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Review Report for Doctoral Thesis

submitted to the Czech Technical University in Prague, Faculty of Mechanical Engineering, Dept. of Environmental Engineering

Thesis author:	**Ing. Petr Zelenský**
Thesis tittle:	**Optimum Representation of Heat Sources in Simulations of Air Flow in Indoor Environment**
Supervisor:	prof. dr. ir. Jan L. M. Hensen
Supervisor Specialist:	Ing. Martin Barták, Ph.D.

Doctoral thesis by Ing. Petr Zelenský proposes a method to simulate free convection induced by heat sources, in particular human body, in indoor environment. As shown in the thesis, computing demands of detailed computation fluid dynamics (CFD) simulation of a human body, or a "thermal manikin" representing it, are very high which can be prohibitive for simulating air flow in complex rooms with many occupants. This justifies the effort of this thesis to develop a simplified boundary condition (SBC) allowing to simulate the thermal effect of a local heat source (in particular a room occupant) without the need to model the complex thermal boundary layer of its physical surface.

After an introduction (Chapter 1) providing a motivation and context of heating, ventilation and air conditioning (HVAC) technology, the author provides a thorough review of the stat of the art (Chapter 2). Mathematical modeling of indoor environment at several levels of detail are discussed. Most attention is given to CFD simulations. Also experimental studies are reviewed in sufficient detail. Statement of the research goals is provided in Chapter 3. Chapters 4 and 5 describe the main original theoretical contribution, which consists in developing and optimizing SBC for efficient CFD simulations of indoor environment. Four modifications of the turbulence models are considered, leaving the Standard k-epsilon model as most suitable for the given task. In particular I appreciate the study of the effect of location of the surface with SBC, the possibility of two SBC reproducing much better the flow and temperature fields of the detailed simulation, and the study of interaction of thermal plumes due to two and more heat sources. Chapter 6 summarizes the results, including definition of User Defined Functions

(UDF) which implement the developed methods in ANSYS Fluent CFD software. In Chapter 7, the author presents a case study of modeling air flow in a complex room of former church used now for cultural events. This study demonstrates the applicability of the developed method for the case of a large (and variable) number of local heat sources (here room occupants).

Although the thesis is quite concise, in a few aspects I was not sure to understand everything and they could perhaps be explained in more detail. In particular, the mathematical structure of developed UFD is not discussed in detail. As it can be seen in APPENDIX III providing UDF listing, the author parameterized the temperature, velocity, and turbulence parameters k and epsilon along the horizontal plane at which SBC is defined. The parameterization is based on data acquired with detailed simulation and it is expressed as a combination of Gaussian and parabolic terms. If these equations are presented in the text, it would make it possible to use them in other software and to appreciate their strength. Also, it would be suitable to show lines produced by these equations in a figure in comparison with the original data. Apparently, these parameterizations are only suitable for the case of single SBC, what about the case of double SBCs (at different elevations)?

Further my question concerns experimental validation described in section 4.2.1., figure 4.3. The temperature field is measured using a thermal imaging camera which observes a sheet of paper stretched vertically above the thermal manikin, either parallel or perpendicular to its shoulders. However, this sheet clearly introduces new hydrodynamic boundary layers. It seems that the experimental configuration is significantly affected by this measuring technique and, to achieve accurate validation, the CFD model should incorporate this sheet. I wonder if this effect has been considered.

Finally, I would like to ask about the effect of moisture on the free convection in indoor environment. Exhaled air is almost 100% saturated at the body temperature. Due to the lower molecular weight of water compared to nitrogen and oxygen, humid air is lighter compared to dry air at the same temperature and pressure. Is the exhaled humidity-driven buoyancy completely negligible compared to the human body heating-driven buoyancy?

The complete view of the thesis is very positive, unaffected by the above given questions. The stated goals have been reached, appropriate methods have been adopted to reach them and these methods have been properly applied. The list of references shows that partial results of Mr. Zelenský thesis have been presented at prestigious international meetings. I believe that the development of the simplified boundary condition method for representing heat sources in indoor environment is sufficient material for publication in a renowned journal.

Considering the formal aspects – the structure of the thesis is logical, illustrations are of good quality and ample. I appreciate that the thesis is written in good English with an adequate technical style.

Based on the above given arguments I recommend the Ph.D. thesis for defense.

In Prague, Dec. 16, 2018

Jan Hrubý