Application of the TEAC software for analysis of Energy Flexible Building Clusters – a case study

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Abstract. Nowadays, natural environment protection and sustainable development became common and necessary issues for all the economic sectors. It is extremely important to focus on all the efforts resulting in the most efficient and sustainable power sources and electric power grid. Typically, the residential districts are connected by electric grids, which with an application of the appropriate technologies might be considered as so-called smart-grids. In the smart-grid neighbourhoods, houses are the consumers, energy supply is performed by the local or/and national power plants, while energy distribution is performed using some monitoring and management systems. Such a residential area can be considered as a Building Cluster, the novel paradigm in the energy and environmental analysis of the built environments. In this article, the exemplary single-family houses neighbourhood is examined, following the Building Cluster paradigm. The analysed area is located in Lodz (Poland), consisting of 202 buildings. The study is performed by means of the home-developed software named TEAC (Tool for Energy Efficiency Analyses of an Energy Cluster). The analysis is focused on the energy, economic and environmental issues of the considered Building Cluster.

1. Introduction
Presently, due to climate change, constantly growing energy prices and energy demand, there is a high interest in the development of energy-efficient and sustainable cities. Various methods of smart city design, especially buildings thermal modernizations follow a concept of Urban Energy Modelling (UEM) [1], within which the Energy Cluster (EC) idea is the most promising approach [2]. Application of Renewable Energy Sources (RES) and smart metering techniques in a residential area allow to establish an Energy Flexible Building Cluster (EFBC), one of the most comprehensive and advanced pattern of UEM [3]. This paper is aimed at a presentation of the home-developed tool called Tool for Energy Efficiency Analyses of an Energy Cluster (TEAC) appropriate for residential region studies. The TEAC software application is shown for a household neighbourhood constituting an EC. The software allows to perform various energy-related analyses; therefore some exemplary outcomes out of the proposed modernisations are presented.

2. Applied procedure
The TEAC software allows to define a neighbourhood consisting of numerous buildings, in order to analyse an urban-scale area [4]. Due to the Neural Network (NN) application for prediction of heating demand, it allows for quick analyses of large areas. The applied network in the TEAC software allows
to predict heating demand with high compatibility with the *Energy Plus* outputs, using much less complex input data. The software is developed for modelling of Polish residential stock, based on representative single-family houses (RSFH) typology. Seven types of Polish RSFH were defined following their characteristics (i.e. construction periods, geometry as well as energy profiles) published in [5]. The comprehensive description of the TEAC software can be found in [6]; it has a modular structure and its simplified schema is shown in Figure 1. Using the predefined weather conditions, as well as the energy consumption outputs it is possible to estimate various energy-, economic- and environmental-related results.

![Figure 1. The simplified schema of the TEAC software (source: own studies)](image)

2.1. The examined case study

The analysed area is a residential neighbourhood consisting of 202 single-family houses, located in Lodz. The examined BC was defined using the satellite map – the zone is a square area 690x690m, which was divided into 23x23 parcels (30x30m), see Figure 2 (on left). Characteristics of buildings within the area were assumed following the RSFH data, while their share is based on the Polish Central Statistical Office database. The examined BC is characterized by rather poor thermal insulation of the building's enclosure, as well as usage of inefficient heating boilers supplied by coal (in approx. 67% of all houses). Thus, a set of modernizations are analysed, in order to improve the energy and environmental performance of the region. Those included buildings’ refurbishment, heating systems upgrade, RES applications (PV systems), as well as smart metering with batteries. Those actions are a basis to transform the examined neighbourhood into an EFBC.

![Figure 2. The satellite view of the selected zone (on left; source: [7]) and the CO₂ emission map of the examined BC before modernisation, obtained from the TEAC software (on right: own studies)](image)

3. Results

The TEAC software outputs can be presented using mapping, Load Duration Curves (LDC) and charts with various data. The heating demand of each building is predicted by the trained NN while the electricity demand is calculated based on the house type and its positioning. The output values are then
post-processed, using the TEAC software modules, to obtain the required results. The analysed BC in
the base (default) scenario consumes 4 913.76 MWh/a heating energy and 1 895.19 MWh/a electricity;
it emits approx. 2 032.16 t/a of CO₂, see Figure 2 (on right). The proposed modernizations aim to
transform the neighbourhood into an EFBC, supplied only with electricity. Heating demand is reduced
by approx. 95 % while electricity demand by around 57 %; also it results in the reduction of CO₂
emissions by close to 89 %. The proposed buildings’ refurbishment will cost approx. 11.16 M PLN and
will pay-off after 12 years (with a total profit of approx. 20.14 M PLN after 30 years of operation),
according to the Life Cycle Cost (LCC) analysis. The annual operation cost of the examined BC is lower
by approx. 84 %. Solar energy is transformed into electricity by the PVs characterized with 18.85 %
efficiency, located on the preselected rooftops. Out of 4 994.55 m² of PV installation, the total amount
of 640.40 MWh/a electricity is produced. Solar energy potential can be maximized thanks to the
application of batteries; it is assumed that each house has energy storage with 10.65 kWh capacity.
Additionally, considering the whole BC as a unity, it is possible to obtain further savings using smart
metering techniques and selection of the proper electricity tariff. Additionally, the peak electricity
demand is lower by 30.71 %, as well as the whole neighbourhood does not require energy for the approx.
16 % time of the year (in the base scenario it was energy-reliant all the time). Moreover, the energy
demand is more stable and uniform (see Figure 3); those actions improve the safety of the grid.

![Figure 3. The LDCs of the examined neighbourhood (source: own studies)](image-url)

4. Conclusions
The developed TEAC software is an effective tool for studies of the Polish household sector, which
might be used by the local authorities or the government in order to plan long-term energy-related
strategies. The tool has been validated in studies such as the presented one, providing a potential
transformation into the EFBC. Further work is planned to improve the TEAC software – in particular to
develop a stand-alone version, ready to share in the nearest future.

References
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