27/28th International Conference
ENGINEERING MECHANICS 2022
Milovy, Czech Republic, May 9 –12, 2022
Paper **#21**, pp. 49–52, doi: 10.21495/51-2-49

INNOVATIVE DEVICE FOR THE SIMULATION OF ENVIRONMENTAL CONDITIONS AND TESTING OF BUILDING MATERIALS

Cacciotti R.[*], Wolf B.[**], Macháček M.[***], Frankl J.[†]

Abstract: *Excessive humidity influences the performance of building envelopes and the safety of their occupants. Moisture related problems can indeed impose significant health risks for buildings' users and even lead, under extreme scenarios, to structural failures. This paper investigates an innovative experimental setup for evaluating the influence of changing environmental conditions on the performance of building materials. It stems out from a broader ongoing research aimed at studying the trends of mould growth on wooden building components. The presented results include the design, construction and numerical validation of a small-scale climatic wind tunnel (2m x 1.8m ca.) to be used for the simulation of natural ventilation and daily humidity and temperature fluctuations. Key findings include the final design of a low cost, modular construction which allows gathering reliable data on the response of building materials exposed to changing boundary conditions, intended for improving current mould growth models. Future work is also suggested.*

Keywords: Building envelope, Moisture, Building material, Wind tunnel, Performance.

1. Introduction

The presence of moisture in buildings may lead to various issues ranging from inadequate usability to material durability and structural integrity. In real life situations, the combination of time-dependent degradation with weather action (e.g. temperature fluctuations, driving rain etc.) can generate synergic effects which may significantly decrease the safety and even lead to serious defects or sudden failures, such as cracking and spalling (Drdácký et al., 2017).

This paper concentrates on the design and construction of a small-scale wind tunnel at the facilities of the Institute of Theoretical and Applied Mechanics, in Czech Republic. The tunnel consists of a square section closed circuit with rough dimensions 180 × 200 cm and cross section 30 × 30 cm. The circuit is thermally insulated and equipped with the following features: an electric blower to control air flow inside the tunnel, a humidifier to control the internal RH, a heating system to allow for variations in temperature. Scales for recording mass changes are also provided as well as other sensors which enable the monitoring of internal environmental parameters (T, RH etc.). The main objective is to develop a new setup that enables simulating representative conditions of the boundary layer (wind speed, turbulences etc.) to which building material specimens can be exposed during the experiments.

The paper contains the following sections: section 2 outlines the materials and methods involved, presenting the design criteria used for the tunnel; section 3 describes the final design of the small-scale wind tunnel, its validation and construction; finally in section 4, the key findings are presented and future work is also suggested.

[*] Ing. Riccardo Cacciotti, PhD.: Institute of Theoretical and Applied Mechanics, Czech Academy of Sciences, Prosecká 809/76; 190 00, Prague 9; CZ, cacciotti@itam.cas.cz

[**] Benjamín Wolf: Institute of Theoretical and Applied Mechanics, Czech Academy of Sciences, Prosecká 809/76; 190 00, Prague 9; CZ, wolf@itam.cas.cz

[***] Ing. Michael Macháček, Ph.D.: Institute of Theoretical and Applied Mechanics, Czech Academy of Sciences, Prosecká 809/76; 190 00, Prague 9; CZ, machacek@itam.cas.cz

[†] Ing. Jiří Frankl, Ph.D.: Institute of Theoretical and Applied Mechanics, Czech Academy of Sciences, Prosecká 809/76; 190 00, Prague 9; CZ, frankl@itam.cas.cz

2. Methods

The design proposed observes a series of heterogeneous criteria. In fact, besides the basic guidelines focusing on the aerodynamic performance of the tunnel (Barlow et al., 1999), designs should be also tailored to meet other requirements ranging for the specific research goals to budget and space limitations. In the context of this research, the small-scale wind tunnel addresses the following:

- flow stability and quality: the main goal of the wind tunnel design is to achieve a controlled flow in the test chamber, ensuring the necessary flow performance and quality parameters. Three commonly used criteria are: maximum achievable speed, flow uniformity and turbulence level. In this research, these criteria have been central from the very initial steps of the design; available technical literature for preliminary dimensioning of wind tunnel components has been employed (Hernandez 2013).
- simulation of natural ventilation: the application of the wind tunnel presented in this work refers mainly to the study of the response of building materials to changing conditions in the boundary layer in the ventilated cavity of a cold flat roof or crawl spaces. For such reason the target flow speed to be simulated in the tunnel is set to reflect that of indoor natural ventilation, i.e., between 0.5 to 1.0 m/s (Aflaki et al. 2016)
- functionalities, control and measurements: the circuit should be thermally insulated and equipped with an electric blower to control air flow inside the tunnel, a humidifier to control the internal RH and a heating system to allow for variations in temperature. Target temperature should be close to laboratory one while humidity should be able to range between 40 and 95% RH. Scales for recording mass changes should be also provided as well as other sensors which enable the monitoring of internal environmental parameters (T, RH etc.).
- dimensions, transportability: the wind tunnel's overall dimensions are key factors in its construction and running costs. In this research, the overall allowable dimensions for the tunnel are those for a standard door size (i.e., roughly 2m height, 0.9 m width). In addition, the tunnel should be moveable and transportable and oriented vertically for reducing its occupied volume in the laboratory.
- adaptability to other research applications: the circuit should be purposely conceived as a modular construction with interchangeable components in order to allow for different simulation requirements other than those specifically in the scope of the research (e.g., different flow speed).
- cleaning and maintenance: the whole circuit should be easily accessible for cleaning and maintenance of the components.

The design method used in this research follows a very straightforward procedure: firstly, the research goals are clearly identified and secondly, the design criteria are established. As seen above, due to the fact that design typically involves fabrication, cost, space, and other conflicting constraints, the process is iterative till a balance among requirements and resources is found. As a preliminary step, the test chamber dimensions and shape are defined; subsequently, all the other principal parts of the circuit such as the contraction, diffuser, settling chamber and driving unit are determined. Adjustments are made to adapt the preliminary design to allow for all the other criteria listed above. The materials employed for the construction of the tunnel are low budget, light for enabling transportability and easy to model. These include plywood, plexiglass and polystyrene for the main panels composing the circuit, and steel for the supporting frame. Parts of the construction are prepared using a laser cutting machine and a 3D printer (e.g., for corner vanes and other smaller components). Further details are provided in the next section.

3. Results and discussion

In its final design, the small-scale wind tunnel (Fig. 1, left) is composed of a top C-shaped part with constant cross-section and a bottom part with varying cross-section. The top part of the circuit features a wire gauze used for filtering the air flow, the settling chamber with a honeycomb layer for flow stabilization, the test section for placing material specimens and corner vanes used for reducing the pressure loss at corners and improving the flow quality at their exit.

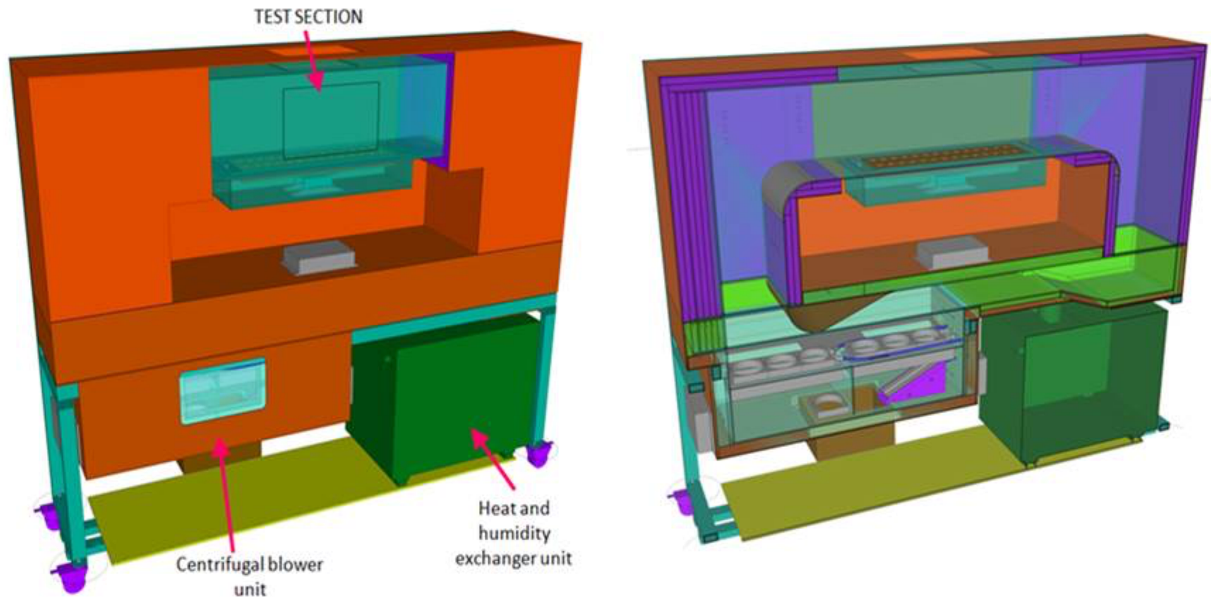

Fig. 1: Left, overview of the wind tunnel; right, internal view of the wind tunnel.

The tunnel consists of custom-made sandwich panels, featuring 40 mm polystyrene layer used for thermal insulation in between an external 4mm layer made of plywood (8 mm at some locations for conferring additional stiffness to the tunnel) and an internal 5 mm plexiglass layer to provide smooth surface for the airflow. The front of the tunnel is provided with a 'lid', i.e., a panel which covers and insulates the whole circuit with exception for the test section which is always exposed and accessible via openings from the front and top. This panel can be removed at any time in order to inspect other parts of the circuit for cleaning or maintenance purposes. The construction is supported by a wheeled steel frame which allows it to be freely moved. The plane of the circuit is oriented vertically, with the control section (blower and heat/humidity exchanger units) at its bottom and the test section at the top.

The overall tunnel dimensions are 200 x 173 x 43,5 cm (WxHxD) (Fig. 1, left). The test section presents a 30 x 30 cm square section and 60 cm of length. The calculated thermal resistance of the whole circuit is 20W/°C. In the heat and humidity exchanger unit (Fig. 1 left and Fig. 1 right), a LINDR AS-160 unit with 1550W cooling power (more than 4 times stronger than theoretically needed for 10°C desired internal temperature) is employed as cooling device while heating is provided by 2 heaters with 1kW of total heating power. Air is dried using an undercooled (frozen) aluminum cooler which is cooled by Peltier blocks against the coolant from chiller. On the other hand, air is moisturized by 2 ultrasonic mist transducers and one air mixing fan. The centrifugal blower unit (Fig. 1 left and Fig. 1 right) is equipped with 6x IP68 fans for mixing the air and providing thermal exchange between radiators with coolant, heaters and the air. Air flow production is controlled using a MAXON BLDC motor with 150W power which rotates a custom-designed propeller of eccentric blower placed at the corner of the tunnel.

The control section of the tunnel (i.e., the cooler, heater, fans, dryer, humidifier and main blower) is controlled by purposely designed electronics featuring 3 microcontrol units (MCU). Control electronics feature the following: 1x internal air, 1x coolant liquid, 1x coolant radiator, 1x drying cooler, 1x heater for temperature measurement; air flow is measured by a) 1x dual measuring point with dynamic pressure measurement (precise for air flows > 2m/s) combined with "hot wire" principle anemometer (precise for low air flows) in the narrower section at the bottom of the tunnel (30 x 10 cm) for calibration purpose of the hot wire anemometry and b) 1x single hot wire anemometer nearby the sample with movable (up and down) sensor for measuring laminarity of the air flow; change in mass of samples is measured at the test section by 2x load cell 0 - 300g range with 0.01g resolution; moisture measurement is carried out employing two sensors 1x at the test section where samples are located and 1x inside centrifugal blower unit. As an initial validation, a numerical simulation is carried out using the software COMSOL ver. 5.2a, by COMSOL MultiphysicsTM (Fig.2). This simulation shows that for the proposed tunnel characteristics, an acceptable quality of flow is obtained in the test section

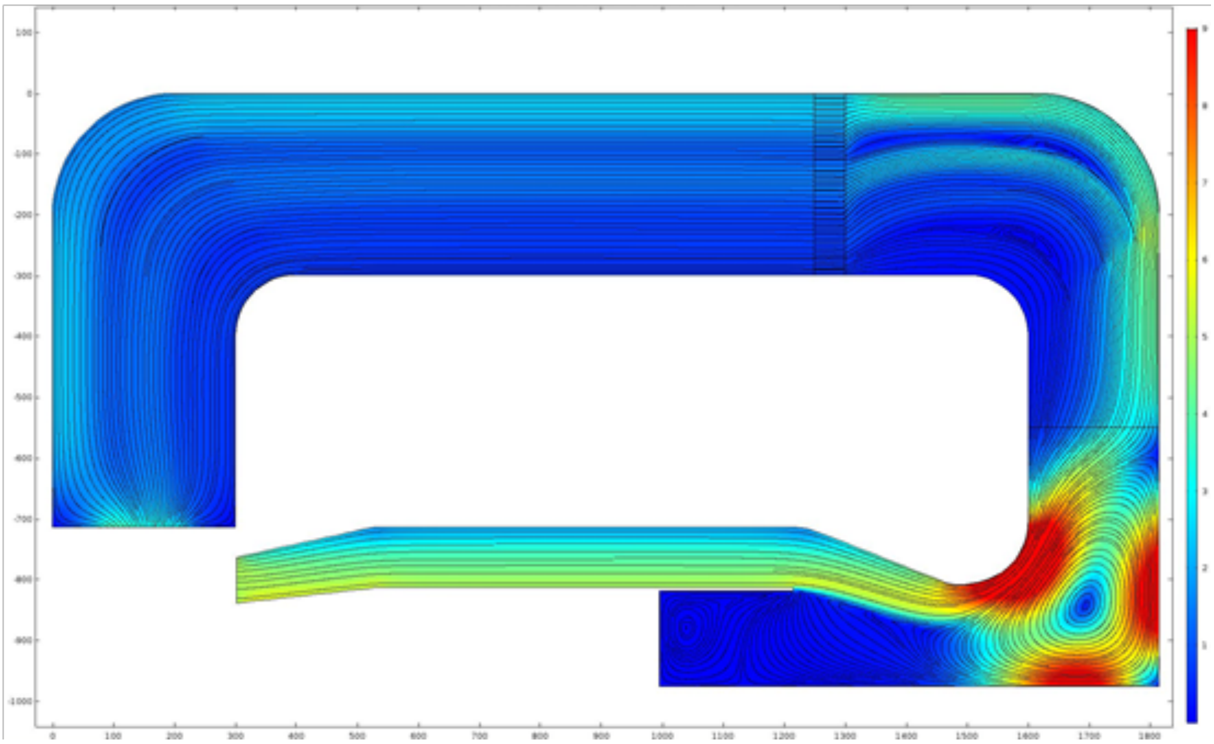

Fig. 2: Simulation of the air flow in the small-scale wind tunnel.

4. Conclusions

This ongoing research concentrates on the development of an innovative device for simulating the environmental conditions to which building materials are subjected in real life scenarios. The main design criteria, methods and materials are presented. The final design of the small-scale wind tunnel is outlined. The main advantages are the low costs considering its functionalities and the possibility to broaden its application. The tunnel is in fact a quite advanced tool which allows controlling multiple environmental parameters such as air flow velocity, RH and temperature. It also ensures monitoring continuously the behavior of specimens in the test section providing optical and physical measurements. Although the tunnel is currently being employed for research in the field of mold growth on wooden surfaces, thanks to its modular construction it could be adapted to other applications in the branch of building physics. As the research is still ongoing, future work is necessary: the tunnel requires further experimental validation and calibration. In addition, a more advanced testing protocol needs to be developed in order to observe the operational limitations of the device, while respecting standard testing procedures.

Acknowledgement

The authors would like to acknowledge the support of the GAČR grant number 20-12941S "Fungal growth on surface layer of solid wood under varying boundary conditions" to this research and publication.

References

Aflaki, A., Mahyuddin, N., and Baharum, M.R. (2016). The influence of single-sided ventilation towards the indoor thermal performance of high-rise residential building: A field study. *Energ. Buildings*, 126, pp. 146-158.

Barlow, J.B., Rae, W.H., and Pope, A. (1999). *Low-speed wind tunnel testing*. John Wiley & Sons, New York.

Drdácký, M., Cacciotti, R., and Slížková, Z. (2017). Dangerous synergies causing failures of historical structures, in: *IABSE Symposium Vancouver, 2017. Engineering the Future.* Vancouver, Canada, pp. 1066-1073.

European Commission (2012). *Reference Document on Best Environmental Management Practice in the building and construction sector*. Brussels: Joint Research Centre.

Hernández, M.A., Moreno López, A.I, Jarzabek, A.A., Perales Perales, J.M., Wu, Y., and Xiaoxiao, S. (2013). Design Methodology for a Quick and Low-Cost Wind Tunnel. Chapter 1 in Ahmed, N., ed., *Wind Tunnel Designs and Their Diverse Engineering Applications*, Tech Open Science.