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# On the impact of the wind speed on the outdoor human comfort: a sensitivity analysis

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**Abstract**

The energy demand of buildings and outdoor human comfort are key elements of a sustainable urban design. The wind speed has an enormous impact on thermal sensation, but the sensation itself is hard to quantify. The objective of this paper is to understand how the wind influences thermal energy exchanges, and to quantify its impact on outdoor thermal sensation. In order to do so, three outdoor comfort models were selected. Each thermal model was then calculated for the EPFL campus (Switzerland) by coupling the software tools CitySim and RayMan. In order to factor the importance of local meteorological data, two different sources of data are used: the software Meteonorm and recorded onsite data. Results obtained underline the impact of the wind speed on the thermal perception of pedestrians, describing the sensitivity of each of the thermal models, as well as the environmental characteristics.


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## 1. Introduction

The energy demand of buildings and the outdoor human comfort are key elements of a sustainable urban design. Nowadays, a correct bioclimatic design is essential in order to impact the urban microclimate positively, and consequently improve people's health and wellbeing.

Several models exist to quantify the outdoor thermal comfort, and they can be subdivided into three broad categories: thermal indices, empirical indices and indices based on linear equations. Thermal indices are based on the human being's energy balance, showing the interrelation between metabolic activities, clothing and environmental parameters (air temperature, mean radiant temperature, wind speed, solar irradiation and relative humidity) on the pedestrian's thermal perception [1]. The wind speed has an enormous impact on the thermal sensation [2], but the sensation itself is hard to quantify as it varies as a function of the physical, physiological and physiological adaptations of pedestrians. Furthermore, the design of urban areas often relies on meteorological data collected at non-urban sites and this can induce considerable errors in the evaluation of design. Wind turbulence and patterns vary quite significantly inside of urban canyons as compared to rural sites [3].

The objective of this paper is to understand how the wind influences thermal energy exchanges, and to quantify its impact on the outdoor thermal sensation. In order to do so, three comfort models, Predicted Mean Vote (PMV), Physiological Equivalent Temperature (PET) and the COMFA* budget were selected. Each thermal model is then calculated by means of the software CitySim and RayMan for the EPFL campus (Switzerland), by coupling the software tools. In order to factor the importance of local meteorological data, two different sources of data are used: (i) the software Meteonorm and (ii) monitoring data from the MoTUS campaign at the EPFL campus. The analyses are performed for the Rolex Learning Center, the library of the campus, as this area is particularly appreciated by visitors and students, and is one of the most liveable places on the campus. The output provided by CitySim and RayMan is then used to create a Comfort Map, where the thermal perception of the pedestrian is designed according to various wind profiles. Results obtained by these analyses underline the impact of the wind speed on the thermal perception of pedestrians, describing the different sensibility of each of the thermal models, as well as the function of the environmental characteristics (ground covering, shadowing, greening and trees). Finally, the impact of a correct meteorological data is also underlined, showing how the provisional thermal sensation could vary depending on whether recorded weather data or yearly averaged data are used.

## 2. Methodology

### *2.1. Site Area*

The analyses of the outdoor human comfort are performed in the EPFL campus (46° 31' N, 06°38' E, 495 m a.s.l.), in the area above and around the Rolex Learning Center. The selection of the site is due to the fact that this area is particularly appreciated by visitors and students, and is one of the most liveable places on campus. Additionally, this area represents a typical urban setting, with a vertical surface mix of glass, metal, concrete and wood constructions, as well as asphalts, concrete and grass covering at the pedestrian level (Fig. 1).

Fig. 1 3D view of the EPFL campus (left) and photo of the Rolex Learning Center (right). Source of the photo: Médiathèque EPFL.

### 2.2. Outdoor human comfort

Between all the available models, we decided to quantify the outdoor human comfort by the following three indices: Physiological Equivalent Temperature (PET) [4], Predicted Mean Vote (PMV) [5] and COMFA* budget [6]. The simulations are performed with Rayman [7] and CitySim Pro [8], and the obtained results, in text file, are then exported in ArcGIS, in order to visualize the results in form of maps. Firstly, the simulations are performed with the climatic data provided by Meteonorm [9], for a typical meteorological year (TMY). Secondly, the outdoor human comfort is quantified by using the wind speed and direction, as recorded by the MoTUS weather station, from 1.5 m to 25.5 m height, every 4 meters. MoTUS (Measurement of Turbulence in an Urban Setup) was installed in 2016, consequently yearly data are not yet available. In order to overcome this problem, we decided to analyze just the month of March 2017 (744 hours of measurements), assuming that during the winter time people spend less time outside, consequently the analyses of the outdoor human comfort are not interesting. Table 1 summarizes the average, maximal and minimal wind speed, as recorded by the weather station, per each height, during the measurement period. The averaged wind speed at 1.5m corresponds to 0.56 $ms^{-1}$, 24% lower than the one recorded at 25.5 m (2.32 $ms^{-1}$).

Table 1 Average, maximal and minimal wind speed ($m \cdot s^{-1}$) as recorder by MoTUS.

| Height (m) | M1_1.5 | M2_5.5 | M3_9.5 | M4_13.5 | M5_17.5 | M6_21.5 | M7_25.5 |
|---|---|---|---|---|---|---|---|
| Average | 0.56 | 0.69 | 0.99 | 1.55 | 1.90 | 2.11 | 2.32 |
| Max/Min | 1.63/ 0.12 | 1.89/0.12 | 3.29/0.18 | 5.1/0.3 | 6.82/0.21 | 7.47/0.19 | 7.95/0.2 |

Pedestrians are located in the outdoor environment, upon a grid of 10m each side; each pedestrian performs a light metabolic activity (80 W). In the proposed methodology, the Mean Radiant Temperature (MRT) is computed, hourly, for each pedestrian. The calculated MRT, as provided by CitySim [10], is then exported as input weather data into the software RayMan. The proposed methodology simplifies the calculations with RayMan, because all the physical characteristics of the site (urban geometry, albedo of the surfaces, greenings etc.) are already calculated by CitySim Pro, and exported to RayMan by the means of MRT calculation.

## 3. Results

### 3.1. Outdoor human comfort, annual analyses

The outdoor human comfort is quantified hourly for each point of measurement (totally 123 points), around the Rolex Learning Center; then detailed simulations are performed for three points of measurement: p1 located on the southern entrance of the building, p2 located inside a courtyard and p3 located on the North entrance of the Rolex

Learning Center. Figure 2 shows averaged COMFA* of the site, as calculated by CitySim Pro. Clearly, pedestrians located on the southern entrance of the building (e.g. p1) are more comfortable than the ones located inside the small courtyards, passing from a "comfortable" thermal sensation (between +50 $W \cdot m^{-2}$to -50 $W \cdot m^{-2}$) to a "slightly cool" thermal sensation (between – 51 $W \cdot m^{-2}$ to -120 $W \cdot m^{-2}$), on average per year (e.g. p2).

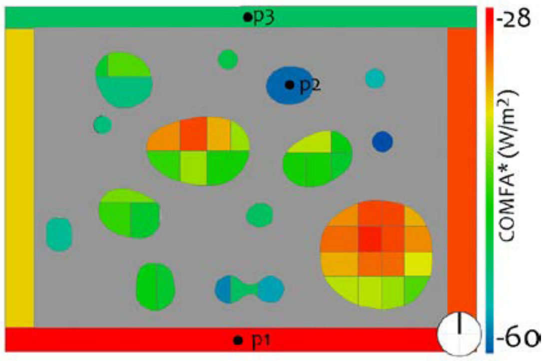


Fig. 2 Comfort Map of the site, averaged annual thermal sensation calculated by the COMFA* budget.

It can be highlighted that the PET corresponds to 7.0°C ("cold" thermal sensation), with a higher sensation for the pedestrians located at the southern entrance of the building (7.8°C) and the lowest one recorded in the small courtyard (5.9°C). The difference is higher when looking at the summer season, when the maximal PET corresponds to 18.3°C and the minimal to 16.3°C, "comfortable" and "slightly cool", respectively. The same behavior is underlined by the Predicted Mean Vote, with a summer averaged thermal sensation corresponding to "comfortable" (PMV=-0.6), with a maximal vote of -0.5 on the southern entrance of the building.

*3.2. Outdoor human comfort, variation of the wind speed by the MoTUS on-site monitoring*

In order to quantify the variation of the thermal perception as a function of wind speed, three points of measurement were selected: p1 located on the southern entrance of the building, p2 located inside a courtyard and p3 located on the North entrance of the Rolex (Fig.2). All the simulations were firstly performed by CitySim Pro, in order to obtain the MRT, and consequently create the new weather profile for RayMan. Figure 3 summarizes the averaged PET, calculated during the daytime, as a function of the wind speed. The variation of the wind has a major impact on the pedestrian's thermal sensation: as an example pedestrian p1 varies its thermal sensation from 9.14°C to 5.3°C, consequently feeling "cool" or "cold", respectively. Naturally, the maximal difference is between 1.5 m and 9.5 m. This is clearly related to the geometry of the site, as 9.5m corresponds to the average height of the campus. The pedestrians p2 and p3 are less influenced by the variation of the winds speed, passing from 5.0°C and 5.3°C to 3.1 and 3.3°C, respectively. Both points are already well influenced by the built environment, as they are located in a courtyard and on the northern side of the Rolex building, consequently the variation of the wind speed has a lower impact on their thermal sensation, which, in any case, passes from "cold" to "very cold". The same analysis is conducted with the other comfort models, COMFA* and PMV. All of them underline the same behavior, as shown in Figure 3. The pedestrian p1, located on the southern entrance of the building, is the one facing the maximal differences in thermal perception, passing from a "cool" to a "cold" thermal sensation, as expressed by the PMV.

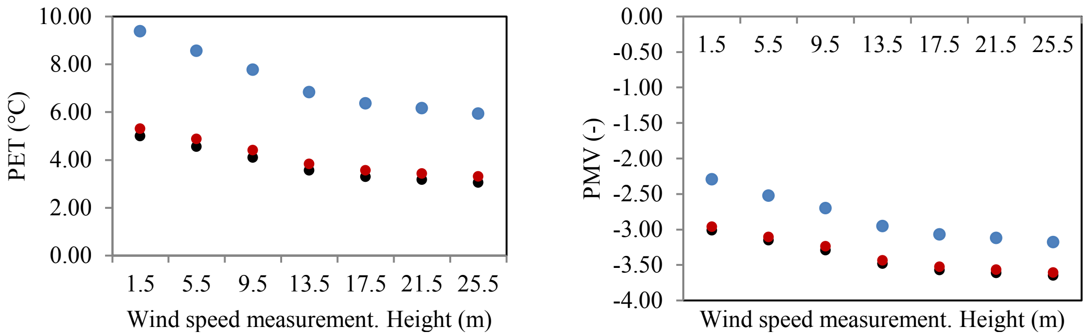


Fig. 3 Average PET and PMV, as simulated with the several wind speed profiles. Pedestrian p1 (blue), p2 (black) and p3 (red).

It is interesting to note that the impact of the wind speed variation varies hourly during the daytime, also as a function of the weather characteristics. Fig. 4 shows the COMFA* budget from the 14th to 16th of March. On the 14th of March, the thermal sensation varies from "comfortable" to "slightly warm", with the wind profile recorded at M1 and M7, respectively. By contrast, during the 16th of March there is no variation between the two models. This difference could be explained by two factors: the wind speed and the nebulosity of the site. The 16th of March is characterized by a low wind speed (1.66 $ms^{-1}$ at 25.5m and 0.96 $ms^{-1}$ at 1.5m), consequently the difference between the point on measurements is lower. By contrast, during the 14th of March a gentle breeze blows on site, up to 4.6 $ms^{-1}$ at 25.5m. Additionally, the 14th is characterized by an overcast sky, whereas during the 16th the nebulosity corresponds to 8 octas. The wind speed impacts, by convection, the energy balance of the surfaces located in the built environment. During a sunny day, the surfaces receive more radiation than during a cloudy day, consequently their temperature increases. It is well known that the convective heat flux is related to the wind speed, and the difference of temperature between the air and the surface. This behavior is also evident throughout the day: the variation between the two wind profiles is higher during the daytime than during the nighttime.

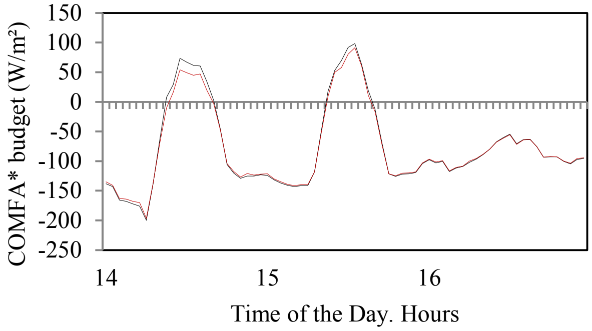


Fig. 4 COMFA* budget during the 14th to the 16th of March. Wind speed recorded at M1 (black) and M7 (red).

Concluding, it is evident that a correct wind profile improves the quality and the precision of the results. Naturally, this impact varies according to the climatic conditions. As an example, in the climate of Lausanne, characterized by a low wind speed, the impact of the wind is lower compared to a windy city. Additionally, in the temperate climate of Lausanne, pedestrians located in a dense urban environment are less impacted by the wind modification, because they are mostly influenced by the urban texture.

## 4. Conclusion

The work presented in this paper is a first attempt to quantify the impact of a wind speed profile in an effort to analyze outdoor human comfort at the district scale. The outdoor human comfort is quantified by PET, COMFA* and PMV, using the software CitySim Pro and RayMan. Firstly, the human thermal sensation is quantified using weather data as provided by Meteonorm. Then, the wind profile is modified, as recorded by the on-site weather station MoTUS, located in the EPFL campus, during the month of March 2017. The impact of the wind speed is then calculated by each thermal model, showing the great impact of a realistic wind profile in thermal comfort analyses. Effectively, pedestrian p1 varies its average thermal sensation from 9.14°C to 5.3°C, consequently feeling "cool" or "cold", respectively. The maximum difference between the recorded wind speeds appears between 1.5 m and 9.5 m, which corresponds to the average building height of the campus. The difference is dependent on the wind speed (light breeze or strong wind), as well as on the nebulosity of the sky.

In order to improve the results obtained, continuing the work realized until now, further investigations are required:

- Quantify the impact of the wind speed by varying the pedestrians metabolic activity
- On-site questionnaire, in order to validate the results obtained by the simulations
- Improve the simulations by CFD calculations, in order to quantify the wind variation within the urban texture.

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