SUMMARY

The thesis entitled '*Urban-scale energy modelling of some residential energy flexible buildings clusters in Poland*' is focused on **U**rban **E**nergy **M**odelling (UEM) field, by means of a home-developed research computer tool named '*Computational **T**ool for **E**nergy Efficiency **A**nalysis of an Energy **C**luster*' (TEAC). The *TEAC* software is capable to perform environmental-, economic- and energy-related analyses of residential areas of Poland. Software flexibility and advisability for numerous applications were presented and tested based on some exemplary **B**uilding **E**nergy **C**luster**s** (BECs) consisting of hundreds of single-family houses. Each of the presented examples is focused on a different issue, to show the possibilities and full potential of the *TEAC* software. Finally, two case studies are examined for residential neighbourhoods located in Lodz.

The dissertation consists of seven main chapters, lists of tables and figures, as well as nine appendices. The first chapter is a kind of introduction, within which the aims, as well as the following hypotheses of the dissertation, are formulated. Firstly, it is possible to use advanced energy computer simulations for the prediction and analyses of energy demand profiles both for a single building, as well as whole residential areas. Secondly, the **E**nergy **C**luster (EC) concept is appropriate for improvement in the energy economy of urban areas. Finally, it is possible to predict the energy demand of the analysed area, based on basic buildings' parameters, their mutual influences and interactions, and appropriate climatic data.

Chapter **2** provides the theoretical background, concerning most aspects related to the **U**rban **B**uilding **E**nergy **M**odelling (UBEM) methodology. In this chapter, a comprehensive state-of-the-art overview is presented for the UBEM field (see more in section Błąd! Nie można odnaleźć źródła odwołania.). Additionally, the actual overview of the Polish power system and the household sector is discussed, accordingly in sections Błąd! Nie można odnaleźć źródła odwołania. and Błąd! Nie można odnaleźć źródła odwołania.; the both aspects were used as a basis in the performed studies. Moreover, the general overview on how to improve buildings' energy efficiency (section Błąd! Nie można odnaleźć źródła odwołania.), as well as their sustainability (section Błąd! Nie można odnaleźć źródła odwołania.) is discussed. The EC concept is introduced, as the approach applied in the performed studies, focusing on various analyses of residential neighbourhoods (see more in section Błąd! Nie można odnaleźć źródła odwołania.). The Błąd! Nie można odnaleźć źródła odwołania. section shows the outline of some computational codes application for various types of analyses concerning both individual buildings and whole urban zones, especially by means of the *Energy Plus* software. Finally, the **A**rtificial **I**ntelligence

(AI) applications for various building energy analyses is reviewed in section Błąd! Nie można odnaleźć źródła odwołania.; the AI is applied in the performed analyses.

In chapter **3** the list of performed studies, as well as applied assumptions are briefly described. It starts with the overview of applied procedure, as shown in section Błąd! Nie można odnaleźć źródła odwołania.. The procedure includes some preliminary steps (which were performed just once, before any calculation), within which the **N**eural **N**etwork (NN) training process was essential; that process is presented in section Błąd! Nie można odnaleźć źródła odwołania.. The gathered data and information were used to develop the *TEAC* software, which is described in detail in section Błąd! Nie można odnaleźć źródła odwołania.. When implemented, the *TEAC* software can be used for some UBEM, as it is shown for some preliminary examples in section Błąd! Nie można odnaleźć źródła odwołania.. The overview of applied assumptions is shown in the remaining parts of this chapter. Those assumptions are listed in section Błąd! Nie można odnaleźć źródła odwołania., while used weather data is presented in section Błąd! Nie można odnaleźć źródła odwołania.. The Polish household sector is examined using computational models of **R**epresentative **S**ingle-**F**amily **H**ouses (RSFH); it is discussed in section Błąd! Nie można odnaleźć źródła odwołania., while the proposed building modernization variants are presented in section Błąd! Nie można odnaleźć źródła odwołania..

In chapter **4** some comprehensive examples of residential ECs are studied. Each example dealing with hundreds of buildings, is focused on different issues, in order to show various capabilities of the *TEAC* software. Also, each case is summarized with some concluding remarks concerning the performed analyses. The first case (section Błąd! Nie można odnaleźć źródła odwołania.) deals with 25 hundred buildings randomly selected from the RSFH (square area, 50 by 50 parcels, all occupied). Examinations of this cluster are focused on energy-related analyses, presented especially by means of local heating and electricity **L**oad **D**uration **C**urves (LDCs). Those type of analyses allows validating the proposed building modernizations in order to select actions, which increase energy stability and safety of the local grid. Out of the performed study, it is possible to outline peak energy demands, as well as to shift time-distributed loads in order to flatten LDC for the analysed area. The second case (section Błąd! Nie można odnaleźć źródła odwołania.) concerns 25 hundred single-family houses, defined using the city centre pattern. It is a square area, 50 by 50 parcels (all occupied) with random buildings' orientations. Those examinations are focused on the economic and environmental issues. In this case, some building modernization variants, including **R**enewable **E**nergy **S**ources (RES) applications, are compared for two different localizations (accordingly Rzeszow and Szczecin). The economic assessments, as well as comparison of the **g**reen**h**ouse **g**asses (GHG) emissions, are performed. Thus, the economic and environmental profitability for the examined EC were analysed. The fourth case (section Błąd! Nie można odnaleźć źródła odwołania.) is focused on mapping various characteristics of the analysed area.

The examined neighbourhood is defined using the street-grid pattern. It is a square zone, 50 by 50 parcels, including some empty ones; thus this EC consists of 2189 single-family houses. This example is analysed for two different localizations, accordingly Wroclaw and Bialystok. The obtained results are presented by means of maps, comparing energy- and environmental-related characteristics for variants before and after buildings' modernizations. Those type of studies allows establishing zones (within the examined neighbourhood) which are recommended to be modernized due to financial profitability and/or environmental protection. The last case (section Błąd! Nie można odnaleźć źródła odwołania.) is a non-uniform area, 50 by 80 parcels. The considered area was defined fully manually, using empty parcels; the examined area consists of 1999 buildings and it is located in Warsaw. In this case, all types of available results obtained by means of the *TEAC* software are presented, to check the energy-, economic- and environmental profitability for some proposed modernizations.

The analyses of two more examples of residential ECs, performed by means of the *TEAC* software, are shown in chapter Błąd! Nie można odnaleźć źródła odwołania.. The both ECs are located in Lodz; the first one (section Błąd! Nie można odnaleźć źródła odwołania.) is a typical, small residential neighbourhood within the city district, while the second one (section Błąd! Nie można odnaleźć źródła odwołania.) can be considered as a wide-spread suburban area, where single-family houses are a majority of all buildings. Those examples might be considered as kind of case studies since they were defined based on the satellite photos of the selected areas. The both neighbourhoods are examined following the **E**nergy **F**lexible **B**uilding **C**luster (EFBC) concept – besides all the methods presented for the examples presented in the previous chapter, including some smart-metering techniques, are applied. The examined modernisation of the analysed clusters is based on highly energy-efficient buildings considered as a unity for energy accounting, providing the energy flexibility of the whole region. It is shown, that the EFBC approach, which assumed highly energy-efficient houses, which use of the RES, batteries systems, as well as smart-electricity management (including prosumer strategy) is arguably the most advanced approach to create sustainable urban areas.

Chapter Błąd! Nie można odnaleźć źródła odwołania. presents some conclusions and observations out of the performed study. The main conclusions are focused on the theses formulated at the beginning of the dissertation. Firstly, it is possible to use advanced energy simulations of a single building (performed by means of the software such as the *Energy Plus*) to be implemented for a whole considered residential areas. Secondly, the UBEM is a very comprehensive approach of urban planning, in which the EC paradigm fits perfectly – within the dissertation numerous ECs analyses were presented to follow-up the formulated statement. Thirdly, the main goal of the performed work was to develop a computational software, which is capable to perform energy-, economic- and environmental analyses of the Polish residential areas; thus, the *TEAC* software was developed and its'

advisability and applicability for those type of comprehensive analyses of ECs were proven based on the presented results. Additionally, some supplementary conclusions were drawn.

Chapter Błąd! Nie można odnaleźć źródła odwołania. proposes some future researches – the most attention will be focused on the *TEAC* software improvements. Presently, the *TEAC* software should be considered as being in the beta stage, thus several actions are still necessary in order to consider it as a **R**eady **t**o **M**anufacture (RTM) software. The most essential improvements will be focused on the development of a **G**raphical **U**ser **I**nterface (GUI), as well as the addition of some upgrades, *e.g.* possibility to use **G**eographical **I**nformation **S**ystem (GIS).

This dissertation also includes nine appendices with some supplementary information about several issues presented in this work. It includes some data of the Polish residential sector (**Appendix 1**), as well as the assumptions used for performed studies of the Polish household (**Appendix 2** and **Appendix 3**). The definition of RSFHs of Poland was introduced into the *Energy Plus* software – the buildings' computational models, as well as the applied HVAC installation schemas, are presented in **Appendix 4** and **Appendix 5,** accordingly. The applied schemas of the closest buildings' surrounding are shown in **Appendix 6**. **Appendix 7** includes the script of the defined NN, which was used for predicting heating demand. Some manuals on how to use the *TEAC* software are presented in **Appendix 8**. Additionally, some supplementary results are shown in **Appendix 9**.