

Ing. Oto Sládek, Ph.D.  
Kybertec, s.r.o.  
Tovární 1112  
537 01 Chrudim

prof. Ing. Tomáš Jirout, Ph.D.  
Fakulta strojní ČVUT v Praze,  
Oddělení pro vědu a výzkum,  
Technická 4  
166 07 Praha

### Oponentní posudek disertační práce

Název disertační práce: Design and analysis of energy efficient indoor-climate control methods for historic buildings

Autor práce: Magnus Wessberg, MSc.

Typ práce: Disertační

Fakulta: Fakulta strojní

Studijní program: Strojní inženýrství

Studijní obor: Technická kybernetika

Oponent práce: Ing. Oto Sládek, Ph.D

Pracoviště oponenta práce: Kybertec, s.r.o.

### **Evaluation of criteria:**

#### **Fulfillment of the objectives set in the dissertation:**

The PhD student defines 3 basic goals:

1. Propose and validate a methodology for shaping the heating power for intermittent heating in massive historic buildings with regard to heat-up time and change rate of RH.

In Chapter 4, as described below, the dissertation defines the theoretical background and methods of the management solution incl. Algorithmisation and verification, when the fact-proven method of control with significant maintenance of RH in a predefined interval, is essential. The procedure was validated using three case studies. An important mention is also the fact that a dissertation in this field has already published some results. References in literature.

2. Perform validation and analysis of adaptive ventilation method for relative humidity control in historic buildings.

The content of the solution to this goal is described in Chapters 5 and 6. Case studies proved that adaptive ventilation is a very suitable, low-energy variant of the microclimate solution when some RH fluctuation is acceptable. The described side effect in combination with FVE appears as a positive side effect. Even in this case, the results of the PhD student have already been published in scientific articles.

3. propose and validate improvements of indoor climate control methods in historic interiors with the focus of mold growth prevention.

The last goal is addressed in Chapter 5 and above all 6. It is essential to compare different ways of removing moisture in relation to the reduction of mold growth. Even in this case, the results are supported by already published works of the C4C project on which the PhD student participated.

It can be stated that despite the possible minor comments, the dissertation was able to meet the set goals.

#### **The level of analysis of the current state of the art in the dissertation thesis:**

The dissertation deals with the analysis of the current state of the art in the first chapters of the thesis, ie Introduction, Problem statement and then also in chapters 4 (theoretical) and 5 (validation and analysis). In the first chapter, the dissertant puts the problem into real practice of microclimate protection of defined building types, from damage functions, through Mold risks to methods of heating and dehumidification incl. A short list of models for control and modeling. These descriptions are generally well done, although the opponent would have a number of small comments, such as a very interesting description of the different approaches across Europe, which also generated interesting temperature maps in the Climate for Culture project and perhaps the issue of climate development to be slightly more accentuated at work because it has interesting theoretical implications. Interesting are the references in Chapter 1.2.1 on the work of F. Jacobsson and Henning, which are quite unknown work here in our branch. For Equal sorption humidity control, it might be a good idea to emphasize technical computing constraints that have hitherto prevented wider deployment. Adaptive ventilation is mentioned as one of the secondary reductions in indoor CO<sub>2</sub>, and in this context it might be interesting to mention the relationship of CO<sub>2</sub> versus mold growth. In the following chapter 2, some initial summary is made. In this regard, the opponent would have a reminder that there is a pity of some limitation of work on conservative heating and dehumidification. Current technical solutions also allow for a relatively effective solution for cooling and humidification is also in some cases a correct method for microclimate control. St. Cross Chapel in Karlštejn Castle. The current state of knowledge and the issue is further described in Chapter 4 and in this respect the opponent has no comments, the text level corresponds to reality and the dissertation proves good knowledge.

#### **Theoretical contribution of the dissertation:**

The main theoretical contribution is concentrated in Chapter 4 of the Intermittent heating of massive historic buildings and partly also in Chapter 5 Validation and analysis of adaptive ventilation method. The author of the dissertation describes in them the theoretical part of the issue in connection with the objectives of the dissertation and in the subchapters 4.1 - 4.3 there are described models of the dynamics of the behavior of building structures (thick walls), parametric identification of these models, models of heat transfer incl. discretized PDE of heat transfer, RH behavior models and theoretical background for RH self-control under conditions defined in the dissertation objective. Although the theoretical part of the thesis has a relatively small range (about 26 pages), it certainly does not mean that it is inadequate or less valuable. In the context of work, on the contrary, it is a compact analysis of the issue, which concentrates on substantial parts and, conversely, does not go unnecessarily beyond the scope of the work defined in the objectives of the work.

#### **Practical contribution of dissertation:**

This dissertation thesis deals with a very beneficial topic of effective management of the quality of the microclimate of historical buildings, which is generally non-trivial, but very important and in connection with demonstrable warming and increasing fluctuations in temperature and especially relative humidity, its importance will increase. The dissertant has elaborated the theoretical and practical part of the dissertation with application in practice. created blocks in LabView and see especially Part 5 Validation and analysis of adaptive ventilation method. The work is therefore application-oriented and therefore has a proven practical benefit and does not have any comments in this respect.

#### **Suitability of the methods used and how the applied methods were applied :**

The dissertant divided the work correctly. He first introduced actual state of the art (chapters 1 and 2), briefly but descriptively updated the state and methods used, formulated his own goals of the work (chapter 3), made a theoretical solution (chapter 4) suggested a variant solution that he defended and validated (chapter 5) and 6).

The aim was to create, implement and validate systems for historic building heating, validation and analysis of adaptive ventilation to control RH in historic buildings and improve RH control to prevent mold growth in interiors.

In order to achieve the objective of the dissertation, it was necessary to solve a number of related problems from the theoretical definition of the procedure and its justification, through simulation (LabView) to practical implementation in the control system (also LabView) and its verification. The theoretical procedure has already been evaluated in the previous commentary. From the implementation point of view in the LabView environment, the evaluator has a general reminder that this environment (HW / SW) is practically unused in the microclimate management practice and it would probably be more appropriate to perform the test implementation in some environment complying with the IEC 61131 standard (neither Rapsberry Pi is not a common and reliable platform in this area). However, the opponent understands the ease of implementation from the point of view of integrating simulation and usable control resources available to the dissertator.

Practical results and verifications are presented in both Chapter 4 and 5, where focus is on validation and analysis of adaptive ventilation method. Both case studies are well chosen, both Klints old farmhouse and Hangvar Church. Especially in the latter case, it is technically interesting to combine with PVP (although this fact itself is outside the scope of work). In 5.5, the dissertation describes and demonstrates the practical effects of adaptive ventilation on measurement results. The dissertant correctly describes that adaptive ventilation is best suited for unheated or occasionally heated buildings. And it also describes the positives and negatives of this approach. Some recommendations are summarized in chapter 5.5.1, but there is no relation to the regional climate. These recommendations will undoubtedly differ in place and time (and it is not clear whether they are related only to case studies or in general). According to the opponent's experience, the climate differs significantly even within the Czech Republic, where it is relatively balanced, the more so, for example, in the case of coastal states (see e.g. Gothenburg versus Stockholm etc.).

Chapter 6 then deals with the comparison of microclimate control methods in relation to the reduction of mold growth. The thesis defines basic theoretical content and case studies in Fide church and Skokloster castle. It is defined the boundaries of suitable and inappropriate environment using isopleth and both simulation and case study verification are performed. However, the interpretation of the results from the opponent's point of view is unclear in the present case, leading to similar results with different energy consumption... dehumidification seems to be more effective in this case (see 6.4), but in 6.5 the analysis

of results is not very decisive. The opponent would expect a somewhat stricter comparison than the description, but the whole chapter is devoted to this issue. However, otherwise these conclusions can be accepted.

#### **Demonstrating adequate doctoral knowledge in the field :**

He studied Control and System Engineering at the Department of Instrumentation and Control Engineering, Faculty of Mechanical Engineering, CTU in Prague.

The assignment of the thesis and its processing is fully in line with the profile of the branch and the department. The importance of the work lies in the qualitative and quantitative analysis of the procedures used for climate control and monitoring in buildings, with particular reference to buildings with high masonry and thus high latency. There is a balanced relationship between the theoretical and the practical part in relation to the work itself. The significance and contribution of the dissertation is evident and fully demonstrable. The dissertant clearly demonstrates sufficient quality knowledge of the field and the current state.

#### **Formal level of work:**

Dissertation thesis is 96 pages length and divided into 9 chapters (Introduction, problem statement, Thesis objectives, Intermittent heating of massive historic buildings, Validation and analysis of adaptive ventilation method, Conclusion, Appendix Bibliography). Part of the work is a list of 100 citations and references. Work can be described as compact, in the good sense. The formal layout and professional language level of the dissertation is very good. It might be possible to make some small comments as a missing list of abbreviations that might be appropriate, but in the context of the content of the work they are marginals.

#### **Questions:**

- On page 13 it is mentioned that a new non-linear model is needed. Is the dissertant sure that a non-linear model is needed? Wouldn't a quality linear model with delays be enough and if not, why ?
- On page 17 the term "invasive control methods" is given. This is a rather unusual term for the opponent. So what are the "invasive and non-invasive" control methods ?
- On page 20, the loss factor is  $F1 \leq 1$ . So can it be less than 0? And if so when?
- Parametric model identification is shown on page 23. What are the practical computational risks of this parametric identification procedure?

#### **Conclusion**

I consider the submitted dissertation to be very successful in its content, form and results and I **recommend** it according to Act No. 111/1998 Coll. §47 for acceptance.

Datum: 16.6.2019