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Micro-article

Towards benchmarking of urban air quality based on homogenous surface emission

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ABSTRACT

Here, it is presented a possible methodology and experimental model for benchmarking of air quality in cities. The concept behind the methodology is that a city's inherent structure affects the potential for contaminant removal due to the resistance it poses to inflow. The approach is based on homogenous emission across the street surface network, representing a worst-case situation. Different levels of complexity can be used for benchmarking, making it valuable for evaluating different layouts. Additionally, an urban ventilation index suitable for these kinds of experimental studies has been suggested.

1. Introduction

Over the last five decades, wind tunnels have played an important role in various research applications. These include studying diverse atmospheric boundary layer flows, analyzing the aerodynamics of different objects, assessing their impact on buildings, and investigating aspects like infiltration and urban micro-climate (e.g. [[1–6]]).

Urban micro-climate, refer to thermal environment, wind environment, pollutant dispersion and other meteorological phenomena. In case of major city expansion, urban redevelopment, or new city design, the science of urban micro-climate can be used as the guideline for planners and architects to achieve the design that is in harmony with the environment. In already existing cities, on the other hand, the micro-climate analysis can propose mitigation strategies for human comfort and air quality concerns. Wind tunnel studies with generic buildings configuration can provide the basic insights of the relationship between urban morphology and urban microclimate and can also provide experimental data for CFD validation [[7,8]].

It appears that both the working methods and the priority given to air quality in urban development plans varies widely between countries and even within countries [9]. It can be problematic to deal with different cases in a consistent way, and it is often difficult to choose the appropriate method when an air quality assessment is required. A worst-case scenario is considered as a good starting point when assessments are intended to be carried out.

In this article it is presented a possible methodology and experimental model based on homogenous tracer gas release in a wind tunnel for benchmarking of air quality in cities. The overarching goal is to create the basis for a methodology based on homogenous emission that can be used for planning of a healthy air quality in cities taking into consideration the release of contaminants within the street network.

2. Methodology

In a city the buildings are a blockage to the wind and only fraction of the approaching flow rate flows into the city. A city is, like a building, ventilated by a certain flow rate which depend to a large extend on the city morphology. The concept of ventilation is referred as the process by which clean air is provided into a space for removal and dilution of contaminants. The concept underpinning the methodology consider that the potential for removal of contaminants is influence by the city itself due to the resistance to inflow it generates. This can be achieved by applying a homogeneous emission of contaminants per volume unit such as the concept of mean age of air, which was derived from building ventilation theory, but it is more applicable for numerical studies of urban air quality [10]. Here instead, the benchmarking method is based on an experimental model where homogeneous emission of contaminants are released at the ground surfaces in the urban canopy layer. Based on the surface emission rate an urban ventilation index is defined, called contaminant removal index (CRI):

$$\mathrm{CRI}_i = \dot{q}_s / c_i U_{ref}, [\text{-}] \tag{1}$$

where c_i (mg/m^3) is the tracer gas concentration in point i, U_{ref} (m/s) is the reference velocity of the incoming freestream flow, and $\dot{q}$ (mg/sm^2) is the emission rate of the tracer gas per street surface area.

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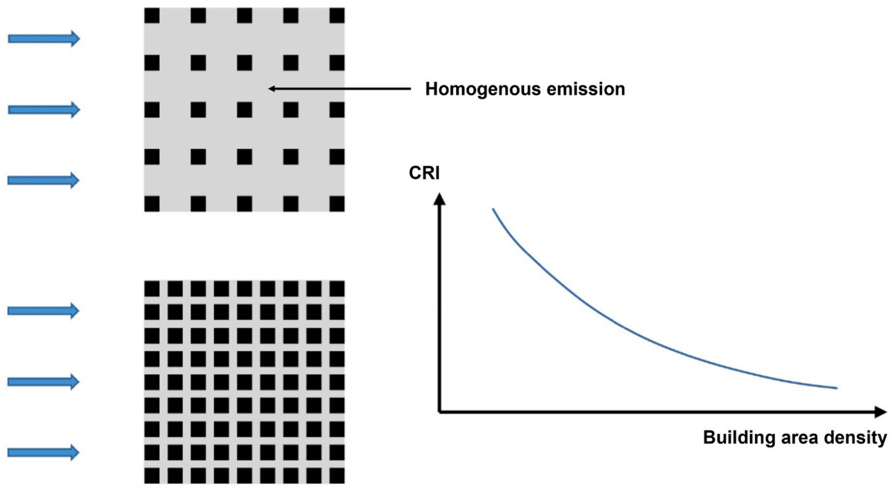

Fig. 1. Illustration of how CRI is affected by building area density.

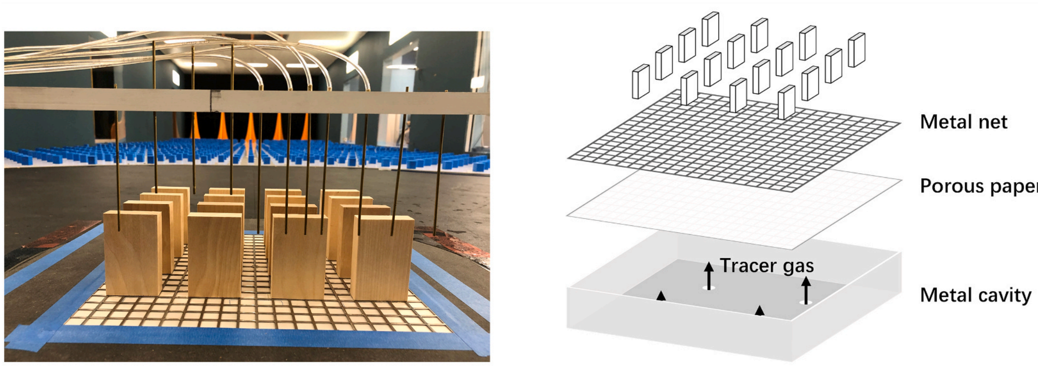

Fig. 2. Illustration of the experimental model.

The CRI strongly depends on the city morphology, se Fig. 1 for an illustration.

2.1. Experimental model and data gathering procedure

An idealized condition was modeled by a surface emission source consisted of a paper cover and a cavity under it, see Fig. 2. The tracer gas was injected into the cavity beneath the paper cover, with sufficient pressure difference, generating a smoothly and homogenous surface release with negligible initial velocity. The whole source was mounted under a turntable in the work section inside the wind tunnel at University of Gävle. The model can easily be scaled up. Model clusters with different building area densities, building height variations, building width variations etc. can be studied, and their influences on the removal of contaminants in the urban canopy layer. The distribution of tracer gas can easily be sampled at different heights and locations.

The flow rate of air and the tracer gas (N_2O) were regulated using two electric mass flow controllers from ScantecNordic, and concentration measurements were conducted with an IR gas detector manufactured by Leybold-Heraeus. Gas samples were collected to the detector by the pump, with the target channel for each sampling controlled via LabView. The incident flow was adjusted by the upstream roughness elements to establish a turbulent boundary layer wind profile. Building blocks had dimensions of 16 × 44 × 70 mm (width × length × height) and were spaced with centers 55 mm separated in the streamwise direction and 70 mm apart in the spanwise direction.

3. Example of experimental data

As an example, Fig. 3 shows the spatial distribution of the CRI in the urban canopy layer at different heights above the ground. Here, the freestream velocity at the building height, H (m), is used as U_{ref}.

Wind brings clean air into the street network for contaminant dilution and removal. Close to the ground and at recirculation regions, where the air velocities are low, the measured tracer gas concentrations are high. Thus, CRI is relatively low close to the ground in downstream regions and recirculation regions. CRI becomes close to 1 at points near the upstream urban canopy layer boundary at height H.

4. Conclusions

The concept underpinning the methodology consider that the potential for removal of contaminants is influence by the city itself due to the resistance to inflow it generates. This resistance is dependent on how the city is built or will be built. Furthermore, it takes care of the complex conditions that is prevailing in cities. Benchmarking can be carried out with different degrees of complexity and making it valuable for evaluating different layouts The method can be seen as a worst-case scenario where emissions are generated evenly along the street surface network. A ventilation index has been proposed for this type of benchmark studies.

CRediT authorship contribution statement

Mathias Cehlin: Conceptualization, Methodology, Writing –

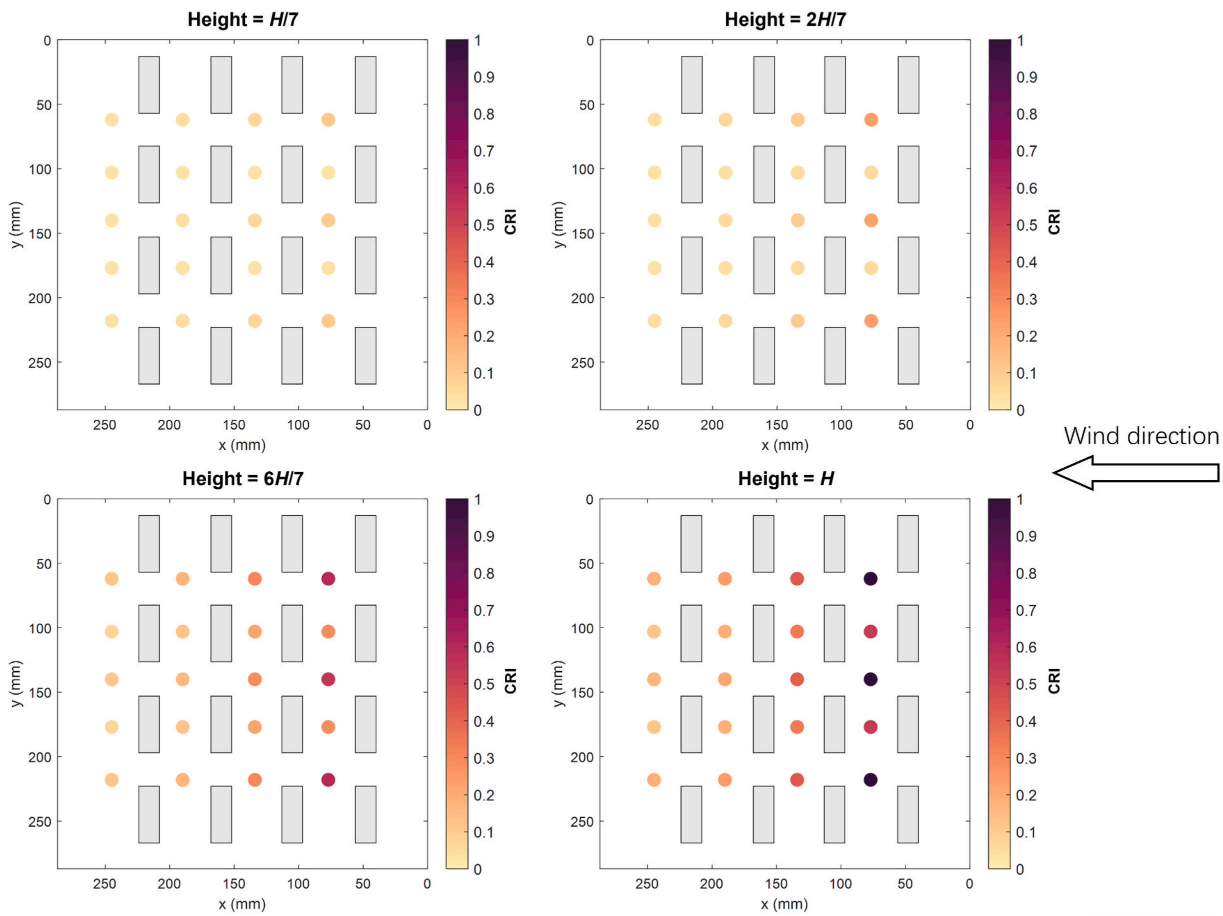

Fig. 3. Distribution of CRI within the urban canopy layer at heights $H/7$, $2H/7$, $6H/7$ and H.

original draft. **Yuanyuan Lin:** Data curation, Investigation, Visualization, Writing – original draft. **Mats Sandberg:** Conceptualization, Methodology, Supervision. **Leif Claesson:** Investigation, Resources. **Marita Wallhagen:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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