Analysis of Energy Performance and Buildings Characteristics Obtained from Croatian Energy Management Information System

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***Abstract* — Analysis presented in this paper utilizes large-scale public sector buildings database obtained from the Croatian energy management information system – EMIS. EMIS system is an on-line application for monitoring and analysis of energy and water consumption in Croatian buildings. Those buildings are mostly public sector buildings, buildings owned by cities, counties and the Government of the Republic of Croatia. Part of EMIS system database presented in this paper comprises over 3500 public sector buildings and contains among other complex data relevant information regarding buildings characteristics and their energy performance. Analysis presented in this research was done in order to statistically analyze buildings from EMIS system database according to their age, purpose, building technology, climatic data, building size and number of users. Further, research results regarding existing average U-values of transparent and opaque parts of buildings as well as energy performance of buildings are also presented. Descriptive statistics of building characteristics for buildings dataset was conducted in order to get the mean value, standard deviation, minimal and maximal values of selected characteristic variables. Presented research is a preliminary analysis for further analysis that is more complex, clustering, machine learning and for the development of energy performance predictive models.**

***Index Terms* — Energy management information system, public sector buildings database, building characteristics, building technology, statistical analysis**

I. Introduction

It is well known that buildings have been recognized as a key pathway and setting for the reduction of consumption of energy and carbon emissions worldwide [1]. The growing concern over the worldwide increase in energy consumption and greenhouse gas emissions by buildings has resulted in huge efforts to improve buildings energy performance [2].

Saving resources of fossil energy was the central requirement at the internationally recognized conferences in Rio de Janeiro, Berlin, Kyoto, The Hague and Bonn. It is expressed in the target of a 20% share of renewable energies in overall EU energy consumption and a 20% reduction of greenhouse gas emissions by 2020 adopted at the EU spring summit 2007 and re-affirmed in 2008 [3].

Buildings are complex energy systems and biggest individual energy consumers, European building sector is responsible for about 40% of the total primary energy consumption [4, 5].

Furthermore, the stock of residential buildings constructed before the 1970's which have low performance regarding energy saving makes up more than 3/4 of the total existing residential buildings in European Union [6]. Same situation is in Croatia where approximately 70% of total existing buildings are constructed before 1980 [7].

When it comes to new buildings that will be built in the near future, the European Directive on Energy Performance of Buildings prescribes that all new public buildings constructed after 2018 shall be almost zero-energy buildings, and after 2020 the same shall apply for all newly build residential buildings [5]. This especially highlights the issue of existing energy-inefficient buildings, which need to be renovated in terms of their energy performance as soon as possible.

Main problem of those existing buildings' is that great amount of energy is partly wasted because these buildings that were constructed several decades ago do not meet the current energy efficiency requirements according to current legislation in Union [7]. Studies have shown that average heat losses in buildings which are constructed several decades ago range mainly between 180 and 250 kWh/m^{2}a [8]. A significant percentage of such buildings will continue to be used for many more years, and unless they are renovated in terms of energy performance, they will continue to needlessly consume great amounts of energy. Therefore, energy renovation of these buildings has a great potential for energy consumption reduction and therefore reduction of CO_2 emission. Reduction of energy consumption and improvement of energy performance of existing buildings also has an important role in promoting security of energy supply, technological development, job creation and opportunities for regional development and also can contribute to significant financial savings [5]. Beside energy savings and financial savings energy

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renovation also increases life quality and comfort of living [9].

Measures to improve energy efficiency are defined as group of actions that generally lead to verifiable and measurable or estimable energy efficiency improvement and reduction of energy and water consumption [10]. Energy efficient measures applied to existing buildings during minor/major retrofits in order to reduce their energy consumption can be grouped into three categories [11]:

- Building envelopes – thermal insulation, thermal mass, windows/glazing (including daylighting) and reflective/green roofs,
- Internal conditions – indoor design conditions and internal heat loads (due to electric lighting and equipment/appliances) &
- Building services systems – HVAC (heating, ventilation and air conditioning), electrical services (including lighting) and vertical transportation (lifts and escalators).

Regarding above mentioned and the fact that heat losses through walls account for 35% of total losses [12], one of the most effective and common measures, provided in *The Ordinance on energy audits of construction works and energy certification of buildings* [13], is the improvement of thermal performance of the envelope by applying thermal insulation.

Considering the all mentioned above, this paper present statistical analysis of 3659 public sector buildings. Analysis contains, among other complex data, relevant information regarding buildings characteristics and their energy performance. This paper also presents the results regarding existing average U-values of transparent and opaque parts of buildings as well as energy performance of buildings. Analysis is done in order to statistically analyze buildings from Croatian energy management information system - EMIS according to building technology that depends on year of construction, building purpose, climatic data, building size and number of users.

Presented research is a preliminary analysis for analysis that is more complex, clustering, machine learning and for the development of energy performance predictive models.

II. Croatian Energy Management Information System – EMIS System

First question to be asked is why is it important to monitor and analyze energy and water consumption and why is this especially important for public buildings? The answer is complex but the main reason for this is the fact that maintenance and operations costs of public facilities are mostly covered by public finance [14]. It is therefore extremely essential to plan and manage above mentioned costs and to take into consideration some peculiarities of public buildings [15] like the:

- Particular nature of public works projects as social rather than investment capital,
- “Cradle to grave” (life cycle) or long periods of analysis,
- Low or zero income/revenue flows and
- Sustainability performance (with a particular emphasis on environmental and societal impacts).

Energy Management Information System – EMIS is a web application for energy sources consumption monitoring and analysis in public sector buildings. It provides a transparent oversight and control of energy consumption, making itself an inevitable tool for systematic energy management [16]. Systematic energy management includes strategic planning and sustainable management of energy resources.

EMIS was developed as a part of common project between Ministry of Economy, Labor and Entrepreneurship and United nation developed program and support of The Environmental Protection and Energy Efficiency Fund [17].

For this purpose for each building of the public sector (buildings owned by cities, counties, and the Government, such as administrative buildings, hospitals, schools, kindergartens, etc.), experts responsible for energy management gather and enter relevant data and information in EMIS. Once the data are in the system, EMIS application enables easy access from any computer with Internet access via username and password authentication [18].

The EMIS database contains static technical data of each facility including general, construction and energy performance data for subject building, and dynamic energy resources usage data, which contains all the data that are present on energy and water usage bills, which are provided on a monthly basis from the energy and water suppliers.

EMIS also allows input of the energy and water consumption readings on a weekly or daily basis, collected direct from a meters. The system is designed and implemented in a way that it can accept both off-line, and real time readings from various meters connected to the system [18].

Some specific functionalities of EMIS system are as follows [19]:

- Managing basic data about buildings,
- Automatic and manual collection of energy and water consumption on a monthly, weekly, daily, or even real-time basis (monthly bills and/or meter reading),
- Easy access to information about the total amount of consumed energy and water, methods and places at which energy is consumed,
- Calculations and analysis in order to observe the unwanted, excessive and irrational energy and water usage and identify opportunities for achieving energy and financial savings,
- Verification of achieved energy and water savings,
- Calculation of different energy consumption indicators,
- Automated alerts on critical events and malfunctions,
- Different user interfaces for each user role,
- Assortment of different building types and
- Collection of automatic energy usage readings.

Data presented in this paper are obtained from EMIS system during the year 2017 for purposes of project titled Methodological Framework for Efficient Energy Management by Intelligent Data Analytics. This paper deals with basic data information about public buildings - their age, purpose, building technology, climatic data, building size and number of users. Descriptive statistics of building characteristics for buildings dataset is presented in next chapter.

III. Statistical Analysis of Data Set

Descriptive statistics of building characteristics for buildings dataset was conducted in order to get the mean value, standard deviation, minimal and maximal values of selected characteristic variables. Analysis was also conducted in order to clear the dataset from user entries that are not possible or logic for individual variables and are most commonly treated as the input errors.

Dataset comprises of 3659 public sector buildings. Variables obtained from EMIS system and presented in this paper can be grouped in four different groups of data [20]:

- *Geospatial data*: County, year of construction, object type according to usage purposes and cultural heritage buildings;
- *Occupational data*: Number of employees, number of users and number of working days per year;
- *Building technology/Construction data:* Type of building, year of last restoration, number of floors, useful surface area of building, heated volume area of the building, building shape factor and share of windows surfaces;
- Heating data: Relative annual energy demand for heating for referential climatic data of non-residential buildings, maximum allowed transmission coefficient of heat loss, transmission coefficient of heat loss and total heating power.

Major characteristics of Geospatial and Occupational data are following:

- *County and region:* Depending on building location, there are 21 county in Croatia and 2 regions according to climatic zones – Continental and Adriatic zones with different climatic data and therefore different energy demands;
- *Year of construction*: There are 7 possible construction periods to categorize each building;
- *Object type according to usage purposes*: There are 11 categories of building purposes in EMIS system: administrative, cultural, educational, general purposes, business, residential, social, tourism, military and health care;
- *Cultural heritage building*: Differentiate buildings whether they are part of cultural heritage or not – 2 categories;
- *Type of building*: There are 4 types of building - buildings in complex, freestanding buildings, complex of buildings and part of the building;

Majority of buildings are located in Continental part of Croatia, 70,51% of buildings, and 29,49% of buildings are located in Adriatic part of Croatia. Fig. 1 to Fig. 5 present detail analysis of following variables:

- Buildings location, Fig. 1, where is worth mentioning how 49,17% of buildings are located in only 5 Croatian counties,
- Year of construction, Fig. 2, 53,70% of analyzed public buildings are 47 years old and older,
- Building usage purposes, Fig. 3, most of the buildings, 70,07%, are for educational and administrative purposes,
- Cultural heritage, Fig. 4, 11,94% of buildings are part of cultural heritage and
- Type of building, Fig. 5, 59,66% are buildings located in complexes.

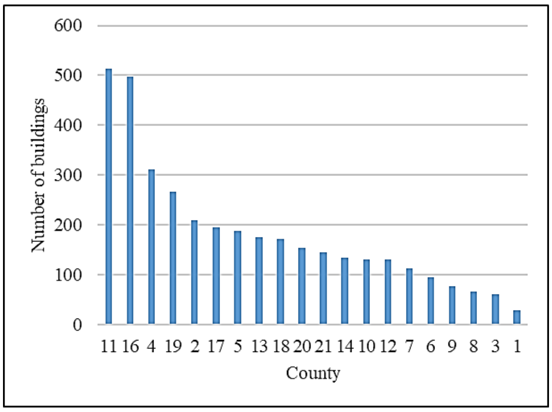

Figure 1. Number of buildings according to location in counties

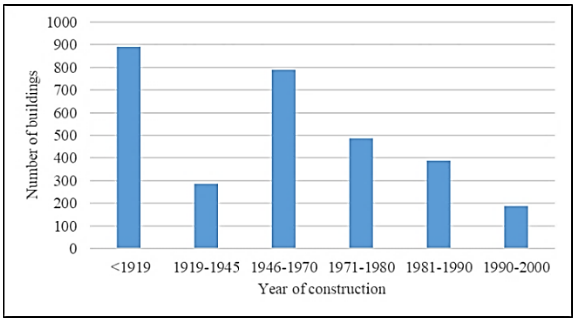

Figure 2. Number of buildings according to year of construction

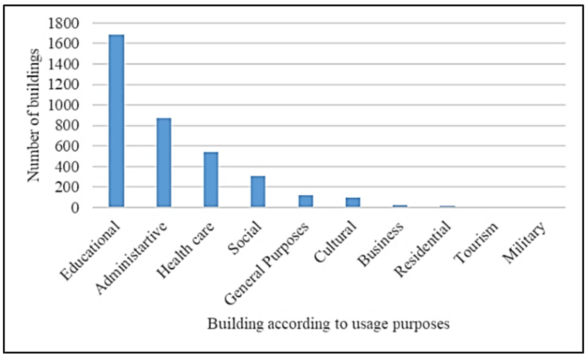

Figure 3. Number of buildings according to usage purposes

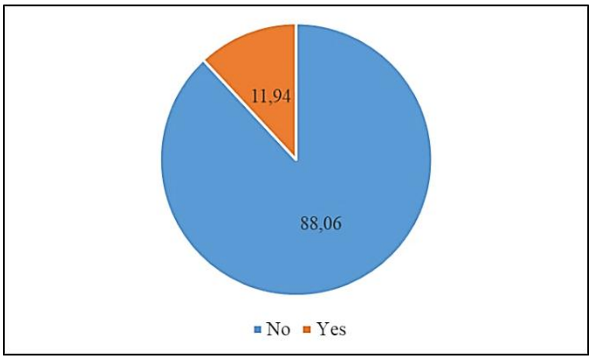

Figure 4. Percentage of buildings according cultural heritage

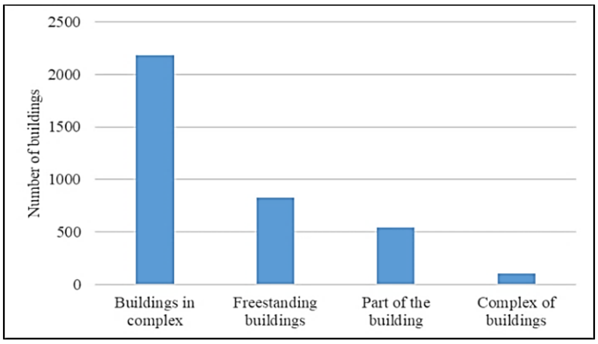

Figure 5. Number of buildings according to type of building

In Table I basic statistical parameters of dataset are presented - Valid numbers of entries, mean values, minimum values, maximum values and standard deviation of sample. Table also presents amount of data entered into a base (Valid N), where is to conclude that not all buildings have all required data entered in EMIS system. This is the consequence of the user's negligence or the lack of data in buildings where energy certification want conducted yet.

Before October 1st 2107 value of relative annual energy demand for heating for referential climatic data of non-residential buildings, ($Q_{H,nd,rel}$ [%]) was used for determination of energy rating of non-residential buildings, from A+ to G, Fig. 6 [13].

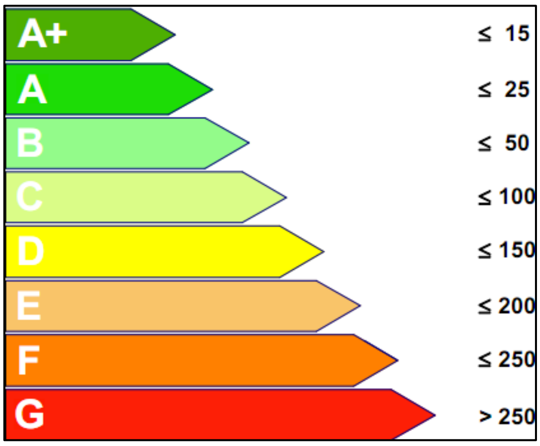

Figure 6. Energy rating of non-residential buildings depending on $Q_{H,nd,rel}$

According to values of relative energy demand most of the buildings in dataset are energy rating D with mean value of $Q_{H,nd,rel}$ of 144,40%.

Best rating in dataset have only 2 buildings - energy rating A with value of $Q_{H,nd,rel}$ of 15,1%.

Best rating in dataset have only 1 building - energy rating G with value of $Q_{H,nd,rel}$ of 501,00%.

Other variables regarding energy data (maximum allowed transmission coefficient of heat loss, transmission coefficient of heat loss & total heating power [kW]) are presented with their statistical values in Table I.

TABLE I. BASIC STATISTICAL PARAMETERS OF DATASET

Variable	Descriptive Statistics				
	N	Mean	Min.	Max.	Std.Dev.
Year of last restoration	3659	1165	0	2016	989
Number of floors	3659	2	0	11	1
Number of employees	3659	56	1	2500	115
Number of users	3659	512	1	50000	1731
Number of working days per year	3659	259	0	365	83
Useful surface area of building, A_k [m^2]	3656	1411	16	60744	2419
Heated volume area of the building, V_e [m^3]	3646	5622	39	189825	10103
Building shape factor, f_0 [m^{-1}]	3162	1	0	3	0
Share of windows surfaces	2772	14	0	3443	123
Relative annual energy demand for heating for referential climatic data of non-residential buildings, $Q_{H,nd,rel}$ [%]	604	144	15	502	83
Maximum allowed transmission coefficient of heat loss, $H'_{tr,nd}$ [W/m^2K)]	3186	1	0	2	0
Transmission coefficient of heat loss, $H'_{tr,adj}$ [W/m^2K)]	588	3	0	101	13
Total heating power [kW]	1689	466	1	25000	1157

Particular attention during the research was devoted to analysis of thermal transmittance coefficient (U-value) of transparent parts of facades and external walls. The most important parameter for determining heat loss through the building envelope for different building forms is U-value.

At this point, maximum value of U-value in Croatia for external wall, which needs to be met, has been set to 0,30 W/m^2K for Continental part of Croatia and 0,45 W/m^2K for buildings at Adriatic see. An average monthly temperature of outdoor air of the coldest month is less or equal to 3 ℃ in Continental part of Croatia and higher than 3 ℃ in Adriatic part of Croatia [21].

Analogously previously explained, for transparent parts of façade (windows, doors…) maximal U-value is 1,60 W/m^2K and respectively 1,80 W/m^2K.

Further analysis of heating data was toward determining thermal properties of different construction parts of buildings. As already stated the most important parameter for determining heat loss through the building envelope is U-value. Table II presents basic statistical parameters of U-values for given dataset. Number of valid samples (N) varies since not all building have same construction parts and due to the user's negligence.

TABLE II. BASIC STATISTICAL PARAMETERS OF U-VALUES FOR DIFFERENT CONSTRU-VAUES FOR DIFFERENT CONSTRUCTION PARTS FOR ENTIRE DATABASE

Construction part	N	Mean	Min.	Max.	Std.Dev.
Transparent parts of facade (windows, doors, etc…)	1110	2,94	0,27	6,12	1,13
Flat and inclined roofs above heated internal space	1145	1,25	0,00	6,67	1,20
Ceilings against external air and above garages	209	1,22	0,25	4,17	0,94
Ceilings between heated spaces of different occupants	106	1,28	0,19	2,86	0,66
Non transparent external doors	314	3,50	0,37	7,00	1,30
External walls, walls against garages and attics	1479	1,33	0,14	5,50	0,81
Walls and ceilings against unheated internal zones > 0 ℃	282	1,33	0,19	4,81	0,84
Walls against ground and floors on the ground	1149	1,72	0,21	5,91	1,18

Since most of the heat loses are through external walls the U-values for those building parts are analyzed in more detail. In addition, when it comes to energy refurbishment of existing buildings thermal insulation of external walls is usually combined with replacement of old joinery – transparent part of building facades. So transparent parts of facade (windows, doors, etc…) are also analyzed also more detailed.

To get results of analysis that are easier to interpret following consensus during this research was agreed: since maximal U-values are different for two different parts of Croatia, this research used their mean values i.e. 1,70 W/m^{2}K for transparent parts of facade and 0,375 W/m^{2}K for external walls. This was done in order to determine the amount of building elements that do not meet current standards proscribed in *Technical Regulation on the Rational Use of Energy and Thermal Insulation in Buildings* [13]. Especially in context of continuous tightening of requirements regarding thermal properties of building elements.

Fig. 7 presents U-values of building elements with valid information about this value. For transparent parts of fa çade there are 1110 elements and for external walls, walls against garages and attics there are 1479 elements.

Horizontal lines present maximal agreed mean U-values in this research.

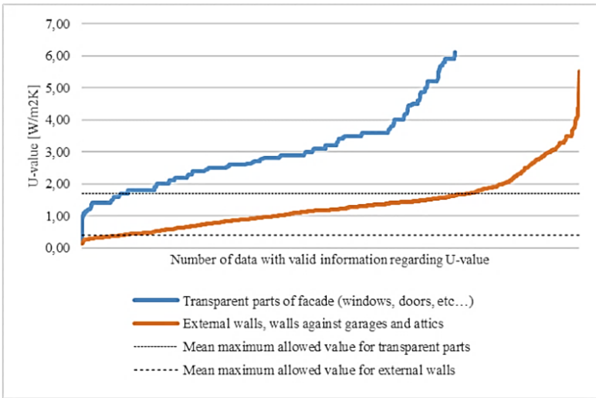

Figure 7. U-values of building elements for entire dataset

In analyzed data set 88% of transparent parts of fa çade and 92% of external walls, walls against garages and attics does not fulfil current requirements according to current legislation for maximal U-values! In the database there are 30,10% of transparent parts and 72,07% of external walls with U values twice as high and higher than it's currently allowed.

Last stage of this preliminary analysis was to determine correlations between dataset variables. Since paper presents only one part of database these results are ought to be observed conditionally.

Table III presents values of correlation between variables of observed database. Presented correlations are only those that are significant at p < 0,05000. Columns and rows where this criterion was not met are omitted from Table III.

TABLE III. CORRELATIONS BETWEEN VARIABLES

Variable	Variable							
	1	2	3	4	5	6	7	8
1	1	0,5305	0,3380	0,4267	0,3205	-0,5174	0,3849	0,1253
2	0,5305	1	0,6601	0,6781	0,4806	-0,3130	0,2933	0,1754
3	0,3380	0,6601	1	0,7038	0,6055	-0,3003	0,2039	0,3111
4	0,4267	0,6781	0,7038	1	0,9181	-0,4798	0,5168	0,3794
5	0,3205	0,4806	0,6055	0,9181	1	-0,4637	0,5008	0,4845
6	-0,5174	-0,3130	-0,3003	-0,4798	-0,4637	1	-0,6502	-0,0691
7	0,3849	0,2933	0,2039	0,5168	0,5008	-0,6502	1	0,0839
8	0,1253	0,1754	0,3111	0,3794	0,4845	-0,0691	0,0839	1

Legend:

1 Number of floors
2 Number of employees
3 Number of users
4 Useful surface area of building
5 Heated volume area of the building
6 Building shape factor
7 Maximum allowed transmission coefficient of heat loss
8 Total heating power

Correlations between variables greater than 0,60 from Table III are following:

- Number of employees & Useful surface area of building (0,6781),

- Number of users & Number of employees (0,6601),
- Number of users & Useful surface area of building (0,7038),
- Number of users & Heated volume area of the building (0,6055),
- Useful surface area of building & Heated volume area of the building– greatest correlation (0,9181) and
- Building shape factor & Maximum allowed transmission coefficient of heat loss – negative correlation (-0,6502).

IV. Conclusion

Statistical analysis of public building characteristics obtained from EMIS system reveled that there are 53,70% buildings in system that are older than 47 years. Most of those buildings do not meet current requirements regarding thermal requirements since most of them are D energy rating. Currently for new buildings and refurbishment of old buildings law prescribes energy rating B. This is especially important because most of those buildings (46,19%) are educational buildings and beside poor thermal properties problem there is also possibility of bad indoor climate. Nevertheless analysis also gives great insight in potential of energy refurbishment of those buildings in the future which will result in reduction of heat energy demands and reduction of CO_2 emissions.

Special attention should be given to buildings that are part of cultural heritage since they require application of particular building technologies during energy refurbishment. This preliminary analysis also reviled correlations between some variables and groups of variables important for future analysis.

Presented results will be used for analysis that is more complex, clustering, machine learning and development of energy performance predictive models and models for predicting energy demands.

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