www.ees.uni.opole.pl
ISSN paper version 1642-2597
ISSN electronic version 2081-8319
Economic and Environmental Studies
Vol. 15, No. 4 (36/2015), 333-347, December 2015

Carbon Footprint for energy efficiency in public buildings

Karina FRĄCZEK
Jerzy ŚLESZYŃSKI

University of Warsaw, Poland

Abstract: The paper presents an empirical analysis of Carbon Footprint indicator applied to the public building of the Faculty of Chemistry at the University of Warsaw. Analysis takes into account direct and indirect CO2 emissions related to the functioning of the Faculty. Analysis concentrates on the year 2013 but also allows for some comparison with two earlier years and with two other public buildings in Warsaw. The final outcome of this study, with a help of thermo visual examinations, proposes a list of undertakings which are necessary to improve the efficient use of energy in the Faculty.

Keywords: Carbon Footprint, energy efficiency, public building
JEL codes: Q54, Q52, Q57

1. Introduction

A family of footprint-indicators includes also Carbon Footprint which measures our contribution to the greenhouse effect. The Carbon Footprint (CF) is defined as the total amount of greenhouse gases produced to directly and indirectly support human activities, usually expressed in equivalent tons of CO_2 (carbon dioxide) (Aryen & Ertug 2012). It can be also described as an emission in the whole life cycle of a given product. When somebody drives a car, the engine burns fuel which creates a certain amount of CO_2, depending on its fuel consumption and the driving distance. When somebody heats a house with the use of oil, gas or coal, then somebody also generates CO_2. Even if somebody heats house with the use of electricity, the generation of the electrical power may also have emitted a certain amount of CO_2. When somebody buys food

Correspondence Address: Karina Frączek, Jerzy Śleszyński, Faculty of Economic Sciences, University of Warsaw, Warsaw Ecological Economics Center, ul. Długa 44/50, Warsaw, Poland. Tel. +48 504168642 E-mail: fraczek.karina.d@gmail.com, sleszynski@wne.uw.edu.pl.

and goods, the production of the food and goods also emitted some quantities of CO_2. The CF is the sum of all emissions of CO_2 which were induced by somebody's activities in a given time frame. Usually, CF is calculated for the time period of a year. The first mention on CF in the scientific literature on the subject appeared in a letter to the journal "Nature" in 2007 (Hammond, 2007: 256).

Energy efficiency is important for the economy and saves the environment. No doubts that it is one of our national policy priorities. Energy efficiency is also mentioned in many documents on strategic adaptation to the climate change. Publications identify industries that emit the most and suggest adaptive activities contributing to the reduction of GHG emissions thanks to more economic use of energy (Fiksel, J. 2006). Controlling GHG emissions in big cities, and first of all controlling emissions from public buildings, belongs to the most advisable and required strategies. In addition, improving energy efficiency is still the cheapest option among tools available in Poland that can be applied to work for reducing GHG emissions.

In this paper, CF was applied to the assessment of energy efficiency of one of the University Faculty specifically the one that conducts laboratory work. For this assessment Faculty of Chemistry of Warsaw University was chosen. This pre-war building, which is the present seat of Chemistry, was carefully analyzed and collected data allowed for calculation of CF. In addition, CF results for the Faculty of Chemistry were compared to CF indicators for some other public buildings in Warsaw as well as the case of Norwegian University of Science and Technology described in literature (Larsen W & Pettersen J. 2013). The results of this study helped to list actions that can improve the efficient use of energy in the Faculty.

2. The Faculty of Chemistry at the University of Warsaw

The object of the study was the building of the Faculty of Chemistry, which is located on the Pasteur Street in Warsaw and belongs to the University of Warsaw. History of the building began in 1934 when the University received a vacant lot situated at the intersection of streets named after Wawel and Pasteur. On June 23, 1939, the finished building was put into operation. Unfortunately, during the Second World War, the building was converted into a hospital and its professional chemical equipment was devastated. What is more, the Nazis blew up part of the building just before the liberation of Warsaw.

The building was made using traditional technology. External walls were made of clay and ceramic bricks, floors were made of reinforced concrete, flat roof was ventilated. Actual and basic technical data on the main building of the Faculty of Chemistry are: building area 4481.60 m^2, usable area of 17700.90 m^2, volume 63658 m^3, the height of 13.05 m, 3 storeys above ground, one underground floor.

In the building there are organizational units related to the functioning of the Department, namely: lecture halls, gyms, laboratories, workshops, administration of the Faculty, as well as technical rooms and a boiler room. There are two gas-oil boilers with a capacity of 1400 kW and one gas-oil boiler with a capacity of 895 kW, Viessmann type Paromat-Simplex. The roof of the building of the Faculty of Chemistry is flat and completely covered with a double layer of tar paper used for making damp insulation and roofing.

The scope of the analysis includes data on internal emissions produced within the building (heat) as well as data on external emissions accompanying production energy used by the building and external emissions emerging outside as a result of the Faculty's waste disposal. This allows to determine emissions that can be linked to the operation of the Faculty of Chemistry of Warsaw University.

Due to the calculation method, the measured impact is not always in the immediate vicinity of the object in question. RWE, who is the supplier of electricity, buys electricity on the power exchange and then sells and delivers it to the consumer. That means that the energy used by the building comes from many sources and pointing out one producer and place of emission is impossible. Regarding waste, it is produced on the territory of the Faculty of Chemistry and then disposed somewhere else.

Most of the external emission caused by the energy production is created in the area surrounding Warsaw. This emission has a strong impact on the temperature and composition of the atmosphere. This observation suggests that PM, SO_2, NO_x , and first of all GHG emissions should be considered on the global scale. However, this statement applies also to the internal source of emission from heat production. In particular, in the specific case of big cities, these pollutants, including also GHG, contribute to the microclimate of Warsaw leading to a well-known "heat island" phenomenon.

Data included in the analysis were the following:

1. Total consumption of electricity.

2. Total consumption of natural gas.

3. Waste divided in two groups: municipal solid waste and laboratory waste.

In this assessment of CO_2 emissions, trips of the employees of the Faculty as well as students' were not taken into consideration. The same decision applied to commuting to and from the workplace for both groups. It was caused by difficulty in gathering data mandatory for a reliable and detailed calculation. The main assumption was that urban transport predominates among people staying in the building and because of that their share in transport emission per person would be negligible.

The Municipal Cleaning Company in Warsaw (MPO) received municipal solid waste produced by the Faculty while "REMONDIS" and "EKO HARPOON" were responsible for treatment of hazardous chemical wastes in a way that minimizes their negative impact on the environment while maximizing retrieval of raw materials. Organic liquid waste with and without halogens (liquid organic, water-organic liquid and liquid halogen) was recycled and was useful for re-solvent recovery. Other wastes were subjected to thermal liquidation.

3. Calculation of Carbon Footprint

There are three basic variants of the CF calculation as far as emission connected to electricity is concerned. The first one takes into account emission coefficient given by the National Center for Balancing and Management of Emissions (KOBiZE) that equals 812 kg CO_2/MWh (KOBIZE, 2011). It can be only applied to carbon dioxide emission. This variant is used in most of CF estimations. Second way of calculations involves using data presented by the energy distributor, in this case in Warsaw it would be RWE. The third and the last method, which can be used in calculations, is based on the document "Energy Policy of Poland until 2030" (2009:26). This document was passed by the Council of Ministers in 2009. The coefficient of emission given by the document is the highest and equals 950 CO_2/MWh.

The third solution seemed to be the most appropriate. This data seems convergent with principles described in ISO/TS 14067, which is the norm that specifies requirements and guidelines for the quantification and communication of the carbon footprint of a product (CFP) (ISO/TS 14067: 2013). Therefore, the third estimate was applied to further calculations of CF in this paper.

As far as thermal energy is concerned, the data were based on the amount of natural gas bought in 2013 by the Administration of the building. The next step was to calculate the emission with the use of calorific value specific to this fuel.

Emissions that were the outcome of the waste treatment, which was connected with Chemistry Faculty activity, was calculated in a similar way. The quantity of different type of waste was converted into energy outcome with the use of specific coefficients. The next and final step was to calculate emission which will be inevitable in the incineration process. This method was not perfect because not every compound emitted in the process will be taken into account. These omissions were due to the fact that there are no reliable data describing amount of compounds other than CO_2 (e.g. ammonium).

There was also one facilitating assumption in the analysis presented below. The Faculty of Chemistry separated plastic waste (66 m^3) according to their type, so mechanical and chemical recycling of plastic was possible. On further stages containers were cleaned, granulated and used in such industries as: energy, cement and lime industry, and packaging industry. Therefore the emissions created during this step were part of another institution's CF and were not considered in this work (Terebuła-Fertak, 2014). As for glass waste (33,6 m^3), smelting glass cullet needs very high temperature (not less than 1500°C). Such temperature is the reason why emissions associated with this process do not belong to six compounds listed in the Kyoto protocol. What is more, emission combined with furnace operation was part of another institution's CF. That was why plastic and glass waste were not taken into account in this analysis.

Table 1. Emissions of CO_2 for the Faculty of Chemistry for the year 2013

Media	Resource	Emission [Mg CO_2]	Total emission [Mg CO_2]
Electricity	Energy	2717	3297.70
Thermal energy	Natural gas	562.46	
Waste	Mixed	6.7	
	Paper	1.54	
	Plastic	0	
	Glass	0	
	Chemical waste	10	

Source: Authors' own elaboration.

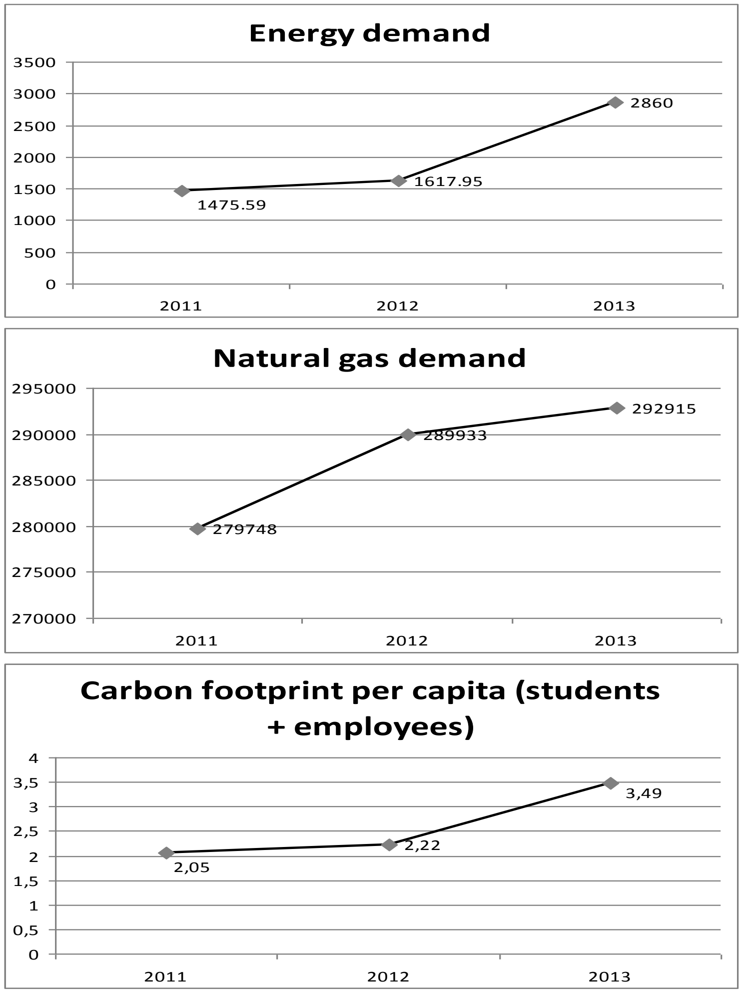
Summary of all the basic data and calculated emissions is presented in table 1. The total emission of CO_2 for the year 2013 was: 3297.70 Mg CO_2. The number of students was 650 and the number of employees was 294. Therefore, CF per one student was 5.07 Mg CO_2, and CF per one person in the building (students plus employees) 3.49 Mg CO_2.

4. Results and evaluation

The sources of CO_2 emissions created a clear structure dominated by the energy consumed by the Faculty of Chemistry in the form of electricity. Analysis of the collected data showed that the most significant emissions connected with the Faculty of Chemistry resulted from electricity intake (82,39 %) and consumption of natural gas (17,06%). They stand for 99,45% of the whole emission. Gas consumption can be divided into three different purposes: water heating (circa 11%), laboratory work (circa 4%), and heating inside the building (circa 85%).

It is clear that the electricity has the biggest share in CF. This is due the fact that energetic mix in Poland consists mainly from hard coal. Knowing that, it is easy to draw the conclusion that minimizing energy consumption is the most effective way to decrease CF of the Faculty. Energy and natural gas demand, and CF per capita for the Faculty of Chemistry are presented on figure 1.

Figure 1. Energy and natural gas demand and CF per capita in years 2011- 2013

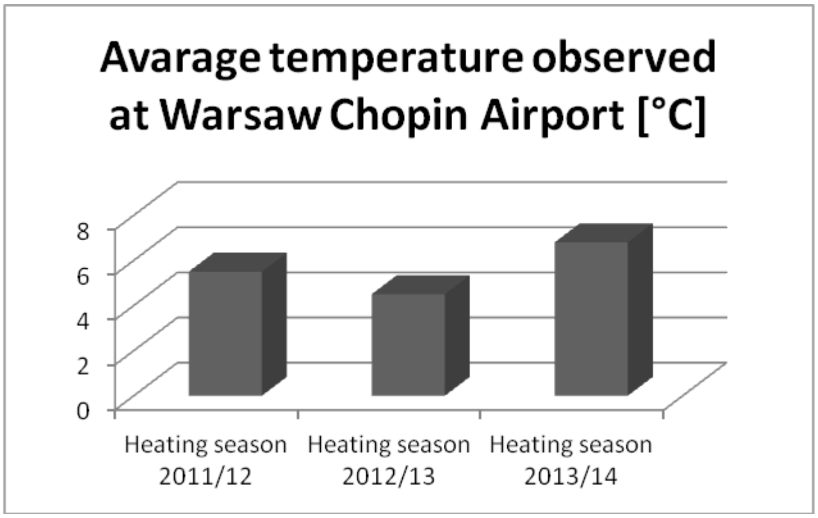


Source: Authors' own elaboration based on information from the Administration of the Faculty of Chemistry.

During three years: 2011, 2012 and 2013, the energy use presented an upwards trend. In 2012 CF per capita was 8% higher than year before, while in 2013 it was 57% higher. This strong trend can be an outcome of constant demand for purchasing new equipment for laboratories and their cooling appliances.

One could suspect that exceptionally cold weather caused higher demand for heating and was responsible for an increase in assessed CF. In the case of natural gas demand the correlation with the weather conditions was not confirmed. The trend of temperature in Warsaw during heating seasons did not coincide with the trend of CF (Dopke, 2014). The cited observation is presented on the figure 2.

Figure 2. The temperatures in Warsaw during heating seasons



Source: Authors' own elaboration based on (Dopke, 2014).

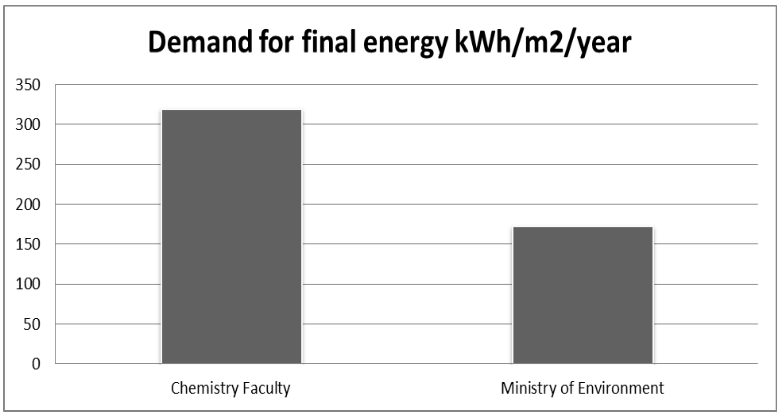
The isolated results of CF calculation presented above was not sufficient to evaluate the magnitude of actual environmental impact of the examined building. Therefore, CF estimates for the Faculty building were compared with some other existing thematic studies focused on public buildings and estimating their CF.

Actually, the Faculty of Chemistry, the Ministry of the Environment, and the Institute of Meteorology and Water Management National Research Institute were compared to some extent. The first two institutions are located in buildings, which were built during the interwar-period (1930s) while the last one occupies building built between 1955-64. There are significant differences in capacities of the buildings (Chemical Faculty - 63658 m^3; Ministry of Environment - 102000 m^3; IMGW-PIB - 61175 m^3). It was also important, that 55 residential apartments situated in the Ministry of the Environment were not taken into account in the analysis.

The buildings compared in this paper are used for different professional, scientific and technical purposes. For instance, the Faculty of Chemistry carries out research with the use of specialized equipment, while the Ministry undertakes activities which are strictly administrative. Institute of Meteorology and Water Management National Research Institute conduct both scientific and administrative work.

While comparing buildings it is crucial to distinguish their demand for usable, primary, and final energy. The definition states that usable energy is directly used, while final energy is delivered to the building. Any losses caused by installations' efficiency are taken into consideration in the second type of energy. Primary energy also includes losses caused by energy production and type of energy carrier. Data available for the Chemistry Faculty and the Ministry of Environment showed the difference between final energy demand for both institutions (on figure 3.). This was caused by the type of activities held in both institutions.

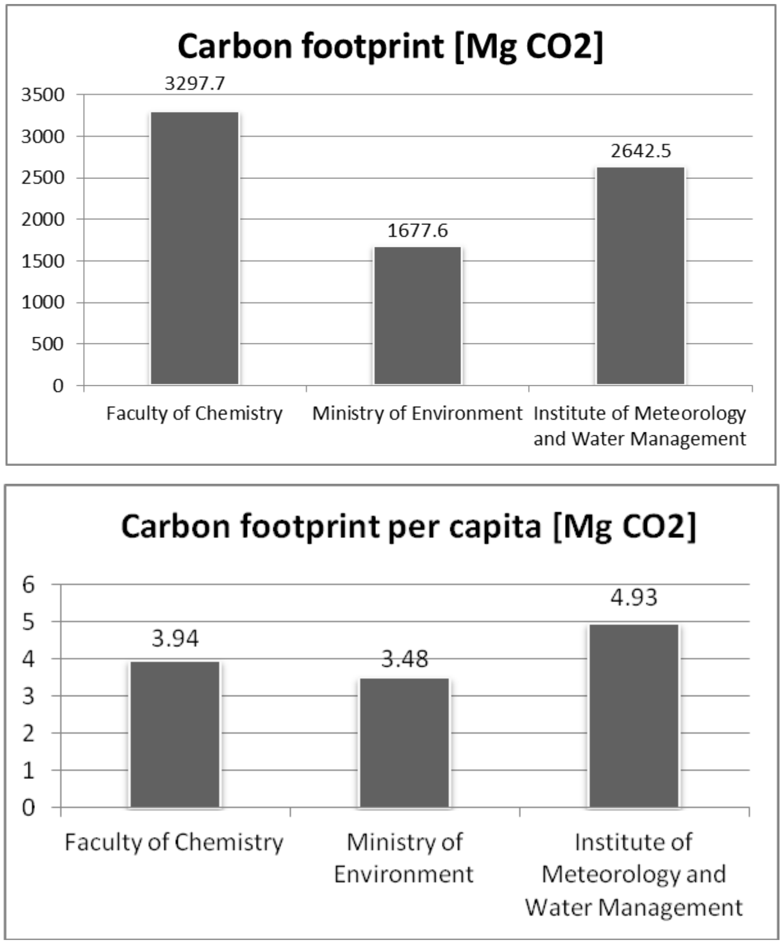
Figure 3. Comparison of final energy demand in the Faculty of Chemistry and Ministry of the Environment



Source: Authors' own elaboration based on (Environmental Declarations, 2014:12, 2013:9).

The assessments presented on figure 4. show interdependencies between the form of activity undertaken by the institution and amount of emissions of CO_2. However, the assessment of CF per capita for all three buildings are quite similar. It may be surprising, but CF per person estimated for the Faculty was similar to values calculated for the Ministry. It can be explained by the differences in amount of people staying on the premises of those institutions (Ministry - 482 employees, Chemistry Faculty - 994 employees and students, IMGW - 536 employees). It was also included in the estimations that students spend only 10 months in the building because of the summer vacation.

Figure 4. CF and CF per capita for three public buildings in Warsaw



Source: Author's own elaboration based on "Environmental Declarations" of the Ministry of the Environment and the Institute of Meteorology and Water Management (Environmental Declarations, 2014:12, 2013:9).

Taking into account all known data and existing and obvious differences, it should be stressed that footprint indicator for the Faculty of Chemistry was characterized by somewhat high CF and quite low CF per capita when compared to two other public buildings located in Warsaw. However, as it was clear from the very beginning, the CF assessment for the Faculty was not enough to formulate solutions to the energy efficiency problem. Action improving the present situation requires identification of inefficiency sources inside the building.

5. Solutions in order to improve energy efficiency

There are three standard solutions depending on the idea of improvement. First, actions that aim to limit losses in energy use. These are: improvement in thermal insulation and building tightness, using equipment characterized by efficient performance, which results in the reduction of time while equipment is used, automation in case of lighting, substitution of dispersed sources with centralized sources (in case of air-conditioning and cooling).

The second group of solutions given is the use of alternative energy sources, such as waste heat. A significant increase in the energy effectiveness can be achieved with the introduction of such economic technologies. The third group of actions is based on the change in consumers' behavior and energy use patterns. It is directly connected with the awareness of users and efficient management.

To adjust action to already identified problems, an analysis of the weakest points in energy management is required. CF assessment can be the starting point and prove energy inefficiency in the course of time. In this paper it was demonstrated, for instance, that the biggest and increasing CO_2 emission was connected with electric and thermal power use in the building.

In order to clarify results of Carbon Footprint assessment an additional tool was used. The thermographic examination with application of advanced measuring equipment and specialized software took place in the Faculty of Chemistry (Frączek, 2014). The thermography-based method is the contact-free measurement of surface temperatures. Only those inspections enabled detailed analysis of thermal insulation in the building. Thermal image showed energy losses, especially due to transmission through windows and coupling between external walls and ceiling. These are typical leak points in most poorly insulated buildings. The combined results of CF and of thermo visual examination showed that the Faculty is very ineffective in thermal energy management.

The ventilation system had the biggest share in electricity demand. The operating characteristics of the Chemistry Faculty required not only maintenance of thermal comfort standards but also optimal indoor conditions such as proper humidity. Two power supply systems that support equipment needed substantial amount of power. The reason for strict indoor conditions and presence of power generators was the fact that advanced equipment used in the Faculty needed to be stored properly and has to work continually. There are 58 fans and their estimated share equals 35-40% in the annual electricity demand. Very energy-intensive was also the server room with two computer clusters (25-30 kW) and the lighting system. During the past 3 years, electricity demand of the Faculty increased by 48%. It can be mainly explained by the larger increase of laboratory equipment.

Increase in energy efficiency would require modernization of the whole building. In particular, these are some practical solutions suggested below:

1. Replacing currently functioning fragmented system of ventilation with centralized system and optimization translated in adjusting the frequency of rotation to existing demand.
2. Lighting automation, especially in the corridors, toilets, social premises and the basement.
3. Decrease in the number of luminaries and use of energy-saving bulbs.
4. Energy recovery explained as conversion of heat energy (outcome of equipment use) into electricity. Introduction of such energy to the system upholds the idea of prosumption. The prosumption is defined as simultaneous production and consumption of the energy.
5. Investment in renewable energy sources, particularly solar panels. According to solar map studied at the Warsaw City Council (Solar map 2014), the amount of solar energy is sufficient for this investment. What is more, the construction of the roof of the building allows making such innovations.

Increase in heat utilization efficiency could be achieved through two basic solutions presented and explained below:

1. The biggest energy loss (45-60%) was caused by external walls and roof heat leaks. It is reasonable therefore to conduct thermal modernization of the whole building.
2. Modern solution would be creating a “green roof” on the building. That means placement of containment, introducing soil and suitable species of plants. Such a solution not only has positive impact on the heat efficiency but also leads to decrease in heating up of the ceiling and counteract the high temperatures in the city (Liu & Minor, 2005).

In both electric energy and heat utilization efficiency the awareness of employees and students of the Faculty plays a crucial role. Understanding outcomes of initiated or abandoned activities is of significant importance. The proper solution in this case would be promotion of innovative attitudes with the use of posters as well as inclusion of such information in the course structure. The success of such "green" campaigns depends on presenting good and massive examples, that is why teaching staff should largely participate in those actions.

6. Conclusion

In a country where the dominant energy carriers are coal and lignite, extremely important factor in reducing greenhouse gas emissions is the reduction of the energy consumption among energy consumers by increasing energy efficiency and reducing waste heat and electricity. This underlines the need to integrate programs to increase energy efficiency, especially in public buildings.

The results presented in this study confirm the usefulness of the footprint method for early monitoring energy and environmental efficiency of public buildings. This method can be used both to design and control building renovation projects, as well as to optimize and improve power consumption. As stated in the Declaration of the Ministry of the Environment (Environmental Declaration, 2014:12) the goal is to reach a very high energy efficiency (of up to 78%), as part of the modernization of the building. It is advised to implement similar projects in all university buildings.

CF analysis showed that the Department of Chemistry in 2013 (with a score of 3297.7 Mg CO_2eq, which stands for the 3.49 Mg CO_2eq per person) was characterized by a relatively high CF and increasing CF per capita. Nevertheless, the data base was very short and not perfect what requires future revision as well as critical analysis of the present state.

The dominant characteristic of the Faculty of Chemistry, where the basic teaching and research facilities are chemical laboratories, were numerous energy-consuming installations powered by electricity. Almost 50% of energy was consumed by distributed systems of ventilation. Therefore, it would be advisable to optimize individual fan systems, and then introduce a central ventilation system.

In general, it seems appropriate to implement an Environmental Management System based on ISO 14001 standard in the Faculty of Chemistry. The most important changes would be expected in the adjustment of energy and electric power consumption to the working hours as well as in implementing more efficient methods of operating a building for teaching and research purposes. Such action will lead to increased transparency in expenditure and give credit to the Warsaw University's activity in favor of sustainable development. Perhaps, among the more conscious individuals reduced CF may also become one of the advantages, that would tip the scales in favor when choosing a college. It would also improve the image of the University of Warsaw on the international arena.

Literature

Aryen, Y. H.; Ertug, A. E. (2012). *Carbon and Water Footprints. Concept, methodologies and policy responses.* Paris: United Nations Educational Scientific and Cultural Organization.

Dopke, J. (2014). *Zużycie energii na ogrzanie budynków w ostatnich sezonach grzewczych.* Available at: http://www.cire.pl/pliki/2/zuzycie_energii_na_ogrzewanie_budynkow_w_ostatnich_sezonach_grzewczych.pdf. Accessed 14 November 2014.

Fiksel, J. (2006). Sustainability and resilience: toward a systems approach. *Sustainability: Science, Practice, & Policy* 2(2):14 – 21.

Frączek K. (2014). Master thesis: *Evaluation of public building exploitation with the use of carbon footprint*. Warsaw: Warsaw University Library

Institute of Meteorology and Water Management - National Research Institute (2013). *Environmental Declaration of Institute of Meteorology and Water Management for 2012*. Warsaw: Institute of Meteorology and Water Management - National Research Institute.

ISO/TS 14067 (2013). *Greenhouse gases - Carbon footprint of products – Requirements and guidelines for quantification and communication.*

KOBIZE (2011). *Wskaźnik referencyjny.* Available at: www.kobize.pl/news/137/116/Referencyjny-wskaznik-jednostkowej-emisyjnosci-dwutlenku-wegla-przy-produkcji-energii-elektrycznej-do-wyznaczania-poziomu-bazowego-dla-projektow-JI-realizowanych-w-Polsce.html. Accessed 26 August 2014.

Liu, K.; Minor, J. (2005). *Performance evaluation of an extensive green roof. Greening sustainable Communities.* Available at: http://archive.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc48204/nrcc48204.pdf. Accessed 19 September 2014.

Ministry of Economy (2009). *Energy Policy of Poland until 2030*. Warsaw: Ministry of Economy.

Polish Ministry of Environment (2014). *Environmental Declaration of Ministry of Environment for 2013*. Warsaw: Polish Ministry of Environment.

Solar map (2014). *Kalkulator energetyczny – Urząd miasta Warszawa*. Available at: http://www.kalkulatorenergetyczny.um.warszawa.pl/index.php?q=informacje-dodatkowe&w=1 Accessed 12 December 2014

Terebuła-Fertak, M. (2014). *Od odpadu do produktu. Recykling tworzyw sztucznych.* Available at: http://www.choczewo.com.pl/wp-content/uploads/2015/03/Od-odpadu-do-produktu-recykling-tworzyw-sztucznych.pdf. Accessed 20 September 2014.

Ślad węglowy w ocenie efektywności energetycznej budynków publicznych

Streszczenie

W artykule przedstawiona została analiza empiryczna wskaźnika jakim jest Ślad węglowy. Obiektem poddanym badaniom jest Wydział Chemii Uniwersytetu Warszawskiego. W analizie uwzględniono pośrednie i bezpośrednie źródła emisji gazów cieplarnianych, które łączą się z eksploatacją budynku. W pracy dokonano także porównania danych dla wspomnianego budynku z dwoma innymi instytucjami. Analiza dotyczy roku 2013, jednak przeprowadzono również obliczenia dla lat 2011 i 2012. W podsumowaniu, po przeprowadzeniu dodatkowych analiz metodą termowizji, zidentyfikowano i podano działania, które mogą być wprowadzone w celu zwiększenia efektywności energetycznej budynku Wydziału.

Słowa kluczowe: ślad węglowy, efektywność użytkowania energii, budynki użyteczności publicznej.