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Modeling the economic dependence between town development policy and increasing energy effectiveness with neural networks. Case study: The town of Zielona Góra

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HIGHLIGHTS

- Artificial neural networks (AI) are suitable to estimate the distribution of potential energy savings.
- Improving the energy efficiency of buildings helps to reduce energy poverty.
- Improving energy efficiency requires monitoring of estates and districts of cities.

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ABSTRACT

Due to the changes in legal requirements, growth of energy consumption from different media and prices increase it is necessary to change the attitude of urban consumers. Achieving the objectives of energy policy in each country requires societies to consolidate the confidence that reducing the demand for energy will pay to each household. Creating a positive investment climate, promoting new models and the dissemination of good examples can also lead to economic growth through the use of low-carbon technologies. In many countries, including Poland, the high energy intensity of buildings is seen as a result of the use of low quality materials, low constructing awareness causing the low standard of residential buildings, which is the reason for forcing thermal renovations.

This article presents the distribution of market potential of savings for energy efficient renovations in construction on the example of a medium-sized city of Zielona Gora (Poland), which may be representative of cities in the country and in the world. The potential was determined on the basis of technology and a year of a construction of the buildings, technologies used, kind of development and dominating kind of heat and power supply. The calculated potential was presented as the value of the investments necessary to reduce energy consumption by 1 kW h/m^2. Artificial neural networks, which represent a sophisticated modeling technique and are among the computational intelligence methods were used to compute a distribution of potential. The article makes use of possibilities of multi-layer artificial neural networks trained by back propagation error technique and neural networks with radial basis functions, which is a new feature in the analysis of the energy potential.

1. Introduction

Participation of cities in global energy consumption in the world continues to increase and there is no indication that this trend will change. Increasing urbanization, growing demand for construction services and upturn of comfort level with the increase in time spent in buildings, will cause a further future increase in energy demand in all countries, both developed and developing. For this reason, reducing consumption of thermal, electrical and gas energy and increasing equipment efficiency in buildings is the main objective of energy policy at regional, national and international levels today [1]. This objective should also be reflected in local politics, defining the framework for investment measures with regard to residential, public, municipal and service buildings [2,3].

In many countries of the world, urban development shows wide variation in the size of demand for energy due to the location, climate, functions, dimensions and technology and construction year.

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Nomenclature

Abbreviations

ANN	artificial neural networks
APE	average percentage error
CHP	combined heat and power
EAM	Energy Urban Audit
EPC	energy performance certificates
GDP	gross domestic product
GIS	Geographic Information System
HBS	Household Budget Survey
IBS	The Scientific Foundation Institute for Structural Research (Poland)
IEA	International Energy Agency
LED	light-emitting diode
LIHC	Low Income High Costs
NCRB	The National Centre for Research and Development
Off. J.	Official Journal
PGNiG	Polish Oil and Gas Company
RES	renewable energy sources
RMSE	root mean squared error
UE	European Union

Indices

N	input space dimension
M	output space dimension
t	iteration number
i	number of the next element of the training or test set
j	radial function number
k	number of weight in a hidden or output layer

Parameters and constants

$f(net)$	activation function
φ	radial function
R^n	input space
R^m	output space
P	number of training or test patterns

Variables

$\mathbf{x}$	input vector
$\mathbf{z}$	output vector
$\mathbf{w}$	vector of weights
d	expected value of the output signal
net	product of the input vector and the vector of weights
λ	activation function slope
η	training factor
c	radial function centers
δ	error signal
σ	width of the radial function
u	neuron summation signal in radial network
$E(\mathbf{w})$	measure of error (function of the objective)
$\nabla E(\mathbf{w})$	gradient of the function of the objective
$\frac{\partial E}{\partial w_i}$	gradient of the function of the objective on ith weight in the t iteration
$\frac{\partial E}{\partial \sigma_j}$	gradient of the function of the objective on jth width of the base function in the t iteration
$\frac{\partial E}{\partial c_j}$	gradient of the function of the objective on jth center in the t iteration

The variation is also caused by a different ways to supply buildings with energy, heating and cooling equipment efficiency, technical condition of buildings and their physical properties and standard of buildings facilities [4,5]. Urban development policy, which can provide an additional incentive for increasing the energy efficiency of buildings is also a considerable issue [6,7].

Poland faces the need to adapt the urban development policy to the European Union requirements in terms of reducing the production of greenhouse gases, mainly through measures to reduce the operational demand for heat, electricity and gaseous fuels. Article 9 par. 2 of the directive 2010/31/EU specifies that Member States "shall furthermore, following the leading example of the public sector, develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings, and inform the Commission thereof in their national plans" Article. 4 of the directive of the European Parliament and of the Council of 2012/27/EU of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC [8–10], hereinafter referred to as "the directive 2012/27/EU" imposes the obligation to establish a long-term strategy for mobilizing investment in the renovation of residential and commercial buildings, both public and private, mainly on the basis of local level policies [8–11].

In the European Union, the introduction of color - labeled certificates and matched energy tariffs, aimed at balancing the development in member countries were adopted as a measure to support reducing energy consumption from fossil fuels [12]. The experience of many European countries provide a range of support mechanisms, corresponding to the local market and providing larger and faster benefits at a lower cost [13]. Adoption of a system of incentives for innovation by investors, in which benefits are greater than the risk, has led to impressive economic growth, especially in Denmark, Germany and Spain [14]. Such a system may be less effective in the countries where the risk of time-consuming legal process and the uncertainty of investors slow down in investment [12], which inter alia, takes place in Poland.

The aim of the presented work is to show the possibilities of using modeling with a use of neural networks, to support decision-making in local policy. Knowledge of a dependence of energy efficiency on a cost of renovation and maintenance of buildings allows prioritization of renovations and investments in city districts and neighborhoods. Prioritizing investment activities allows rational spending of public funds. The price of heat delivered to buildings from a CHP plant, is competitive in comparison with other media. Urban energy policy must take reducing energy poverty of the inhabitants into account. Such actions can be implemented directly, in the form of housing benefits and other forms of financial assistance or by controlling the price of heat and the amount of its users.

Modeling for the cost of raising energy efficiency was carried out on the actual data, which is a big advantage and it can be transferred, in a similar context, to other cities throughout the world. A way of energy modeling presented here can be executed with a use of commercial computer software that enables carrying out simulation for buildings with varied degrees of use, installed equipment and energy consumption [15].

2. Cost of energy and energy saving - programmes

Despite the high potential for energy savings and reduction of greenhouse gas emissions in urban buildings in Poland, the lack of appropriate planning records is currently a common obstacle