Building and Environment 92 (2015) 504–517

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Viewpoints on wind and air infiltration phenomena at buildings illustrated by field and model studies

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A R T I C L E I N F O

Article history:
Received 9 January 2015
Received in revised form
30 April 2015
Accepted 3 May 2015
Available online 15 May 2015

Keywords:
Infiltration
Wind
Particle image velocimetry
Openings
Stagnation points
Drag force

A B S T R A C T

Ventilation and infiltration caused by wind are difficult to predict because they are non-local phenomena: driving factors depend on the surrounding terrain and neighbouring buildings and on the building orientation with respect to the wind direction. Wind-driven flow through an opening is complex because wind can flow through the opening or around the building, in contrast to buoyancy driven flow. We explored wind and air infiltration phenomena in terms of pressure distributions on and around buildings, stagnation points, flow along façades, drag forces, and air flow through openings. Field trials were conducted at a 19th-century church, and wind tunnel tests were conducted using a 1:200 scale model of the church and other models with openings.

The locations of stagnation points on the church model were determined using particle image velocimetry measurements. Multiple stagnation points occurred. The forces exerted on the church model by winds were measured using a load cell. The projected areas affected by winds in various directions were calculated using a CAD model of the church. A fairly large region of influence on the ground, caused by blockage of the wind, was revealed by testing the scale model in the wind tunnel and recording the static pressure on the ground at many points. The findings of this study are summarized as a number of steps that we suggest to be taken to improve the analysis of wind driven flow in buildings and with these suggestions as a basis for further improvement of prediction methods for wind-driven flows.

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1. Introduction

Hayati et al. [1] compared predictions of ventilation rates with an extensive database of ventilation rates recorded under various meteorological conditions. For wind-dominated cases, the agreement between the measured and predicted ventilation rates tended to be less than satisfactory. This is typically the case for wind-dominated cases. This study was conducted to gain insight into the causes of the poor agreement between measured and predicted ventilation rates in such cases, to suggest improvements in the prediction methods, and to identify additional research needs. The subject of the study, the same buildings as in Refs. [1], was a 1850s stone church (Fig. 1) in Hamrånge, in mid Sweden. The interior volume of the church is 7620 m^3, and its outer dimensions are L × W × H = 63 × 18.5 × 17.2 m, with a 45-m-high tower. It is a hall church with 1.3-m-thick stone walls, weather-stripped double glazing, and a wooden floor with a crawl space underneath. The whole church, including the crawl space, is naturally ventilated through infiltration. The inner walls and the ceiling are plastered. Three rather leaky porches are located at the middles of the walls facing west, north, and east. The church is situated on a 10-m-high hill with wooded slopes (visible in Fig. 1) in the westward direction (from the southeast to the north). Beyond the wooded slopes, there are mainly open fields in that direction. In the eastward direction (from the north to the southeast), approximately 200 m from the church, is the border of a rather small village, consisting of low-rise (one-to three-story) buildings and some wooded areas.

The nave of the church has a vaulted ceiling with a maximum height H = 13.7 m. The main large windows are 4.7 m in height. The dimensions of the church in relation to the height H of the nave are shown in Fig. 2.

Because of its location on a hill, the church is exposed to wind. The only purpose-provided openings are twelve vents to the crawl space, shown in Fig. 2. These vents are located under the windows.

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http://dx.doi.org/10.1016/j.buildenv.2015.05.001
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Fig. 1. Hamrånge church.

A church like this one is a composed building whose parts have different heights and the silhouette of the church varies substantially with the wind direction. Therefore it is a challenging object for exploring the interaction between wind and buildings; due to that one can expect the interaction to vary strongly with the wind direction. It is our hypothesis that the identification of the stagnation point(s) is the first step to be taken in an improved analysis method for exploring and characterizing the interaction between the wind and a building. The stagnation points are the distribution points for the air flow over the façade on the windward side of a building. The position of the leakage with respect to the stagnation point we believe is an important parameter. One can expect that a building like this have a non-standard setup of stagnation point(s). Therefore it is an excellent test case with respect to finding the location of stagnation points and exploring methods for finding the stagnation points. The outcome of this test is of course also of importance for buildings of more common shapes. In addition to this identifying the location of leakages in a church building is also a challenge and of general interest.

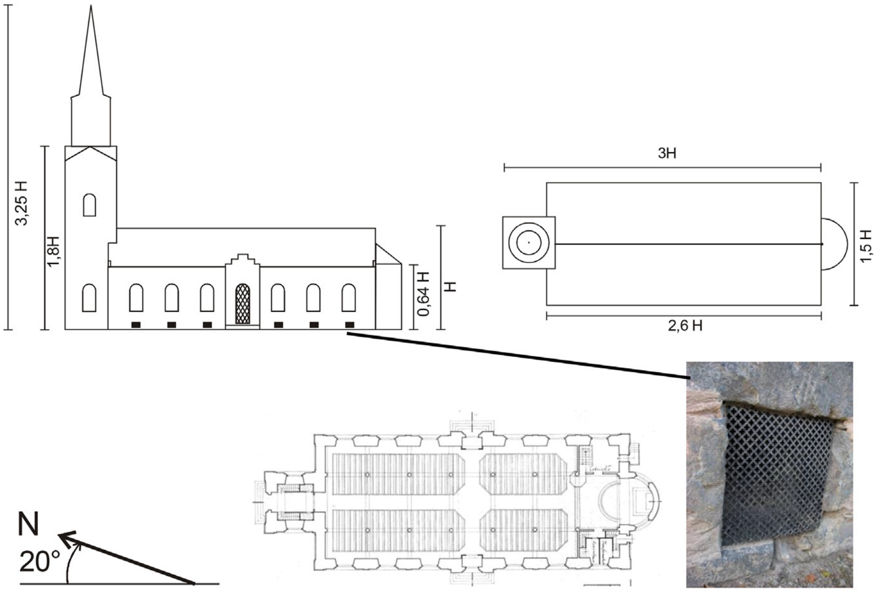

Fig. 2. Top: Dimensions of the church in relation to the height, H, of the roof. Bottom: Vent (30 × 30 cm) to the crawl space.

2. Recorded wind speed and static pressure on site

2.1. Wind speed

The outdoor air temperature, humidity, wind speed, and wind direction were recorded at a local weather station (Vaisala WXT520), situated 1 km from the church. An example of a one-year record is shown in Fig. 3. The wind speed was recorded at 17 m above ground.

2.2. Example of recorded pressure on windward and leeward side and in the crawl space

Measurements of the indoor–outdoor pressure difference were obtained using three manometers in parallel (FCO44, ±20 Pa, Furness Controls Ltd, East Sussex, UK).

A sample of the pressure measurements is shown in Fig. 4, illustrating the variation (at 1-s intervals) in the outdoor–indoor pressure difference at the middles of the long sides of the eastern and western façades (the church is oriented along a north–south axis). The measurement location was at keyhole level, and a stack effect added a few Pascals of pressure to the curves. There was a weak wind from the east at the time of collection of the measurements shown.

The variation in the wind is reflected in the recorded pressure. The pressure in the crawl space exhibited less variation. The pressure in the crawl space is almost the same as the average pressure on the leeward side. The largest pressure drop was measured on the windward side. One reason for this is that the floor is leaky; there is an outflow through the floor above the crawl space. As a result, the outflow area is larger than the inflow area.

This type of pressure pattern is also typical for large openings [2], which generate flows that cross entire spaces and reaches openings on the opposite side. This is described as a flow contact. If there had been no purpose-provided openings but only cracks, the pressure within the crawl space would have been close to the average value of the pressure on the façades.

3. Wind as a driving force for ventilation and infiltration

Often wind driven infiltration is treated in a similar way as infiltration by buoyancy, which is dealt with as a flow driven by a

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