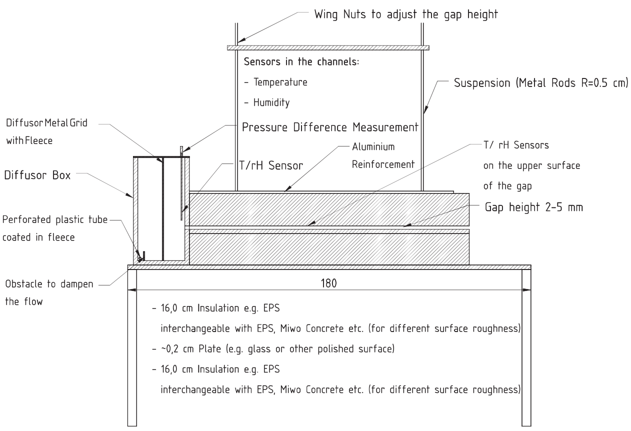


Figure 1: Schemata of the experimental setup for the small-scale experiments.

The experiments are conducted by varying the gap size and for certain gap sizes the pressure difference, depending weather the experimental setup is able to provide the needed volume flow rate.

Physical Model

Due to the instanteneous changes in the air domain compared to the other transport processes in HAM, treating air transport as a steady state phenomenon is acceptable. [5, 1, 2].

In our model the Navier-Stokes Equation can be reduced to the Hagen-Poiseuille Equation 1 [4].

$$v = \frac{h^2}{12\mu} \nabla P \tag{1}$$

Adapting Equation 1 to our experiment and multiplying with the cross section perpendicular to the flow, we get Equation 2, with h, b and L being the gap height, width and length in m, μ the dynamic viscosity in Pa s, ΔP the pressure difference in Pa and $\dot{V}$ the resulting volume flow-rate.

$$\dot{V} = \frac{h^2 bh}{12\mu} \frac{\Delta P}{L} \tag{2}$$

Assuming that there is an influence of the surface roughness on the volume flow-rate and not just the friction factor we can say that

$$\dot{V} = \left(\frac{h^2}{12} \mp k_{measured} \right) \frac{bh}{\mu} \frac{\Delta P}{L} \tag{3}$$

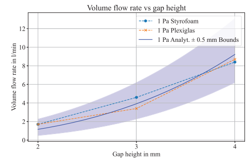
with $k_{measured}$ being the influence of the surface roughness on the volume flow-rate in m^2

Results

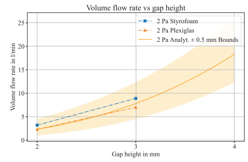
The error analysis in regard of $k_{measured}$ show that the error $\Delta k_{measured}$ **is mainly dependant on the height of the gap**. **A tolerance of 1e-3 mm would be needed** to create results with acceptable measurement errors since $k_{measured}$ is ranging between ≈ 1.e-08 to 1.e-06 m^2 in our test-measurements.

This is further solidified by a comparison of the results of the test measurements with the analytical solution of the expected volume flow-rate in such a gap, Equation 4 [1], taking into account upper and lower bounds due to expected measuring tolerance of the gap height (∓0.5 mm), Figure 2.

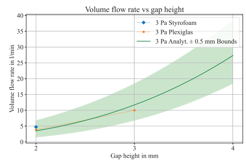
$$\dot{V} = \frac{1}{2 \cdot S'_e} \cdot \left(\sqrt{S_g^2 + 4 \cdot \Delta P \cdot S'_e} - S_g \right) \tag{4}$$



(a) Measurement of the volume flow-rate for different gap sizes and materials under 1 Pa and comparison with the analytical solution.



(b) Measurement of the volume flow-rate for different gap sizes and materials under 2 Pa and comparison with the analytical solution.



(c) Measurement of the volume flow-rate for different gap sizes and materials under 3 Pa and comparison with the analytical solution.

Figure 2: Measurement of the volume flow-rate for different gap sizes, materials, pressure differences and comparison with the analytical solution.

Conclusions

- **A precision of 1e-03 mm is needed to measure the influence of other factors than the gap-height on the volume flow-rate in the gap**
- **Despite the known- and unknown-unknowns due to the current state of the experimental setup, the analytical solution still allows qualitative recreation of the expected volume flow-rates**

Forthcoming Research

The measurement of the advective moisture transport, the analysis of bends and smaller gap sizes 0.5 - 1.0 mm with soft materials like mineral wool will be part of our upcoming works.

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