Building and Environment 92 (2015) 578–590

Contents lists available at ScienceDirect

Building and Environment

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

Impact of eaves on cross-ventilation of a generic isolated leeward sawtooth roof building: Windward eaves, leeward eaves and eaves inclination

J.I. Perén [a, b, *], T. van Hooff [c], B.C.C. Leite [a], B. Blocken [b, c]

[a] Civil Construction Engineering Department, Polytechnic School of the University of São Paulo – USP, Av. Prof. Luciano Gualberto, travessa 2 n° 83, CEP 05508-900 São Paulo, SP, Brazil

[b] Building Physics and Services, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

[c] Building Physics Section, Leuven University, Kasteelpark Arenberg 40, P.O. Box 2447, 3001 Leuven, Belgium

A R T I C L E I N F O

Article history:
Received 18 February 2015
Received in revised form
16 April 2015
Accepted 11 May 2015
Available online 20 May 2015

Keywords:
Computational fluid dynamics (CFD)
Urban physics
Leeward sawtooth-roof geometry
Natural upward cross-ventilation
Eaves configuration
Building envelope optimization

A B S T R A C T

An eaves is a roof extension that can protect the indoor environment from direct solar radiation, the exterior facade from wetting of by wind-driven rain and can be useful to enhance cross-ventilation. This paper evaluates the impact of eaves configuration on wind-driven cross-ventilation of a generic leeward sawtooth roof building. Both the type of eaves (windward versus leeward) and the eaves inclination angles are investigated. Isothermal Computational Fluid Dynamics (CFD) simulations are performed using the 3D steady Reynolds-Averaged Navier–Stokes (RANS) approach. A grid-sensitivity analysis is performed and validation of the CFD results is conducted based on wind-tunnel measurements with Particle Image Velocimetry from literature. The ventilation evaluation is based on the volume flow rates and the indoor mean velocities. The eaves length is 1/4 of the building depth and the inclination is varied between 90° and −45° for both the windward and leeward eaves. The results show that windward eaves with an inclination of 27° (equal to roof inclination) result in the highest increase of the volume flow rate (15%) compared to the building without eaves. Furthermore, the flow through the occupied zone is more horizontally directed. Leeward eaves have a smaller influence on the ventilation volume flow rate than windward eaves; the maximum increase in volume flow rate is only 6% when a 90° inclination is employed. Application of both (windward and leeward eaves) results in an increase of the volume flow rate of 24%, which is 3% more than the sum of the increases by the two eaves separately.

1. Introduction

An eaves is a roof overhang which can be seen as a multi-purpose building component. As an extension of the roof construction, it can protect the building from solar radiation and wind-driven rain. As a result, eaves are commonly used in tropical climates. The solar shading that is provided by eaves can reduce the energy consumption for cooling significantly. Depending on the building, climate and other factors, this reduction can range from 5.3% [1] to higher than 10% [2,3]. In addition to their known effects on solar radiation and wind-driven rain, eaves can be employed to increase cross-ventilation flow (e.g. Ref. [4]).

Several studies focused on the effects of eaves (e.g. Refs. [5–7]) and parapets (vertical extension on a roof top) (e.g. Refs. [8,9]) on wind loads. Other studies evaluated the protection from wind-driven rain (e.g. Ref. [10]), snow loads (e.g. Refs. [11,12]) and the influence of eaves on convective heat transfer in a roof (e.g. Ref. [13]). The majority of the studies focusing on wind loads highlighted the potential of eaves and parapets to reduce the underpressure near the roof edges, where flow separation occurs.

Regarding the potential of eaves to reduce the heat gains due to solar radiation some studies analyzed the shading effects of eaves in for example high-rise residential buildings (e.g. Ref. [1]), and school buildings (e.g. Ref. [4]). However, to the best of our knowledge, only two studies focused on the impact of eaves on the

* Corresponding author. Building Physics and Services, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands. Tel.: +31 (0) 40 247 3667; fax +31 (0) 40 243 8595.

E-mail addresses: j.i.peren.montero@tue.nl, jiperen@usp.br (J.I. Perén).

http://dx.doi.org/10.1016/j.buildenv.2015.05.011
0360-1323/

ventilation flow (e.g. Refs. [14,15]). Kindangen [14,15] performed Computational Fluid Dynamics (CFD) simulations and observed that in buildings with symmetric opening locations (inlet and outlet openings located at the same height) the use of eaves can increase the cross-ventilation flow rate. Unfortunately, the cases in these studies combined the effect of the eaves with other parameters such as the roof inclination angle, roof shape, roof height and roof orientation, which makes it difficult to isolate the impact of the eaves on the ventilation flow from the impact of other parameters. Furthermore, these studies only considered the impact of eaves with a 0° inclination (horizontal eaves).

There is a clear lack of research on the impact of the eaves configuration (both eaves at the windward and the leeward side of the building) on wind-driven cross-ventilation. This holds particularly for leeward sawtooth roof buildings. In previous studies by the authors [16,17], the impact of the roof inclination angle [16] and the roof shape [17] on cross-ventilation of leeward sawtooth roof buildings were assessed. The present study builds further on these achievements by reporting a detailed and systematic study on the impact of both windward and leeward eaves on wind-driven upward cross-ventilation of a leeward sawtooth roof building. The study is based on isothermal CFD simulations with the 3D steady Reynolds-Averaged Navier–Stokes (RANS) approach. The performance of each eaves configuration (windward, leeward or the combination of both) is evaluated based on the volume flow rate through the building and the mean air velocity ratios in the occupied zone, measured at four different heights: h = 0.1 m, 0.6 m, 1.1 m and 1.7 m, which are considered as reference for the evaluation of thermal comfort conditions of a seated or standing person, at a steady-state and moderate environment, i.e. where the environmental conditions are close to the thermal comfort standards proposed by ISO 7730/2005 [18]. As mentioned above, the results presented in this paper are part of a large research project on the enhancement of wind-driven cross-ventilation of residential buildings by adjusting the roof geometry. For the sake of brevity and to enable a detailed assessment of the flow behavior in and around the building resulting from the addition of eaves, this paper will only focus on this part of the results obtained in this larger research project.

In the past 50 years, CFD has been increasingly developed and applied as a powerful assessment tool in urban physics and wind engineering [19–23], including natural ventilation in buildings [24–28]. While Large Eddy Simulation (LES) is intrinsically superior to steady RANS simulations, due to the higher computational cost and increased model complexity of LES, a detailed review of the literature [19] shows that RANS simulations still constitute the most frequently used computational approach in urban physics and wind engineering, especially in natural ventilation studies [22,24,26–28].

The paper is structured as follows. The building geometry of the reference case is presented in Section 2. Section 3 presents a brief overview of the CFD validation study using wind-tunnel experiments from literature. The computational settings and parameters for the current study are presented in Section 4. The CFD simulation results of the different eaves configurations are analyzed for a windward eaves and subsequently for a leeward eave, the results of which are outlined in Section 5. Section 6 shows the effect of the simultaneous application of both a windward eaves and a leeward eave. Discussion and conclusions are given in Sections 7 and 8, respectively.

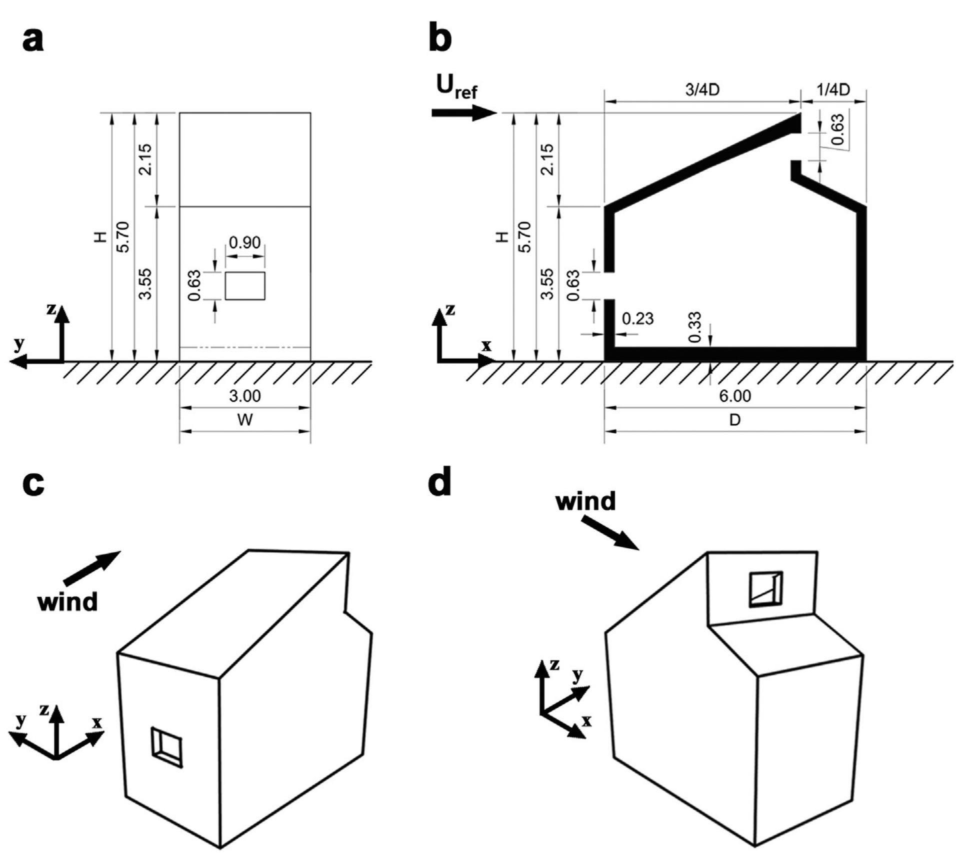

Fig. 1. Overview of geometry of the reference case (geometry A) (dimensions in meter). (a) Front view (windward facade) with opening size and dimensions. (b) Vertical cross-section with opening size and dimensions. Perspective views: (c) windward facade, (d) leeward facade.