Ma’an – a new approach to the autonomous building

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Abstract. The paper describes the general principles of autonomous building operation. Derived from those, a building concept, which ensures energy and water self-sufficiency, has been presented. Another important benefit is the minimization of a carbon footprint – both during construction and operation. The proposed solutions are based on a system combining the technology of a cooling tower and a solar updraft tower enhanced with reverse osmosis technology and others. All of this has been achieved by creating an original architecture that matches its place of origin and functions.

1. Introduction
The last year has specifically left its mark on the awareness of societies in making the dependence of climatic phenomena on the development of civilization visible for the first time. We are all aware that further development based on the current model is impossible. Hence, many different initiatives and activities that are undertaken in virtually all areas of human activity. One of the most important areas in which such action is necessary is civil engineering and architecture. It is this human activity that is responsible for 36% of greenhouse gas emissions, such as carbon dioxide [1], despite the dramatic decline in direct carbon production in buildings over the past 50 years [2]. In addition, buildings that consume huge amounts of energy for heating or cooling are also one of the main consumers of fresh water. Regardless of how you handle wastewater generated in buildings, obtaining clean water is a problem. Of course, the answer to the first challenge is to reduce the energy consumption of buildings. But modern buildings, despite far-reaching changes in connection with constantly developing, not only new, technologies, based on energy consumption (automation, IT), but also the human search for new forms of activity (entertainment, work), are far-removed from the only currently implemented form of a relatively environmentally neutral building, i.e. a passive building [3]. Moreover, although the idea of a passive building is clearly commendable, it is neither complete nor sufficient. Especially if we are talking about a public or functional building. Of course, the energy demand of such a building can be significantly reduced, thanks to the use of passive design techniques, but it is impossible to satisfy the full energy needs or demand for other utilities, such as water.
In order for a building to be considered as burdensome to the environment during operation, it must meet a number of conditions. Therefore, a house that is truly environmentally friendly should be self-sufficient in terms of:

- energy management,
- wastewater management,
- waste management,
- management of gases that are not neutral to the environment.

2. Building autonomy
A self-sufficient building is of course an autonomous building, but this work is not about full autonomy, but about as far-reaching self-sufficiency as possible. Self-sufficiency is understood here as the building's ability to function without adversely affecting the external environment.

2.1 Energy self-sufficiency
The technologies already available today provide the opportunity to erect residential buildings with low building intensity as energy self-sufficient buildings. The technology that made this possible is photovoltaics supported by energy storage. Although the solution is still expensive, the increasing energy costs and favorable legal solutions for prosumers are causing a rapid increase in this type of installation. It should be noted, however, that it is not yet common to achieve full energy independence. Firstly, because of the cost of energy storage, and secondly because of the construction of installations that do not cover full daily energy demand. The latter is dictated by the high variability of solar energy acquisition conditions not only during the day but most of all, during the year. Suffice it to say that in winter our latitude receives less than 20% of solar energy available in summer [4]. The problem is exacerbated when buildings with a larger number of inhabitants are taken into account (for them, an additional problem is the availability of space to construct the appropriate number of solar panels), and it becomes unsolvable for the time being when we consider the latitude of Poland and buildings, e.g. high-rise buildings, for which the ratio of available space for solar cells to usable space is particularly adverse. Therefore, with the current development of solar technology, this energy source can only play a complementary role. Nor is the classic wind energy the answer to the problem due to its strong dependence on temporary atmospheric conditions. Although it has adequate performance, it is impractical due to its unpredictability. However, technologies that do not have this disadvantage already exist.

2.2 Water and sewage self-sufficiency
Of course, close circulation in homes is still a matter of the distant future. Not because of the lack of technology, but because of its cost. Nevertheless, today a certain analog of this system is widely used, in the form of a cycle involving the collection of water, its use, and re-disposal of used water after at least preliminary cleaning. In the case of single-family houses, the system works, however, when using larger installations of this type, the issue of salt accumulation in the environment, into which purified water is discharged, arises [5]. On the other hand, it is the size of the installation, or more precisely the cost of obtaining good, fresh water, which is the main premise for using this technology [5]. It is also important that self-sufficiency in water supply does not affect the disruption of other economies. It is mainly about the so-called carbon footprint. So, for example, desalination of seawater cannot cause a carbon footprint. The cost of obtaining fresh water is therefore one of the most important determinants indicating not only the possibility but also the necessity of using this type of solution. As indicated, due to climate change, this cost will increase rapidly in the coming years.
Another problem with the use of natural water resources is the issue of degradation of aquifers. According to a report from the World Bank [6], in the Arabian Peninsula, there is a so-called unsustainable groundwater consumption. This phenomenon occurs in areas where water is taken from rivers and underground water-saturated rock layers at a faster rate than it is replenished by rain. When this happens, the aquifer begins to degrade, because low rainfall cannot balance out the amount of water that it draws, which in turn can damage the entire ecosystem. Therefore, many countries in the region are trying to remedy water shortages by using the desalination process. The countries of the Middle East and North Africa are undeniably leaders in desalination, making up nearly fifty percent of this type of undertaking conducted in the world [6]. However, unlike most places in the world where reverse osmosis is used for desalination, processes used in the Arabian Peninsula generate a significant carbon footprint. Two-thirds of the produced water comes from thermal desalination based on fossil fuels, while the rest from membrane desalination, which uses electricity generated using natural gas [7].

2.3 Self-sufficiency in waste management
As of today, waste management at the building level boils down to segregating waste before it is removed and very rarely to compressing it. It is not a self-sufficient economy in any way. Nevertheless, there are solutions that can definitely bring closer the moment when buildings become self-sufficient in this respect. An example of this is a device for converting used paper into printing paper [8]. More and more solutions of this type will appear. However, there are solutions that can operate today in buildings, which are not taken into account, mainly due to their very high inconvenience. An example is a possibility of installing bioreactors for composting biodegradable waste. Such a system, apart from the undoubted ecological advantages, would also have its share in the building's energy management due to the exothermic nature of the organic matter decomposition process. An interesting fact is the existence of a Polish patent for this type of device [9]. It should be noted here that this type of installation makes sense primarily in large residential buildings, due to its costs.

2.4 Non-neutral gas management
It might seem that the building cannot help much in reducing greenhouse gas emissions, because it is mainly about these gases, although of course, this does not exhaust the topic, especially when it comes to emissions of radioactive gases [10]. This is not true. It is obvious that the building materials used have a long-term effect on the level of greenhouse gas pollution. If we consider only concrete [11], the material's long-term ability to absorb CO₂ and NO₃ has been confirmed. Although at present the overall balance, including production, absorption, and emission, is not favorable for concrete, it should be noted that concrete buildings are constructed mainly where carbon dioxide emissions from other sources occur (city centers). This balance can be beneficial locally. In addition, new cement production technologies are emerging, not as energy-consuming as the ones currently used [12], or even a new version of these known materials, such as geopolymer binders. Here, CO₂ reduction can be at a level of 70% to 90% compared to classic cement production [13].

3. Proposal of solutions
Paradoxically, the near future of self-sufficient buildings belongs to large buildings. This is due to the high cost of solutions ensuring an adequate level of self-sufficiency. The proposal for a self-sufficient building presented below is based on this assumption. In addition, all technologies presented to ensure self-sufficiency are already available, although some at the experimental level. To ensure effective use of technology today, the presented solution is only applicable at low latitudes (up to about 40 degrees).
This is due to the average solar exposure of the Earth [14]. It would not be so important if the project did not assume water self-sufficiency based on the desalination of seawater, with the inviolable assumption that the desalination process will not leave a carbon footprint. Solar energy remains the only source ensuring that these requirements are met. The amount of energy needed to desalinate the right volume of water is so large that the sun can provide it only for the indicated locations.

4. **The concept of a self-sufficient building – Ma’an Tower**

Being aware of the fact that the simplest social problems often require very complex solutions, the project covers a wide range of technological functions and processes. Since the basis of the design is to provide fresh water with minimal environmental impact, low energy, highly efficient desalination equipment based on seawater evaporation, condensation in the cooling tower, and reverse osmosis filters, has been provided. As the project is located between two environments – the desert and the sea – it has direct access to seawater, which is organized in salt evaporation ponds, which additionally allow the collection of this salt remaining from the evaporation process. Although technology is significant, it cannot change the world without raising public awareness of water scarcity and recycling. This is the goal that the second part of the building helps to achieve. Trying to reach people of all ages and in different professional groups, the project includes various educational and scientific functions, including an educational park and biology and chemistry laboratories. The park is designed primarily for children to show them the true importance of water, as well as to educate and create new, more aware citizens, while laboratories are to support any new research aimed at solving the biggest problems of humanity.

4.1 Location

Considering the sun exposure values at various latitudes, it is easy to see that one of the warmest places on Earth is the Arabian Peninsula and the Persian Gulf. However, because of the temperatures there, it is also a big challenge for people living there, while one of the key challenges is to ensure access to drinking water. Based on these premises, the conceptual object was placed in Kuwait, a country that is among the leading drinking water importers in the world [15]. Its own reserves account for less than 1% of the population's needs. Moreover, one cannot ignore economic factors, because due to the rich oil deposits, the Kuwaiti authorities are one of the few that can provide sufficient financial support to pioneering ventures. The last, but no less important factor is placing the project in the newly planned city of Subiya, which thanks to symbiotic development next to the Ma'an Tower can become the first water-oriented city in the world.

4.2 Architectural form

The form of the building has been largely dictated by technological solutions. As mentioned earlier, the designed object is a high-rise building, measuring 300 meters in height. Its shape resembles a cooling tower and a chimney located in the center of the building performs a similar function. It constitutes the structural and technological core of the entire project, being an important element of the desalination and water distribution system, as well as an important element of the energy generation system. A communication path runs around it, which is surrounded by service risers. In this way, all technological and installation elements are located inside the building and allow for the free arrangement of the space around them (Figure 1).
Figure 1. Visualization (Own work)

Figure 2. Floor Plan functional scheme (Own work)
The wide base of the building on a circular plan is a thermal collector. Between the base with a diameter of 100 meters and the outer ring with a diameter of 200 meters, a membrane with features similar to an ideal winter window [16] was stretched on ropes, under which the air heats up and allows seawater to evaporate. The building rests on active supports, which not only add to the attractiveness of the external form but above all allow the passage of heated air from under the membrane up to the chimney. The main backbone of the entire building, containing all necessary installations was designed in such a way so as to make it possible to add further functional elements (Figure 2, 3). Individual modules have been superimposed on the building core, which, by connecting them to the zone containing all the necessary installations, can be freely located within the story. A sample division into zones in the facility was designed, separating those that should be constructed at the very beginning and subsequent ones that appear over time.

The construction of the proposed building can be divided into stages to suit the needs and capabilities of the city. The first stage is to guarantee the operation of desalination technologies, for which a chimney with a heat collector, as well as technological and production facilities are needed. In the next stage, a research center will be developed, followed by an educational part. In the end, the hotel and conference facilities will be added. Such a solution is possible thanks to the proposed architectural form that can adapt to current needs. (Figure 4)
The building façade has been largely glazed using photovoltaic glass (PV glass). As a result, the climate conditions prevailing in Kuwait were used, because the panels let in natural sunlight, also providing thermal and acoustic insulation and filtering harmful UV and IR radiation [17] [18]. In addition, the possibility of using colored glass significantly increases the aesthetic value of the building, which shimmering in the sun brings to mind the golden sands of the desert.

4.3 Energy self-sufficiency
The use of a chimney is not limited to transporting water vapor. This system is also an element of a wind power plant with constant air flow caused by a temperature difference [19], in which turbines generate electricity as a result of hot air flow. As in the evaporation process, the dry part of the solar collector allows such a system to operate regardless of the time of day. In this way, we use one system, supplying water to the building to meet the subsequent needs of the facility - in the field of energy management. Energy estimates indicate that the amount of energy that this system will provide is sufficient to meet the building's basic needs. This is indicated by the results obtained in an experiment in the Spanish city of Manzanares [20], as well as numerical calculations [21]. Furthermore, compared to the indicated studies, the effectiveness of this solution is increased by the fact that water vapor condensing in the chimney is used, which increases the pressure difference. In addition, the location of the building allows supplementing energy resources with energy obtained from photovoltaic installations, which, having been made in the version of transparent panels [22], will not only provide energy but due to decreased transparency will limit strong insolation inside the building, reducing the energy demand for air conditioning operation.

4.4 Water and sewage self-sufficiency
The problem at the basis of the presented concept is water. In the anticipated location, the only sufficient source of it is the sea. The proposed way to obtain it for the needs of the building is based on evaporation. Studies have shown [23] that evaporation of salt water is weaker than that of fresh water. However, conditions such as warm wind and reduced pressure increase the amount of water that evaporates. In the abovementioned experiment, approximately 1000g/hm2 was obtained in the case of seawater blown by wind at a speed of 4m/s and a temperature of 40°C under a reduced pressure of 10 kPa. Under the conditions of the presented building, with an effective evaporation area of 10,000 m2, this would give
at least 10,000 liters of evaporated water per hour. On top of that, it should be noted that in specially created conditions (such as saline), water evaporation differs from typical evaporation from the surface of open water due to the shallowness of the water. In this situation, the results of water evaporation tests on roof surfaces become interesting, indicating the possibility of obtaining more water vapor than the results of tests on an open sea surface would indicate [24].

Returning to the building concept, however, it should be noted that favorable evaporation conditions indicate a possible solution to the problem. This solution must include the presence of warm wind and reduced pressure. Both of these conditions are caused by the fluid flow between points at different pressures [25]. The conditions of the presented project use natural pressure differences resulting from a different fluid (air) density depending on its temperature. The temperature difference itself is caused by the heating of the air in the collector zone on the one hand, and a decrease in temperature as height increases, on the other. The created pressure difference causes an intense air flow, which is used twice - to increase the rate of evaporation and to transport water vapor. (Figure 5)

*Figure 5. The functioning of a Ma’an Tower (Own work)*
The basic element of the fresh water production system is a 260-meter chimney acting as a cooling tower in which, due to the temperature and pressure differences, hot and humid air flows from bottom to the top, cooling down and eventually leading to condensation. Hot, humid air is drawn as a result of the evaporation of water from desalination ponds. The temperature required for this process is obtained by means of a heat collector. This collector extends over a large area both above water and ground, taking advantage of the greenhouse effect. Division of the collector into wet and dry parts allows it to work both during the day and at night, thanks to the heat accumulated in the ground. The water accumulated in the condensers, whose efficiency is increased by the use of cool air from the building's ventilation system, then flows, in the drinking section, through reverse osmosis filters. These filters require a supply of water under pressure, which will be produced thanks to the difference in height between the condensing station and the osmotic filter station. Then, using the height of the building, excess water is distributed to the city in the same way as in traditional water towers. The necessity for additional filters results from the use of vapor generated at the seashore, which causes a high content of micro salt crystals in the air flowing in the chimney together with vapor. Water obtained from condensation will, therefore, contain a relatively large amount of NaCl and other impurities. In installations which use evaporation to obtain domestic water (e.g. installations on the Australian coast), water obtained in this way is considered unsuitable for human drinking, without further treatment. An additional source of water is water vapor condensation outside the building, which is air-conditioned. A similar system was used in the Burj Khalifa super tower block, which thus obtains 56 million liters of water per year - 15% of its annual demand [26].

Sewage generated in the building is a separate problem. Although the technology of its full treatment is known [27], in the present concept only partial water treatment is proposed, up to the II / III ecological status class within the meaning of Polish regulations [28] (water of this purity class can be used as a source of water supply for breeding animals, for recreational purposes, water sports and swimming areas, as well as fish farming), as is currently the case in small open systems. The possibility of discharging only partially treated sewage into the sea eliminates the basic problem of open installations, which is the already mentioned soil salinity.

4.5 Self-sufficiency in waste management
The presented building has a fully integrated system of transporting pre-sorted waste from the floors to rooms located in the underground part of the building, where installations for sorting and compressing garbage are located. Biodegradable waste as well as sewage are subject to utilization in bioreactors located next to the sorting plant. The heat generated by bioreactors is used to increase the temperature of the air flowing through the installations, especially at night, when solar heating is based on heat accumulated in the ground. From the building, rubbish comes out only in segregated, recyclable, or processed form. A small part of the garbage, not subject to this process, could be disposed of by pyrolytic decomposition, however, this concept was abandoned due to its controversial nature [29].

4.6 Non-neutral gas management
The management of environmentally non-neutral gases in buildings involves two basic stages. First of all, it is construction, and secondly exploitation. The basic parameter conducive to the proper management of greenhouse gases in the latter case is the minimization of the production of these gases, which is primarily due to the previously described technologies. Both those used for obtaining fresh clean water as well as those used for producing energy. Traditional desalination methods cause huge
carbon footprints. For example, 1000 cubic meters of desalinated water per day during the year require burning the equivalent of 10,000 tons of coal [30]. With RO (reverse osmosis), the carbon footprint is reduced more than four times. More importantly, it basically comes down to the cost of producing the right pressure difference, therefore, in this project, where the pressure difference is obtained without additional energy expenditure, the carbon footprint is many times smaller and is practically limited to the need to replace semi-permeable membranes and possible repairs and maintenance (the production of semi-permeable membranes is currently an energy-costly process).

In order for a building to become neutral to the environment, it should also have a zero balance associated with greenhouse gases introduced into the environment during its construction. Therefore, geopolymer binders were selected as the base material for the chimney structure, which is also a load-bearing element of the building structure, and which should ensure a long-term favorable balance of CO₂ and NOₓ due to the carbon footprint left during the building period. The selection of both construction and finishing materials includes checking their carbon footprint as the main selection criterion after meeting the requirements related to the function of a given material. An additional element is the numerous green areas introduced into the building that support the reduction of carbon dioxide produced by the building.

5. Conclusions

The construction of an environmentally neutral building is already possible today. All the necessary technologies exist. However, its costs remain a problem. These are the costs of new solutions that, being individual or even experimental, are expensive methods. Therefore, the present work postulates starting with large installations related to large buildings. There are two reasons for this. First of all, energy self-sufficiency in large buildings is more difficult to achieve than in small buildings, in the latter, it almost becomes a standard. And yet energy self-sufficiency is a prerequisite for achieving building independence in the other aspects mentioned in the present work. The second reason is the issue of obtaining fresh water, which is growing almost every day and is now becoming the basic challenge of civilization. For small buildings, the use of fresh water resources (mainly underground) is still available for some time. However, this is not the case for large installations in many areas. The remaining elements of self-sufficiency, although important, do not constitute the essence of the solutions used and were indicated only for the completeness of the image.

Unfortunately, the solutions presented in the work are not yet available everywhere. For example, the presented solar chimney in the energy aspect will not work with sufficient efficiency, e.g. in our country. On the other hand, water shortages in Poland, while important, are not yet dramatic. The selected solutions direct their attention to the conditions of countries where water scarcity is already much more severe nowadays, and the carbon footprint left by buildings erected there is significant on a global scale. That is why the Gulf region was chosen. There, as in a lens, all problems and possible solutions are clearly visible. The presented desalination method based on the evaporation process intensified by the solar tower collector, as well as the condensation process, whose efficiency is improved by the cold air from the ventilation system of the air-conditioned building, is an important novelty not yet used in the world. The use of the same system to obtain energy necessary for the operation of the building complements and completes the system - the building has full grounds to become fully self-sufficient. It is these two solutions that ensure, for example, the building's long-term neutrality in terms of greenhouse gases, thus fulfilling the next postulate.
The analysis and proposed solutions point to the existence of technologies that implement self-sufficiency requirements, in particular in the field of energy and access to fresh water. In addition, it should be noted that not all currently available technologies are implementable at all latitudes. And finally, the costs of constructing a building that meets all postulates, for now, makes constructing large buildings more preferable.

References
[1] T. Abergel, B. Dean, and J. Dulac, “The Global Status Report 2017 International Energy Agency (IEA) for the Global Alliance for Buildings and Construction (GABC).” United Nations Environment Programme, 2017.
[2] IEA, “CO2 emissions from residential buildings and commercial and public services.” [Online] 2014 [Accessed 5 January 2020]. Available at: https://data.worldbank.org/indicator/EN.CO2.BLDG.ZS?view=chart (in Polish).
[3] W. Feist, U. Münzenberg and J. Thumulla, “Podstawy budownictwa pasywnego.”, Gdańsk: Polski Instytut Budownictwa Pasywnego, 2009 (in Polish).
[4] Ministerstwo Rozwoju, “Typowe lata meteorologiczne i statystyczne dane klimatyczne dla obszaru Polski do obliczeń energetycznych budynków.” [Online] 2016 [Accessed 15 December 2019]. Available at: https://www.dane.gov.pl/dataset/797 (in Polish).
[5] C. Stanghellini, F. Kempkes, A. Pardossi and L. Incrocci, “Closed water loop in greenhouses: Effect of water quality and value of produce.” Acta Horticulturae 691, pp.233-242, 2005
[6] World Bank, “Beyond Scarcity: Water Security in the Middle East and North Africa” [Online] MENA Development Report. Washington DC: World Bank. 2018. [Accessed 24 November 2019]. Available at: https://openknowledge.worldbank.org/handle/10986/27659.
[7] M. Walton, “Commentary: Desalinated water affects the energy equation in the Middle East” [Online]. The International Energy Agency, January 2019 [Accessed 20 January 2020]. Available at: https://www.iea.org/newsroom/news/2019/january/desalinated-water-affects-the-energy-equation-in-the-middle-east.html.
[8] Paper recycling device. [Online], [Accessed 25 November 2019]. Available at: https://global.epson.com/innovation/paperlab/.
[9] J. Kramarz, “Sposób pozyskiwania energii cieplnej z odpadów i urządzenie do pozyskiwania energii cieplnej z odpadów.” PL383489 - 05.10.2007r. - PATENT NR 207154 – Issued in Poland, 2007 (in Polish).
[10] F. Bochicchio, J. P. McLaughling and S. Piermattei, “Radon in indoor air. report No 15”, European Commission. Directorate-General for Science, Research and Development. Joint Research Centre-Environment Institute 1995.
[11] B. Zajac and I. Gołębiewska, “Możliwość redukcji CO2 przez zastosowanie betonu zrównoważonego i kruszywa recyklingowego.”, Inżynieria i Aparatura Chemiczna. Vol 51, issue 5, pp 262-264, 2012 (in Polish).
[12] C. D. Popescu, M. Muntean and J. H. Sharp, “Industrial trial production of low energy belite cement.”, Cement and Concrete Composites. Vol. 25, issue 7, pp. 689-693, 2003.
[13] B. C. McLellan, R. P. Williams and J. Lay, “Costs and carbon emissions for geopolymer pastes in comparison to ordinary portland cement.”, Journal of Cleaner Production, Vol. 19, issues 9-10, pp. 1080–1090, 2011.
[14] ABB, “Technical Application Papers No.10, Photovoltaic plants”, ABB 2010.
[15] A. K. Chapagain and A. Y. Hoekstra, “Water footprints of nations: Water use by people as a function of their consumption pattern.”, Water Resour Manage, Vol. 21, pp. 35–48, 2007
[16] Collaborative work under M. McKinley, “Ortho’s All about Greenhouses”. Des Moines, Iowa USA, 2001.
[17] OnyxSolar: Technical Guide. [Online] Onyx Solar Energy S.L., 2011 [Accessed 7 February 2020]. Available at: http://onyxsolardownloads.com/docs/ALL-YOU-
[18] C. Woodford, “Heat-reflecting low-e glass.” [Online]. 2010/2019. [Accessed 9 February 2020] Available at: https://www.explainthatstuff.com/how-low-e-heat-reflective-windows-work.html.

[19] M. Bernardes, “Solar Chimney Power Plants - Developments and Advancements.” Solar Energy, Book edited by: Radu D. Rugescu, INTECH, Croatia, p. 432. January 2010.

[20] D. Mills, “Advances in solar thermal electricity technology.” Solar Energy, Vol. 76, issues 1–3, pp. 19-31, 2004.

[21] L. B. Mullett, “The solar chimney-overall efficiency, design, and performance.” International Journal of Ambient Energy. 8, pp. 35-40, 1987.

[22] C. D. Bailie, M. G. Christoforo, J. P. Mailoa, A. R. Bowring, E. L. Unger, W. H. Nguyen, J. Burschka, N. Pellet, J. Z. Lee, M. Grätzel, R. Noufi, T. Buonassisi, A. Salleo and M. D. McGehee, “Semi-transparent perovskite solar cells for tandems with silicon and CIGS”, Energy and Environmental Science., Vol 8/3, pp. 956-963, 2015.

[23] M. Al-Shammiri, “Evaporation rate as a function of water salinity.” Desalination, Vol. 150, issue 2, pp. 189-203, November 2002.

[24] W. Żarnowiec, A. Policht-Latawiec and K. Ostrowski, “Szacowanie wielkości parowania wody z powierzchni dachowych na podstawie wybranych wzorów empirycznych.” Acta. Sci. Pol., Formatio Circumiectus, Vol.15, issue 4, pp. 17–28, 2016 (in Polish).

[25] R. Puzyrowski and J. Sawicki, “Podstawy mechaniki płynów i hydrauliki.” Wydawnictwo Naukowe PWN, Warszawa 2013.

[26] Burj Khalifa. [Online], [Accessed 23 November 2019]. Available at: https://www.burjkhalifa.ae/en/the-tower/structures/.

[27] A. Zouboulis and I. Katsoyiannis, “Recent Advances in Water and Wastewater Treatment with Emphasis in Membrane Treatment Operations.” Water, Vol. 11, p.45, 2018.

[28] Ministerstwo Gospodarki Morskiej i Żeglugi Śródlądowej, “Rozporządzenie Ministra Gospodarki Morskiej i Żeglugi Śródlądowej z dnia 11 października 2019 r. w sprawie klasyfikacji stanu ekologicznego, potencjału ekologicznego i stanu chemicznego oraz sposobu klasyfikacji stanu jednolitych części wód powierzchniowych, a także środowiskowych norm jakości dla substancji priorytetowych (Dz.U. 2019 poz. 2149)”, 2019 (in Polish).

[29] J. A. Conesa, R. Font, A. Fullana, I. Martin-Gullón, I. Aracil, A. Gálvez, J. Moltó and M. F. Gómez-Rico, “Comparison between emissions from the pyrolysis and combustion of different wastes.”, Journal of Analytical and Applied Pyrolysis, Vol. 84/1, pp. 95-102, 2009.

[30] A. Tal, “Addressing Desalination’s Carbon Footprint: The Israeli Experience.” Water, Vol. 10(2), p. 197, [Online] 2018 [Accessed 12 December 2019]. Available at: https://www.mdpi.com/2073-4441/10/2/197.