# Improving Local Wind Estimation for the Automated Control of Blinds

**Dasaraden Mauree – Ecole Polytechnique Fédérale de Lausanne – dasaraden.mauree@epfl.ch**
**Ali Motamed – Ecole Polytechnique Fédérale de Lausanne –ali.motamed@epfl.ch**
**Laurent Deschamps – Ecole Polytechnique Fédérale de Lausanne – laurent.deschamps@epfl.ch**
**Jean-Louis Scartezzini – Ecole Polytechnique Fédérale de Lausanne – jean-louis.scartezzini@epfl.ch**

## Abstract

Blinds are usually installed on building façades to improve the visual and thermal comfort of the occupants. They are now often linked to an automated system that helps control the glare and decrease overheating. These automated systems are linked to a weather station that is located on top of the buildings in which they are installed. In the current study, we show that the use of such stations does not provide accurate and reliable information to the control algorithm. It is proposed to couple a model that can calculate wind speed and direction in an urban canopy to the control algorithm. The model is compared to data from an experimental setup on the EPFL campus, Switzerland. We demonstrate that there is very good agreement between the models and the data that have been collected. Furthermore, a new control algorithm is proposed in order to improve the response of the system during strong gusts and to prevent an erratic behaviour of the automated system.

## 1. Introduction

Several control mechanisms have been developed in recent years to implement automation systems in buildings to enhance the thermal and visual comfort of the occupants.

The replacement cost of blinds, due to damage caused by strong wind gusts and turbulence patterns, is substantial for the building owner and installer. To protect such installations, a weather station is usually set on top of the buildings to provide information to an automatic control system. However, the location and limited number of weather stations for a particular building give an incorrect or unreliable source of information as these do not always reflect properly the meteorological conditions on the building façade (e.g., wind speed or turbulence patterns). Thus, the trigger command given to the algorithm to raise the blinds in order to protect them against breakage is based on unreliable information. This frequently contributes to the perception of the occupants that there is an erratic behaviour of the system that often leads to a complete shutdown of the system, often with a visual and thermal discomfort in the building.

It is well known that the urban climate depends on a series of processes taking place at different spatial (from global to local) and temporal scales (Oke, 1982); building energy demand and urban climate are also closely related and interdependent (Ashie et al., 1999; Salamanca et al., 2011; Mauree et al., 2015). It is thus essential to have access to tools, which can evaluate precisely the interactions that exist between buildings and their local climate. Several models have been developed in recent years to better represent the various phenomena influencing the urban climate (Masson 2000; Martilli et al., 2002; Krpo et al., 2010; Mauree et al., 2017).

The monitoring of high resolution vertical meteorological profiles is essential to determine the impact of urban areas/buildings on these variables: it is necessary to represent these effects when evaluating building energy use, air pollutant dispersion and renewable energy potential in urban planning scenarios. Monitored meteorological data are scarcely available with at a vertical resolution. Campaigns such as the BUBBLE (Rotach et al., 2005) observation period provide useful information and data to develop and generalize new parameterizations schemes. However, there is a strong need for such data and in multiple configurations in order to develop new tools and methodologies which can then be used in the evaluation of building energy use. The vertical profiles of variables such as wind speed

Part of
Pernigotto, G., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). 2018. Building simulation applications BSA 2017. bu,press.
https://doi.org/10.13124/9788860461360

and direction, and the air temperature in the vicinity of buildings are crucial in the determination of the momentum and heat fluxes.

In the current study, we first give an overview of the experimental setup, the model used and the new algorithm to control the blind movements. We then give the preliminary results from the setup and compare them with the model. Finally, we conclude and give a few perspectives for the current study.

## 2. Materials and Methods Setup

This experiment was set up in the framework of the MoTUS (Measurement of Turbulence in an Urban Setup) project (motus.epfl.ch). In the following sections, we describe the setup, the model used to calculate high-resolution vertical profiles and new control algorithm implemented for the control of the blinds.

### 2.1 Mast

For this purpose of the study, a 27 m mast was installed on the EPFL campus in Lausanne, Switzerland to measure various meteorological parameters. The average building height in this district is around 10 m. Seven 3D sonic anemometers have been placed along the vertical axis every 4 m. Data from the instruments are collected with a frequency of 1 Hz based on the recommendations by Kaimal and Finnigan (1994) and stored in a database at EPFL.

Fig. 1 gives an illustration of the experimental setup of the meteorological tower.

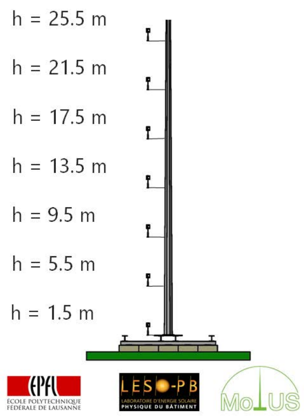


Fig. 1 – Experimental setup

A KNX meteorological station measuring the tradetional variables (wind speed and temperature) is also available on the top of the LESO building. Similar meteorological stations are usually used in automated system to control the blinds.

### 2.2 Canopy Interface Model

A one-dimensional Canopy Interface Model (CIM) was recently developed (Mauree, 2014; Mauree et al., 2017) to improve the surface representation in mesoscale meteorological models and to prepare the coupling with microscale models, too. 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. Equations 1 and 2 are used to calculate the wind speed and potential temperature profiles.

$$\frac{du}{dt} = \frac{d}{dz}\left(\mu_t \frac{du}{dz}\right) + f_u^S \qquad (1)$$

$$\frac{d\theta}{dt} = \frac{d}{dz}\left(\kappa_t \frac{d\theta}{dz}\right) + f_\theta^S, \qquad (2)$$

where $U$ is the horizontal wind speed in either the $x$- or $y$-direction, $\theta$ is the potential temperature, $\mu_t$ and $\kappa_t$ are the momentum and heat turbulent diffusion coefficients and $f_u^S$ and $f_\vartheta^S$ 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:

$$\frac{de}{dt} = \frac{d}{dz}\left(\lambda_t \frac{de}{dz}\right) + C_\varepsilon \frac{\sqrt{e}}{l}(e_\infty - e) + f_e^S \qquad (3)$$

where $e$ is the TKE, $\lambda_t$ is the diffusion coefficient (assumed here to be equal to $\mu_t$) 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:

$$\mu_t = C_e\sqrt{e}l \qquad (4)$$

$$\kappa_t = \Pr \mu_t \qquad (5)$$

where $C_e$ is a constant equal to 0.3. $l$ is defined as the mixing length and is taken from Mauree et al. (2017)

to account for 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.

### 2.3 Control Algorithm

In order to increase the reliability of the system, as well as to decrease the perception of an erratic behaviour of the automation system a new control algorithm was proposed. The objective was to couple the CIM results with the automation system to have more reliable information that could be used to protect the blinds.
Fig. 2 gives an overview of the decision process by the system. CIM calculates at every time step T (every minute in our case) a vertical profile. The simulated value for the wind is then used as an input for the control algorithm. Since we do not want to raise the blind every time there is a gust, we used an additional condition to verify that the wind is blowing above a pre-determined threshold (5 $ms^{-1}$ in our case). Note that the control algorithm also accounts for the daylighting needs of the user, as well as the glare index calculated using sensors inside the controlled offices.

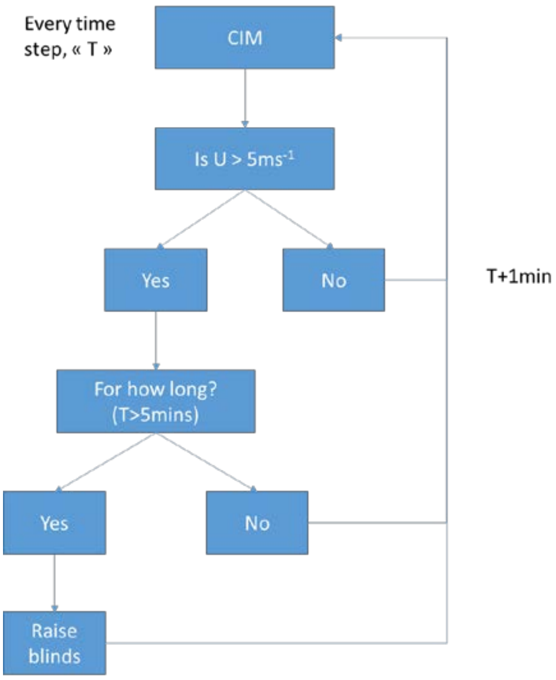


Fig. 2 – Proposed algorithm flow chart

The blinds that are controlled are located on the south-eastern part of the LESO-PB building on the EPFL campus.

## 3. Results Analysis and Discussion

### 3.1 Measured Wind Speed

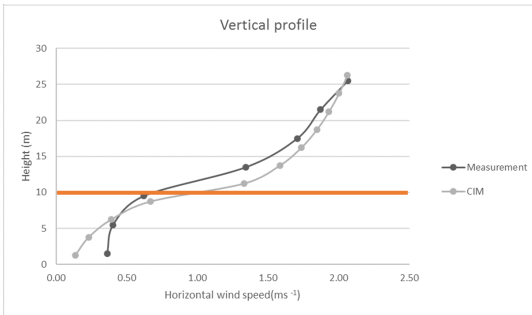


Fig. 3 – Vertical profile of the horizontal wind speed ($ms^{-1}$) from the sonic anemometers (in black) and results from CIM (in grey) with the height (m) on the vertical axis. The orange line represent the building height (10 m)

As can be expected in an urban context, the wind profile is highly impacted by the presence of buildings. It can be noted from Fig. 3 that the characteristic logarithmic profile is present above the building roof and that below in the canopy layer there is a low horizontal wind speed. This corresponds to results previously reported (Rotach et al., 2005; Santiago and Martilli, 2010).

Table 1 – Wind speed measured at each floor v/s at top

| Floor | *U* ($ms^{-1}$) | Relative difference |
|---|---|---|
| 1st | 0.36 | 73% |
| 2nd | 0.40 | 71% |
| 3rd | 0.62 | 54% |

Table 1 shows the variation of the wind speed measured at each floor with respect to the wind speed measured on top of the building, as usually done with the current automated system. It should be highlighted here that the wind measured can be up to 73 % less strong than the wind measured at the top. Furthermore, the turbulent patterns (not shown in the present paper) can be significantly altered in the urban canyon.

### 3.2 Simulated Wind Speed

Boundary conditions from the highest anemometer are then used to force the CIM model. The results are shown in Fig. 3. It can be seen that CIM can reproduce with a very good agreement the measurement. There is however a slight underestimation of the wind speed close to the ground. This might be due to the drag force coefficient parameterization that is usually overestimated (Santiago and Martilli, 2010). The drag force parameterization used in this study is based on the occupied volume (density of the neighbourhood). Since CIM is a 1D model, there is a simplification of the 3D representation of the buildings. This can be the reason for the over-estimation of the drag force close to the ground.

### 3.3 Control of Blinds

Based on the results that we have obtained, we implemented the new control algorithm in our system to improve the automation of the blinds on the LESO façade.
It was shown that a more realistic and appropriate behaviour of the blinds was possible in an urban context, where the wind speed is usually erratic and can have a significant impact on turbulent patterns.

## 4. Conclusions and Perspectives

This paper presents the results from an experimental setup that measures meteorological variables in an urban setup. Seven 3D sonic anemometers have been installed along a vertical axis to provide high frequency measurements of the wind speed.
It was shown that the wind speed is highly impacted by the urban context and that this can considerably influence the decision of an automated system to control blinds on a building façade. Differences of up to 73 % were noted in the current case. The vertical profiles from the measurement campaign were then compared with the simulation from CIM. The results showed very good agreement between the computed and measured data. A new control algorithm was then derived to improve the automation system installed in a building on the EPFL Campus.
The current study will be expanded in the near future to include six more sonic anemometers that will be installed directly on the façade. Furthermore, the experiments will be prolonged for one whole year and the results will be analysed in more details to understand the behaviour of the blinds and of the control algorithm.

## 5. Acknowledgements

The authors wish to thanks 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 Centre for Energy Research, Future Energy Efficiency Buildings and Districts, FEEB&D (CTI.2014.0119).

## Nomenclature

### Symbols

| | |
|---|---|
| $U$ | Wind speed ($ms^{-1}$) |
| $\theta$ | Air temperature (K) |
| $e$ | Turbulent Kinetic Energy ($m^2\ s^{-2}$) |
| $e_\infty$ | Stationary TKE value |
| $\lambda_t$ | TKE diffusion coefficient ($m^2\ s^{-1}$) |
| $\mu_t$ | Momentum diffusion coefficient ($m^2\ s^{-1}$) |
| $\kappa_t$ | Heat diffusion coefficient ($m^2\ s^{-1}$) |
| $z$ | Height (m) |
| $l$ | Mixing length (m) |
| $Pr$ | Prandtl Number |
| $C_e$ | TKE constant |
| $C_\varepsilon$ | Dissipation constant |
| $f_u^s$ | Momentum surface fluxes |
| $f_\vartheta^s$ | Heat surface fluxes |
| $f_e^s$ | TKE surface fluxes |

### Subscripts/Superscripts

| | |
|---|---|
| $t$ | Refering to turbulent coefficient |
| $s$ | Refering to surface fluxes |

## References

Ashie, Y., Vu Thanh Ca, T. Asaeda. 1999. "Building canopy model for the analysis of urban climate". *Journal of Wind Engineering and Industrial Aerodynamics* 81(1–3): 237-248. doi:10.1016/S0167-6105(99)00020-3.

Kaimal, J.C., J.J. Finnigan. 1994. *Atmospheric Boundary Layer Flows: Their Structure and Measurement*. Oxford, UK: Oxford University Press.

Krpo, A., F. Salamanca, A. Martilli, A. Clappier. 2010. "On the Impact of Anthropogenic Heat Fluxes on the Urban Boundary Layer: A Two-Dimensional Numerical Study". *Boundary-Layer Meteorology* 136(1): 105-27. doi:10.1007/s10546-010-9491-2.

Martilli, A., A. Clappier, M.W. Rotach. 2002. "An Urban Surface Exchange Parameterisation for Mesoscale Models". *Boundary-Layer Meteorology* 104(2): 261-304. doi:10.1023/A:1016099921195.

Masson, V. 2000. "A Physically-Based Scheme For The Urban Energy Budget In Atmospheric Models". *Boundary-Layer Meteorology* 94(3): 357-397. doi:10.1023/A:1002463829265.

Mauree, D. 2014. "Development of a multi-scale meteorological system to improve urban climate modeling". Strasbourg, France: Université de Strasbourg.

Mauree, D., N. Blond, M. Kohler, A. Clappier. 2017. "On the Coherence in the Boundary Layer: Development of a Canopy Interface Model". *Frontiers in Earth Science* 4. doi:10.3389/feart.2016.00109.

Mauree, D., J.H. Kämpf, J.L. Scartezzini. 2015. "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, India: IBPSA.

Oke, T.R. 1982. "The Energetic Basis of the Urban Heat Island". *Quarterly Journal of the Royal Meteorological Society* 108(455): 1–24. doi:10.1002/qj.49710845502.

Rotach, M.W., R. Vogt, C. Bernhofer, E. Batchvarova, A. Christen, A. Clappier, B. Feddersen, et al. 2005. "BUBBLE – an Urban Boundary Layer Meteorology Project". *Theoretical and Applied Climatology* 81(3-4): 231-261. doi:10.1007/s00704-004-0117-9.

Salamanca, F., A. Martilli, M. Tewari, F. Chen. 2011. "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* 50(5): 1107–1128. doi: 10.1175/2010JAMC2538.1

Santiago, J.L., A. Martilli. 2010. "A Dynamic Urban Canopy Parameterization for Mesoscale Models Based on Computational Fluid Dynamics Reynolds-Averaged Navier–Stokes Microscale Simulations". *Boundary-Layer Meteorology* 137(3): 417-39. doi:10.1007/s10546-010-9538-4.