Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 122 (2017) 325–330

Energy Procedia

www.elsevier.com/locate/procedia

CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

Localized meteorological variables influence at the early design stage

Dasaraden Mauree[a]*, Daniel Sang-Hoon Lee[b], Emanuele Naboni [a,b], Silvia Coccolo[a], Jean-Louis Scartezzini[a]

[a]*Solar Energy and Building Physics Laboratory, École Polytechnique Fédérale de Lausanne, Switzerland*
[b]*Performance Simulation Laboratory, Institute of Architecture and Technology, School of Architecture, The Royal Danish Academy of Fine Arts, Schools of Architecture, Conservation and Design*

Abstract

A measurement campaign was set up in Lausanne. The objective of this study is to define the importance of using local meteorological variables in the design of urban spaces and in the evaluation of building energy use. Urban simulation tools typically use average climatic data to calculate the convection coefficient, the building thermal balance and the pedestrian comfort. For this purpose, two simulation tools, a CFD model and CIM (Canopy Interface Model) are used to simulate the meteorological variables on the EPFL campus, Lausanne, Switzerland. The simulation results from the CFD model and the CIM are compared with the experimental data and both models provide trends that are in very good agreement with measurement. CIM can provide high resolution vertical profiles without significant computational resources and thus be used at an early stage in the design phase. The CFD should be used when a more precise local evaluation is needed.

Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale

Keywords: Building energy demand; CFD models; CIM; Early stage design; Urban climate; Turbulence parameterization

* Corresponding author.
E-mail address: dasaraden.mauree@epfl.ch

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale
10.1016/j.egypro.2017.07.331

1. Introduction

The IPCC (Intergovernmental Panel on Climate Change) in their Fifth Assessment report in 2013 [1], stressed on the fact that there is clear proof that the current climate change is being caused by human activities. There is compelling evidence this is due to the release of greenhouse gases (GHG) such as carbon dioxide (CO2) from the combustion of fossil fuels to produce energy [1]. A large proportion of global energy demand has been related to buildings which, therefore, are one of the main sources of air pollution. Approximately half of the primary energy use in Switzerland occurs in buildings. Of this energy, about 30% is consumed by space heating, cooling, and water heating; 14% through electricity use, and 6% through construction and maintenance [2]. In addition, the building sector accounts for more than half of the CO2 emissions in Switzerland, which shows that it is among the most significant contributors to carbon emissions. This implies also that the building sector provides a real opportunity for a large improvement with regards to energy efficiency and reduction of CO2 emission.

For the efficient planning of future buildings and districts urban planners need to have access to appropriate tools and information. For example, the future development of the EPFL campus will imply densifying the existing building stock [3], but the question still remains how to design the space in order to reduce the energy consumption while at the same time increasing the liveability of the outdoor environment [4].

It is now well known that the urban climate depends on a series of processes taking place at different spatial (from global to local) and temporal scales [5]; building energy demand and urban climate are also closely related and interdependent [6]–[8]. It is thus essential to have access to tools, which can evaluate - with precision - the interactions that exist between buildings, their energy use as well as the local climate. Several models have been developed in recent years to better represent the various phenomena influencing energy use and urban climate [9], [10]. Besides these models, CFD tools have been used to evaluate with more precision the turbulent processes in urban areas [11]–[13]. One of the major drawbacks with these models is the lack of data to validate and the lack of comparison with real data from urban areas.

Acronym

CIM	Canopy Interface Model
CFD	Computational Fluid Dynamics
CO2	Carbon dioxide
EPFL	Ecole Polytechnique Fédérale de Lausanne
GHG	Green house Gases
MoTUS	Measurement of Turbulence in an Urban Setup

For this purpose, a project (MoTUS) to monitor high resolution vertical meteorological profiles was set up. The aim is to determine the impact of urban areas / buildings on meteorological variables (such as wind or temperature) and to represent these effects when evaluating building energy use, air pollutant dispersion and renewable energy potential in urban planning scenarios. Such monitored meteorological data are scarcely available with high vertical resolution. Campaigns such as the BUBBLE (Rotach et al. 2005) observation period provided useful information and data to develop and generalize new parameterization schemes. However, there is a strong need for such data in multiple configurations in order to develop new tools and methodologies which can then be used in the evaluation of building energy use.

In the current study, we use two different modeling tools and compare them with data from the monitoring tower. We then define the most useful parameters influenced by the presence of buildings and how they can be simulated. We first give an overview of the two models used. In Section 3 we briefly explain the experimental setup, the type of instruments that have been installed and details related to their configuration. We then describe and discuss the results from the simulations and how they compare with the monitoring. Finally, we conclude and give a few perspectives for the current study.

2. Models

2.1. CIM

A one-dimensional canopy interface model was recently developed (D. Mauree 2014; Mauree et al. 2017) to improve the surface representation in mesoscale meteorological models and to also prepare the coupling with microscale models. For the purpose of this study, CIM will provide high-resolution vertical profiles that will be used as input for the control algorithm.

CIM uses a diffusion equation derived from the Navier-Stokes equations but reduced to one direction only. Equation 1 is used to calculate the wind speed and potential temperature profiles.

$$\frac{du}{dt} = \frac{d}{dz}\left(\mu_t \frac{du}{dz}\right) + f_u^s \,;\, \frac{d\theta}{dt} = \frac{d}{dz}\left(\kappa_t \frac{d\theta}{dz}\right) + f_\theta^s, \qquad (1)$$

where U is the horizontal wind speed in either the x-or y-direction, θ is the potential temperature, μ_t and κ_t are the momentum and heat turbulent diffusion coefficients f_u^s and f_θ^s are the source terms representing the fluxes (from the surface or buildings) that will impact the flow.

CIM solves for a 1.5-order turbulence closure using the turbulent kinetic energy (TKE). The TKE is calculated using Equation 3:

$$\frac{de}{dt} = \frac{d}{dz}\left(\lambda_t \frac{de}{dz}\right) + C_\varepsilon \frac{\sqrt{e}}{l}(e_\infty - e) + f_e^s \qquad (2)$$

where e is the TKE, λ_t is the diffusion coefficient (assumed here to be equal to μ_t), is a constant equal to 1, $e^\infty$is considered to be a stationary value of the TKE and f_e^s is source term representing the additional production of TKE due to the obstacles. The momentum and heat diffusion coefficients are calculated using:

$$\mu_t = C_e\sqrt{e}l \,;\, \kappa_t = \Pr \mu_t \qquad (3)$$

where C_e is a constant equal to 0.3. l is defined as the mixing length and is taken from Mauree et al., [10] to account to the obstacles density and height in the canopy. The CIM has been developed to function in an offline mode and can hence be forced directly at the top using traditional meteorological boundary conditions.

2.2. CFD

The EPFL campus within a 300m radius around MoTUS was digitally reconstructed in Rhino 3D. The buildings were modelled in simplified rectilinear forms, which would be more suitable for CFD analysis. The models were meshed and solved in ANSYS Fluent 18.0 (Fluent). The mesh was constructed with tetrahedrons of minimum 5e-2m and maximum 15.0m in size. The total number of elements was around 18.6 million, with maximum skewness of 0.78, and average skewness of 0.23. For the inlet boundary conditions, two wind speeds measured by MoTUS at two particular times (1 AM and 1 PM) were used; 7.12 m/s @ 232 dir. and 2.83 m/s @ 230 dir. respectively.

The wind flows around EPFL campus models were defined as an incompressible fluid in Fluent using pressure-based solver. For the given simulations, the Reynold Stress (Linear Pressure-Strain) turbulence model was used. For the simulations, ANSYS Fluent solves the conservations equations for mass and momentum, and for additional heat transfer characteristics (an aspect not discussed in the current paper) it solves the energy equation. The equations are as shown below:

Mass Conservation:

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho\vec{v})=S_m \tag{4}$$

Momentum Conservation:

$$\frac{\partial}{\partial t}(\rho\vec{v})+\nabla\cdot(\rho\vec{v}\vec{v})=-\nabla p+\nabla\cdot(\bar{\bar{\tau}})+\rho\vec{g}+\vec{F} \quad , \tag{5}$$

and

$$\bar{\bar{\tau}}=\mu\left[\left(\nabla\vec{v}+\nabla\vec{v}^{T}\right)-\frac{2}{3}\nabla\cdot\vec{v}I\right] \quad , \tag{6}$$

where, p is the static pressure, $\bar{\bar{\tau}}$ is stress tensor, $\rho\vec{g}$ is gravitational body force, $\vec{F}$ is external body force, μ is molecular viscosity, and I is unit tensor.

3. Experimental setup

A 27m high mast was installed in September 2016 on the EPFL campus for the high resolution monitoring of vertical meteorological variables (motus.epfl.ch). Table 1 gives an overview of the different instruments installed while

Fig. 1shows a schematic of the installation.

Table 1. Instruments installed on the tower.

Instrument	Brand	Type
3D sonic anemometers	Gill	WindMaster
Meteorological station	Gill	GMX 300
Surface temperature sensor	Optris	OPTCSLT15K

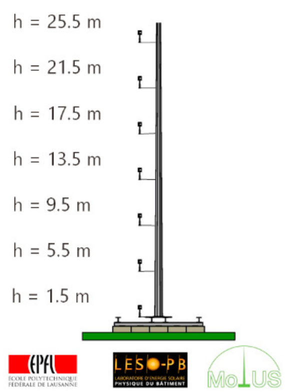

Fig. 1. Schematic of the MoTUS tower on the EPFL campus, Lausanne

4. Results and discussion

4.1. CIM

Two simulations were run using CIM for two particular time steps (01h00 and 13h00) on the 13th of January 2017. Buildings in this area of the EPFL campus have an average height of 10m and are considered to have a width of 30m and a length of 40m. The horizontal wind speed was averaged at an hourly time step from the data monitoring from MoTUS. Fig. 2(a) and 2(b) show the normalized horizontal wind speed as measured by MoTUS (in orange) and as calculated by CIM (in blue). It can be seen that in both cases CIM can reproduce the general trend quite well.

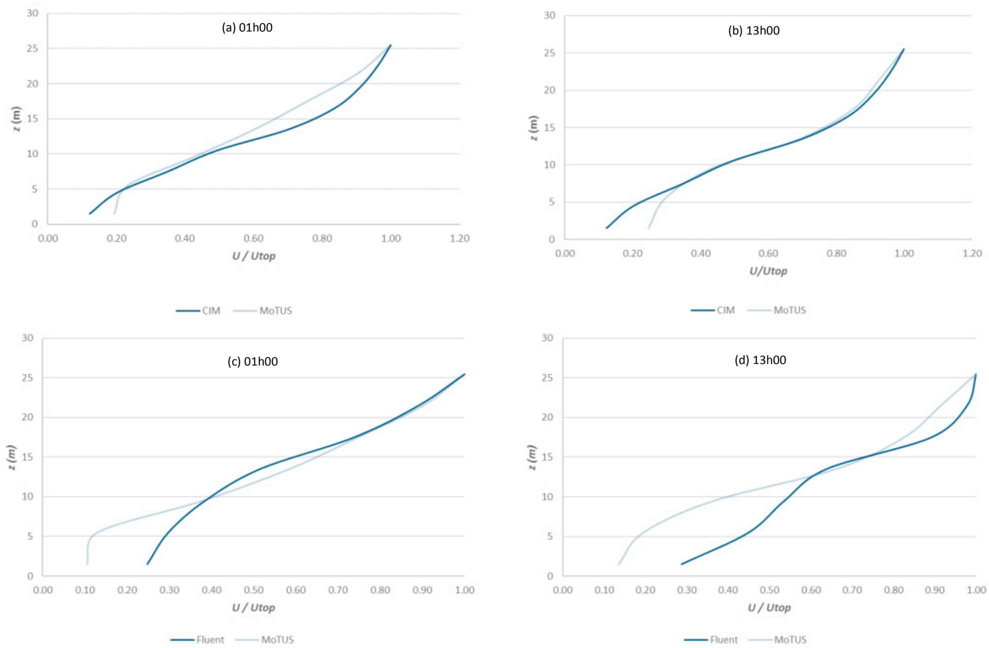

Fig. 2. Comparison of the normalized horizontal wind speed between MoTUS (pale blue) and CIM (dark blue) (1(a) 01h00 and 1(b) 13h00) and MoTUS and ANSYS Fluent (dark blue) (1(c) 01h00 and 1(d) 13h00).

If we compare the different horizontal wind components calculated and measured by MoTUS (not shown here), there was also a very good agreement between the monitored and simulated data. It must however be highlighted that some discrepancies can be noted between the measured and CIM data. This can be due to a couple of reasons: (1) CIM does not resolve a 3D flow, hence the vertical component can induce significant draft that can impact the horizontal wind components. (2) An idealized description of the built environment is given to CIM. This obviously results in a simulation that can neglect some turbulent flows around the obstacles.

4.2. CFD

The results by Fluent show patterns coherent with MoTUS readings. It can be seen in both Fig. 2(c) and 2(d), that the results show greater similitude, especially above the building roof (H=10m). As the measurement point moves to the top, the airflow is less affected by turbulence, which is formed by the presence of the adjacent buildings. Thus, the wind velocity profile at lower levels has greater dependence on the adopted turbulence models and drag force definitions. Unlike the results by CIM, Fluent overestimates the speeds closer to the ground. In addition, greater discrepancies have been observed for the case of 13h00 with slower wind boundary conditions.

The discrepancies are also affected by a number of factors including the level of details in 3D models, meshing sizes and mesh element types with respect to the direction of flow. Thus, on-going investigations will take place to explore the way to reduce the discrepancy between CFD results and the site-measure values by MoTUS in adoption of different turbulence models and drag force definitions among others.

Conclusions

An experimental setup for meteorological variables was installed on the EPFL campus, Switzerland. The aim of this study was to define which main meteorological variables are mostly influenced by the presence of buildings / obstacles in an urban setup and to define what kind of tools are needed at an early design stage of buildings. We showed from the measured variables that there is a significant distortion of the wind speed in the urban canopy. We compared two different models with the monitored data and demonstrated that with both CFD and CIM, it is possible to reproduce the general characteristics of the horizontal wind profile and its components.

Future work should focus on the improvement of the drag force parameterization and also on the improvement of other turbulent flows in the CFD model. The experimental setup is typical of urban areas in most European cities and hence the results could be extrapolated and taken into account when constructing or when designing new energy efficient and sustainable areas.

Acknowledgements

The authors wish to thank EPFL and the ENAC faculty for their financial support for the equipment and the Commission for Technology and Innovation of the Swiss Confederation for the funding of the Swiss Competence Center for Energy Research, Future Energy Efficiency Buildings and Districts, FEEB&D (CTI.2014.0119).

References

[1] IPCC, *WORKING GROUP I CONTRIBUTION TO THE IPCC FIFTH ASSESSMENT REPORT CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS*. Geneva: Intergovernmental Panel on Climate Change, 2013.

[2] S. F. O. of E. SFOE, 'Public Energy Research in Switzerland', 2011.

[3] S. Coccolo, J. Kaempf, and J.-L. Scartezzini, 'The EPFL Campus in Lausanne: New Energy Strategies for 2050', *Energy Procedia*, vol. 78, pp. 3174–3179, Nov. 2015.

[4] D. Mauree, S. Coccolo, J. Kämpf, and J.-L. Scartezzini, 'Multi-scale modelling to assess human comfort in urban canyons', *Expanding Boundaries - Systems Thinking in the Built Environment - Proceedings of the Sustainable Built Environment (SBE) Regional Conference Zurich 2016*, 2016.

[5] T. R. Oke, 'The energetic basis of the urban heat island', *Quarterly Journal of the Royal Meteorological Society*, vol. 108, no. 455, pp. 1–24, 1982.

[6] Y. Ashie, V. Thanh Ca, and T. Asaeda, 'Building canopy model for the analysis of urban climate', *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 81, no. 1–3, pp. 237–248, May 1999.

[7] F. Salamanca, A. Martilli, M. Tewari, and F. Chen, 'A study of the urban boundary layer using different urban parameterizations and high-resolution urban canopy parameters with WRF', *Journal of Applied Meteorology and Climatology*, vol. 50, no. 5, pp. 1107–1128, 2011.

[8] D. Mauree, J. H. Kämpf, and J.-L. Scartezzini, 'Multi-scale modelling to improve climate data for building energy models', in *Proceedings of the 14th International Conference of the International Building Performance Simulation Association*, Hyderabad, 2015.

[9] A. Krpo, F. Salamanca, A. Martilli, and A. Clappier, 'On the Impact of Anthropogenic Heat Fluxes on the Urban Boundary Layer: A Two-Dimensional Numerical Study', *Boundary-Layer Meteorol*, vol. 136, no. 1, pp. 105–127, Jul. 2010.

[10] D. Mauree, N. Blond, M. Kohler, and A. Clappier, 'On the Coherence in the Boundary Layer: Development of a Canopy Interface Model', *Front. Earth Sci.*, vol. 4, 2017.

[11] J. L. Santiago, O. Coceal, A. Martilli, and S. E. Belcher, 'Variation of the Sectional Drag Coefficient of a Group of Buildings with Packing Density', *Boundary-Layer Meteorol*, vol. 128, no. 3, pp. 445–457, Sep. 2008.

[12] A. Martilli and J. Santiago, 'CFD simulation of airflow over a regular array of cubes. Part II: analysis of spatial average properties', *Boundary-Layer Meteorology*, vol. 122, no. 3, pp. 635–654, 2007.

[13] J. Allegrini and J. Carmeliet, 'Simulations of local heat islands in Zürich with coupled CFD and building energy models', *Urban Climate*.