

**Supervisor's review on Mgr. Zuzana Kluková "Flow dynamics and pollutant transport in street canyons of different roof heights and geometries: a wind tunnel and LES modelling" doctoral thesis.**

After completing his master's studies in 2016, Mgr. Zuzana Kluková started her doctoral studies in the Department of Meteorology and Climatology at the Department of Atmospheric Physics of the MFF UK. The training workplace became the Institute of Thermomechanics of the Academy of Sciences of the Czech Republic, v. v. i. (32-UTAV), where I became its supervisor. Ing. Štěpán Nosek, Ph.D. from the same institute, was appointed as a consultant. Since the focus of her bachelor's and diploma thesis was different from the proposed topic, it was necessary from the beginning to get acquainted with the basic principles and methods of physical modelling, to conduct a literature search on this topic and, in particular, to learn how to operate a laboratory and sophisticated measuring systems. She gained additional knowledge at three courses organized by the von Karman Institute for Fluid Dynamics (Large Eddy Simulations and Related Techniques; Introduction to Measurement Techniques; Machine Learning for Fluid Dynamics) and the Urban Physics Winter School organized by ETH Zurich. As is usual in standard universities or laboratories, another source of knowledge and skills was cooperation with members of the laboratory. Most of them have already completed or were completing their doctoral studies. The doctoral student's regular active participation in international conferences and workshops was inspiring for the solution of the dissertation. The regular (once every two years) international workshop called Physmod with the addition of the year of organization should be underlined here. Its participants are mainly experts and doctoral students in the field of physical modelling. In its framework, newly solved projects, newly proposed methods, and often unpublished results are discussed. It was here that the doctoral student received further suggestions and recommendations for continuing her work.

The original intention of the dissertation was to build on and continue the study of the flow and diffusion of passive admixture on a generally three-dimensional model of a street canyon inside urban development, which was carried out at the Institute of Thermomechanics within the framework of GAČR projects and international COST projects. The three-dimensionality of the original studies rested on the different heights of the individual buildings with sloping roofs forming the street. At that time, the tasks of the laboratory focused on a model of urban development, which realistically corresponds to the development of European cities, where buildings are in the shape of closed blocks with inner courtyards (an example is the development of Vinohrady in Prague), on which it is also possible to change the shape of the roofs and the height of individual buildings.

The actual experiments were carried out in a special aerodynamic tunnel of the Institute of Thermomechanics of the Academy of Sciences of the Czech Republic, in Nový Knín. On this model, the PhD student studied flow and diffusion as part of the GA UK project 1583217: The influence of the geometry of urban development on the flow and spread of pollutants in the urban canopy. The measurements were carried out with a unique system that was developed at ÚT and consists of simultaneous measurement of the turbulent characteristics of the flow field with the LDA system and the turbulent characteristics of passive admixture concentrations with the FFID system (derived by my previous doctoral student Libor Kukačka, Ph.D.). Here it is necessary to point out that the measurements are carried out gradually at individual points of the studied area. So the experiments are quite time-consuming. The results were processed and evaluated. They demonstrated essential transmission properties in such a complicated environment. Therefore, the project was evaluated

successfully. During the study, the institute acquired a new device for measuring turbulent characteristics referred to as PIV. This device makes it possible to determine the instantaneous flow field over entire limited areas. It means a significant shortening of the experiments and, above all, the acquisition of data on which it is possible to study the properties of the currents more deeply on the one hand, but it does not yet allow simultaneous measurement of concentration fields.

This connection, on the other hand, is made possible by numerical simulations using DNS or LES. Such is, for example, the ELMM model developed by colleague Fuka at the department. And here it is necessary to draw attention to the shortcomings of numerical models (as well as all models in general). Therefore, the doctoral student was first forced to compare the results of the numerical solution with the results of the experiments. The comparisons were first qualitative, then quantitative statistical methods. Validation met criteria matching criteria.

Thus, the doctoral student managed to obtain three relevant data sets describing the flow and diffusion of passive admixture over a model of urban development typical of European cities. Based on these data, the doctoral student conducted a thorough discussion of the spread of pollutants in urban areas and, in particular, the influence of different configurations on this spread. A new trend in the study of turbulent flows is to study files containing instantaneous values of turbulent quantities with the help of modern statistical methods. These were, for example, quadrant, Proper Orthogonal Decomposition (POD), dynamic mode decomposition (DMD), oscillation pattern decomposition (OPD) and others. The author was thus able to reveal the existence of substantial non-stationarities in the flow and a complicated vortex structure inside the urban canopy. In addition, it has been proven that the mentioned behaviour is related to the presence of so-called coherent structures. Therefore, the objectives of the dissertation were specified to reveal and study these structures.

I can therefore state that the work performed substantially exceeded the requirements for a doctoral dissertation and the work is at a high international professional level. The doctoral student successfully presented her results in twelve publications. In five articles in a professional imputed periodical (in one case, in a journal with IF = 4.4, she is the first author) and three international conferences. Two research reports, one national conference and one extended abstract are also listed in the database of the Academy of Sciences of the Czech Republic. According to WoS, the publication was cited 33 times (without self-citation), which means that its h-index is equal to 3. According to Scopus, the publication was cited even 40 times, with the same h-index value. Regarding this assessment, I can also state that similar professional results have so far been obtained only at a few top foreign workplaces. The results were awarded as part of the "Make our planet great again" competition organized by the French Embassy in the Czech Republic, in which the doctoral student took 2nd place and spent month study stay at Ecole Centrale de Nantes. For the sake of objectivity, it is necessary to state that due to the complexity of the problem, the complexity of the experimental methods and evaluation methods, the length of the solution was considerably longer than is usual for a dissertation, and I can imagine that many shortcomings can certainly be found in the work. An expert in the field of meteorology will certainly find such deficiencies in his field, an expert in the field of fluid mechanics will similarly find deficiencies in his field.

In order to complete the description, it is necessary to state that the doctoral student is currently fully involved in the scientific work of the laboratory and, moreover, in the teaching

activities of the department. For the reasons stated, I can state as a supervisor that the original goals of the doctoral studies were not only achieved, but were significantly exceeded. A large part of the results have been successfully published both in recognized journals and at conferences. I further state that she has fulfilled all study obligations according to the study plan.

**Based on the above, I recommend that the submitted thesis be accepted as a doctoral dissertation for the defence and, after its successful defence, Zuzana Kluková be awarded by the Ph.D. degree.**

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