Appendix 2

Summary of professional accomplishments

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Wroclaw, 23rd of March 2019

I. Diplomas and academic degrees - with the name, place and year of obtaining them, and the title of the doctoral thesis

In 1998 I graduated from the High School no. 1 in Wroclaw (Poland) in the class with a mathematics and IT profile, obtaining GCE A-Levels (General Certificate of Education Advanced Levels). In the same year, I started full – time master studies at the Faculty of Environmental Engineering at Wroclaw University of Science and Technology. In 2003 I achieved my MSc in the specialization air-conditioning, heating and sanitary installations with a very good grade. I continued my education at doctoral studies, developing my scientific skills under the supervision of Prof. Jan Danielewicz. I defended my doctoral thesis entitled *Construction of solar collector models based on research in natural conditions* in 2007.

II. Information on employment in scientific units

In 2007, immediately after the defence of my doctoral thesis, I started working as an assistant at the Faculty of Environmental Engineering at Wroclaw University of Science and Technology.

After two years, in 2009 I was promoted to the position of assistant professor at the Faculty of Environmental Engineering at Wroclaw University of Science and Technology. I have been remaining at this position continuously until today, and the only break in my professional work was the six-month maternity leave.

III. Indication of the achievement resulting from art. 16 sec. 2 of the Act of 14 March 2003 on academic degrees and academic title and on degrees and title in the field of art.

Title : Monthly energy efficiency of air/water heat pump systems.

Author: Małgorzata Szulgowska-Zgrzywa.

Publisher: Oficyna Wydawnicza Politechniki Wrocławskiej. Wrocław 2019.

Reviewers: Prof. Jan Danielewicz, Prof. Robert Sekret.

Description of the research work

The main subject of the work are the methods of analysing the energy efficiency of air/water heat pumps. The choice of such a research topic results from the significant level of complexity in the heat pumps sizing and the analysis of their work, as well as the serious consequences of improper decisions at the design stage of this type of heating systems. An equally important reason for choosing the air/water heat pumps as a research topic is the fact that this is a renewable energy source, and the continuous development of this technology by increasing their energy efficiency makes them an important factor in limiting the negative human impact on the environment.

The work presents the systematics of available methods for analysing the operation of such devices in the context of compatibility with the time step of the analysis of the energy efficiency of buildings, which is now an important element of the design process. Typically, a monthly or hourly step is used for building energy simulations. The accuracy of hourly models is high. They take into account (or may take) most of the parameters that affect the heating energy demand for the building. The accuracy of monthly models for calculating the energy demand in buildings is slightly lower, but they are commonly used. These calculations are the basis for the process of energy certification of buildings in Poland. In addition to the analysis of the energy efficiency of a building, an analysis of the efficiency of energy distribution systems should be performed. The review of available calculation methods has shown that currently the SCOP value of the heat pump is assigned to the results of the energy calculation of the building made in a monthly step resulting from the annual or temperature step. This is not the appropriate procedure, as the time steps of individual models should be adjusted to each other, and the lack of information on changes in the energy efficiency of the air/water heat pump during the year prevents the calculation of changes in the final energy demand profile in the building. This value is useful in many cases, for example when planning the cooperation of these devices with photovoltaic systems.

Hence, the following thesis was put forward: modelling the energy efficiency on an air/water heat pump system in a monthly step can meet the requirement of adequate accuracy of analyses, providing precise information about changes in the device performance during the year, providing a short calculation time and allowing for adaptation to commonly used calculation step in determining the energy demand for space heating.

In order to find a solution confirming the thesis, a number of problems related to methods of energy efficiency analysis of air/water heat pumps have been considered. The scope of the work and conclusions are described below.

In order to determine the required quality of input data for the monthly model of efficiency of air/water heat pumps operating in the heating mode, the influence of the accuracy of determining the thermal load profile and accuracy of the coefficient describing the impact of partial load of a heat pump in the simulation results was analysed. For this purpose, an algorithm to calculate the energy efficiency of the heat pump in an hourly step was used. The model uses three different methods for calculating the partial load impact on the energy efficiency of a heat pump and allows to perform calculations for various heat load profiles. With the measurement data of the actual heating system, the coefficients determining the effect of the partial load on the efficiency of the system were calibrated, verifying which method allows the best accuracy. It has been shown that the best method of modelling the partial load impact on the energy efficiency of an air/water heat pump is to use a logarithmic function, and that the accuracy of the parameter adopted to determine the heat load impact is important for simulation results. It was also found that in the case of air/water heat pump simulations, sufficient accuracy is ensured by the use of the heat load profiles created on the basis of monthly values of energy demand for heating. The model of the monthly energy efficiency of an air/water heat pump operating in the heating mode was developed assuming the division of each month into areas differing in the mode of operation of the device and the calculation of a representative effectiveness for each of them respectively. Thanks to the knowledge of the share of particular areas in the total monthly energy demand of the building, it was possible to precisely determine the effectiveness of the device in a given month. The model of energy efficiency of heating systems with air/water heat pumps in a monthly step was developed using hourly simulations. The calibration process of model parameters using non-linear regression (using the *Statistica* software) was supported by a total of 1,838 cases. Each case was the simulation results for a single month in all areas of the operation of the device. For the purposes of the model, it was necessary to develop functions describing the changes in the thermal load of the building and the predicted profile of ambient air temperatures in each month. In the case of the first function, an assumption about the linear course of changes in heating demand in each month was made. The monthly energy demand for space heating was used as an input value. As a result, a simple and effective method to create individual thermal load profiles for each month of the year was developed. In the second function it was assumed that the frequency of occurrence of ambient air temperature in the month is similar to the normal distribution. This presumption concerns a situation when the analysis will be performed for statistical climatic data from a broad period, and not for data from a specific year. Adding such a function to calculations made it possible to change the calculation period from hourly or temperature steps to monthly steps. The temperature frequency function was developed for climatic data of 13 cities located in Poland. Climatic data (from 1961-1990) were downloaded from the *Meteonorm* database. Using non-linear regression (utilizing the *Statistica* software package) the parameters of the temperature frequency function were determined. This function, based on minimum, maximum and average ambient air temperatures in a specified month, allows to approximate the operation time of the device. To confirm the correctness of responses obtained, the verification on different climatic data, among others, for several European cities: Copenhagen, Milan, Brussels and Budapest was performed. The precision of the examined function was high in each case. Deviations of the trend line, illustrating the correlation between the results for the temperature frequency function and exact calculations, from the diagonal indicating the perfect correlation did not exceed 7%. The proposed monthly model was compared to the results from the hourly and temperature step models, thus assessing the accuracy of the obtained results. Monthly SCOP values, monthly energy demand for the heat pump and for the energy required to be delivered from an additional energy source were checked. It was found that the differences between the simulation results using the developed monthly model and the hourly simulations in most cases do not exceed 5%. Therefore, the postulate of the accuracy of this model is satisfied.

In order to determine the quality of input data for the monthly model of the energy efficiency of air/water heat pump operating in domestic hot water (DHW) preparation mode, the influence of the accuracy of the thermal load profile on the simulation results of these devices was discussed. For this purpose, an algorithm for calculating the energy efficiency of the heat pump in an hourly step was used. The algorithm enables analysis for various energy demand profiles for DHW preparation and for various degrees of system accumulation. By analysing the errors of the modelling results for the different methods of determining these profiles in relation to the results for the actual profile, acceptable simplifications in the process of simulating the energy efficiency of air/water heat pumps were assessed. It has been shown that it is important to take into account the changes in the hourly profile and it is even more important to include monthly changes in DHW consumption, tap water temperature and the impact of the accumulation system on the required heating power of the heat source. It was found that for the accuracy of simulation results it is important to take into account the acceptable DHW tank loading time and the operation of the back-up heating system supporting the operation of the air/water heat pump. For the purpose of developing a monthly model of energy efficiency of an air/water heat pump operating in DHW preparation mode, similarly as for space heating mode, the division of each month into areas differing in the mode of operation of the device was applied. Then, the representative efficiency in each of the areas was calculated. Thanks to the knowledge of the share of particular areas in the energy demand for the purpose of DHW preparation, it was possible to precisely determine the effectiveness of the system in a given month. To calculate these shares, the temperature frequency function was used. In order to obtain the required precision, a method for calculating the representative heating power of the system was developed.

The proposed monthly model was compared to the hourly and temperature step models, thus assessing the accuracy of the obtained results. It was found that the simplification of the energy demand profile of the DHW preparation taking into account changes only in the monthly step rather than hourly is acceptable, while errors in monthly results are satisfactory (less than 5% in relation to the simulation in the hourly step). Simulations based on the developed monthly model give very good results of the correct monthly value of *SCOP*, the monthly electricity demand for the heat pump and the energy required to be delivered from an auxiliary energy source. Therefore, the postulate of the accuracy of the model has been fulfilled.

The last chapter of the work describes the algorithm of the integrated model for the analysis of the monthly energy efficiency of the air/water heat pump system. The model enables proper sizing and analysis of the air/water heat pump operating simultaneously for the purposes of heating and the domestic hot water preparation. The proposed model gives similar accuracy to the model calculated in an hourly step, reducing the number of necessary calculations from 8,760 to 12 lines. The calculation process requires that for each of these lines, seven heat pump operating states should be evaluated. Even considering these additional calculations, this gives 84 lines instead of 8,760. Similar accuracy to the results of the monthly model can be achieved by performing calculations in a temperature step, but only for calculations carried out individually for each month. Hence, the development of 12 climate curves and about 40 rows of calculations for each of them is required, which gives a total of 480 rows, omitting former preparation of the climatic data. The basic input data for the proposed model are: minimum, maximum and average ambient temperature in the month, monthly energy demand for the DHW preparation and heating, capacity of the DHW tank and the characteristics of the air/water heat pump. These data are widely available. Therefore, the postulate of the calculation time and availability of input data has been fulfilled.

The integrated model makes it possible to assess the correctness of the air/water heat pump selection. This diagnosis is supported by the calculated contribution of the electric heater (or other alternative heat source) and the share of energy losses associated with the operation of the air/water heat pump in "on/off mode" work range in the heating needs of the building. As a result, both the under- and oversizing of the device are evaluated. It is stated that this is a more accurate method of sizing of a heat pump than the approach based on one heat load profile and one bivalent point value. The proposed model takes into account the issue of calculating the additional heating output required for domestic hot water preparation. In the first calculation step, the working time for domestic hot water preparation is estimated. This working time can be checked and corrected by the designer. Afterwards the required heating output of the heat pump is determined with respect to this working time in such a way as to provide the required thermal energy to the building within the available time. When the heat output shortage occurs one can observe an increase in the share of auxiliary source. All these calculations are carried out for each month of the year, giving the opportunity to check the effectiveness of the device in each of them. The ability to check the energy losses resulting from both, oversizing and undersizing allows to optimize the selection of the air/water heat pump in terms of the building heating needs under given climatic conditions. In the process of sizing a heat pump, the model takes into account both, the value of the heating output of the device and the value of *COP* (Coefficient of Performance) of the device working under partial load, and thus improves the precision of whole process.

The developed model allows to perform calculations applying the statistical climatic data. However, the model is not appropriate to carry out analyses based on data of a specific heating season. The developed function of the temperature frequency has been verified on the basis of statistical data from ten-year or longer periods, and for such provides a good correspondence of the answers with the calculations carried out on detailed climatic data.

It is necessary to emphasize the wide possibilities of practical application of the results of calculations obtained using the developed model of the monthly efficiency of air/water heat pumps. The model allows for precise selection of the device for the heating needs of the facility and gives the opportunity to diagnose the correct operation of the heat pump during a year. These results can be particularly useful for analysing the operation of heat pumps in bivalent systems, where precise information on the monthly energy deficit allows better planning of the cooperation of both systems. The model enables better planning of cooperation of air/water heat pumps with photovoltaic cells, which is pivotal in the concept of nearly-zero energy buildings and for planning the cooperation of these devices with the power grid. In addition, it should be emphasized that the model enables precise planning of operating costs throughout the year.

IV. Discussion of other scientific and research achievements

Statistics of scientific achievements

In Appendix No. 3: "List of published scientific papers and information about didactic achievements, scientific cooperation and popularization of science" I included bibliographic description of all publications from the entire period of my employment at Wroclaw University of Science and Technology. I have collected a total number of 64 pieces in my scientific output, 47 of them are published academic works. Below I presented the statistics of my scientific achievements, and afterwards I discussed my interests and scientific achievements (in chronological order) by placing relevant references to the list of scientific achievements contained in Appendix 3.

During my PhD studies (from 2003 to 2007) I collected in total 12 scientific works where 8 of them ware published. After achieving my doctoral degree (form 2008 to 2019) I collected in total 52 scientific works. I published 39 of them. Detailed information is included in table 1.

Table 1. Detailed classification of publications

Type of publication	Years 2003 - 2007	Years 2008 - 2019	Total
Chapters in monographs	0	11	11
Publications with Impact Factor	1	6	7
Other publications	3	13	16
Conference papers indexed in Web of Science	1	7	8
Conference papers	3	2	5
SPR reports	2	8	10
PRE reports	2	5	7
Published	8	39	47
Unpublished	4	13	17
Total	12	52	64

The total scientific achievements (according to the list of Ministry of Science and Higher Education) of published articles gives 445 points, including 248 points for articles in journals with Impact Factor. During the period after obtaining the doctoral degree 420 points were collected, including 235 points for articles in journals with IF. The total sum of IF amounts to 22.481, including IF of 21.854 achieved in the period after obtaining the doctoral degree. Bibliometric indicators (number of works, number of citations, Hirsch index) of my scientific achievements are presented in table 2.

Table 2. Bibliometric indices depending on database.

Database	No. of scientific works	No. of quotations	Hirsch Index
Web of Science	14	73	4
Scopus	14	93	4
Google Scholar	29	148	6

Period before obtaining the doctoral degree (2003-2007)

Between 2003 - 2007, i.e. before obtaining the doctoral degree, my scientific interests concerned the following topics:

(1) Solar energy , research on parameters describing the efficiency of solar collectors, modelling of solar radiation intensity and the influence of solar radiation structure on the efficiency of solar collectors;
(2) Energy efficiency and buildings energy auditing.

Ad 1. Between 2003 and 2007 I was focused on the issues of the solar energy utilization in civil engineering, in particular through the use of solar collectors (E25) for this purpose. I conducted research on the influence of the solar radiation structure on the efficiency of these devices (F7) and on the methods of determining the solar collector's working parameters under the quasi-dynamic conditions (E26,A7,L5,L6). The result of this research was the doctoral dissertation, which was defended in 2007.

Ad 2. The issues of energy efficiency of buildings and energy auditing have been my objects of interest since the beginning of doctoral studies to the present day. Before the completion of the doctoral thesis, these interests were more practical. I participated in trainings to improve my qualifications and I was performing energy audits for buildings. I was a co-author of the solutions concepts for thermo-modernizations of Wroclaw’s hospitals (m4,m5) and co-executor of pilot audits on thermo-modernization of historic tenement houses in Wrocław (m2). I was also the co-author of the expertise “Feasibility study - alternative energy sources for housing stock of SM Podzamcze in Wałbrzych” (F8). The acquired knowledge allowed me to prepare two scientific publications (E27,L7) in this field.

Period after obtaining the doctoral degree (2008-2019)

After obtaining the doctoral degree, I continued the research related to the energy efficiency of buildings (2), the scope of which was transformed into the issue (3), and I started new research including the topics listed below:

(3) energy efficiency in building industry and nearly-zero energy buildings;
(4) problems of designing low-energy detached buildings in Poland;
(5) research on the effect of ground regeneration intensity on the temperature around the vertical ground exchangers of brine/water heat pumps,
(6) modelling of energy efficiency of mechanical ventilation systems with heat recovery and the utilization of solar energy in air conditioning systems;
(7) the utilization of waste heat from cooling of the photovoltaic systems;
(8) utilisation of air/water heat pumps for heating buildings in relation to the climate conditions in Poland; modelling of energy efficiency of these devices;
(9) energy auditing, revitalization of urban areas and the research on the conditions of energy poverty in cities.

Ad 3. I have been conducting the research work on the energy efficiency of buildings from the start of doctoral studies to the present day. Since 2009, I have been involved in the implementation of knowledge on energy efficiency, energy certification and energy auditing in Poland. I conducted trainings, postgraduate studies and research in this topic. I was the project manager and co-author of the architectural/energy concept of an innovative, zero-energy building of the Faculty of Environmental Engineering at the Wrocław University of Science and Technology. This concept has gained great recognition both in Poland and abroad. This was confirmed by the prize awarded in the competition organized by PLGBC and publications in international magazines and books related to the architectural industry. The result of these works are also scientific publications (A5,E3,E6,E12,E17,E22,E33). In recent years, I continued my work on this topic (in the area of energy efficiency of domestic hot water preparation systems) as an auxiliary supervisor of the doctoral dissertation of Agnieszka Chmielewska, currently PhD. In addition, I was a co-creator of many studies related to energy efficiency. I passed my knowledge to students in the form of original lectures (i2,i3) and during camps and student internships, which resulted in relevant reports (j5).

Ad 4. In parallel to the above, I conducted work on the issue of energy efficiency in single-family buildings. These studies were carried out in cooperation with the Centre of Energy Technologies in Świdnica, Poland. The result of this cooperation was a series of training trips to Germany, Denmark and Austria, which allowed me to significantly increase my practical knowledge in this topic. This knowledge enabled me to apply to the program supporting the cooperation of scientists with industry and the implementation of a 6-month 2-person internship as part of the "Innovative transfer" project (Human Capital Operational Program, Priority VIII Regional human resources for the economy, Measure 8.2 Transfer of knowledge, Submeasure 8.2.1 Support to cooperation of scientific environment and enterprises) implemented by ARI in the topic of "Increasing the energy efficiency of low-energy buildings, considering their location in Lower Silesia, through integrated optimisation of architectural, construction and installation solutions". This project was carried out in cooperation with Łukasz Nowak, PhD, employed at the Wrocław University of Science and Technology at the Faculty of Civil Engineering.

Ad 5. The research topic that I started after the end of the doctoral thesis were issues related to brine/water heat pumps. The cooperation with CET in Świdnica enabled me to carry out the research projects in this area. I have realised in their facility an original concept of a research installation for the regeneration of the low energy source system of the brine/water heat pump. Together with Natalia Fidorów-Kaprawy, PhD, we have obtained a grant under the program of development of young scientists and participants of doctoral studies. The topic of our project was *Experimental and simulation research of soil regeneration, utilised as a low heat source for a brine/water compressor heat pump using vertical probes, solar collectors and a natural cooling system*. This project was carried out in cooperation with CET, Viessmann and Aspol. The result of this work are publications [A2,A4,E2,E4,E7,F4,L3] including two printed in journals with IF. The continuation of this work was an 8-month scientific-research internship at the Centre of Energy Technologies in Świdnica, Poland. The internship was a part of the "Cumulation of competences" project organized by EIT+ and was co-financed by the European Social Fund. Currently, my research still concerns the issue of ground temperature modelling in the low sources of heat pumps. I am also an auxiliary supervisor of the doctoral dissertation of Ewelina Stefanowicz, MSc. This work concerns the accuracy of tests providing data for the analysis of the work and the design process of vertical ground heat exchangers of brine/water heat pumps. The result of this cooperation is a number of publications in which the accuracy of input data (E13,E16,E29,E32) has been shown to have a significant impact on the quality of the simulation results.

Ad 6. During the aforementioned internship I started work on the issues of energy efficiency of ventilation systems in cooperation with Maria Kostka, PhD. The result of this cooperative work was a tool to simulate the energy efficiency of ventilation systems with heat recovery and publications (E18,E19,E23,E31). At the same time, similar research, allowing me to return to my interests from the period of my doctoral dissertation, developed as a result of the project entitled "*Analysis of work and research of air-conditioning systems supported by solar energy*" led by Dariusz Kwiecień, PhD, and financed by the National Science Centre. In this project, I was responsible for the design, measurements and analysis of the efficiency of the solar collectors system. The installation, equipped in two storage tanks, was designed to collect and store solar energy in the form of hot water. This energy was transferred via water heating coils to the regeneration air of the desiccant rotary dehumidifier or to the heating coil to heat up the room supply air. Conducted research of the system of flat plate solar collectors allowed to describe expected effects and recommendations for the operation and design of solar systems for flat plate solar collectors supplying the SDEC (Solar Desiccant Evaporative Cooling) system (E1,E5,F2,F3,F5,F6)

Ad. 7. In 2013 - 2016, I dealt with the problems of utilising waste heat from photovoltaic systems cooling and utilising heat pipes in the environmental engineering. I conducted simulation studies on the impact of PV cells cooling (using heat pipe heat exchangers) on their temperature and simulation studies on the way of utilising the waste heat from such systems. My experience in the field of energy simulations and solar energy became useful in these works. This three-year cooperation with an international team of researchers allowed me to participate in the preparation of several publications in the journals with IF (A1,A3,A6).

Ad 8. During my cooperation with CET, I developed my interests in the problems of energy efficiency analysis of heating systems with air/water heat pumps. With time, this issue has become the main thread of my research. The studies I carried out concerned modelling of the energy efficiency of heat pumps using monthly steps. The result of my work is a statistical function that approximates the distribution of the frequency of ambient air temperatures. This function has been integrated with the model describing the operation of the device in a given month. These studies were described in details in the habilitation thesis. The developed correlation model was tested on input data obtained according to the tests recommended by the PN-EN 14511 standard. In the wide range of publications (E14,E20,E21,E28,E30) prepared together with Krzysztof Piechurski, MSc., the necessity of replacing the method of heat pumps testing recommended by PN-EN 14511 with the quasi-dynamic method has been demonstrated, thus replacing also the model of describing the COP of the device. The procedure of this test is to be developed by Krzysztof Piechurski, MSc., as part of his doctoral thesis, which I am the auxiliary supervisor.

Ad. 9. In the last two years I returned to research related to energy auditing. I was a co-author of several energy audits for large housing estates and several historical buildings. As a result, my research interests have evolved to the issue of revitalization of urbanized areas and research of the determinants of energy poverty in cities. I have started cooperation with an architect Magdalena Baborska-Narożny, PhD, and the *Research Center for Sustainable Built Environment of the Wrocław University of Science and Technology* (becoming its member). I started cooperation with *Wroclaw's Revitalization*, which enabled the execution of pilot studies on the state of heat sources, thermal comfort and attitudes of residents towards planned changes in the ways their premises are heated. The research was carried out on a sample of over 400 residential and service premises in a quarter of the buildings of Przedmieście Oławskie in Wrocław, Poland. The research ended with a report posted on the *Wrocław's Revitalization* website (http://w-r.com.pl/projekty/cieplozimno/). Currently, I am a coordinator of the research subsidized by the Municipal Office of Wrocław, entitled *Density of occurrence of heat sources utilising solid fuels in relation to age, typology and function of the buildings tissue and* *attitudes of residents towards changes in the heating system in the city of Wrocław*. These studies are underway and cover the entire area of Wrocław. Their scope is the analysis of data describing selected parameters of the city's buildings tissue, analysis of available databases collecting information helping in the diagnosis of residential premises heating, and surveys on a representative samples of residential premises located in buildings with a known function, age and typology. Through field studies, the types of heat sources utilising solid fuel and social attitudes of habitants (such as: satisfaction with the existing heating method, willingness to change the existing system, fear of heating costs increase) will be identified and determined.

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Wroclaw, 23rd of March 2019