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Tel. +4021.4113617, +40733882137
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Smart Solutions for Building Energy Performance: The Role of Artificial Intelligence

Soluții inteligente pentru performanța energetică a clădirilor: rolul inteligenței artificiale

Constantin Cilibiu[1], Ancuța Coca Abrudan[1]

[1]Universitatea Tehnică din Cluj-Napoca, Facultatea de Inginerie a Instalațiilor,
Departamentul Ingineria Instalațiilor,
Bulevardul 21 Decembrie 1989 nr. 128-130, 400604 Cluj-Napoca, Romania
E-mail: constantin.cilibiu@insta.utcluj.ro
E-mail: ancuta.abrudan@insta.utcluj.ro

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Abstract. *The increasing need for energy-efficient buildings has led to the development of smart solutions that integrate cutting-edge technologies, such as artificial intelligence (AI), into building services systems. This paper explores the role of AI in improving building energy performance, highlighting the benefits and challenges of integrating AI into building systems. The paper presents a review of relevant literature on AI-based building energy management systems and provides a case study of some AI-based solutions for building services systems management in an administrative building. The results show that AI can significantly improve building energy performance. However, successful implementation of AI-based solutions requires careful consideration of various factors, such as data quality, system complexity, and user acceptance.*

Key words: *energy-efficient buildings, AI-based solutions for building services, energy management*

Rezumat. *Nevoia tot mai mare de clădiri eficiente din punct de vedere energetic a condus la dezvoltarea de soluții inteligente care integrează tehnologii de ultimă oră, cum ar fi inteligența artificială (IA), în sistemele de instalații pentru clădiri. Această lucrare explorează rolul IA în îmbunătățirea performanței energetice a clădirilor, subliniind beneficiile și provocările integrării IA în sistemele unei clădiri. Lucrarea prezintă o trecere în revistă a literaturii relevante despre sistemele de management energetic al clădirilor bazate pe IA și oferă un studiu de caz al unor soluții bazate pe IA pentru managementul sistemelor de instalații într-o clădire administrativă. Rezultatele arată că IA poate îmbunătăți semnificativ performanța energetică a unei clădiri. Cu toate acestea, implementarea cu succes a soluțiilor bazate pe inteligență artificială necesită o analiză atentă a diferiților factori, cum ar fi calitatea datelor, complexitatea sistemului și acceptarea de către utilizatori.*

Cuvinte cheie: clădiri eficiente din punct de vedere energetic, soluții bazate pe inteligență artificială pentru instalații în clădiri, managementul energiei

1. Introduction

In an international context, in industrialized countries, the construction sector represents nearly 40% of the total consumption of non-renewable energy, 40% of greenhouse gas emissions, and 70% of electricity consumption [1].

At the national level, according to current regulations, new buildings, for which acceptance at the end of works is carried out based on the building permit issued starting from December 31, 2020, will be buildings whose energy consumption is nearly zero [2]. Thus, the necessity of innovative solutions to reduce carbon emissions and energy consumption is emerging.

One potential solution to this challenge could be the use of Artificial Intelligence (AI) for various analyses, predictions, or control strategies of systems that ensure indoor comfort conditions in buildings.

In recent years, the field of AI has seen a significant improvement in various domains, including civil engineering and maintenance of existing buildings. The capability of AI to process massive amounts of data, recognize patterns, and build large-scale statistical models is a key facilitator of the construction sector [3] towards a future with reduced emissions and nearly zero-energy buildings.

The literature in the field of AI [4] presents an approach that utilizes human-computer interactions for the improvement of energy consumption with a focus on energy efficiency. Existing solutions attempting to explore the concept of consumer-oriented energy efficiency models based on AI are, however, heavily customized for utilities administrative users rather than ordinary energy consumers. [5]

This study proposes the integration of AI-based solutions into the analysis and planning of energy efficiency strategies for end consumers, namely buildings that are to be rehabilitated or modernized to increase energy efficiency.

2. Materials and methods

The analyzed building is an existing administrative building, most of the interior rooms being used as offices. Its location is in Cluj-Napoca Municipality. The interior spaces are spread over three levels, namely basement, ground floor and first floor. The heated area of the building is 6593 m^2.

The outer envelope of the building consists of solid brick walls 60 cm wide, without thermal insulation. The windows have a PVC frame and two sheets of glass. The slab on the ground is made of reinforced concrete with a thickness of 15 cm over which a leveling screed with a thickness of 5 cm is poured. The floor above the last level is also made of reinforced concrete with a thickness of 10 cm, above it there is also a thermal insulation layer of expanded slag 80 cm thick.

The building is heated by means of a thermal plant, which is located to the basement, and which is composed of two boilers operating on methane gas, each of the boilers having a nominal power of 350 kW. The indoor heating system consists of cast iron radiant heaters with elements.

In the building proposed for optimization from the point of view of energy efficiency, measurements were made regarding the provision of comfortable indoor temperatures in the rooms for a period of two months, from 14.02.2022 to 14.04.2022, being measured permanently, every 15 minutes, the indoor temperatures of two spaces located on opposite sides of the building, respectively one space being located on the eastern side and the other on the western side of the building. Figure 1 shows an overview of the building.

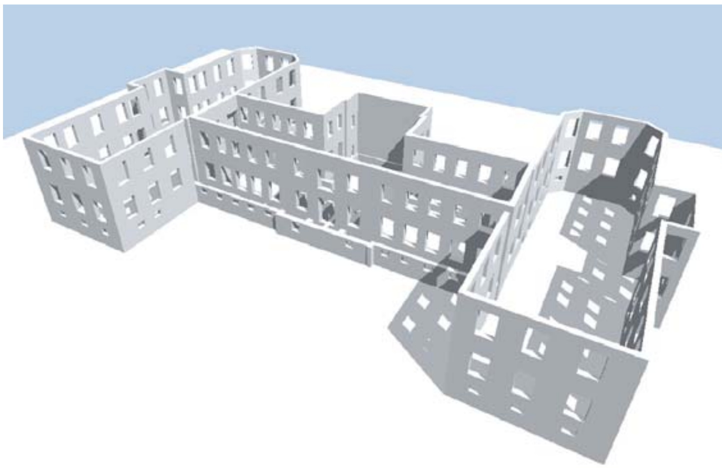

Fig. 1. Overview of the building - view on the north side

The measurements were made with two electronic measuring devices of the RC-5 Data Logger type, calibrated by the manufacturer, with an accuracy of ±0.5°C for a temperature range from -20°C to +40°C.

For the first space, located on the ground floor, on the eastern side, a minimum temperature of 14.7°C and a maximum temperature of 31°C were recorded. The average indoor temperatures recorded during the considered period was 25.4°C, the results being presented in figure 2.

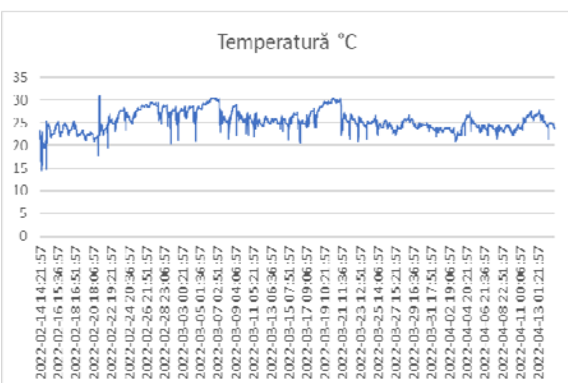

Fig. 2. Recorded temperatures
in the space on the east side

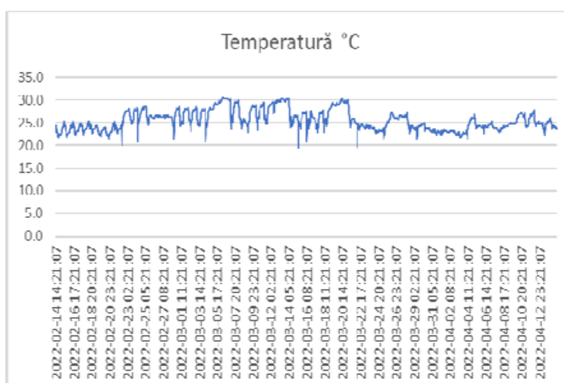

Fig. 3. Recorded temperatures
in the space on the west side

For the second space, also located on the ground floor, on the western side, a minimum temperature of 19.4ºC and a maximum temperature of 30.6ºC were recorded. The average indoor temperatures recorded during the considered period was 25.6ºC, the results being presented in figure 3.

From the images presented, it can be easily observed that the interior spaces are overheated, the interior temperatures obtained being above 25ºC in most of the analysis period.

In accordance with the national technical regulations [6], the indoor comfort temperatures in the heating season for buildings whose function is administrative type are in the range of 20÷24ºC, considering an ambience category II. It should be considered that these temperatures are recommended to be ensured permanently for the entire period of occupation of the building.

To optimize from the energy point of view, the thermal loads for heating the building were calculated [7] for several internal temperatures, respectively for 20ºC, 22ºC, 24ºC, 25.4ºC and 25.6ºC.

Thus, for an average indoor temperature of 20ºC, a heating thermal load of 666.27 kW was obtained, and for an average indoor temperature of 25.6ºC, a heating thermal load of 768.17 kW was obtained, the intermediate results being presented in table 1.

Table 1

Heating loads depending on average indoor temperatures

Building level	$T_{i\ med.}$ [ºC]	Heating load [kW]
S+P+E	20	666.27
S+P+E	22	702.63
S+P+E	24	739.11
S+P+E	25.4	764.57
S+P+E	25.6	768.17

Considering the values obtained, it can be observed that the thermal load for heating the building at an average indoor temperature of 25.6ºC is higher by 15.29% compared to the thermal load required to ensure an average indoor temperature of 20ºC.

This foreshadows a possibility of optimizing the internal heating systems so that the energy efficiency of the building can be improved.

The Role of Artificial Intelligence [8]

Artificial Intelligence (AI) can play an important role in improving the energy performance of buildings by providing intelligent control solutions for heating systems.

Specifically, by analyzing data collected by temperature and humidity sensors in the building, AI can help optimize the performance of heating systems, quickly identify, fix technical problems, and predict future energy consumption.

To be able to offer intelligent solutions to improve the energy performance of the building, a detailed analysis of the data collected through measurements should be carried out, with the help of analysis and machine learning algorithms.

First, the temperature patterns and trends recorded in the two rooms should be identified to determine when the temperatures are highest or lowest and what factors might influence these fluctuations.

After that, the efficiency of the existing heating system should be determined, checking if it is working optimally or if there are areas where heat losses are higher. For this, it would be useful to carry out an analysis of the level of thermal insulation of the building and the efficiency of heating equipment, such as existing boilers and radiators.

After analyzing the data and identifying the factors that affect the indoor temperature, intelligent solutions can be proposed to improve energy performance, such as:

1. Implementation of automated temperature control systems (through presence sensors coupled with thermostat valves) in each room, which adjust the heat level according to the comfort needs of the occupants and the outside weather conditions.
2. Improving the thermal insulation of the building, by installing thermally insulating windows and doors, as well as by insulating the external walls and the roof.
3. Replacing the existing heating system with a more energy-efficient one, such as a heat pump or cogeneration system, which can produce electricity and heat simultaneously.
4. Implementation of an electricity consumption monitoring and control system that provides the building owner with real-time information on energy consumption and associated costs to make better informed decisions about energy savings.
5. Development of a program of education and awareness of building occupants regarding the importance of energy saving and efficient use of the heating system and other electrical equipment in the building.

AI Predictions [8]

The optimum indoor temperature may vary depending on local conditions and occupant preferences. In general, an indoor temperature between 20-22 degrees Celsius is recommended for office buildings.

If the average indoor temperature is reduced to 22 degrees Celsius, the heating load will decrease to approximately 697.22 kW. This would represent an energy saving of approximately 71.95 kW, i.e., approximately 10.8% of the building's heating load.

By thermally insulating the building, heat loss can be reduced by approximately 20%, which can lead to an annual thermal energy saving of approximately 131.86 MWh and a reduction in heating costs of approximately 17688.69 euros.

The installation of energy-efficient windows can reduce heat loss through glazed surfaces by approximately 40%, which can lead to an annual thermal energy saving of approximately 263.72 MWh and a reduction in heating costs of approximately 35954.8 euros.

By implementing an intelligent indoor temperature control system, the electricity consumption for heating can be reduced by about 30%, which can lead to an annual electricity saving of about 36.56 MWh and a reduction in heating costs of about 2479.34 euro.

3. Conclusion

AI could be described as a key technology that can help improve the energy performance of buildings, by providing intelligent control solutions for heating systems and real-time data analysis.

In addition, AI can also be used to help the building owner or manager make more informed decisions about heating equipment investments by providing analysis and predictions on maintenance costs, energy savings and operating costs investment.

Of course, this technology is still in its infancy, being in an early stage of development, the algorithm used for predictions being only in the 4th generation. Because of this, it is necessary to analyze, verify and interpret the results and suggestions provided, by an HVAC specialist.

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The way from gas boilers to heat pumps

De la boilere pe gaz la pompe de căldură

George Dragomir[1], Alin Ionuț Brezeanu[1], Nicolae Iordan[1], Ferenc Deák[2], Ioan Boian[1]

[1]Transilvania University of Brasov, 29 Eroilor Blvd., Brasov, Romania
[2]S.C. Euro K & D S.R.L.
boian.ioan@gmail.com, segadproiect@gmail.com, alinionut.brezeanu@gmail.com, nicolae.iordan@gmail.com, euro_k@yahoo.com

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ABSTRACT. *The paper presents challenges to be considered by engineers and by owners, managers and occupants in the perspective of the global warming, requiring measures for replacing the fossil fuel sources with renewable ones, as used by HVAC equipment. Air Source Heat Pumps, ASHP and Ground Source Heat Pumps GSHP are issues considered for the transition to "A Clean Planet for All" as a decarbonization path of the building sector. Retrofitting the envelope and using heat pumps is aimed for a greenhouse gas GHG mitigation in order to limit the climate change. Reaching a net reduction in CO_2 emission involve a series of stages- envelope insulation, replacing the boiler with a heat pump, new, oversized heat emitters (and pipes), adapted circulation pumps, predictive control systems, and possible new network concepts.*

Key words: *heat pumps, greenhouse*

1. Introduction

The recent REHVA-issued "Report on the Shift Away from Natural Gas in Buildings" presents some innovative solutions concerning some supply possibilities for space heating and for the domestic heat water, DHW in terms of greenhouse gases, GHG mitigation. The Sustainable Development Goals established by the United Nations for 2050 and having the European Commission as a stakeholder with its strategic long-term vision for "A Clean Planet for All" aims at the decarbonization of the building sector in order to achieve the climate neutrality.

In Romania approx. 53% of residential buildings are built before 1970 and more than 90% before 1989 (in terms of m^2), having an energy performance level between 150-400kWh/m^2. Heating energy represents around 55% of the overall energy use in apartments and up to 80% in individual houses. The buildings built before 1990 have poor energy performance at around 180-400kWh/m^2/yr. [2]

Central heating systems used in the existing block of flats have been designed for higher temperatures, i.e., 90/70^{o}C, or 80/60^{o}C. The supply water temperature designed for later buildings was then decreased from 90ºC to 70ºC, with a return temperature of 55ºC as the building envelope became better insulated. This trend is about to continue and supply temperature of 50ºC with a return one of 40ºC exist in case of condensing gas-boilers installed in better insulated buildings.

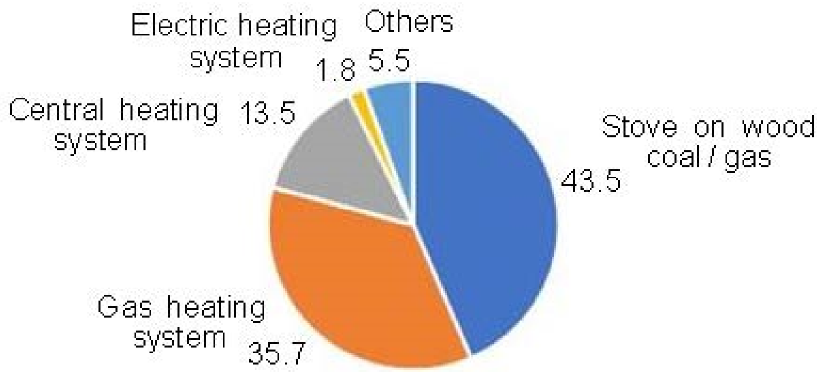


Figure 1. Home heating sources used during the cold season in Romania 2019 [7].

Optimizing the operation of heating installations with condensing boilers and heat pumps. In many cases, with existing heating systems, which have been dimensioned for high temperatures supply (90/70ºC ... 80/60ºC), after the rehabilitation of the building envelope, we will need lower temperatures supply. These temperatures are usually higher than those required for optimal operation for condensing boilers.

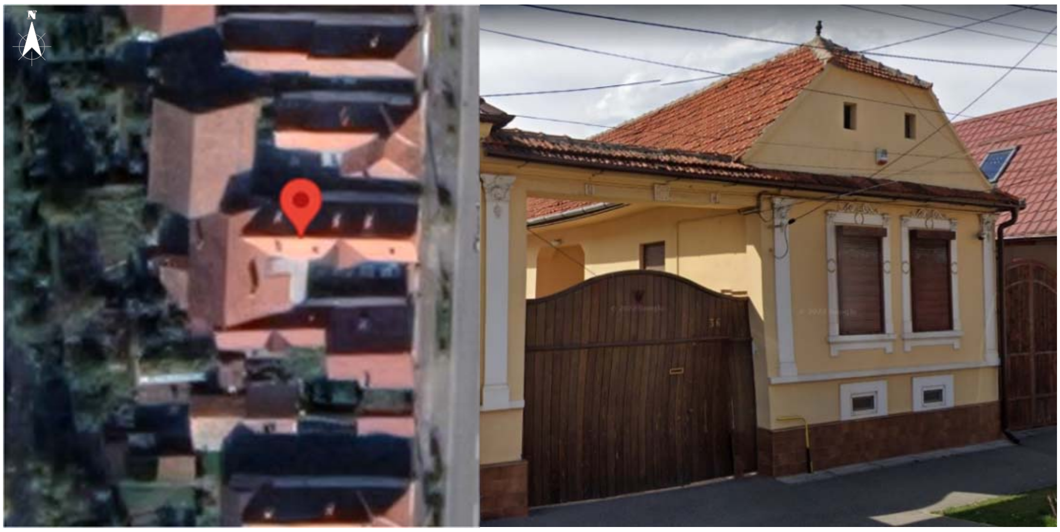
The heating installations are dimensioned for unfavorable winter situations, a period of time that is relatively short, on the order of days, maybe weeks. In order to optimize the existing heating installations, with a view to the optimal operation of the condensing boilers and heat pumps, it is necessary to provide external temperature sensors and regulate the supply temperature of the heating agent, according to a pre-imposed operating curve.

Hydraulic aspects. In the case of condensing boilers, there are no negative influences on the hydraulic regime of the existing heating installations, as they operate at the same temperature difference. With heat pumps, they can be disturbed in operation, because of some lower temperature difference, i.e., 8 ... 10ºC. It can cause an increase in heat flow rate, and in circulation speed with higher hydraulic losses. Because of this, it is necessary to check by calculation the existing heating installations and adapt them to the new requirements.

2. The building envelope insulation and the supply temperature reducing

The heating demand of an existing building is reduced after the renovation of the envelope and as a result the supply temperature of the water entering the radiator can be decreased.

Figure 2. The investigated house.



Considering the case of a building (117 sqm) located in Rasnov, near Brașov (climate zone IV), see figure 2 and having a *design* heat consumption of 33141 kWh/year, that is *reduced* to 9688 kWh/year as a result of the renovation. The corresponding heat loads are $\phi_d = 4681$ W and $\phi_{d,r} = 1740$ W respectively.

These values lead to a reduced dimensionless heat load [8]

$$\Upsilon_{d,r} = \frac{\phi_{d,r}}{\phi_d} = \frac{1740}{4681} = 0,37$$

The designed heat load ϕ_d will be covered by a radiator having the same heating capacity depending on the radiator constant, K_m determined by test and published by the manufacturer, and on the radiator design excess temperature, $\Delta\theta_{ar} = \frac{\theta_{\sup;d} + \theta_{ret;d}}{2} - \theta_{i;d}$, where $\theta_{\sup}$ is the design radiator supply temperature, and $\theta_{ret;d}$ is the design radiator return temperature, and $\theta_{i;d}$ represents the design indoor temperature; the exponent *n* depending on the radiator type (cast-iron, baseboard radiation, convectors, ceiling, or floor heating/cooling [5]. The recommended value for cast-iron radiators [1] is *n*=1.3.

As the heat load is reduced after the building envelope renovation, $\theta_{d;r}$ a similar expression can be written for the radiator supplied with a lower water temperature $\theta_{\sup;r}$

$(\Delta\theta_{ar,r} = \theta_{\sup;r} - \frac{\Delta\theta_r}{2} - \theta_{i;d})$, $\phi_{d,r} = K_m \cdot \Delta\theta_{ar,r}^n$

$$\Upsilon_{d,r} = \frac{\phi_{d,r}}{\phi_d} = \frac{\Delta\theta_{ar;r}}{\Delta\theta_{ar}^n}$$

$$\theta_{\sup;r} = \theta_{i;d} + \frac{\Delta\theta_r}{2} + \Upsilon_{d,r}^{1/n} \cdot \Delta\theta_{ar}$$

For the discussed case ($\theta_{\sup;d} = 90^{o}C$; $\theta_{ret;d} = 90-20 = 70^{o}C$ and $\theta_{i;d} = 20^{o}C$, $n = 1.3$)

$$\Upsilon_{d,r} = \frac{\phi_{d,r}}{\phi_d} = \frac{\left(\frac{\theta_{\sup;r} + \theta_{ret;r}}{2} - \theta_{i;d}\right)^n}{\left(\frac{\theta_{\sup;d} + \theta_{ret;d}}{2} - \theta_{i;d}\right)^n}$$

$$0.37 = \frac{\left(\frac{\theta_{\sup;r} + \theta_{\sup;r} - \Delta\theta_r}{2} - 20\right)^{1.3}}{\left(\frac{90+90-20}{2} - 20\right)^{1.3}}$$

For $\Delta\theta_r = 10^{o}C$, $\theta_{\sup;r} = 60\cdot(0.37)^{1/1.3} + 25 = 52.96^{o}C$ $\theta_{ret;r} = 52.93 + 10 = 42.96^{o}C$ and for $\Delta\theta_r = 15^{o}C$, $\theta_{\sup;r} = 60\cdot(0.37)^{1/1.3} + 27.5 = 55.43^{o}C$, $\theta_{ret;r} = 55.43 - 15 = 40.43^{o}C$

Such low-values for the reduced supply temperature $\theta_{\sup,r}$ are specific for condensing boilers.

The supply temperature reducing depends on the extent of the renovation: if in the presented example the building was initially in a poor state of insulation, a substantial improvement after the renovation resulted in a diminution of heat losses, so that the reduced dimensionless heat load $\gamma_{d,r}$ has a low value, i.e., 0.37. But in other cases, as that of an apartment in a block of flats, the reduced dimensionless heat load usually is in the range of 0.8…0.6 and that will lead to a reduced supply temperature of only $\theta_{\sup,r} = 70...80^{o}C$ as can be seen in figure 3.

3. Condensing boilers-a step to the heat pump technology

As the dew point is around 55ºC in case of the natural gas boilers, the temperature of the water in the return pipe (exiting from the radiator) needs to be 55ºC or lower for an efficient operation of the condensing boiler. But even if the condensing onset will start at 54ºC it must be specified that the best boiler efficiency occurs for a much lower temperature of the entering water. i.e., less than 27ºC.

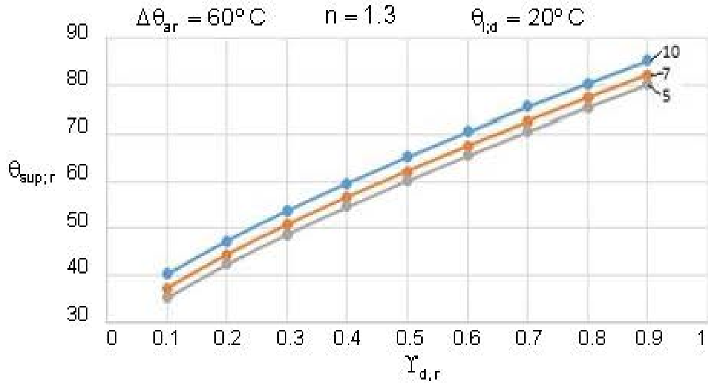


Figure 3. The reduced supply temperature vs. the reduced dimensionless heat load.

From the point of view of a condensing boiler, temperatures for the water supplying radiators in the range of 53 to 54ºC are feasible with no impact on thermal comfort when considering a building with an improved envelope insulation and draft proofed. Very well insulated buildings-walls, floor and loft too, with triple glazing- will be comfortable even in a cold day when the condensing boiler is set to 50 … 45ºC.

If in the case of a condensing boiler the return temperature is important for an efficient operation of the system, then when replacing it with a heat pump, the supply temperature is becoming crucial: temperatures of around 40 to 45ºC are the operational ones. Some specificities exist when considering boilers, condensing or traditional ones, and heat pumps, i.e., the temperature differential and the flow rate. If boilers usually operate with 20 to 15ºC temperature differential between supply and return, in case of heat pumps it reaches only 8 to 10ºC (some heat pumps have an even lower Δt=5ºC) see figure 4.

As a result, a higher flow rate is characteristic for heat pumps in contrast with boilers: when shifting away from boilers to heat pumps larger circulation pumps to move the fluid will be required.

Considering the transition of the supply temperature from higher values to the lower ones when improving the envelope insulation, followed by the replacement of the traditional boiler with the condensing one, and then with the heat pump it can be noticed the optimization trend in exergy efficiency of the energetic system. [3]. A similar trend exists for the temperature differential.

By the lowering of the supply temperature, the capacity of the heat emitters will be altered. Figure 5 shows the effect of the design excess temperature, $\Delta\theta_{ar}$ as a mean water to air temperature difference, on the radiator capacity, [5].

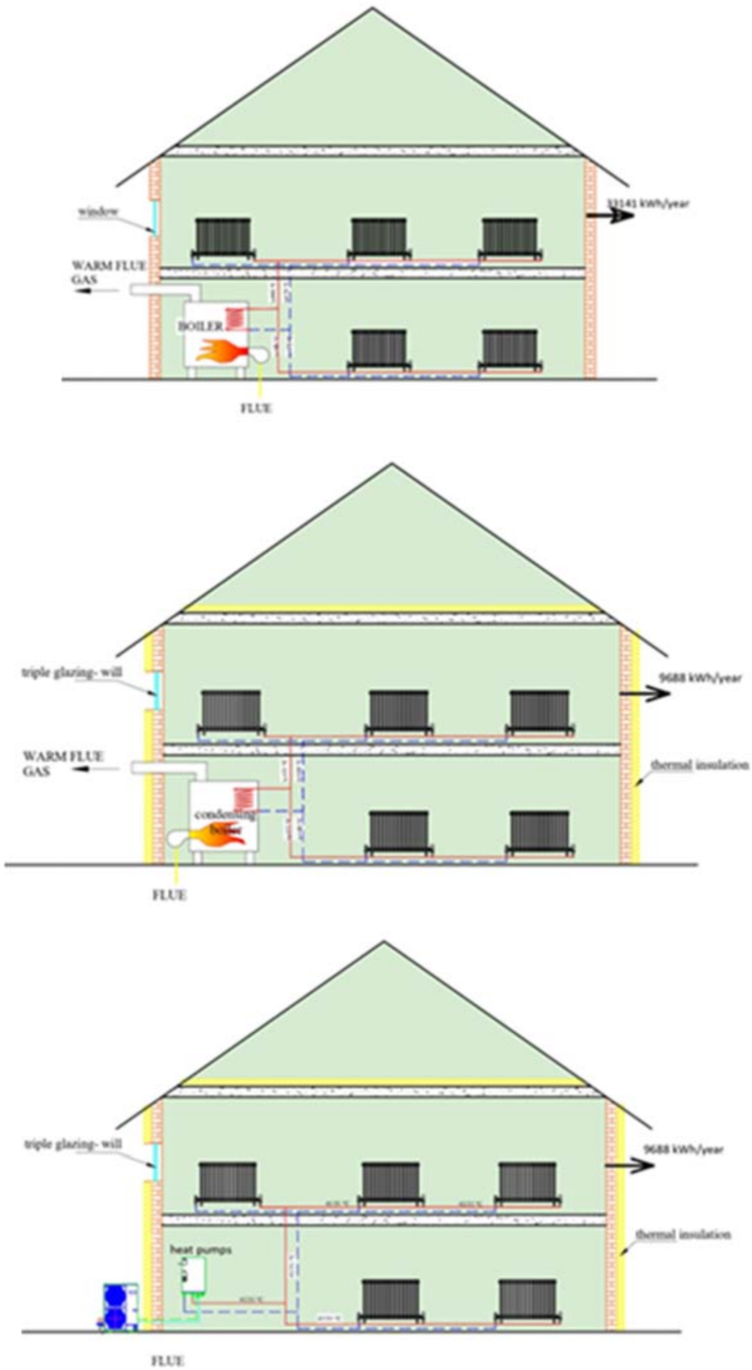


Figure 4. The transition from boiler to heat pump technology after an improvement of the building envelope insulation.

The correction coefficient c_t takes into account changes in the design excess temperature, $\Delta\theta_{ar}$ related to the standard one $\Delta\theta_{ar,n}$ and having as an effect the altering of the heating system capacity

$$c_t = \left(\frac{\Delta\theta_{ar}}{\Delta\theta_{ar,\,n}}\right)^n$$

where, the exponent n=1.3 is for standard and skirting radiators, 1.1 - for fan coils units, and 1.0 - for fan convectors.

It can be seen that a reduced design excess temperature, $\Delta\theta_{ar} = \frac{(80+60)}{2} - 20 = 50^{\circ}C$ will result in a diminished capacity of 80% (c_t=0.8) compared to that traditional, i.e., $\Delta\theta_{ar} = \frac{(90+70)}{2} - 20 = 60^{\circ}C$

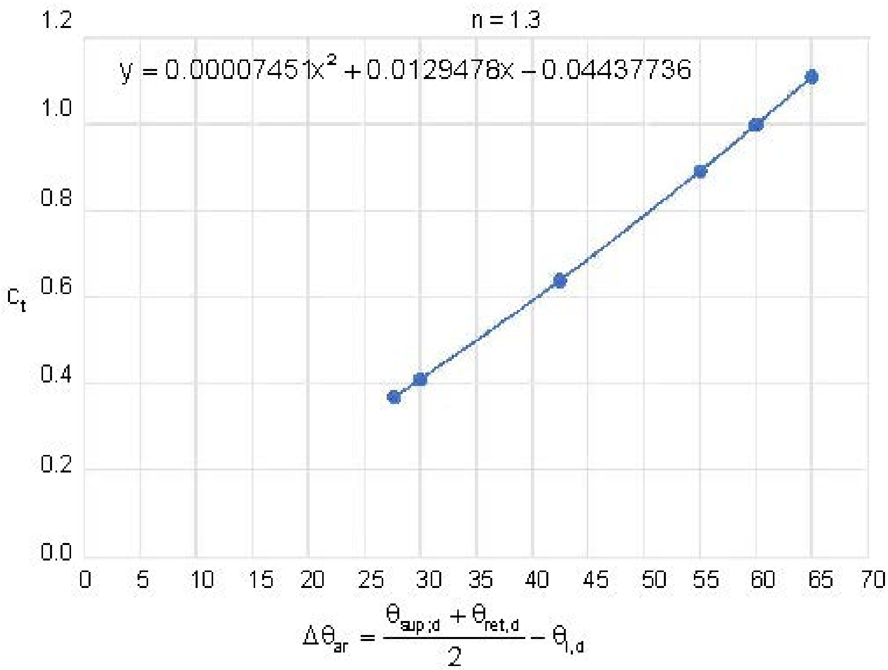


Figure 5. The correction factor as a function of the design excess temperature.

In case of heat pumps, running most efficiently and providing water having a supply temperature of 45 … 40 ^{o}C, a larger heat emitter is to be selected in order to assure the necessary output. When sizing a standard radiator supplied by a heat pump, the heat load calculated in advance (W) must be multiplied by an 'oversize factor' [6] that depends on the design excess temperature resulted from figure 6.

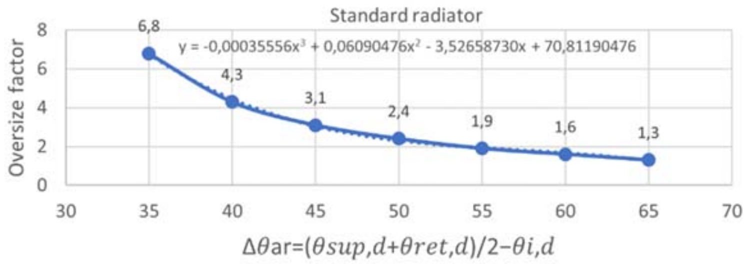


Figure 6. The oversize factor for a standard radiator as a function of the design excess temperature.

Then a suitable radiator having at least that output will be selected from a list of products. Attention must be paid if the output tables are rated on a 60ºC or on a 50ºC design excess temperature base.

When the wall surface is limited then some other devices are useful: fan assisted radiators, or fan coil units. These ones can provide higher outputs for a reduced volume. Figure 7 shows the corresponding oversize factors for different heat emitters. The underfloor heating offers the advantage of a larger surface but it is convenient especially in case of new constructed buildings.

The underfloor heating is characterized by the lowest possible temperature able to perform the necessary heating output. This system is able to avoid the air stratification, reducing de energy costs especially in high-ceilings buildings. Floor construction and floor covering must be treated with care so that the temperature on its surface should not exceed 28°C and the thermal resistance to be kept under 0.15 m^2K/W. The usual pipe spacing is 100 … 300 mm for underfloor screed, closer for carpet-covering and more distant for tile or wood covering.

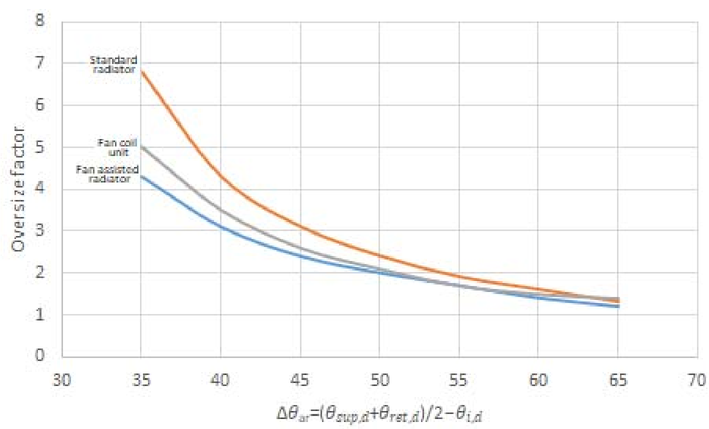


Figure 7. The oversize factor for a *standard radiator*, a *fan coil unit,* and for *fan assisted radiator* as a function of the design excess temperature.

4. Heat pump specific conditions

Delivering the adequate heat is possible if the flow rate of water leaving the heat pump to the emitters is in a correct range, not too little, but not excessive. For the existing installations being in the process of replacing the fossil fuel boiler with a heat pump it is essential to consider the fact that a reduced temperature differential -1/2 to 1/4 from that used in case of combustion boilers, will lead to a proportionately increasing in mass flow and in fluid velocity. As a result, load losses and pressure drops are affected, requiring a resizing of the pipes and of the circulation pump with higher cost for the electricity consumption. As a general rule, pipes having a bore diameter over 10 mm are suited, with velocities under 1m/s so that pressure drops not to exceed 300 Pa/m [4].

When selecting a heat pump for a specific application it must correspond to the heat load and to the comfort temperature, i.e., the evaluated Seasonal Performance Factor must comply with the oversize factor, as shown in figure 8.

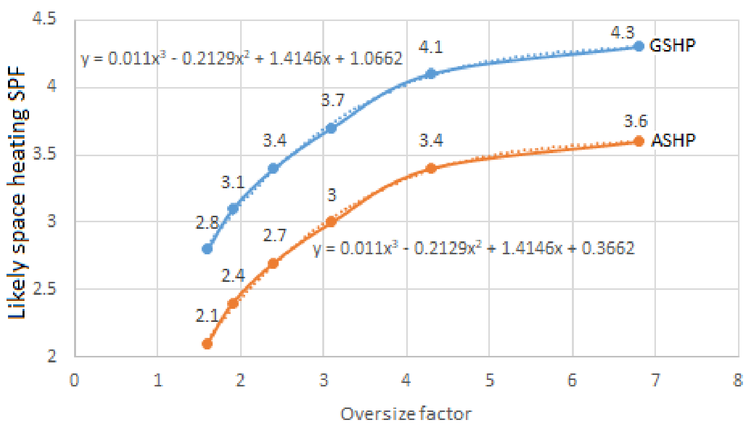


Figure 8. The required SPF corelated with the oversize factor.

As the outside-air temperature increases heat losses of the building decrease and a lower load result. A load correction correlated with the ambient air is necessary to have an improved efficiency of the system, meaning that the flow temperature will be reduced proportional with that of the ambient air.

Radiators react in a linear manner to flow temperature reduction but fan convectors and underfloor heating require a specific compensation curve for the inverter controlling the speed of the compressor.

During such milder condition, the output of the heat pump could be less than the inverter is able to control, and an *on and off* operation will result. Usually, less than six cycles per minute -*on and off*- is accepted in order to avoid a reduced system efficiency and a poor comfort control, not to mention the excessive wear on the components.

Inverter controlled ASHP require a minimum content of water, as shown in figure 9. This is necessary to avoid an excessive compressor cycling resulting in case of low loads, specific for higher outdoor temperature.

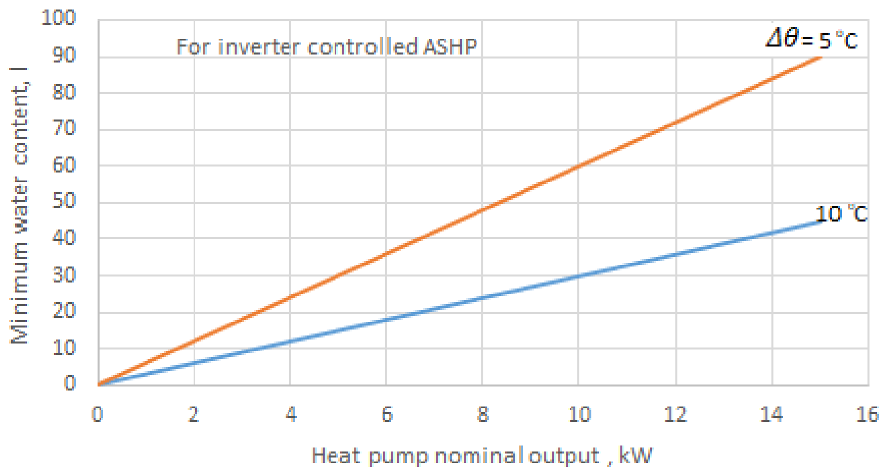


Figure 9. The minimum water volume required in case of inverter controlled ASHP corelated with the nominal output of the heat pump, for a number of 6 cycles per minute (*on and off*).

5. Conclusions

The decarbonizing of the building stock by shifting away from natural gas boilers to heat pumps as a renewable energy user, is considered a robust step. If in the case of new designed and constructed buildings the process can be considered as a feasible one, the big majority of the existing buildings, with its residential component, seems to be a major challenge. Replacing the boiler with a heat pump will be followed by a complex of actions involving radiators, pipes, control systems and having in the backstage the knowledge of specialists and owners, managers and occupants must be open to change.

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Low temperature district heating concept in the smart energy system: challenges and benefits

Conceptul de termoficare la temperatură scăzută în sistemul energetic inteligent: provocări și beneficii

Viederyte-Ziliene Rasa[1], Labanauskaite Daiva[2], Andziulis Arunas[3]

[1] Department of Economics, Faculty of Social Sciences and Humanities, Klaipeda University, S. Neries st. 5, Klaipeda, Lithuania
[2] Department of Economics, Faculty of Social Sciences and Humanities, Klaipeda University, S. Neries st. 5, Klaipeda, Lithuania
[3] Department of Informatics and Statistics, Faculty of Marine Engineering and Natural Sciences, Klaipeda University, Bijunų st. 17, Klaipeda, Lithuania
[4] Corresponding author's e-mail: rasa.ziliene@ku.lt

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Abstract. In modernizing energy systems, European countries are focusing on a smart energy system, and one of the goals of which is the rational use of energy resources and the reduction of negative environmental impact. The concept of the low temperature district heating in the smart energy system is one of opportunities to decrease loses and waste of energy and to implement a systemic approach to the energy use. A roll-out could begin selectively, based on experimental project activities in the near future, new construction will be used to develop the business infrastructure necessary for later, more widespread deployment. The aim of the research is to summarize challenges and benefits in the implementing of the low temperature district heating concept in the smart energy system. The object of the research: challenges and benefits in the implementing of the low temperature district heating concept. The objectives: to systemise the smart energy approach in sustainable future; to analyse the concept of the low temperature district heating in a smart energy system; to characterise risks and opportunities of the low temperature district heating concept. There were used these scientific methods: induction, systemic analysis, comparative analysis and synthesis of partial scientific knowledge. Analysis of various scientific articles and studies shows energy conservation, increased use of renewable energies, smart grids to promote renewable energy utilization, cleaner technologies, multigeneration, and efficient storage of energy carriers are necessary conditions for the transition to smart energy systems for a sustainable future. The low temperature district heating concept is associated with some forms of risk, but the dissemination of experience and on modern digital technologies based management can help to achieve ecological benefits although reduced CO2 emissions, minimize heat loses and waste of energy, to reduce costs of energy production and to improve the image of heating companies.

Key words: *smart energy, energy resources, renewable energy*

1. Introduction

The district heating is an important part of the energy system, and this importance is still growing. In the EU, district heating accounts for 13% of total heating sales, however in particular areas, the market is more established and has a longer history [23]. District heating is the fastest opportunity to modernize the heating system. The development of district heating can significantly contribute to the solution of the complex heating system problem, strengthening innovation and efficiency. The level of development of district heating differs in various EU countries. According to the investigation of E. Wheatcroft et al. (2020), In Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, and Poland, district heating contributes to more than 50% of the total energy consumption. In terms of absolute numbers, Germany and Poland have the largest EU district heating markets. The four categories that the authors propose to divide the European district energy landscape into are consolidation nations, refurbishment countries, expansion countries, and new developing countries [23].

Concentrated efforts are orientated to implement existing alternative solutions to decarbonize the heating sector, to turn to the smart energy systems of the circular economy. Currently about 7% of heating in Europe is done by electric heating, which requires about 175 TWh per year [17], however, in the context of energy sustainability, this is not the most effective solution, a detailed review of energy efficiency improvements available in all energy using sectors. Different organisations are working on the new energy efficiency programs for the next years. According to the "Roadmap 2050" (2010), "smart" technologies and systems will be key enablers to proactively manage power flows and minimize increases in network capacity required. The concept of the low temperature district heating in the smart energy system is one of opportunities to decrease loses and waste of energy and to implement a systemic approach to the energy use. A roll-out could begin selectively, based on experimental project activities in the near term in new construction to build up the commercial infrastructure required for wider application later on.

The aim of the research is to summarize challenges and benefits in the implementing of the low temperature district heating concept in the smart energy system.

The object of the research: challenges and benefits in the implementing of the low temperature district heating concept.

The objectives:

• to systemise the smart energy approach in sustainable future;

• to analyse the concept of the low temperature district heating in a smart energy system;

• to characterise risks and opportunities of the low temperature district heating concept;

• to figure out which benefits of the low temperature district heating concept are implemented in the behaviour of the population of the Baltic Sea Region in the context of the transition to smart energy.

Scientific approaches such as induction, comparative analysis, and synthesis of partial information, as well as quantitative research (a questionnaire survey), were employed in the study. Data processing techniques were also used in the empirical research.

2. Materials and methods

The future energy system should be based on the concept of the renewable energy, free of fossil fuels and should not cause CO2 emission into the atmosphere. D. Skaarup Østergaard (2018) commented it as an ambitious, but necessary goal, as fossil fuels are a limited resource, and continuous CO2 emissions will cause climate change that will endanger our way of life. In view of the limited oil resources, the direction of the development of the country's heat supply in the context of energy conservation takes on special relevance in the energy sector as well [2].

The challenge for the developers of innovative energy projects is not only to minimize losses of energy, to avoid the pollution of the atmosphere, but how to transform the energy system in the cost saving way. District heating can be an example for a potential successful transition of the energy system on a way to a sustainable functioning smart energy system. Geothermal heat, solar thermal heat, excess heat from industry, and heat sources from power production based on biomass or trash can all be effectively used in district heating and would otherwise go unused [19].

2.1. Smart energy approach in sustainable future of smart cities

Smart city concept is immensely popular model of the city development nowadays. The Smart Cites share the two common features as follow [14]:

• the widespread and development of Information and communication Technology (ICT) infrastructures of Internet, data sharing, e-government, public services, innovation and entrepreneurship, and social cohesion;

• green policies for a smart growth with environmental protection policies, and traffic congestion.

A smart energy system can be analysed as a part of priorities in a green policy of the sustainable development. Smart energy systems are investigated and assessed as a tool to solve major global energy and environment related issues. H. Lund et. al. (2014) has defined a smart energy system - is a strategy in which intelligent electrical, thermal, and gas grids are connected and coordinated to find synergies between them and arrive at the best possible solution for both the sector in question and the entire energy system.

A smart energy system is described by different scientists and experts as a prerequisite for sustainable growth and sustainable future. Energy conservation, increased use of renewable energies, smart grids to support renewable energy utilization, cleaner technologies, multigeneration, and efficient storage of energy carriers and chemicals [6] are the key prerequisites for the transition to smart energy systems for a sustainable future. These systems include cutting-edge infrastructures and technology that produce new kinds of flexibility, particularly during the energy system's conversion phase [11].

Main expectations from the smart energy systems are summarized by I. Dincer et. al. (2017) and characterized as:

• energetically sound - a system could not only conserve the quantity, but also the quality of its energy content.

• energetically secure - end users can obtain a dependable, useful, safe, and efficient energy supply with the help of smart energy systems, which finally leads to energy security.

• environmentally benign - more effective systems, lower emissions, and a cleaner environment for future generations all result from less waste and loss.

• economically feasible - smart energy systems provide reliable, economical, and useful end-use options as well as considerable economic advantages.

• commercially viable - the ability to compete effectively and to be profitable.

• socially acceptable - since these systems may satiate social requirements and harmonize available options, they are anticipated to be socially acceptable.

• integrable - integration is a final operation that combines energy sources and systems in a synergetic way to improve efficiency, cost effectiveness, resource consumption, and the environment.

• reliable - smart energy systems should be dependable, which includes using reliable and conveniently accessible/available resources, dependable energy processing/ conversion technologies, and dependable end-user service.

Smart energy systems help to implement a responsible approach to the use of energy resources increasing their economic and technological efficiency. Energy efficiency improvements are significant in a process to reduce greenhouse gases emissions. The implementation of priorities and targets of a “Roadmap 2050” (2010) depends to a large extent on the success of the implementation of a smart energy system.

Targets of a smart energy system are concentrated on [6]:

• better efficiency: efficiencies could be increased by cutting back on waste and losses.

• better resources use: this target strives to lessen reliance on resources that aren't readily and affordably available locally.

• better cost effectiveness: smart energy systems offer higher cost effectiveness by minimizing losses and waste, producing numerous products from the same energy source, and using dependable, accessible, abundant resources.

• better environment: the worldwide CO2 emissions from the energy sector and industry must be reduced to 30–70% of 2000 levels before 2050 in order to meet this wise goal.

• better energy security - one of the main goals of smart energy systems is to reduce reliance on energy import/export and deliver dependability, flexibility, availability, and cost.

• better design and analysis: smart energy systems are made to boost productivity and the quantity of desired products while reducing losses and waste.

A smart city development may be an ideal chance for creating and testing of a smart energy system, where the low temperature district heating would be a significant element to achieve goals of economic and technological efficiency.

2.2. The concept of the low temperature district heating in a smart energy system

District heating can contribute significantly to a more efficient use of energy, but old infrastructure and technologies can be a reason for the absence of the progress in the framework of sustainability. D. Schmidt (2018) has determined, that district heating pipes (type of pipes, insulation materials/conditions), district heating operation (heating load, temperature level, bypass operation, and other factors such as leakages), and geometrical condition (network dimension, length, and ground conditions/properties) all contribute to the district heating network's heat loss.

The use of lower temperature heat medium in district heating networks, according to Rhys Jones et al. (2019), has the following advantages:

• improved heat load distribution due to the ease with which lower temperatures can be controlled;

• reduced distribution pipe heat losses of up to 75% when compared to high-temperature district heat networks;

• using low-temperature heating sources such waste heat, solar thermal collectors, and heat pumps;

• a smaller margin for system design;

• less risk of high-pressure explosion and scorching;

• a longer lifespan for the piping infrastructure as a result of less pipe damage from temperature stress.

H. Averfalk et. al. (2018) mentioned that from a system perspective, low temperature operation has the following synergistic supply benefits: increased access to geothermal heat, increased use of industrial waste heat, increased use of heat from cooling processes, improved efficiency of solar thermal collectors, increased use of ambient heat sources by heat pumps, increased efficacy of flue gas condensation, and increased electrification.

Low temperature district heating is expected by experts as one of the factors facilitating the shift to an eco-friendly, low-carbon civilization. The switch to the new generation system is a paradigm shift that aims to improve citizen quality of life while also maximizing resource and material consumption, reducing environmental effect, and increasing socioeconomic benefit [12]. To improve both efficiency and economic performances of district heating, the fourth district heating generation, also called “low temperature district heating” was first proposed in 2014 [7]. Through a holistic strategy to increase communications between heat generation, distribution, and consumption, more system efficiency improvement can be found [12].

Four basic criteria in particular were noted [7, 18, 8, 3]:

• the capability of supplying thermal energy at low temperatures to both new and existing structures,

• the capability of decreasing heat losses throughout the network,

• the integration of low enthalpy heat plants while retaining the present supply circumstances; and

• to participate in smart energy systems and thereby help the transition to a 100% renewable energy supply system that integrates several energy sectors.

When providing district heating to low energy buildings or buildings in scarce locations, the low temperature district heating idea was initially introduced to ensure district heating was more cost-effective than local heat generation. The network supply temperature is lowered from 80°C to 55°C to prevent network heat loss (Li et al., 2016). The system temperatures that each type of district heating technology employs can be used to classify the technology [19]. Modern systems are frequently based on lower temperatures, which enable higher efficiency in both heat production and heat distribution. But in a world without fossil fuels, with less garbage to burn and a greater need for biofuels for alternate purposes, the use of urban heat sources will be crucial [23]. D. Skaarup Østergaard (2018) mentioned that the future district heating system should therefore be based on temperatures that are lower than the current district heating temperatures of roughly 80-85 °C and 40-45 °C for supply and return in order to enable an affordable transition to a new sustainable energy system.

In addition, fifth generation district heating is being discussed, which integrates heating and cooling, enables demand side response and related thermal energy storage, and widens the integration of waste/surplus heat sources [4]. The fourth generation district heating with a supply temperature below 70°C enables lower heat losses, integration of renewable heat (solar, geothermal, wastes, and biomass sources), and compatibility with cooling networks and smart energy systems. Fourth or fifth generation district heating technology is used for low temperature heat recovery, with the fifth generation representing lower distribution temperatures than the fourth [23]. The same authors contend that because technology change is now young and in its infancy, there is opportunity because waste heat sources are widespread and frequently found adjacent to urban regions with high heat demand. These factors increase the resilience of the energy system as a whole [23].

Modernization of the district heating system requires significant investments: between 2016 and 2050, it is predicted that 27 trillion USD must be invested in renewable energy in order to achieve the goals of the 2016 Paris Agreement [23]. Achieving sustainable change in the energy system requires a systemic approach to energy system reforms, continuity on the political level and governmental support.

2.3. Challenges to realize the smart low temperature district heating concept

According to the nearly zero energy requirements specified by the European energy performance directive, new buildings will have decreased heating requirements. Buildings undergoing major renovations should be renovated to meet minimum energy performance standards, which means that in the near future there will be a rise in the number of passive and highly efficient buildings, resulting in very diverse loads on the district heating demand side [22]. The challenges and opportunities of low temperature district heating system are discussed in various studies.

Different authors describe main challenges in the transition towards lower temperatures in existing district heating networks:

• The district heating business may decide to lower the supply temperature, but as the return temperature is a function of client installations and needs, it is not directly under the company's control [19]. However, there is an issue with high return temperature and the low temperature differential between the supply and the return temperature in the network when the switch to low temperature district heating is being made [16]. This presents a general issue because several tests in existing building areas show that, while supply temperatures can often be reduced quite a bit without causing problems for the comfort of customers, there is no guarantee that the return temperature will also be reduced equally. A smaller temperature difference between supply and return would result in an increased mass flow that might not be sustainable with the current pipe dimensions [19].

• H. Li et. al. (2016) argue that traditionally, the The district heating system is designed with a large safety margin based on experience, which is reflected in both the oversized equipment and the high network supply temperature. This type of system design is more dependable and can withstand situations where individual components fail or when many users are simultaneously using the tap water, for example. Low temperature district heating tends to reduce system design margin in comparison to traditional systems in order to reduce heat losses and investment costs; distribution network and building installation designs should be more precise and should reflect the best knowledge currently available gathered from cutting-edge demonstration projects and model-based design and optimization practices [10, 12].

• The legionella risk can be identified in the low temperature energy system. The use of systems without domestic hot water storage and pipes with modest volumes from the heat exchanger to the taps could enable the safe use of domestic hot water at supply temperatures in the range of 50 oC in the case of low temperature domestic hot water supply. By doing so, the risk of legionella growth could be reduced without the need of higher temperatures [21].

• The planning of renewable heat generation technologies and capacities should be coordinated with building energy conservation plans because renewable energy will likely make up a significant portion of the total energy supply in the future and because it is capital demanding by nature. Demand Side Management and significant building refurbishment can meet customers' heating demand with less installed capacity, saving money and improving partial load operation [10, 12].

The use and implementation of low temperature district heating networks offers various benefits. Global benefits are ecological benefits, related to the environmentally friendly concept of energy system. Low temperature district heating systems have better opportunities for utilization of waste heat and for the use of renewable heat sources [16]. An additional advantage of this is a lower dependency on foreign fuel supplies [21].

Benefits for district heating networks are mostly based on technological and economic advantages [21, 3, 8, 18]:

• Lower heat losses in the district heating networks make low temperature district heating advantageous for utility companies.

• District heating networks can use plastic piping, which can be more cost effective than conventional district heating metal based pipes.

• Using low temperature heat enables the district heating system to incorporate additional heat sources including solar thermal collectors, deep geothermal wells, and low temperature waste heat. The low temperature of the utilised heat, when produced by cutting-edge CHP plants like combined-cycle plants, can increase power production and, consequently, boost energy sales revenues. While offering consumers district heating without increasing the capacity of heat production at the central production unit, adopting environmentally friendly energy solutions benefits the company's reputation. [13].

Customer benefit in various ways [21]:

• Using district heating guarantees a safe supply.

• Customers do not need to be concerned about heating system maintenance, fuel availability, or optimal performance.

• Due to the great overall system performance that low temperature district heating may accomplish, fewer resources would be consumed, resulting in cheaper fuel expenditures. Additionally, this would improve price stability and might even make heating extremely affordable.

With properly functioning real-time monitoring, control, and decision-support tools, the low temperature district heating supply of the future will become "smarter," increasing system efficiency, lowering capital expenditures, and maintaining consumer comfort [19]. Digitalisation based management concepts in the district heating system can be a tool for the shift of the traditional energy system to modern, fourth or fifth generation district energy systems and will accelerate change, allowing to provide sustainable energy at competitive prices.

2.4. Benefits of the low temperature district heating concept are implemented in the behaviour of the population of the Baltic Sea Region in the context of the transition to smart energy: methodology of the research

A quantitative survey has been conducted in the nations of the Baltic Sea Region to examine how customers' behavior orientation toward the core components of smart energy concept is expressed. Multiple choice and Likert scale items were included in the survey. Eight EU-member nations from the Baltic Sea region are included in the study: Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, and Sweden. The survey's participants were chosen using the snowball sampling method [14]. The sample size of the research has been calculated using Paniotto’s formula [9]:

$$n = 1/(\Delta 2 + 1/N) \qquad (1)$$

where Δ is the error allowed. The error of the sample of the research is 0.05.

According to the calculations using this formula, the sample size of 400 respondents has been chosen. The survey has been carried out in 2021 April. The survey questionary has been filled by 440 respondents. The research data were organized and processed using Microsoft Excel software.

2.5. Benefits of the low temperature district heating concept are implemented in the behaviour of the population of the Baltic Sea Region in the context of the transition to smart energy: methodology of the research

The research involved 440 respondents. 238 females and 202 males participated in the survey. The biggest part of the respondents – 198 people – belongs to the group within 30 - 50 years. The inclusion of respondents in the representation of the countries of the Baltic Sea Region was carried out in accordance with the principle of proportionality according to the share of the population in the total general population of the region (Table 1).

Table 1.

Demographic factors of the research respondents.

Demographic factors	Frequency (N)	Percentage (%)
Gender		
Female	238	54,1
Male	202	45,9
Rather not to say	0	0,00
Age		
29 below	162	36,81
30-59	198	45,01
Above 60	80	18,18
Country		
Denmark	23	5,30
Estonia	5	0,96
Finland	15	3,37
Germany	234	53,49
Latvia	7	1,45
Lithuania	10	2,17
Poland	110	25,06
Sweden	36	8,19

Source: compiled by the authors.

Responding to the question of how to understand the concept of smart energy, what characteristics most express the essence of the concept of smart energy, the opinions of the respondents were distributed as follows (Fig. 1).

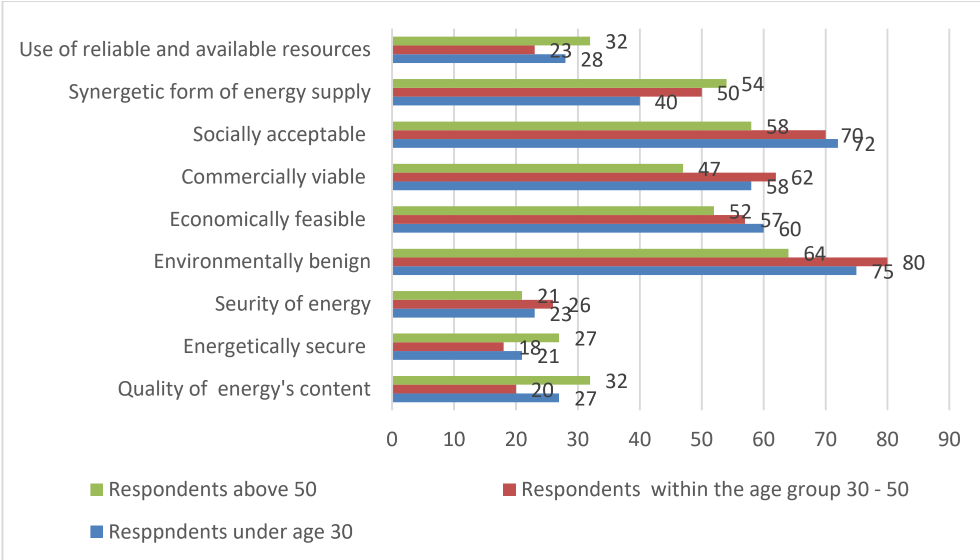

Figure 1. Distribution of respondents' opinions, highlighting the most important components of the smart energy concept (in percent)

It should be noted that there are no significant differences between respondents representing different age groups. Smart energy concept for respondents is mainly associated with social acceptance and environmental benign.

Table 2.
Respondents' acceptance of the key elements of low temperature district heating concept in the smart energy system.

Elements	Mean (total)	Standard deviation (total)	Mean							
			Denmark	Estonia	Finland	Germany	Latvia	Lithuania	Poland	Sweden
1. Economic dimension	***3,81***	***0,94***	3,79	3,56	3,91	**4,02**	3,54	3,95	**4,05**	3,65
(E1.1) I consider my heating costs to be relatively high	**3,99**	1,08	4,1	4,25	3,64	4,28	3,67	4,33	3,90	3,76
(E1.2) I am interested in heating cost saving opportunities	3,83	0,88	3,59	3,25	4,14	3,85	3,67	4,11	4,38	3,65
(E1.3) I am ready to invest in energy-saving solutions	3,65	0,92	3,64	3,50	3,79	3,96	3,17	3,93	3,83	3,41
(E1.4) I agree that the smart energy concept will give me some economic benefits	3,77	0,86	3,82	3,25	4,07	4,01	3,67	3,44	4,08	3,79
2. Security dimension	***3,88***	***0,73***	3,69	3,88	3,77	**4,01**	3,53	**4,07**	**4,03**	3,87
(E2.1) Smart energy ensures energy security	3,66	0,69	4,11	3,72	3,28	4,01	2,71	3,48	3,82	4,16
(E2.2) Lower temperatures of heating are more readily controlled	3,90	0,63	3,45	3,82	4,12	4,04	3,88	4,16	4,08	3,68
(E2.3) Low temperature heating concept reduces risk of scalding and high-pressure explosion	3,61	0,82	3,04	3,74	4,06	3,82	3,38	3,84	3,58	3,42
(E2.4) I agree that low temperature heating increases piping infrastructure lifetime	**4,34**	0,79	4,16	4,25	4,32	4,16	4,12	4,82	4,64	4,24

Elements	Mean (total)	Standard deviation (total)	Mean							
			Denmark	Estonia	Finland	Germany	Latvia	Lithuania	Poland	Sweden
3. Environmental dimension	***3,79***	***0,93***	3,86	3,94	3,93	3,87	3,42	3,67	3,98	3,70
(E3.1) It's important for me that lower temperatures of heating are minimizing losses and waste of energy and are specifically designed to cause as little damage to environment	3,88	0,99	3,77	4,50	3,86	3,86	3,50	3,78	4,21	3,56
(E3.2) It's important for me that lower temperatures of heating are minimizing global CO2 emissions from the energy sector	3,6	0,96	3,73	3,75	3,86	3,67	3,00	3,22	3,75	3,82
(E3.3) I agree that low temperatures heating is more efficient	3,38	0,93	3,68	3,00	3,50	3,86	3,17	3,00	3,65	3,21
(E3.4) It's important for me that low temperatures heating saves resources	**4,32**	0,83	4,27	4,50	4,50	4,07	4,00	4,67	4,31	4,21
4. Self-positioning in the transition to smart energy	***3,73***	***0,84***	3,74	3,78	3,88	3,89	3,75	3,59	3,67	3,55
(E4.1) I am willing to join smart energy system	**4,11**	0,74	4,32	4,12	4,08	4,26	3,98	3,84	4,06	4,22
(E4.2) My household infrastructure has energy-saving solutions in place	3,42	0,91	3,50	3,54	3,48	3,28	3,48	3,26	3,62	3,18
(E4.3) In choosing an energy supply company, it is important that the company practices green energy policies	3,27	1,02	3,26	3,25	3,14	3,71	3,17	3,44	3,19	3,03
(E4.4) I describe myself as responsible consumer of energy	3,38	0,84	3,52	3,54	3,82	3,64	3,31	3,06	3,13	3,06
(E4.5) I agree that smart energy system could not only conserve the quantity, but also the quality of its energy content	**4,46**	0,68	4,12	4,44	4,82	4,54	4,82	4,34	4,36	4,28
5. Attitude towards smart energy transformation	***3,53***	***1,12***	3,24	3,40	3,66	3,86	2,97	3,44	3,90	3,42
(E5.1) The depletion of the world and SDG, Green Deal strategies changed my attitude towards energy	3,09	1,18	2,86	2,95	2,48	3,29	3,12	3,41	3,37	3,27
(E5.2) The depletion of the world and SDG, Green Deal strategies encouraged me to prefer more responsible way of energy consumption	3,05	1,09	3,09	2,58	3,16	3,03	3,05	3,01	3,17	3,29
(E5.3) I support innovative solutions	3,94	1,15	3,98	3,82	4,31	3,72	3,84	4,32	3,79	3,74
(E5.4) I think a smart energy system can be easily integrated into an existing system	3,37	1,18	3,87	2,54	3,71	3,82	2,77	3,38	3,14	3,73
(E5.5) It's important for me that low temperatures heating contributes to a better future	**4,21**	0,85	4,27	4,62	4,42	4,27	3,83	3,95	4,06	4,25

Source: compiled by the authors.

Table 2 reveals respondents' acceptance of the key elements of the smart energy concept. The results are split into five sections: economic dimension, security dimension, environmental dimension, self-positioning in the transition to smart energy and attitude towards smart energy transformation. Looking at the first economic dimension, which includes four statements, as the respondents evaluate each statement in number from 1 to 5, the average meaning for the whole dimension, is 3.81 points. That means residents of the Baltic Sea Region agree with economic benefits and efficiency of a low temperature district heating concept in the smart energy system. As the standard deviation averagely fluctuates around 0.94, that means respondents had quite similar opinion, which did not vary far from the average meaning. The next, security dimension was evaluated with 3.88 points on average, what is the highest point of agreement comparing all dimensions. These results reveal that respondents quite strongly agree with the level of the low temperature energy security. The average standard deviation of 0.73 reveals that the answers of the respondents evaluating these statements were quite unanimous. The third dimension is environmental dimension. The average evaluation for the statements of this dimension is 3.79 points, the standard deviation, averagely fluctuating around 0.93, means that respondents had quite similar opinion with the little distribution of the choices. Analysing separately each dimension, economic dimension was highly evaluated by respondents from Poland and Germany. Security dimension gain the highest result from Poland, Lithuania and Germany. Environmental dimension had the strongest agreement from respondents from Poland, Finland and Estonia as well. The highest points in the self-positioning in the transition to smart energy and in the attitude towards smart energy transformation are given from respondents in Finland, Germany and Poland.

Identifying on the possible challenges of implementing low temperature district heating solutions, the majority of respondents indicated the risk of legionella in the low temperature energy system (74% of respondents), high installation costs (62% of respondents), technical risks (53% of respondents).

Concluding the results of the survey of the behaviour of consumers in the transition to smart energy concept, it was revealed that residents of the Baltic Sea Region agree with the key elements of a smart energy concept. It was confirmed that respondents' behaviour and attitude links to the transition to smart energy concept.

3. Discussion

Green energy, the smart energy concept and the low temperature district heating are seen as a future energy solution that solves a sufficiently wide range of problems and ensures more rational use of resources, reduction of energy supply costs, increase of efficiency, but at the same time it is noticeable that relatively little research has been done on how the perspective of low temperature district heating is assessed by entities closer to the final consumption chain. A survey of the population in the Baltic Sea region showed that smart energy and low temperature district heating solutions focused on household needs are mostly supported by the respondents representing the population of Germany, Finland and Poland.

4. Conclusion

A smart energy system is built on renewable energy generation and synergies to create an optimal solution for each specific sector as well as for the entire energy system. It is a cost-effective, sustainable, and secure energy system that reflects a green development policy. Energy conservation, increased use of renewable energies, smart grids to support renewable energy utilization, cleaner technologies, multigeneration, and efficient storage of energy carriers and chemicals can all be summed up as essential requirements for the transition to smart energy systems for a sustainable future. Focused on the goals of technological and economic efficiency, smart energy is a part of a sustainable future, which provides a supply for a basic need of companies and households – secure energy at competitive prices.

Low temperature district heating is expected as one of the enablers in the transition to low-carbon society. Main indicators of the low temperature district heating as a part of smart energy system are the capacity to supply the demanded amount of low-temperature thermal energy, to reduce thermal losses along the network, to integrate low enthalpy heat plants maintaining the current supply conditions, and to contribute to the transition towards a 100% renewable energy supply system between which different energy sectors are integrated. Low temperature district heating contributes to the achievement of smart energy system goals through rational use of resources and reduction of negative impact on the environment.

The low temperature district heating concept is associated with the following forms of risk: the return temperature is a result of customer demands and installations, and this cannot be controlled directly, potential legionella risk, less experience in implementing projects compared to traditional heating systems and ensuring the safe operation of the system, but the dissemination of experience and on modern digital technologies based management can help to achieve ecological benefits although reduced CO2 emissions, minimize heat loses and waste of energy, to reduce costs of energy production and to improve the image of heating companies.

According to the results of the study, the population of the Baltic Sea region is generally in favor of the low temperature district heating concept, its advantages being mainly related to the security and economic dimensions. The main challenges are related to the risk of legionella in the low temperature energy system, high installation costs and technical risks.

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Exploiting the energy potential of landfill gases from organic materials derived from municipal waste - using sustainable alternative fuel on natural gas utilisation facilities

Exploatarea potențialului energetic al gazelor de la depozitul de deșeuri din materiale organice derivate din deșeurile municipale - folosind combustibil alternativ durabil în instalațiile de utilizare a gazelor naturale

Diana-Laura Merțan[1*], Adrian Retezan[2] , Daniel Dan[3], Roxana-Iuliana Blezniuc [4], Florin Bumbar[5]

[1,2,3,4]Politehnica University Timisoara
[1,2,3,4] Faculty of Construction, Department of Civil and Engineering Equipments
Traian Lalescu Street, nr.2 A, Timișoara, România
[5] SC Somial Construct SRL
*Corresponding author
e-mail: mertan.diana@yahoo.com; phone:+4078 7739 000

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Abstract. *In the light of the increasing exploitation of natural resources, a rigorous approach and an effective identification of practical solutions needed to ensure the conservation of the environment is required, given the crucial importance of this issue. This scientific work explores an innovative method of treatment and improvement of landfill gas produced from municipal and similar wastes, for a carefully selected and thoroughly studied landfill, in order to obtain a sustainable alternative fuel that can be used in natural gas installations.The method analyzed in this study is called high-pressure water scrubbing, which allow the production of biomethane. Additionally, using the mathematical model LandGEM, the energy potential and gas generation rate was determined, for a selected landfill located in Alba Iulia, Romania country. This article also provides a review of technology that uses the high-pressure water scrubber for the integration of improved landfill gas into the mobile cylinder. Through this investigation, the landfill in Alba Iulia, Alba administrative territorial unit, Romania, can be considered as an energetic resourse who can be used through a sustainable potential solution for protecting current natural resources.*

Keywords: organic material, sustainability, natural gas, fuels, utilization installation.

Nomenclature	
Adsorption column - AC	
Atmospheric pressure - AP	Methane - CH_4
Carbon dioxide - CO_2	Residual gases - RG
Compressed gases - CG	Regenerative adsorption - RA

Compressed biomethane storage reservoir – CBMSR	
Desorption column - DC	
Flash Column - FC	Storage reservoir - SR
High pressure - HP	Single-pass water scrubber - SPWS
High-pressure water scrubber - HPWS	Water scrubber - WS
Hydrogen sulphide - H_2S	
Landfill gases - LFG	

Introduction

European Union waste landfill practices [1] emphasize the importance of preserving the environment, protecting the health of participants and using natural resources rationally.

The sustainability of the gas sector is currently the subject of intensive debates, due to the supplier dependency and the increasment of the prices market. In Romania, current energy strategies focus on the use of fossil fuels as a raw material for heat production [2]. However, innovative national technologies that would allow energy from waste are still not very applicable and need further development. Therefore, a careful assessment on options available to reduce the environmental impact of the energy sector and encourage sustainable development is needed.

Currently [3] there are 47 compliant municipal landfills in Romania at the level of year 2022. In the reference period 2006-2018, 56 non-compliant landfills were registered and had to stop their activity, being permanently closed. Due to the fact that landfills that stopped their activities were not permanently monitored, there are no statistics available at the national level on the amount of total existing municipal waste (t/year).

In 2020, according to statistics [4] of municipal waste deposited in operation landfills, an amount of about 286 kg/capita of waste was recorded [5]. For a population of about 19.02 million inhabitants [6], in December 2021 Romania is estimated to have produced about 19,290 t/year of waste, an upward trend compared to the period 2015-2019, when about 259 kg/capita of municipal waste was recorded [7].

At the same time, the target to be achieved by 2025 [8] is to reduce the amount of municipal waste left in landfills by up to 55% by mass for energy recovery or recycling. In the same order, the amount of municipal waste landfill should be reduced by 60% until 2030 and 65% until 2035. At national level, we have no information on the potential for obtaining alternative fuels from municipal waste for collection and storage in SR and mobile cylinders.

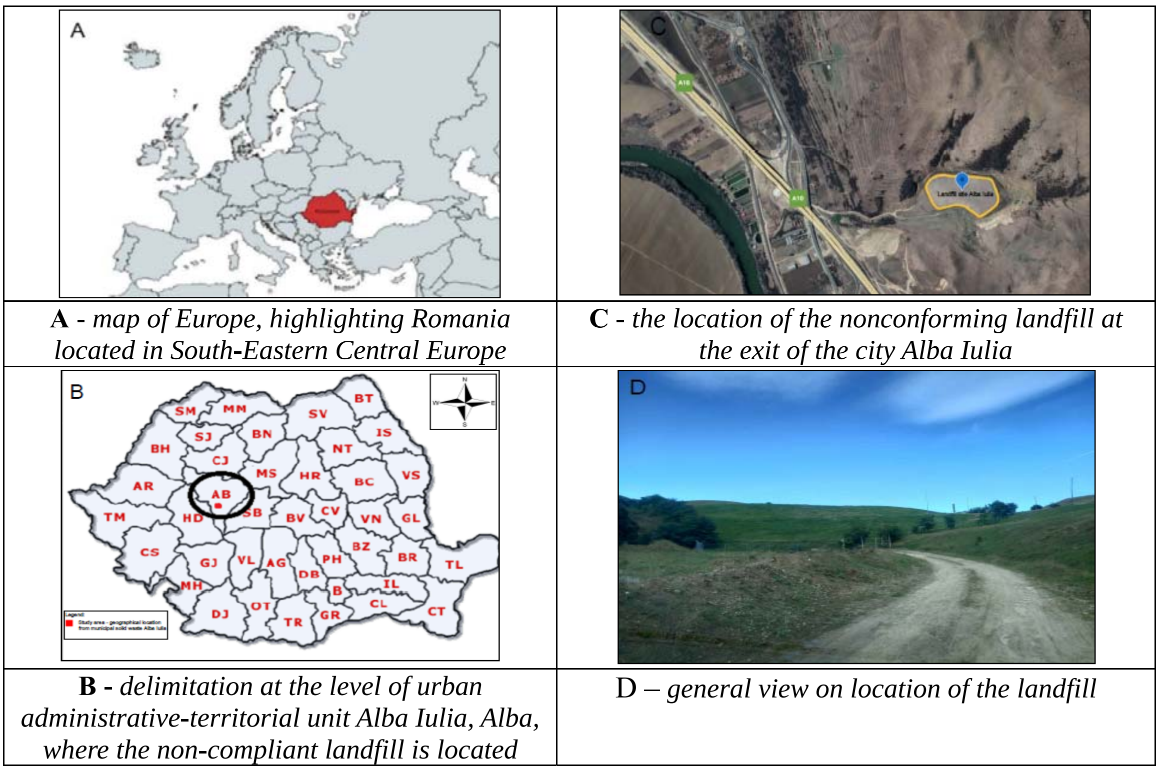
Case study: Investigating the current state in Alba Iulia landfill

This scientific article provides an investigation of the current situation of a noncompliant landfill site, closed permanently in 2015 in Alba Iulia, Alba County, Romania. In addition, a possible technical solution has been identified to use the landfill gas as an alternative fuel, compared to the traditional solution based on natural gas from fossil fuels.

Using the LandGEM calculation software, it has made an estimate of gas emissions from municipal solid waste to evaluate the energy potential with a reference period of at least 100 years from the opening of the landfill.

The area occupied by waste of the non-compliant landfill in Alba Iulia that stopped its activity was, before the final closure in 2015, 5,99 ha, and after the systematization by compacting the waste mass, the surface of the site became 3,47 ha. The landfill capacity is 660 000 cubic metres and the amount of waste landfilled is approximately 238 260 t. The types of waste are municipal and similar waste, classified in the "b" category of importance – non-hazardous waste landfills. Waste disposal has not been carried out taking into account selective collection. The period of storage of these wastes in the mentioned location was more than 30 years.

In the Figure 1 could be observed the identification of the area studied, who is composed by four parts: the geographical location, the territorial delimitation where the landfill is located, its location and a general view taken on site.



A - *map of Europe, highlighting Romania located in South-Eastern Central Europe*

C - *the location of the nonconforming landfill at the exit of the city Alba Iulia*

B - *delimitation at the level of urban administrative-territorial unit Alba Iulia, Alba, where the non-compliant landfill is located*

D – *general view on location of the landfill*

Figure 1 - Location of the study area

Upon completion of the landfill closure process, the landfill gas collection and combustion system was implemented, consisting of 14 landfill gas collection and transfer wells, 1,370 m collection pipelines, landfill gas collection station and gas combustion unit with a capacity of 150 Nmc/h.

The 14 storage gas collection and transfer wells have the role of collecting LFG inside the waste mass, with LFG transmission system going to the unit with a flame for combustion. LFG collection and transfer wells are made up of boreholes drilled directly into the waste mass.

The pipeline networks are of the branched type, connected to the LFG gathering and transfer wells, these are also connected to the storage gas gathering and transfer station.

The LFG collection and transfer lines are connected to a manifold, and from this main manifold they are distributed to the combustion unit via a pipeline. The LFG flame combustion unit is provided for the purpose of controlled combustion of surplus gas and is equipped with a blower and combustion control system.

Below, in Figure 2 and Figure 3 is shown the components of the landfill gas collection and transfer system site which include: the LFG collection and transfer well, the concrete manhole, the combustion unit and the gas collection station.

A - *Collecting well and storage gas transfer*	**B -** *concrete manhole*

Figure 2 – Collecting well and storage gas transfer, concrete manhole

A - *Landfill gas combustion unit*	**B -** *Landfill gas collection station*

Figure 3 - Landfill gas combustion unit and landfill gas collection station

The main component of landfill gas is CH_4, followed by CO_2. The other component gases are trace amounts of hydrogen sulphide (H_2S), oxygen (O_2), and the rest of the gas mixture is of unknown composition. In the raw phase, the CH_4 concentration is approximately 40-70% and the CO_2 concentration approximately 30-60% [9]. The other secondary constituents are expressed in ppm.

According to the 2015-2022 Test Reports [10], regarding the generation rate of CH_4 in landfill site in Alba Iulia, it reached an average value of 65%. The composition of CH_4 falls within the range of 40-70%, reaching phase IV – the stable methanogenic phase.

Among the key factors that favoured the production of LFG within the noncompliant landfill waste mass are:

- bacteria content - methanogenic bacteria that favoured the methane formation process;
- nutrient content - present in organic waste;
- temperature - anaerobic bacteria have an optimal production range of 30-41°C while their activity decreases at temperatures below 10°C;
- waste category - municipal, non-hazardous;
- waste age - uncertain, over 30 years;
- landfill classification - the landfill is a standard landfill with a high initial moisture content, and no separate collection of household waste was ordered before the shutdown [9].

Energy potential and landfill gas generation rate

To estimate the production of landfill gas from Alba Iulia landfill, the LandGEM mathematical model developed by US EPA it was used. This model assumes a first-order equation quantifying emissions from municipal solid waste landfills, called DMS. This mathematical model is preferable when information on landfills is limited. The calculation formula used is:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k \cdot L_0 \cdot \left(\frac{M_i}{10}\right) \cdot e^{-k \cdot t_{ij}} \text{ [11,12]}, \quad (1)$$

where:

Q_{CH4}- approximate annual methane production in Mg / year;
i - the time period of one year during which the LFG increased;
n - the calculated reference year when the waste is accepted;
j - growth for 0.1 years;
k - constant methane generation rate (an^{-1});
Lo - potential methane generation capacity in m^3/Mg;
M_i –mass of waste accepted in year i, expressed in Mg;
t_{ij} - age of section j of the waste mass M_i, accepted in year i.

The LandGEM mathematical model automatically calculates landfill gas emissions, taking into account the annual removal rate, time variation and total landfill capacity. The main parameters used are "Lo" - potential CH_4 generation capacity of the waste, and "k" - CH_4 generation rate over time. The last parameter is the practical reduction of the percentage of landfill gas generation considering its main constituents when the maximum rate is reached. The simulation LFG production rate in Mg/year is shown in Figure 4.

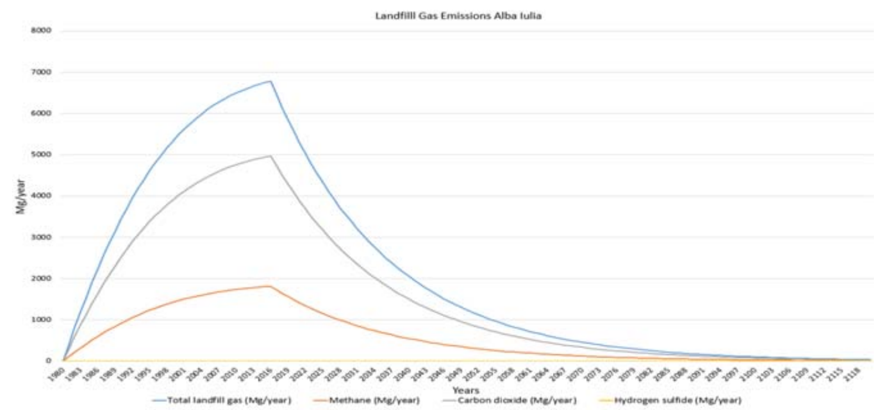


Figure 4 - LFG production rate from Alba Iulia deposit, calculated over a reference period of at least 100 years from the opening of the deposit

The landfill was established in 1980. The waste generation rate was calculated taking into account Eurostat reports [13] on municipal waste generated per person in Romania. It also took into account the nationally declared population census [14] between 1980 – 2015; last year marked the closure of landfill. The maximum LFG production was expected to be completed in 2017, 2 years after the closure of the landfill site, recording about 6 800 Mg, i.e.7 456 t. subsequently, these generation rates of the main constituents from LFG will decrease to about 150 Mg, i.e. 165 t in 2055, as the organic fraction is depleted, decreasing continuously for up to 100 years. At present, LFG effects persist until the inert phase is reached.

Enhancing LFG through water scrubbing system: A Pathway to Biomethane Production

In order to improve the quality of raw LFG, the treatment process is indispensable to remove contaminants and moisture content. This operation is necessary for the treated LFG to obtain biomethane.

In order to obtain purified LFG - biomethane, a technological process must be adopted from the LFG treatment technologies. The chosen method, called water scrubbing, is based on the physical effect of dissolving gases in the liquids with which they come into contact. This type of installation required in Alba-Iulia is designed and shown in Figure 5.

Following the application of the LFG treatment and improvement method by WS system [15, 16], located in Alba-Iulia deposit, the concentration of CO_2 and other contaminants can be reduced to less than 2%, obtaining a methane purity at least 97%.

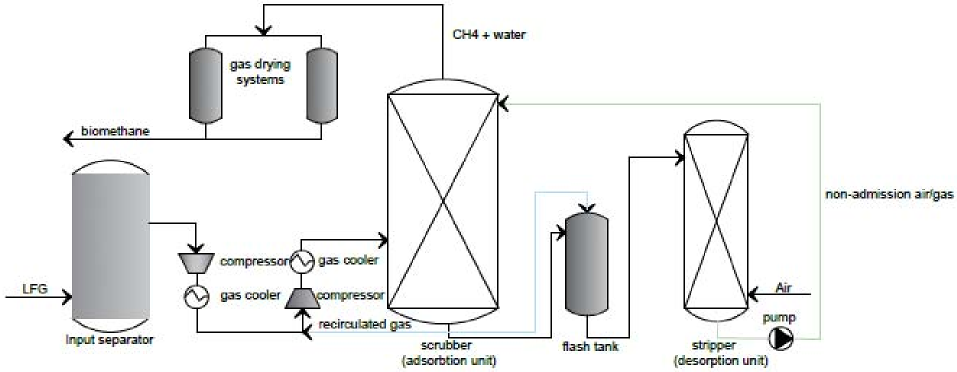


Figure 5 – Design of high-pressure water scrubber installation for Alba Iulia landfill

This method was chosen as a result of comparing several methods involving CH_4 treatment and enhancement, and is a simple and less expensive method than the other methods, such as physical adsorption, chemical adsorption, pressure swing adsorption, membrane separation, and cryogenic separation [17].

The chosen process also includes several ways in which the operation can be achieved: the water used to remove unwanted chemicals can be used once (SPWS) or the already used water can go through a regenerative process (RA) [9, 18]. The first option implies that the water requirement will be higher than regenerative process, but in this case, there will be no possible contamination of the water with traces of H_2S and CO_2. This method is adopted when H_2S concentrations are low. Regenerative absorption means that the water requirement used in the methane treatment and upgrading process will be much lower [19].

The WS can also be performed at AP or HP (6-10 bar) [20, 21, 9], with operating pressures and temperatures provided by each equipment manufacturer. The compression of raw gases is carried out in two stages, using the two connected compressors connected in series, up to 4-8 bar and partly up to 10 bars [22]. After each compression operation, cooling is achieved and then enters the AC. The technique using HPWS has the advantage that LFG enters AC at HP, thus increasing the dissolution rate of the gas in the water it comes into contact with, implying a smaller amount of liquid required [23]. Due to the fact that CH_4 is only partially soluble in water, the saturated water is passed to the FC, which operates in the pressure range 2-4 bar in order to separate the dissolved CH_4, and is then directed to the AC [22]. After these operations, the saturated water passes to the DC, making contact with air for the water desorption process. It should be noted that the efficiency of the desorption process is recorded when the temperature is low [20].

This process does not require a preliminary desulfurization step, because H_2S is removed by the AC, and it is also a physisorption process, which involves reversible absorption based on physical binding forces (van der Waals) [22]. However, as mentioned in the following lines, in some situations desulphurization is recommended when it involves recovery of methane from the waste gas stream.

RG dissolved in the mass of the liquid substance are removed toward the ends of the DC. In this process, small concentrations of CH_4 can be removed together with waste gases, and a "catalytic oxidation" is recommended for their treatment, which implicitly requires a previous activity involving desulphurization, since elemental sulphur contamination affects the catalyst [20]. Also, this process of precision desulphurization is recommended to be carried out before starting the actual WS operation, as the manufacturers of this equipment allow a tolerance of 300-2500 ppm H_2S in case of elemental sulfur contamination [15].

Based on *Figure. 4*, the landfill site in Alba Iulia recorded an approximate 39 300 Mg raw LFG, during the reference period of 2017-2022. Of this value, 69% represents CH_4, while 28% represents CO_2. The remaining 3% consists of unwanted constituents. Through the implementation of treatment and improvement method on the raw LFG, approximately 38 121 Mg of usable purified LFG was obtained, representing 97% usage gas.

This emphasizes the superior effectiveness of the realised WS method for purifying the raw LFG, compared to the existing conventional approach of burning the excess gas at the Alba Iulia landfill. The results highlight a significant improvement in LFG purification using WS technique.

Storage in cylinders of LFG resulting from gas treatment and improvement using high pressure water scrubber

After application of the LFG treatment and improvement method by WS at Alba Iulia landfill, which led to improve the composition of the combustible gases generated from organic material in municipal waste, the issue of storage the resulting gases will be further investigated. This is accomplished in two steps using SR and mobile cylinders.

The CBMSR is an ergonomic alternative. From a financial perspective, the compressor is more expensive, as it compresses the resulting gas to the desired pressure, thereby reducing the need for storage. The introduction of improved LFG into SR can be done over short periods of time, in just a few minutes, or over long periods of time, which can reach fullness in a few hours, the long filling cycle having the advantage of lower energy consumption and constant temperature of the introduced gas [24]. At the same time, the SR can be used for high or low pressure applications. Nevertheless, for scenarious involving transportation in locations that necessitate a significant distance, the HP biomethane SR solution is recommended. In the next step, we will connect the HPWS to the stepper gas compressor as shown in *Fig. 6*, together with the HP SR that can operate up to 300 bar, in order to create a resistance to gas flow [24]. For HP storage a cylindrical reservoir was designed. These types of SR vary in terms of their size, shape and storage capacity, alloys used, depending on the equipment put on the market by the manufacturers.

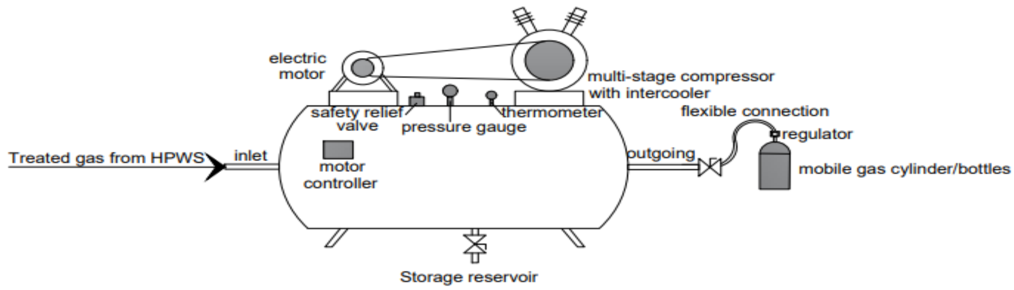


Figure 6 – Design of treated and improved LFG, storage in reservoir and subsequently in mobile cylinder for the Alba Iulia landfill

However, in order for the alternative fuel to reach the beneficiaries, it must be placed in a smaller cylinder to facilitate transport and storage in the buildings. Biomethane bottled in small cylinder provides end-users access to fuel for domestic use and/or heating of buildings, where a transportable cylinder has a pressure greater than 0.5 bar [25]. This type of storage can be obtained after the results of the first stage from the SR, as these reservoirs are used to distribute CG. In this case as well, stepwise compression is required. These cylinders must be equipped with shut-off valves, a gas flow limiting device and a pressure reducing device to correspond to the low working pressures of appliances consuming gaseous fuels for domestic use and/or space heating. The maximum allowable loading pressure is up to 200 bar for CH_4 CG transportable cylinders according to national requirements [26]. As with the compressed biomethane SR, the cylinders differ in size, shape, storage capacity, and alloys used.

Combustible gases obtained from organic materials derived from landfill site, for the purpose of being used by the end consumers, are bottled in small cylinders. The quantity of resulting gases could support a significant proportion of the demand. Knowing that the production of purified LFG obtained trough the HPWS method from the Alba Iulia landfill is approximately 38 121 Mg for the reference period 2017-2022, this would correspond to approximately 1 440 mobile cylinders considering storage purified LFG, each weighing 11 kg.

This has a positive impact on the environment and contributes to supporting sustainability principles. By using gases derived from organic materials, the dependence on fossil fuels is reduced, and the environment is protected. This represents an efficient way to preserve avaible resources and promote sustainable development.

Conclusions

Landfill gas, as well as the technological system for treating and improving these types of gas, in Romania is not enough discussed. They are seen mostly as generators of hard difficulties and there are no energy recovery solutions for them. Natural gas utilization strategies to improve the energy sector at national level only target the fossil fuels and do not include landfill gas as an alternative fuel. New strategies and policies are needed to regulate the use of auxiliary fuels, i.e. LFG. This requires new methods of treatment-purification, storage and transport of these gases resulting from organic materials to the final consumers for use as alternative fuels for natural gas installations.

Starting from the assumption that CH_4 and CO_2 are the main components of LFG, we showed that using a complex LFG treatment and improvement system, together with the application of the HPWS method, can increase methane purity to 97%, reducing CO_2 concentrations to less than 2%. Using the LandGEM mathematical model, we estimated LFG production, starting from the probable year of its opening and culminating with the moment when it would become inert, while analyzing gas storage solutions, such as cylinders and storage reservoir, in order to ensure access to sustainable alternative energy sources for end-users of natural gas installations.

Analyzing the situation of non-conforming municipal waste landfills in Romania, it is important to take into account that many of them have stopped their activity due to the lack of selective collection at the time of their establishment, the resulting gas still being burned in combustion units and released into the atmosphere. In essence, a solution indicated would be the establishment of a legal framework for the valorization of alternative energy sources from these deposits, by means of normative acts, issued at national level.

The treated and improved LFG represents a potential solution to the current energy crisis, felt both nationally and internationally, with the potential to reduce dependence on fossil fuel use. In the years ahead, these innovative technologies to produce purified LFG are expected to play a key role in shaping the future, because energy from renewable sources could contribute to alleviating current environmental and energy problems.

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The integration of air-water heat pumps in existing office buildings. Case study

Integrarea pompelor de căldură aer-apă în clădirile de birouri existente. Studiu de caz

Alexandru Dorca[1], Dănuț Tokar[1], Adriana Tokar[1], Daniel Muntean[1], Simona Popa-Albu[1]

[1]Politehnica University of Timișoara, Faculty of Civil Engineering
Str. Traian Lalescu Nr. 2, 300 223, Timişoara, Jud. Timiş, România
alexandru.dorca@upt.ro, daunt.tokar@upt.ro, adriana.tokar@upt.ro, daniel-beniamin.muntean@student.upt.ro, simona.popa-albu@upt.ro

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ABSTRACT
In an existing office building, integrating air-to-water heat pumps into a district heating system can bring multiple benefits in terms of energy efficiency and thermal comfort. The article deals with the implementation solution for the efficiency of district heating systems, exemplified by a case study related to an existing office building. The study was carried out following the multiple breakdowns that occurred in the thermal energy distribution system from the district heating company, as well as the interruption of thermal energy for long periods of time.

Key words: *air-water heat pumps, district hesting systems*

1. INTRODUCTION

A heat pump and a district heating system are two distinct elements, but which can be integrated to provide efficient heating and cooling of an existing office building.

The district heating system refers to the infrastructure and components used to provide heat inside the building. This includes ducts, fan coils, ventilation and other relevant components.

In Romania, district heating systems register a high percentage of inefficiency, determined by the diversity of problems in the production-transport-distribution chain, the implementation of rehabilitation and modernization measures that would lead to their energy and economic efficiency. The solution that can ensure the energy efficiency of district heating systems in Romania is presented in the case study presented below [1].

2. PRODUCTION TECHNOLOGIES OF THE THERMAL AGENT

➢ ***The air-water heat pump***

The surrounding air contains heat even when temperatures drop below zero degrees Celsius. Therefore, we can take advantage of this with the help of an air-water heat pump, which in the cold season extracts the heat from the air and water, with the help of the compressor, and then distributes it inside the home through the consumers. In the warm season the above cycle is reversed, with the pump extracting coolness from the air and introducing it into the building.

In terms of efficiency, in the case of this type of device, it is shown by the COP indicator – the higher it is, the more efficient the heat pump is [2]. Of course, not only the COP index is important in the choice, but also other factors. Put simply, heat pumps have the same operating principle as air conditioners, only their efficiency is much higher. How an air-to-water heat pump works can be seen in the simplified diagram below (Figure 1).

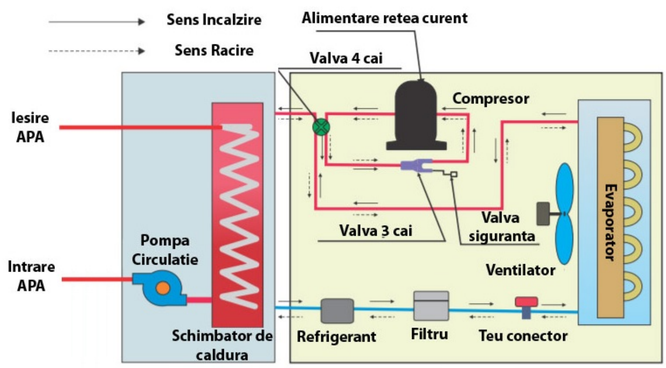

Figure 1. Operating diagram of the air-water heat pump

From this diagram it can be seen that the device can heat the building, but it can also cool it, changing the direction of rotation of the thermal path. Heat pumps that can heat and cool the home are called reversible heat pumps.

➢ **The district heating system**

District heating systems are technical systems designed to provide heating and hot water in buildings and urban areas. These systems are used especially during the cold season to maintain a comfortable temperature in homes, offices, public institutions and other spaces.

There are several types of district heating systems, but the most widespread is the centralized heating system. It consists of a thermal plant located in a central area of the city or neighborhood, which generates heat by burning fuels such as natural gas, coal or oil. The heat produced in the plant is then distributed via a network of pipes to neighboring buildings, where it is used for heating and domestic hot water.

District heating systems have the advantage of providing a centralized source of heat, eliminating the need to have individual heating plants in each building. This can lead to greater energy efficiency and cost savings as more efficient centralized heat production can be achieved. However, there are also disadvantages associated with district heating systems, such as heat losses in the network, dependence on complex infrastructure and the risk of breakdowns in case of failures.

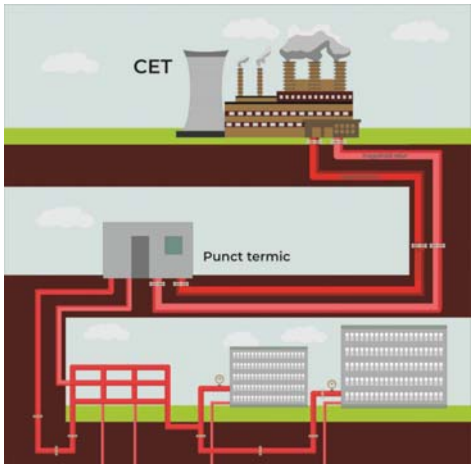

Figure 2. Scheme of the district heating system [3]

In recent years, more advanced heating technologies have appeared, such as geothermal systems, heat pumps or solar thermal panels. They use renewable or non-conventional energy sources to generate heat, reducing environmental impact and contributing to sustainability.

Each country and region may have its own rules and regulations regarding the implementation and management of heating systems, and the provision of these services may be carried out by specialized companies or local authorities.

3. CASE STUDY. INTEGRATION OF AIR-WATER HEAT PUMPS IN THE DISTRICT HEATING SYSTEM

In order for an existing office building to be able to integrate a heat pump system and a district heating system, certain modifications and adaptations of the existing installation may be required. Here are some important steps in implementing this project:

• Assessment of the existing installation to determine how a heat pump system can be integrated. It is important to consider existing parameters such as the type of heating used (eg radiators, fan coils), temperature control and the configuration of the heating network.

• Heat and cooling demand analysis [4], [5]: It is important to assess the heat and cooling demand of the office building, based on the heated surfaces and the local climate. This will help to properly size the heat pump system and determine the capacity needed to meet the heating and cooling requirements.

• Selection of the appropriate heat pump: Based on the analysis of the heat and cooling needs, the right heat pumps can be selected for the office building. It is important to consider the energy efficiency, costs and specific technical requirements of the building.

• Adaptation of the existing heating system: Depending on the type of existing heating system, modifications to the installation may be required. It is also important to ensure compatibility between heat pumps and the existing heating system to achieve optimal performance.

• The implementation of an advanced control system is essential to efficiently manage heat pumps and the thermal system as a whole. It should allow temperature monitoring and regulation as needed and optimize system operation to save energy.

Prepared following the study of the requirements from the design theme submitted by the beneficiary, the solution complies with the norms and standards in force, so as to ensure the comfort of the users and the necessary performance levels.

The heating system had a high number of breakdowns in the last 2 years, with long periods of interruption of the heating agent, but also with low temperature supply. Following the contract signed with the heating system, the building had to be supplied with a constant heating agent at a temperature of 90ºC. In the cold season of 2021 and 2022, there were several days when the building was fed with agent at a temperature of 60-70ºC. At this temperature, it was not possible to ensure the entire heating and preparation of hot water for consumption. Following these thermal agent breakdowns/ interruptions, the beneficiary decided, in addition to the existing system, to supplement with a solution provided with air-water heat pumps.

Figure 3 shows the temperature variations of the thermal agent recorded by the BMS system of the building, for a period of 14 days. It can be seen how the temperature of the thermal agent dropped below 70ºC over a long period of time, of approximately 4 days. There were also interruptions of the heating agent, where the temperature dropped to around 25ºC over a period of 10-12 hours.

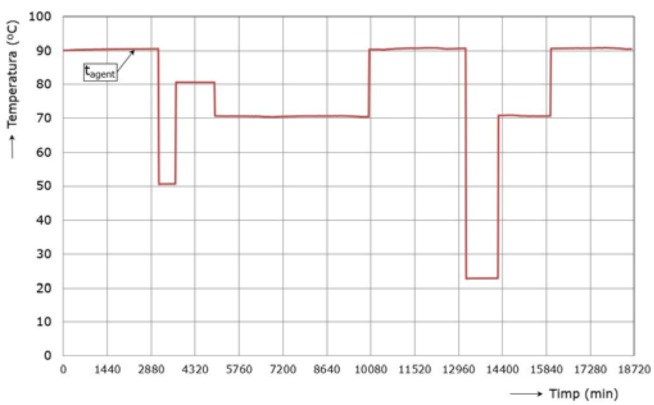

Figure 3. Flow temperature of the thermal agent that supplies the thermal module

To better understand the studied situation, we will present some data about the building:

• Building destination: office building
• Floors: S+P+6E+Ft
• Façade type: Glass front, with a very high thermal transfer coefficient
• Useful area: 9000 sq m
• Heat requirement: 650 kW
• Cooling requirement: 930 kW

- **Description of the existing situatio**

- **The building's heating system**

The building is heated using a thermal point that produces 80/60ºC hot water thermal agent and consists of a fully equipped and automated thermal module, circulation pumps, expansion plant. The heating agent is transported to the distribution points through pipes made of steel. A distributor-collector set, pressure equalization cylinder, adjustment elements, circulation pumps are located at the distribution point.

The thermal point is located in a specially designated space in the basement of the building that contains the thermal modules.

The distribution of the thermal agent is carried out through a two-tubular system, made of drawn black steel pipe, thermally insulated against temperature loss with a mineral wool mattress cased on aluminum foil, with a thickness of 50 mm, considering the fact that through this system 80/60ºC hot water circulates for the cold season.

Space heating is carried out differently using various systems, depending on the destination of the respective space. Thus, the following heating elements are used:

- the office spaces, which also require cooling, are heated by means of uncased fan coil units mounted in the false ceiling, provided with two batteries: one for heating and one for cooling;
- the rooms in the basement are heated by means of steel radiators;

- **The building's cooling system**

The air conditioning of the building is carried out by means of fan coil type cooling equipment, air treatment plants and chillers. Two chillers are installed, one operating in the "free cooling, no glycol" system, for operation also during the cold season with high electricity savings, and one operating only during the warm season, with a highly efficient "turbocor" compressor. . The chillers produce cold water 7/12ºC, with air-water heat pump operation, in the case of the "free cooling" chiller, respectively water-water, in the case of the "turbocor" chiller, by direct expansion of the freon. For the water-cooled chiller, an open cooling tower is mounted, which will supply the water from the condensing circuit of that chiller.

The fan coil units used are non-encased, mounted in the false ceiling. All fan convectors are provided with two batteries each: one for heating and one for cooling. Thus, regardless of the season, the spaces benefit from both cooling and heating, depending on the needs.

The air cooling unit is mounted outside the building, on the common platform for the air conditioning and ventilation equipment, located on the terrace of the building; the water-cooled chiller is mounted on the technical level inside the technical room.

The distribution of the thermal agent from the chiller to the fan convectors is done through a two-tubular system made of drawn steel pipe. To prevent the formation of condensation and the loss of cooling energy, the distribution system is insulated with tubes or a porous rubber mat, with a thickness of 19 mm.

- **Describe the proposed situation**

The alternative and backup solution for the emergency heating, or backup cooling as the case may be, of the studied office building is treated.

The need for this solution appeared with the multiple breakdowns that occurred in the thermal energy distribution system from the heating company, as well as the interruption of thermal energy for long periods of time.

Thus, an alternative system was implemented for emergency heating of the building in case of total interruption of thermal energy from the heating company and a complementary backup system, when the energy supplied by the heating company is not at the required/necessary parameters for correct operation of the installations. The system can also ensure the cooling reserve in case of a breakdown on the existing cooling equipment of the building.

In detail, 3 operating scenarios are distinguished:

✓ When the district heating company completely interrupts the supply of thermal energy - in this case, the 2 heat pumps will be turned on and will supply the heating agent glycol solution 63/58C, so that, on the heat exchanger's secondary, we can supply to the building, to the heating system VCV thermal agent 60/50C, and thus we can ensure an emergency heating of the building, during the day (when the building is functional, occupied) with the 320-360-380kW that can be delivered by the 2 heat pumps, depending of the outside temperature. This power was also selected in order to use the pipes already existing in the building and not have to replace/recreate routes in the functional building. In this scenario, the ventilation units will not work permanently, but only when the outside temperature is higher (the period from the middle of the day - 11-15 hours), so that we do not cool the building, considering that we do not deliver all the necessary energy the building to reach comfort parameters;

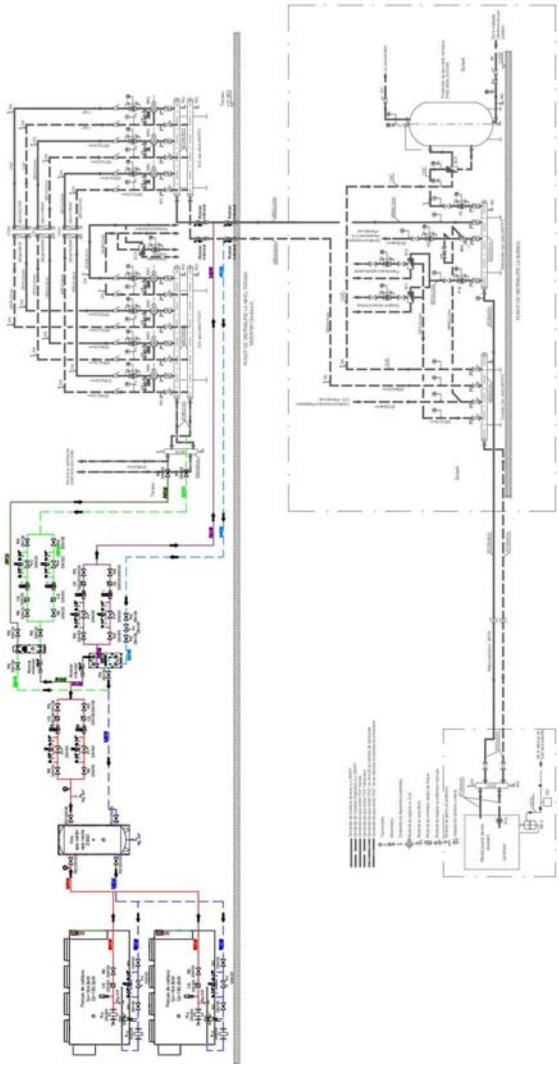

Figure 4. Functional diagram of the proposed solution

- ✓ The district heating company does not interrupt the supply of thermal energy, but delivers it at lower parameters, and thus it is not possible to maintain the comfort temperature in the building - in this scenario, the system will work with the 2 heat pumps on, providing the heating agent glycol solution 63 /58C, so that, on the secondary side of the heat exchanger, we can supply to the building, only for CTAs, thermal agent 60/50C, and thus we can ensure the heating of the ventilated air, with the 320kW delivered by the 2 heat pumps. The rest of the energy will be taken from the heating system. In this scenario, comfort parameters can be ensured for the entire building, both for the VCV system and for the CTA;
- ✓ Summer operation, in case of failure of the existing main cooling equipment of the building - in this case, the solution allows starting the heat pumps in cooling mode, delivering glycol agent at 7/12ºC, which does not allow us to

deliver after the heat exchanger heat, chilled water agent with a temperature of 9/14ºC and thus being able to supply to the VCV or to the CTAs a power of 370kW.

The equipment that will have to be installed to realize the scenarios described above are:

- Heat pumps, model Zeta Rev HP XT 18.4

- Simple circulation pumps for the circuit Storage vessel - Heat exchangers, Hot heat exchanger - Building installation, Cold heat exchanger - Building installation.

- Plate heat exchanger for heating and cooling.

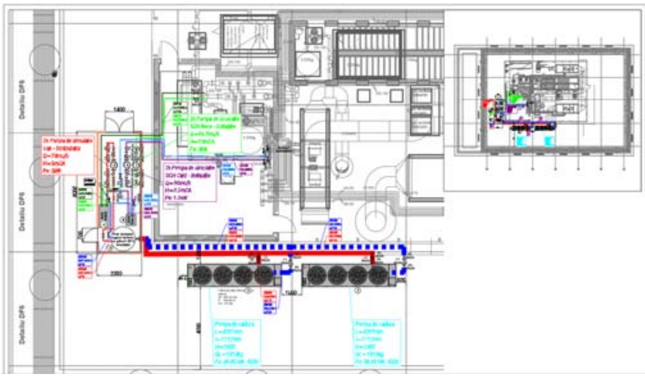

Figure 5. Location plan of the equipment in the proposed solution

4. CONCLUSIONS

The need for this solution appeared with the multiple breakdowns that occurred in the thermal energy distribution system from the heating company. Implementation of an alternative system for emergency heating of the existing office building, in case of total interruption of thermal energy from the heating company and a complementary backup system, when the energy supplied by the heating company is not at the required/necessary parameters for operation the correctness of the installations.

The alternative system distinguishes 3 operating scenarios:

• the district heating company completely interrupts the supply of thermal energy - in this case, the 2 heat pumps will be switched on and will supply heating agent to the building, the HCV system, and thus we can ensure an emergency heating of the building, during the day, when the building is functional, occupied. the heating company completely interrupts the supply of thermal energy - in this case the 2 heat pumps will be switched on and will supply heating agent to the building, to the HCV system and thus we can ensure an emergency heating of the building, during the day, when the building is functional, occupied.

• the district heating company does not interrupt the supply of thermal energy, but delivers it at lower parameters, and thus the comfort temperature in the building cannot be maintained - in this scenario, the system will work with the 2 heat pumps on, supplying thermal agent to the building, only for CTAs and so we can ensure the heating of the ventilated air.

• Summer operation, in case of failure of the main existing cooling equipment of the building – in this case, the solution allows the heat pumps to be started in cooling mode.

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Infectious airborne risk measurement in a classroom

Măsurarea riscului de infecții în aer într-o sală de clasă

Emilian-Florin Țurcanu[1], Vasilică Ciocan[1], Nelu-Cristian Chereches[1], Sebastian-Valeriu Hudișteanu[1], Ana Diana Ancas[1], Verdeș Marina[1], Cătălin-George Popovici[1]

[1] Technical University "Ghe. Asachi" of Iasi, Faculty of Civil Engineering and Building Services, Department Building Sevices, D. Mangeron 67 str., 700050, Romania,
E-mail: florin-emilian.turcanu@academic.tuiasi.ro

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Abstract. *This study investigates the airborne transmission risk of infectious diseases in a classroom setting, aiming to develop a comprehensive risk measurement model. The research employs a combination of computational fluid dynamics simulations, viral load measurements, and epidemiological data to analyze airflow patterns, ventilation efficiency, and viral dispersion in classrooms. Real-time monitoring of air quality, temperature, and humidity is integrated to establish a risk assessment framework. The findings reveal the significance of proper ventilation and strategic classroom layout in mitigating airborne disease transmission. This research offers practical insights for educational institutions to implement informed strategies to minimize airborne risks, ensuring a safer learning environment.*

Keywords: Ventilation, Classroom layout, Aerosol dynamics, Viral load, Risk assessment

1. Introduction

The ongoing global COVID-19 pandemic has highlighted the critical need for understanding and mitigating infectious airborne risks in various indoor settings. Among these, classrooms present a unique challenge, as they serve as essential spaces for learning and social interaction while potentially facilitating disease transmission. Thus, there is an increasing demand for evidence-based strategies to minimize the risk of airborne infections in educational environments.[1, 2]
In recent years, the research on infectious airborne risk measurement in classrooms has expanded rapidly due to the COVID-19 pandemic. Several key areas of investigation have emerged, with a focus on understanding transmission dynamics and implementing effective mitigation strategies. These areas include:

1. Airflow and Ventilation Studies: Research has emphasized the importance of proper ventilation to mitigate the spread of airborne pathogens in indoor environments. Computational fluid dynamics simulations have been employed to model airflow

patterns, revealing the significance of air exchange rates, filtration systems, and natural ventilation strategies (e.g., opening windows and doors) in reducing airborne transmission risk [3, 4].

2. Classroom Layout and Occupancy: Studies have explored the impact of classroom configurations and occupancy levels on the risk of airborne infections. By analyzing different seating arrangements, desk spacing, and occupant behavior, researchers have identified optimized layouts that minimize disease transmission [5, 6].

3. Aerosol and Droplet Dynamics: The dispersion and deposition of respiratory droplets and aerosols generated by talking, coughing, or sneezing have been investigated to understand their role in disease transmission. These studies have shown the significance of droplet size, evaporation rate, and environmental factors (e.g., temperature, humidity) in pathogen persistence and exposure risk [7, 8].

4. Viral Load and Infectious Dose: Research has focused on quantifying viral load in indoor air and surfaces, as well as the relationship between exposure dose and infection probability. By understanding the infectious dose required for transmission, researchers can better inform risk assessment models and mitigation strategies [9, 10].

5. Risk Assessment Frameworks: Integrating the above factors, researchers have developed comprehensive risk assessment models to evaluate airborne disease transmission in classrooms. These models incorporate real-time monitoring of environmental parameters and account for various intervention strategies (e.g., mask-wearing and vaccination status) to inform decision-making and policy recommendations [3, 6].

The ongoing state-of-the-art research in infectious airborne risk measurement in classrooms has dramatically advanced our understanding of transmission dynamics and provided valuable insights for implementing effective mitigation strategies. Future research will continue to refine these models, incorporating emerging knowledge on pathogen characteristics, human behavior, and technological innovations to ensure safer learning environments.

2. Material and method

In this study, we focus on infectious airborne risk measurement in a classroom setting, aiming to develop a comprehensive risk assessment model. Airborne transmission of pathogens such as SARS-CoV-2 and influenza viruses poses a significant threat to public health, particularly in enclosed spaces with limited ventilation and prolonged human contact. Understanding the factors influencing airborne disease transmission in classrooms is vital for formulating effective preventive measures and ensuring a safe learning environment.

We use a multidisciplinary approach that combines simulations of computational fluid dynamics, measurements of viral load, and epidemiological data to find out how ventilation, classroom layout, and how people act affect the spread of airborne pathogens. Moreover, we incorporate real-time monitoring of air quality, temperature, and humidity to establish a robust risk assessment framework.

The results of our research contribute to the growing body of knowledge on infectious disease transmission in indoor environments, providing valuable insights for educational institutions, policymakers, and public health authorities. By implementing informed strategies to minimise airborne risks, we can enhance the safety and well-being of students and teachers, fostering an environment that supports effective learning and engagement.

The following materials and methods outline the steps taken to model, simulate, and evaluate various scenarios to understand the impact of classroom configurations, ventilation systems, and occupant behaviors on airborne disease transmission:

- Classroom Geometry and Configuration: A three-dimensional (3D) model of a typical classroom is created, accounting for dimensions, furniture (e.g., desks, chairs), and architectural features (e.g., windows, doors, and vents). Different classroom layouts and seating arrangements are also considered, representing various occupancy levels and spatial configurations.
- Ventilation System Modelling: The ventilation system in the classroom is modelled, specifying supply and exhaust airflows, filtration efficiencies, and air exchange rates. Different ventilation strategies, such as natural (e.g., opening windows and doors) and mechanical (e.g., HVAC systems with HEPA filters), are investigated.
- Occupant Behaviour: Occupants' behaviour (students and teachers) is incorporated into the model, accounting for activities such as talking, coughing, or sneezing. The generation, dispersion, and deposition of respiratory droplets and aerosols are modelled using appropriate source terms and boundary conditions.
- CFD Simulation Setup: Governing fluid flow, heat transfer, and mass transfer (e.g., Navier-Stokes equations, energy equations, species transport equations) are solved using a CFD software package. The model is broken up into smaller pieces using an appropriate numerical method (like the finite volume method), and turbulence is modelled using an appropriate method (like Reynolds-averaged Navier-Stokes (RANS) equations with k-epsilon or k-omega turbulence models).
- Boundary Conditions and Parameters: Boundary conditions for airflow, temperature, humidity, and aerosol/droplet sources are specified based on experimental data or literature values. Environmental parameters such as ambient temperature and humidity are also considered.
- Simulation Scenarios: Various scenarios are conducted, considering different classroom layouts, ventilation strategies, and occupant behaviors. The impact of interventions such as mask-wearing and vaccination status is also assessed.
- Post-processing and Analysis: The CFD simulation results are post-processed to visualise airflow patterns, temperature and humidity distributions, and aerosol/droplet concentrations. Key performance indicators (KPIs), such as air exchange rates, exposure risks, and infection probabilities, are calculated to evaluate and compare different scenarios.
- Validation and Sensitivity Analysis: The CFD model is validated against experimental data or literature values, ensuring the accuracy and reliability of the results. Sensitivity analyses are performed to identify the most critical factors influencing airborne disease transmission and to assess the robustness of the model predictions.

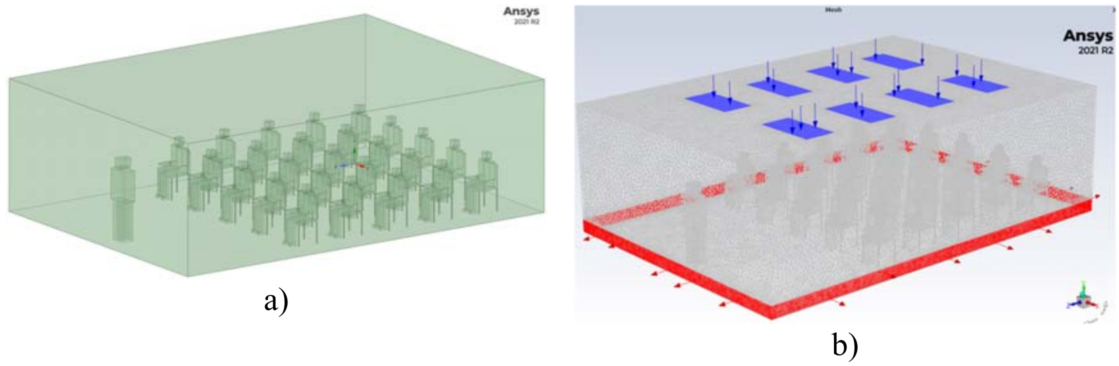


Fig. 1. a) Classroom geometry; b) boundary conditions and geometry meshing

Covid 19 airborne risk measurement using ANSYS Fluent software in a classroom is the subject of this simulation. We carry out this CFD project and do a CFD analysis to look at it.

The Corona (COVID-19) virus is currently regarded as the greatest threat to humankind worldwide since it not only poses a threat to human health but also has a high propensity for spreading between sick and healthy individuals. In a confined public setting, a patient's breathing without a mask spreads the infection to their neighbours. Maintaining a suitable social distance between people in such locations is one of the doctors' crucial recommendations for minimising viral transmission.

For instance, proximity between a student's seat at a university and a student in a classroom can enhance the likelihood that a patient will spread the COVID-19 disease to others nearby.

Through this effort, pupils who are sick or coronavirus carriers in the classroom can inhale contagious air. This project intends to look into how well the ventilation system in the classroom works to clean the air and remove pollutants.

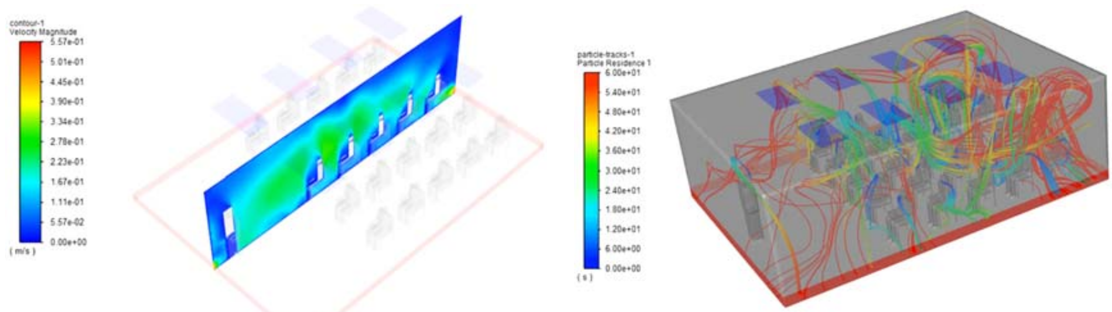
This concept makes use of a ventilation system with numerous vents for the entry of fresh air flow from the classroom's ceiling and numerous panels for the escape of the old airflow at the bottom of the sidewalls of the classroom.

Design Modeller software is used to draw the geometry of the current model. A student is represented on each of the chairs in this model's computational zone, representing a classroom with chairs. A surface is designated as the mouth's source for breathing and viral transmission for each student. The ANSYS Meshing program then meshes the model. 2745511 cells have been produced, and the model mesh is unstructured.

3. Results

The outcomes of the two scenarios—where the teacher is ill and when it is one of the students—are considered. Therefore, regulating mechanical ventilation carries a more significant risk of contamination, which may be decreased when using natural ventilation without wind. There are two causes for this decrease in risk. The first is an increased ventilation rate, which results in a decrease in droplet concentration. (Figure 2)

The second is a decrease in the surrounding relative humidity. Comparing the CFD data reveals that natural ventilation results in significantly lower average ambient humidity than mechanical ventilation. The simulations were run using entering air at 20°C and 40% relative humidity. This is typical of the late spring and early summer climate in Europe. Since the relative humidity of the entering air would be reduced by heating it, these conclusions would still be valid in colder climates. They might be questioned in a hot, muggy environment.



b)

a)

Fig. 2. a) Contours of Velocity Magnitude; b) Particle Tracking Dispersion

4. Discussion

The COVID-19 pandemic outbreak has highlighted the significance of creating a safe and healthy indoor environment, such as by boosting outdoor air delivery to diluted contaminants (viruses). This is a complex undertaking, especially for naturally ventilated buildings when the weather outside is erratic. In this situation, using cost-effective ventilation solutions is crucial to enhancing the effectiveness of air dispersion and reducing the spread of infectious diseases. This study focuses on changing the size and placement of windows that open as well as how they work with fans. Utilizing the best window apertures and installing window-integrated fans will increase ventilation efficiency and reduce the risk of infection. This study demonstrated how a supply fan integrated into the window opening could create a safe and healthy indoor environment in a naturally ventilated area. This approach is affordable and straightforward to implement in practically every classroom in developed and developing nations. However, in practical applications, it is also essential to consider the potential effects of fan noise.

5. Conclusion

After simulation, particle tracking of the virus particles is obtained based on the residence time of 60 s. Also, 2D and 3D contours of temperature and air velocity inside the classroom have been obtained. The flow path lines are also obtained in 3D.

The results show that this ventilation system is inappropriate for the classroom and increases the risk of virus dispersion. This is because the virus particles spread entirely inside the classroom. In other words, the classroom ventilation system's mechanism helps the virus survive in space.

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Theoretical study for an air -water heat pump with low GWP refrigerant

Studiu teoretic privind agenti frigorifici cu GWP scazut utilizati la pompa de caldura aer-apa

Gratiela Tarlea [1], Mioara Vinceriuc [2], Viorel Constantin[1]

[1] Technical University of Civil Engineering of Bucharest
Pache Protopopescu Boulevard, no.66 Bucharest Romania
E-mail: gratiela.tarlea@gmail.com

[2] Romanian General Association of Refrigeration
Pache Protopopescu Boulevard, no.66 Bucharest Romania
E-mail: vinceriuc@gmail.com

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Abstract. *The paper shows alternative refrigerant mixtures for R134a that can be used in heat pump air-water systems with ecological alternatives R1234yf, R452A and R513A. In the article it is shown the calculation of COP with Chemours Refrigerant Expert software for single stage heat pump cycle. As a result of the new legislative strategy at international level regarding the refrigerants, in the following years must be find ecological alternatives in terms of global warming potential (GWP) in according with F-gas Regulation.*

Key words: heat pump, refrigerant, GWP, COP, TEWI factor

1. Introduction

The ecological refrigerants (AF) proposed in this scientific article are chemicals obtained by mixing in different proportions various current ecological refrigerants with one or more natural or synthetic substances that have zero values of ozone depletion potential (ODP) and low global warming potential (GWP).

At the international level in the last 10 years from the point of view of AF study [1], a lot of research has been done in the field, taking into account the severe restrictions stipulated by law: Kyoto Protocol, Regulation (EU) 517/2014, Paris Agreement / 2015, Kigali Amendment / 2016 / Montreal Protocol [2,3,4,5].

In 1987 a comprehensive agreement was developed to phase out production and

use of CFC's. Montreal Protocol was considered one of the most successful international implemented agreements. Climate change was attributed directly or indirectly to human activity which alters the composition of global atmosphere.
In Figure 1 it is shown the Ozone on October 1 for various years between 1979 and 2021 the view being made by NASA TOMS [6,7].
Global warming and ozone depletion are two separate environmental problems, but finally are in connection.

In the early 1970's that the Earth's ozone layer had become thinner so that it could cause damage due to emissions of chemicals known as halocarbons, containing chlorides, fluorides, bromine, carbon and hydrogen.

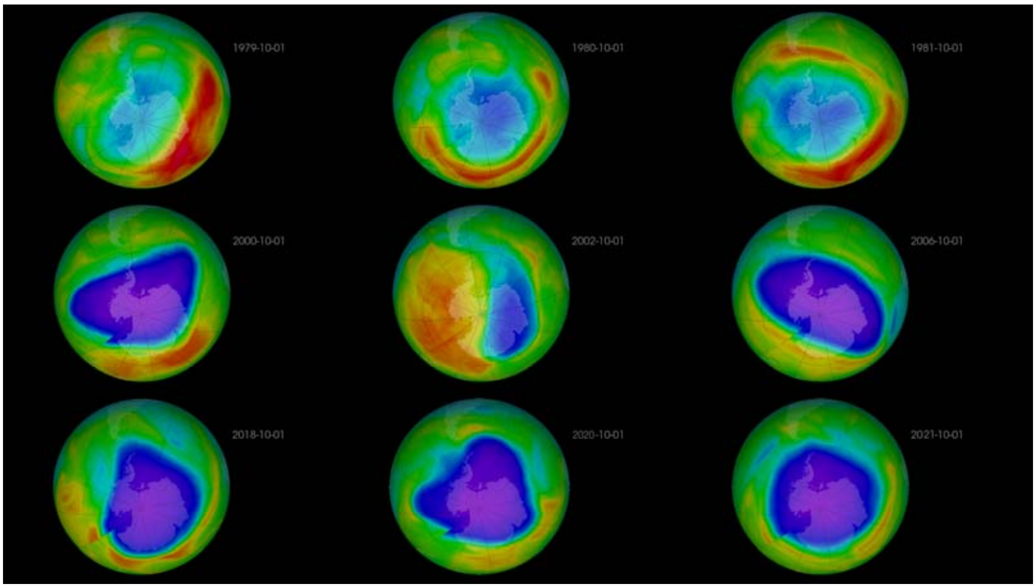

Fig.1. The ozone on October 1 for various years between 1979 and 2021 [6,7]

Romania signed Kyoto (1997) and Montreal Protocol (1987) and in the same time as a new member of EU has obligations to respect environmental legislation [9]. CFC's have been replaced in many applications with HFC's (hydrofluorocarbons) and HCFC's (hydrochlorofluorocarbons). Globally, legal regulations have already been developed with great effort to reduce greenhouse gas emissions. In the EU, Regulation no. 517/2014 also known as "F-gases" [3].

2. Thermodynamic properties

In this paper there are presented some proposals as ecological alternatives (R513A, R1234yf, R452B) for the refrigerant R134a [9,10] in according with F-gas Regulations.

R134a has been an extremely useful refrigerant gas in a number of applications. In fact, it is the most common refrigerant gas in mobile air conditioning (MAC) systems. R134a has a global warming potential (GWP) of 1430. R1234yf is a next-generation HFO refrigerant that combines environmental benefits with excellent cooling performance.

R-452B is a non azeotropic blend containing refrigerants from the hydrofluoro-olefin (HFO) family, designed to replace in new installations, particularly in heat pumps, commercial rooftop air conditioners, VRF systems and medium pressure liquid coolers (air/water chillers).

R-513A is an approved low-pressure substitute with negligible temperature glide that has been used in a wide variety of medium-temperature commercial refrigeration applications. With its A1 classification, it provides the lowest possible GWP (631) among available non-flammable refrigerant alternatives and presents no risk of ozone depletion. Compared to R-134a, R-513A provides a 56% reduction in GWP. Thermodynamic properties of these simulations were done using software RefProp.

Table 1

Thermodynamic properties and safety group comparisons alternatives for R134a [9,10,11,12]

Refrigerant	R452B	R134a	R513A	R1234yf
Safety group	A2L	A1	A1	A2
Critical temperature [°C]	79.67	101.06	97.67	94.7
Critical pressure [bar]	50.57	40.59	36.80	33.82
Critical density [kg/m^3]	438.36	511.9	490.89	475.55
Molar mass [kg/kmol]	63.52	102.03	108.43	114.04

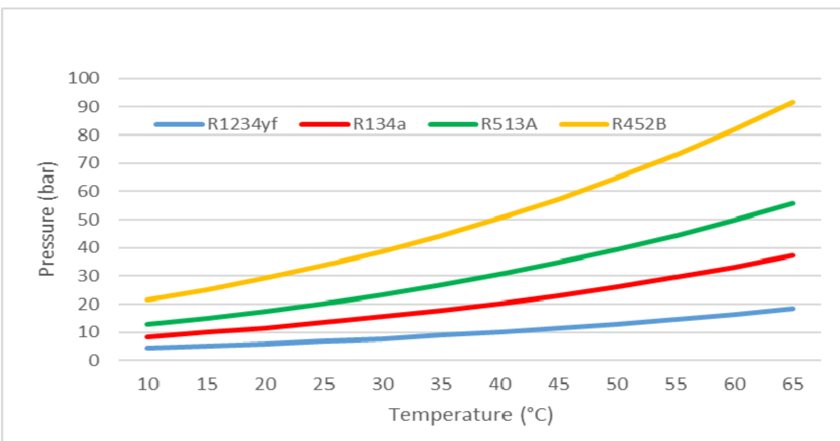

Fig.2. Pressure refrigerants vs. temperature

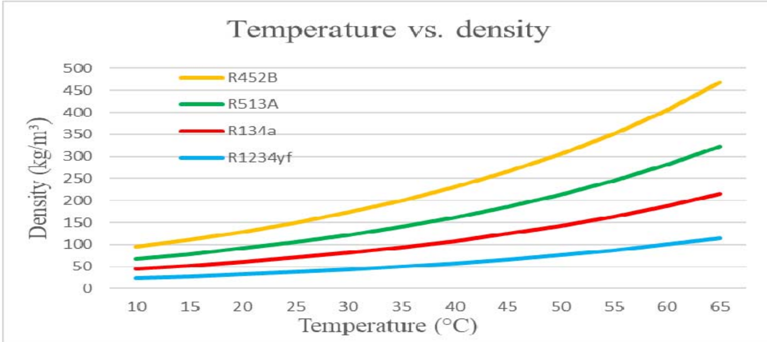

Fig.3. Vapour Density vs. temperature

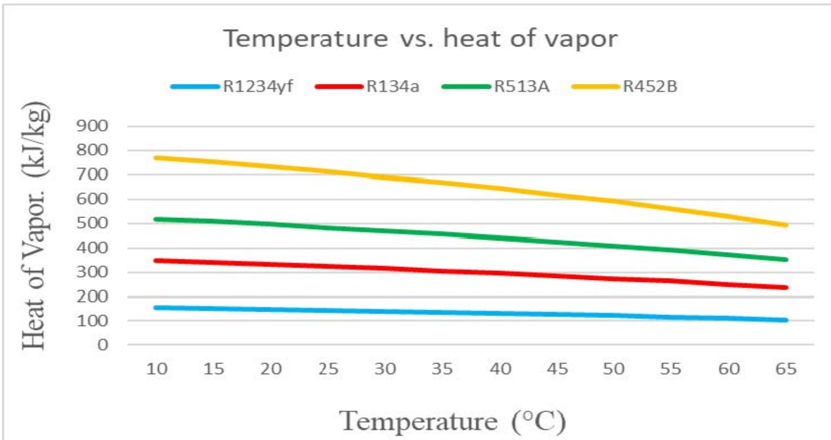

Fig.4. Heat of vaporization vs. temperature

3. Ecologycal And Energy Efficiency Analysis

The study case has a refrigeration capacity of 1,742 kW. The temperature of vaporisation for the refrigeration system is +10°C and condensation temperature is +63°C. The COP for the heat pump systems was calculated with Chemours Refrigerant Expert software [13] and TEWI factor [14] was calculated in according with UE legislation.

The total global warming potential method calculation (GWP) of Ecological Alternative was done in according with REGULATION (EC) No 842/2006 (from 1 January 2015 REGULATION (EC) No 517/2014).

The TEWI factor was determinate taking account of the Standard SR EN 378-1. The calculation relationship for TEWI is presented in detail in standard SR EN 378-1 / 2017 [14] and takes into account the amount of refrigerant in the installation, the amount of expandable refrigerant in the insulation, the amount of CO2 escaped into the atmosphere to produce the energy unit of the refrigeration system, the energy consumed for operating the refrigeration system during its operation, the efficiency and tightness of the refrigeration system, the production mode of the electric energy of the refrigeration system, the lifetime of the refrigerant.

To calculate TEWI factor were following assumptions: mass for Alternative (R1234yf - 0,725kg, R452B – 0,668 kg, R513A - 0,748 kg) and 0,780 kg for R134a. The refrigeration system operated 24 hours per day, 365days per year [15,16,17,18,19]. The leakage of refrigerant was 8% from refrigerant charge with a recovery factor of 0.75. Operating time of the system was 15 years, and CO2 emission was 0.6 kg / kWh.

Table 2

The theoretical results for factor TEWI of the ecological alternatives (R454A, R452A, R449A) for R134a[14,18,19]

Refrigerant	R452B	R134a	R513A	R1234yf
GWP	676	1430	631	4
L	0.053432	0.0624	0.059832	0.057968
n	15	15	15	15
m	0.668	0.780	0.748	0.725
Recovery factor	0.75	0.75	0.75	0.75
Eannual	1221.48	1252.8	1033.56	1879.2
β	0.6	0.6	0.6	0.6
TEWI tones of CO2	48.77	44	45.62	47.31

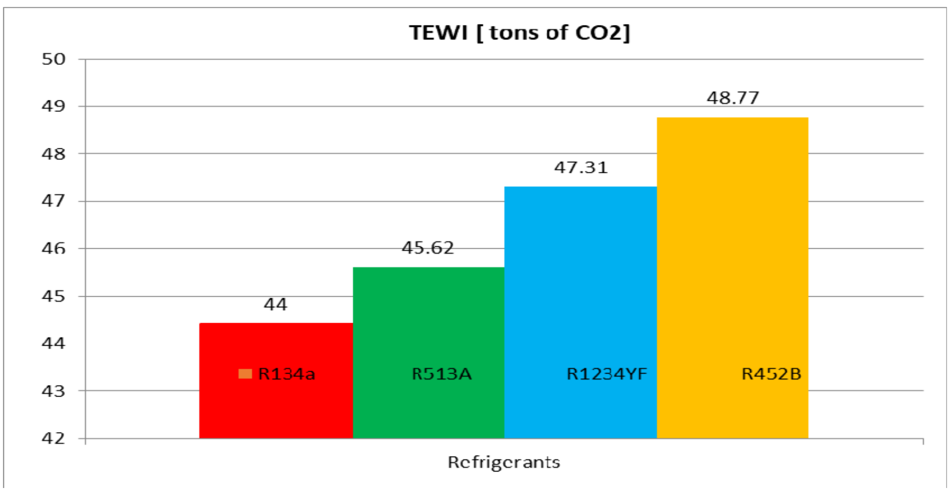

Fig.5. TEWI Factor

Calculation of COP and EER were done using Chemours Refrigerant Expert software.

Table 3

Efficiency Analysis of refrigerant retrofit [13]

Refrigerant	R452B	R134a	R513A	R1234yf
COP	2.85	3.22	3.05	2.92
EER	1.85	2.22	2.05	1.92

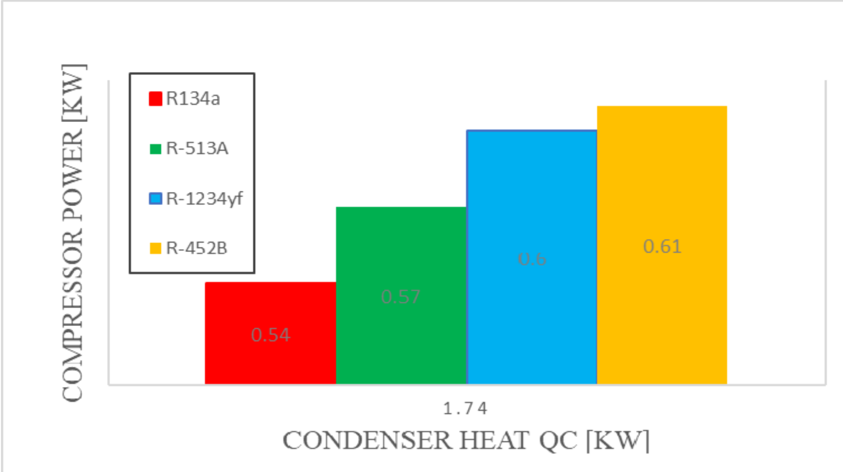

Fig.6. Condenser Heat vs. Compressor Power

4. Conclusions

In conclusion, from an ecological point of view, the refrigerant must be chosen so that according to the regulations of the current legislation, it has zero ODP and GWP low and TEWI as small as possible.

Regarding the safety requirements that refrigerants must meet, they are provided by standards both at national and international level and refer to: flammability, danger of explosion, toxicity, danger of biological contamination and the effects they may have. have on the products to be cooled. The location of the refrigeration installation (dwellings, public places, industrial areas) as well as the amount of refrigerant contained in the installation must also be taken into account.

After determinations of the COP with Chemours Refrigerant Expert software it could be observed (Table 2) that the alternative R513A is the best alternative in comparison with R1234yf and R452B refrigerants and a best option for R134a replacement. From an environmental perspective of lower global warming potential (GWP) alternative R513A has the advantage of 56% GWP than R134a.

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Experimental research on the mechanical characteristics of mortars containing wasted photovoltaic panels

Cercetări experimentale privind caracteristicile mecanice ale mortarelor care conțin panouri fotovoltaice uzate

Andreea-Miruna Tokar[1], Iuliu Lazăr[1]

University Politehnica Timisoara, Civil Engineering Faculty, St. Traian Lalescu No. 2, 300 223, Timisoara, Jud. Timis, Romania

tokar.andreea-miruna@moisiltm.ro, iuliu.lazar@student.upt.ro

Coordinator: Asist. Drd. ing. Tokar Dănuț

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ABSTRACT. *In the current context regarding energy sources' problems, it is estimated that photovoltaic panels will produce a high percentage of waste that will put pressure on the environment. Thus, the study focuses on recycling them by incorporating them into mortars by four new mortar recipes (R1, R2, R3 and R4) that integrate photovoltaic panels' dust (PVd) and pieces of photovoltaic panels (PVp), replacing the sand with PVd and PVp (1/3 to 100% of the total amount). All samples were subjected tensile bending and compression tests and were compared with the control sample (R0). As a result of the experimental research, a change in the apparent density of the proposed samples was found, and from the point of view of the tensile strength, R2 and R4 were found similar to sample R0 in both tests. The obtained results show that used photovoltaic panels can constitute raw material for the creation of new construction materials.*

Key words: wasted photovoltaic waste

1. INTRODUCTION

The electrical context of this situation is based on the recent problems regarding the way we collect electricity. It is believed that the photovoltaic panels, which transform sunlight into direct electricity, to become the main generator of electricity in the near future [1]. The photovoltaic industry will continue its growth and the problem lies with the waste generated after a period of 25-30 years of usage. This issue must be fixed through the use of new legislation and regulations regarding the recycling of photovoltaic panels for each country. It is known that photovoltaic panels, besides having precious material (silver, aluminium, copper, steel, etc.), contain toxic materials such as lead [1], [2], [3], [4]. Even if you try to prolong the life of a photovoltaic panels by fixing and reusing them, in the end they will still end up as waste. The problematic thing is that the current technology for recycling photovoltaic panels is expensive and not at all efficient [1], [2]. In the European Union the legislation forces the recycling of photovoltaic panels (PV), however, in most part only the materials in bulk are collected, such as the aluminium frames and glass, which represent 80% of the total mass of the silicious panel. The remaining mass is usually incinerated even if it contains certain elements such as silver, copper, and silicon which together represent the two terms of economic value of the materials of a photovoltaic panel [2]. Similar measures are taken in Japan, India, and Australia that intervene through plans of recycling. On the other hand, in the USA there is an exception in some state laws, the recycling of photovoltaic panels being inefficient and rarely used thus at a global level it prognosed that they will generate approximately 6 million tons of new solar electronic waste annually starting with 2030 [3], [4]. Top countries in the number of photovoltaic panels are Australia China and India, but it is also shown that third world countries such as Taiwan and Pakistan have installed over 2GW of photovoltaic panels [5]. In this paper we will discuss those aspects (the recycling and reusing of the waste) and the benefit which it brings to the environment. Give all of the above, this paper approaches new options of recycling, by integrating photovoltaic panels (the panel part) in its form, after separating the components (framework) in construction materials. Similar recipes were proposed beforehand, and the result were positive [6]. This article proposes 4 new recipes from which 3 samples of each were created. All were tested for bending tensile strength and compressive strength.

2. METHODS

In the study, the lack of necessary materials such as shredded material and pieces of photovoltaic panel required obtaining them by our own means. Also, a series of tools and equipment were used: diamond disc cutting machine, handheld pneumatic compactor, manual scissors.

The usual materials used are cement (CEM II A-LL 42.5R), sand (0.5/1-Sort 3), release agent (Master Finish RL 450) and water.

For the proposed research, monocrystalline and polycrystalline photovoltaic panels that were removed from use and stored were used. The used photovoltaic panels were cut into pieces using a diamond disc cutting machine. (Figure 1).

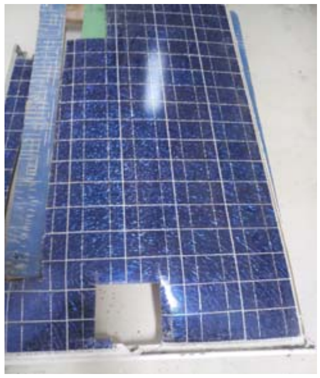
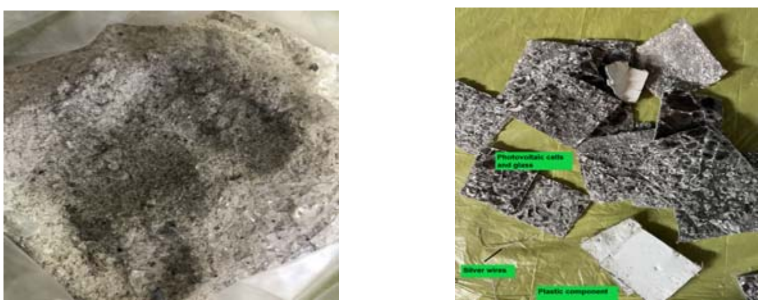


Figure 1. Slitted photovoltaic panels

The cut pieces of the panel were crushed by compaction with a compactor (handheld pneumatic compactor), resulting in crushed glass and pieces of photovoltaic cells together with plastic material (supporting material for photovoltaic cells and for sealing) and residues from auxiliary material (adhesive, other unknown elements). The pieces of material resulting after the first compaction phase are shown in Figure 2.



a) b

Figura 2. The final materials obtained at the end of the compaction process, used for the study

a) PV dust, b) PV crushed

Due to the fact that it was also desired to integrate larger pieces of cut PV into the mortar, manual slitting continued, the cells were made into smaller pieces, with scissors. The result of the obtained material (used in recipe R2 and R3) is shown in Figura 3.

Figura 3. Material obtained after manual cutting of PV-pieces (glass + plastic)

At the same time, the aluminium frame was collected whose recycling process is established and was not the subject of our study.

3. PROCEDURE

After obtaining the materials necessary to study four recipes were made: R1, R2, R3 and R4. The mixture R0 (control sample) was realised and tested in conformity SR EN 196-1 [7]. Testing was done on all 15 samples and the results from the new recipes were compared with R0.

The steps of this project are:

- ❖ determining the recipes for the series of probes R1, R2, R3 and R4 (Table 2);

The number of materials used to create R0 are presented in Table 1, and for recipes R1, R2, R3 and R4, in Table 2.

Table 1 Recipe for sample (R0)

Recipies for the mixtures	Cement CEM II A-LL 42,5R [g]	Sand 0,5/1-Sort 3 [g]	PVd [g]	PVp [g]		Water for mixtures [g]
				glass	plastic	
R0	450	1350	-	-	-	250

Table 2 Recipies for (R1-R4)

Recipies for the mixtures	Cement CEM II A-LL 42,5R [g]	Sand 0,5/1-Sort 3 [g]	PVd [g]	PVp [g]		Water for mixture [g]
				glass	plastic	
R1	450	450	300	-	-	220
R2	150	300	-	-	150	210
R3	450	450	525	275	100	250
R4	450	-	1350	-	-	280

- ❖ the weight of the materials used (Figure 4) which were made with the electronic scale KERN, with a precision of 0.0001 g.

a) b) c) d) e)

Figure 4. The weight of the materials used

a) cement, b) sand, c) PV crushed, d) pieces of PV, e) water

- ❖ the mixture which was initially made manually and then with the help of a mixer for mortar Auto-Mortar Mixer;
- ❖ pouring the samples (Figure 5) mould with oil previously with an agent of with a removing agent of the type MasterFinish RL 450, followed by the compaction of the mixture through the usage of mechanical socks (manual). The mould used has the standard dimensions of: b × h × L [mm].

Figure 5. Pouring and compacting the mixture

❖ Taking the samples out of the moulds after 2 days. No degradation of the edges of the concrete can be observed (Figure 6).

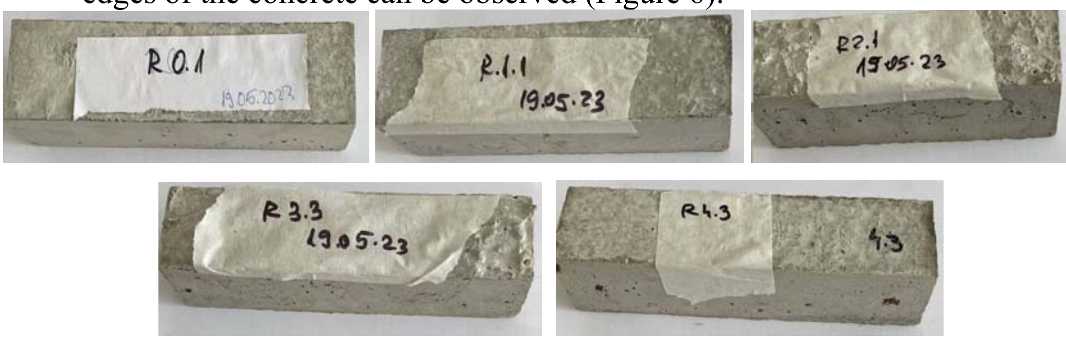


Figure 6. The appearance and the weight of the sample after taking it out of the mould

The dimension of the weight of the sample are presented in Table 3 and Figure 7.

Table 3 Dimensions and weight of the samples taken out of their mold

Sample	Dimensions and weight			
	m[g]	b[mm]	h[mm]	L[mm]
R0	530	40	40	160
R1	553	40	40	160
R2	535	40	40	160
R3	506	40	40	160
R4	488	40	40	160

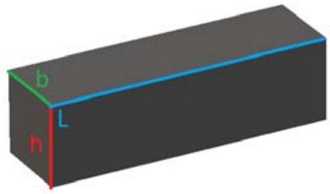
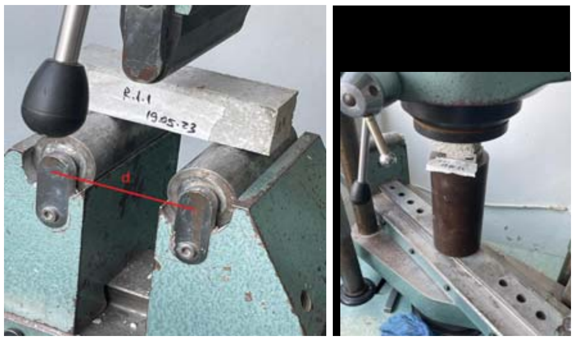


Figure 7. The dimension of the sample without the mould

- the making of the mechanical trials (Figure 8) with a hydraulic press, using a speed of charge of (50±10) N/sec for the bending test and (2400±200) N/sec for the compression test.



a) b)

Figure 8. Mechanical tests

a) tensile bending test, b) compression test

Table 4 The pressing forces P [daN], at which the break was initiated, are presented in

Sample	R0	R1	R2	R3	R4
7 days					
Pt [daN]	160	145	165	115	170
Pc_{01}[daN]	3680	3860	2850	1650	2790
Pc_{02}[daN]	3710	3870	2610	2250	2840
Pc_{avg}[daN]	3695	3865	2730	1950	2815
28 days					
Pt [daN]	228	145	165	192	194
Pc_{01}[daN]	4125	4000	2425	1790	3080
Pc_{02}[daN]	3720	3860	2565	1500	3750
Pc_{avg}[daN]	3922	3930	2495	1645	3145

For analysing the results it has been used:

- The equation of the resistance at traction Ft [daN/mm²]:

$$F_t = \frac{3}{2} \cdot \frac{P \cdot d}{b \cdot h^2} \qquad (1)$$

where:
P -the potential force of the machine [daN];
d- distance [mm];
b- width of the sample [mm];
H-height of the sample [mm].

- The equation of the resistance at compression Fc [daN/mm²]:

$$F_c = \frac{F}{A} \qquad (2)$$

Where:
F-the potential force of the machine [daN];
B-the width of the sample [mm];
H-height of the sample [mm];
A-the area of the section (A=b×h) [mm²].].

4. DATA AND ANALYSIS

The attempt to recycle and use photovoltaic panels and repurposing them into construction materials materialized in this research through the creation of 4 new mortar recipes.

Their structure is a combination of the mortar recipe (according to SR EN 196-1) [7] and the two materials obtained from PV (dust, glass and plastic pieces). Thus, sample R1 (33.33% Sand + 66,66 % Glass), R2 (66,66% Sand, 25,92% Glass, 7,4% Plastic pieces), R3 (33,33% Sand, 20,37% Glass, 38.88% Dust, 7,4% Plastic pieces), R4 (0% Sand, 100% Dust)

The physical and mechanical characteristics of the samples that have been analysed after 7 and 28 days, under the influence of mentioned loads, is presented in Figures 9-11.

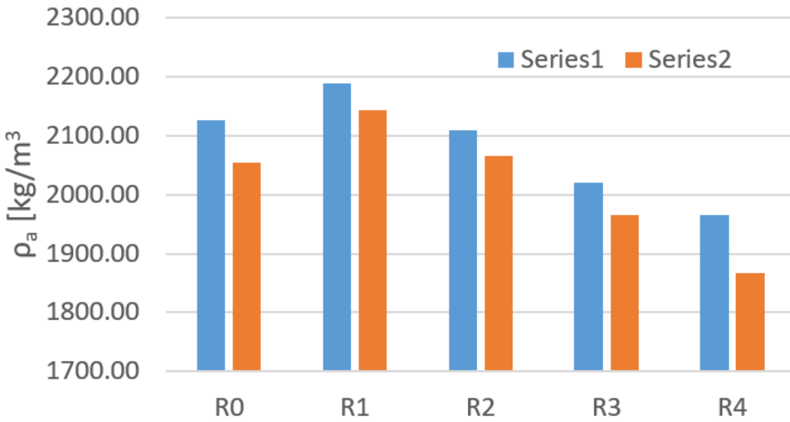


Figure 9. The apparent density

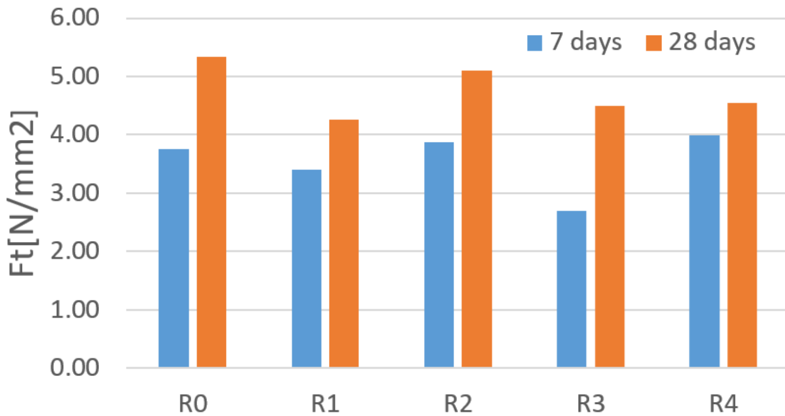


Figure 10. The resistance at traction

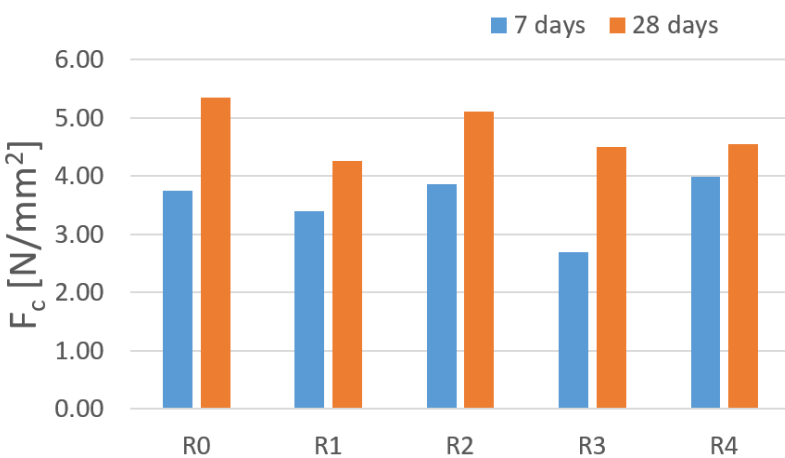


Figure 11. The resistance at compression

It can be noted that there is a growth in the density of the sample R1 with a 1,03% after 7 days and with a 1,04% after 28 days, compared to the control series

(R0), no significant change in the density of R2, and a decrease in density of samples R3 and R4 with 2,75% and 5,03%, after 28 days. From the comparative analysis of the values of the physical-mechanical characteristics determined at 7 and 28 days (Figures 10-11), and from the point of view of the tensile strength, R2 and R4 were found superior to sample R0 by 3,03% (7 days) and 5,88% (7 days) respectively and in the compressive test R1 was found superior to R0 by 2,17% (7 days) It can be seen that after 28 days the proprieties of samples R1-R4 have grown compared with the ones that were tested at 7 days.

Although in some areas the proposed recipes performed less than the control sample, they were still in parameters regarding functionality the main benefit being their small density.

The new materials obtained, both the crushed (PVc) and the one in bigger pieces (PVp) have superior mechanical characteristics compared to the material obtained by the standardized recipe (R0). In addition, the R4 material is lighter (Figure 9).

Therefore, a possibility of recycling by reusing the degraded photovoltaic panels is the creation of new materials such as new mortars which could be included in the field of construction repair mortars.

5. Conclusion

Nowadays, PV waste starts to become a global problem, especially in countries that invested in photovoltaic systems. However, given results presented earlier show that these can be used as a resource in the field of construction. The study has shown and proved experimentally two different recipes for new materials which integrate different forms of wasted photovoltaic panels resulting in new materials with superior properties compared to the classic material made through R0. Through R4 a lighter material was obtained, with 7,57% (7 days) and 9,13% (28 days) lighter density than the classic recipe R0.

The R2 and R4 samples' traction and compression resistance are similar to the control sample R0.

With the fast evolution of photovoltaic technology, it is important that the industry of recycling plans an adaptable recycling infrastructure. However, unfortunately, there is no major action referring to prevention, reduction and recycling of PV waste. Remaking the whole chain of production could lead to the concept that the waste resulting from a process can become primary source for another one or even the same. That way, earlier presented results show the fact that wasted PVs can become a resource for the construction industry. From the point of view of the journey that wasted photovoltaic panels have in present it is stated that the introduction of them in constructions and infrastructure can have a significant impact on reducing the waste quantities which are deposited in nature, waste which puts pressure on the surroundings. That way, this study shows that something that is considered useless can be seen as waste or resource depending on the way it is used.

6. Further Research Questions

As future research directions, we propose to create new recipes (in different mixtures) to obtain construction materials that use these wastes and the results to be a basis for research in the field. At the same time, we propose to test these materials in real operating conditions. Physical-mechanical characteristics were determined at 7, 28 days, to be determined at 90 days, and the ongoing experimental program will continue with other new mortar/material recipes.

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Assessment of Tricycles as a Public Transportation Mode in Ibadan City, Nigeria

Evaluarea tricicletelor ca mod de transport public în orașul Ibadan, Nigeria

Ifedayo Olaiya [1], Olufikayo Aderinlewo [1], Omoniyi Olukanni[1]

[1] Civil Engineering Department
Federal University of Technology Akure, Nigeria
E-mail: ifedayoolaiya@gmail.com, oluade2010@gmail.com, oeolukanni@futa.edu.ng

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Abstract. *Two road corridors in Ibadan City where the use of tricycles is prominent namely Mokola to Agodi Prison Gate Road (MAR) and Challenge to Orita Challenge Road (COR) were identified. Traffic volume data were collected from Monday to Friday during the peak periods, likewise the socio-economic characteristics of tricycle operators using questionnaires. Traffic volume counts revealed that the percentage of tricycles compared to other transportation modes ranged between 9.54% and 20.08% along MAR and between 13.27% and 19.61% along COR. The socio-economic characteristics data showed that 98.5% of the operators were male, their ages ranged between 18 and 60 years and 26.5% had a monthly income of more than N40,000. Tricycle had the second highest arrival rates along MAR and COR of 6.17 and 7.91 respectively.*

Key words: *corridors, traffic volume, socio-economic, arrival rates*

1. Introduction

The importance of urban transportation within any given setting cannot be over emphasized. This is because transportation is an integral part of almost all human activities and it affects the way in which societies are organized. It is a known fact that transportation is the heart beat of any city, whereby without it everything within the city or town would come to a standstill. Transportation plays a key role in the existence and survival of any urban community, this is because it forms the basis of interaction for work, leisure and residential activity, at the same time transport has a strong force in the emergence of early settlements [1].

In the Nigerian road transportation system, varieties of buses, taxis, omnibuses, vans and motorcycles are used to move material and people from one place to the other [2]. In the research on passengers' satisfaction with transport services in Nigeria, a high level of discomfort leading to lack of satisfaction of passengers with the available public transport services was noted [3]. One of the causes reported for the users' discomfort is poor condition of necessary facilities [4]. Others are non-compliance of seat design to standards, long term confined postures and whole-body vibrations [5].

In recent times, the use of paratransit (tricycle) has become popular for transportation [6]. The expansion of paratransit is gradually becoming a means of full public transport in some areas of the country due to poor public transport systems and road networks [7]. Assessment of tricycle operations revealed that the emergence of various modes of transportation occasioned by the need to cope with socio-economic trends and the adverse economic situation of the country gave rise to its operation and gave rise to its use [8]. It was reported that because of its relative affordability and availability, some passengers in some areas of the country prefer using it [9].

The low level of transport services provided by conventional transport systems have led to the expansion of paratransit operations along busy corridors in Nigerian cities. Bus systems and paratransit operations are major competitors. Typically, passengers wait at the curb for a bus to arrive and paratransit operators interlope on the scheduled service; the result is that passengers will probably board the vehicle that comes first.

Low-capacity vehicles operate in many cities as an alternative to public transport in developing countries, for instance in Aba City, Abia State, Nigeria. Some examples are auto rickshaws and cycle rickshaws, responsible for 15% of the public transport market in India [10]; *tuk-tuks* (a three-wheeled motorcycle) which are called *Keke Napeps* in Nigeria; while *silor-leks* (a small four-wheeled vehicle) play an important role in moving persons as well as goods in Bangkok, Thailand [11]. [12] presents examples of other low-capacity vehicles used for passenger transportation in different cities.

However, studies have revealed that ergonomics consideration for users' comfort is not common in the design of tricycles in the country. To minimize discomfort among public transport users, which should be paramount among other design considerations, there is need for proper assessment of seat design [13], access and exit door/stairs [14] among others

Therefore, this study intends to investigate the problems as well as assess the effectiveness of this paratransit mode of urban transportation and bring to the fore it economic, socio-political, strategic and ergonomic function.

2. Methodology

Ibadan is the capital and most populous city of Oyo State, in Nigeria. It is the third-largest city in Nigeria after Lagos and Kano, the 2006 National Population Census estimated the metropolis to be inhabited by 1.34 million people. To conduct a detailed assessment of tricycles as a public transportation mode in Ibadan, road corridors where the use of tricycles is prominent were selected. This is to ensure that the data collected is correct and can be used for the assessment of tricycle as a mode of transportation. Two routes where the use of tricycle is prominent were identified namely Mokola to Agodi Prison Gate Road (MAR) and Challenge to Orita Challenge Road (COR).

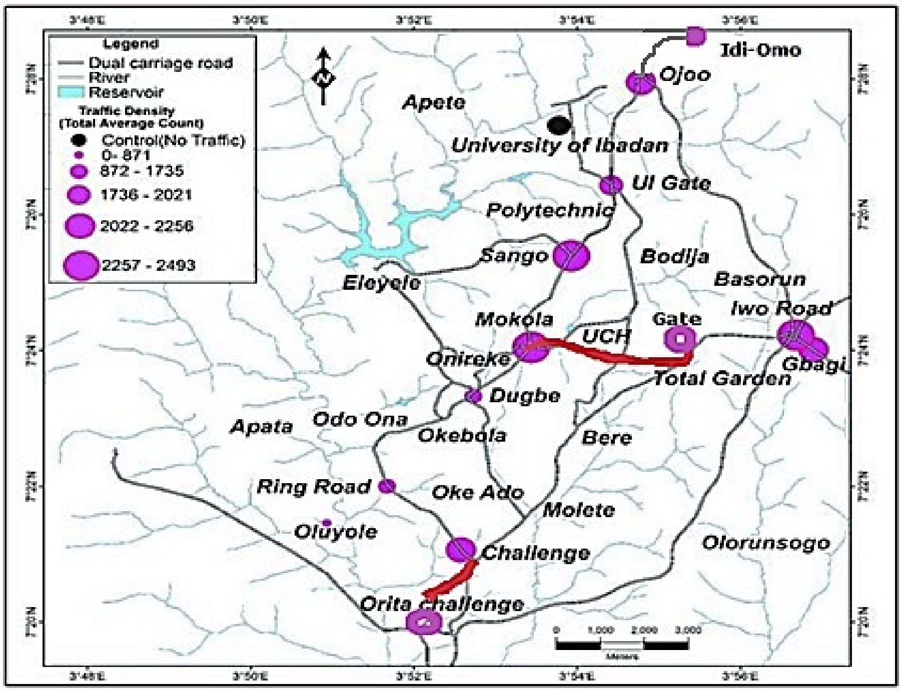

Figure 1: Map of Ibadan showing the MAR and COR routes

Along each route, data on traffic composition, traffic volume and tricycle occupancy were collected during the peak periods (7:00 am - 8:00 am and 3:00 pm- 4:00 pm). Data for the research was collected through an intensive field survey carried out for seven (7) days.

2.1 Experimental Setup

To determine the effectiveness of tricycle as a paratransit mode of transportation, the traffic volume and composition on the selected roads within Ibadan metropolis was measured. The traffic composition and volume data were collected with a digital video recording camera, which was positioned adjacent to the road to record the flow of traffic; vehicles were classified into motorcycles, tricycles, passenger cars, minibuses, lorries (2 axles) and trailer (3 axles). Traffic composition and volume data were extracted from the digital video camera recording.

The number of passengers in a vehicle during a trip known as vehicle occupancy was also measured. The most widely used roadside windshield method that involves stationing one or more observers along the roadside to count vehicles and occupants was used. For safety reasons, the observers stood in a protected area where they will be able to conduct the count without interfering with the free flow of traffic.

Slovin's formula in Equation 1 was used to determine the sample size from the population of study area based on the 2006 census figures for the local governments where the study locations were situated.

$$n = \frac{N}{(1+Ne^2)} \quad (1)$$

where n is the sample size;
N is the known population size; and
e is the margin of error.
Questionnaires were designed with well-structured questions to collect socio-economic data at the study locations. Both self-administered questionnaires and interviews were used in this research to ensure that a larger sample, as well as adequate distribution of the sample and the collection of a large amount of data in a relatively short time.

2.2 Poisson Distribution Function

Consider a time t in which some number n of tricycle may arrive at the bus park. Suppose that the events are independent, i.e., the occurrence of one event has no influence on the probability for the occurrence of another. Furthermore, suppose that the probability of a single event in any short time interval δt is

$$P(1;\delta t) = \lambda \delta t \quad (2)$$

where λ is a constant.
Consider also the time interval t broken into small subintervals of length δt. If δt is sufficiently short then the probability that two events will occur in it can be neglected. one event with probability

$$P(1;\delta t) = \lambda \delta t \quad (3)$$

and no events with probability

$$P(0;\delta t) = 1 - \lambda \delta t \quad (4)$$

To find is the probability of tricycles arrival times in time t, it can start by finding the probability to find zero events in t, $P(0;t)$ and then generalize this result by induction.

Suppose $P(0;t)$ is known, it could then ask what is the probability to find no events in the time $t + \delta t$. Since the events are independent, the probability for no events in both intervals, first none in t and then none in δt, is given by the product of the two individual probabilities. That is,

$$P(0;t + \delta t) = P(0;t)(1 - \lambda \delta t) \quad (5)$$

This can be rewritten as

$$\frac{P(0;t + \delta t) - P(0;t)}{\delta t} = -\lambda P(0;t) \quad (6)$$

which in the limit of small δt becomes a differential equation,

$$\frac{dP(0;t)}{dt} = -\lambda P(0;t) \quad (7)$$

Integrating to find the solution gives

$$P(0\,;\,t) = Ce^{-\lambda t} \quad (8)$$

For a length of time $t = 0$ the number of events must be zero, i.e., the boundary condition is required
$P(0;0) = 1$. The constant C must therefore be 1 to obtain

$$P(0;t) = e^{-\lambda t} \quad (9)$$

Now consider the case where the number of events n is not zero. The probability of finding n events in a time $t + \delta t$ is given by the sum of two terms:

$$P(n;t + \delta t) = P(n;t)(1 - \lambda\delta t) + P(n - 1;t)\lambda\delta t \quad (10)$$

The first term gives the probability to have all n events in the first subinterval of time t and then no events in the final δt. The second term corresponds to having $n - 1$ events in t followed by one event in the last δt. In the limit of small δt this gives a differential equation for $P(n;t)$:

$$\frac{dP(n;t)}{dt} + \lambda P(n;t) = \lambda P(n-1:t) \quad (11)$$

We can solve equation (11) by finding an integrating factor $\mu(t)$, i.e., a function which when multiplied by the left-hand side of the q ` in a total derivative with respect to t. That is, a function $\mu(t)$ in needed such that

$$\mu(t)\left[\frac{dP(n;t)}{dt} + \lambda P(n;t)\right] = \frac{d}{dt}[\mu(t)P(n;t)] \quad (12)$$

the function can easily show that as

$$\mu(t) = e^{\lambda t} \quad (13)$$

has the desired property and therefore,

$$\frac{d}{dt}\left[e^{\lambda t}P(n;t)\right] = e^{\lambda t}\lambda P(n-1;t)] \quad (14)$$

using this result, for example, with $n = 1$ to find

$$\frac{d}{dt}\left[e^{\lambda t}P(1;t)\right] = \lambda e^{\lambda t}P(0;t)] = \lambda e^{\lambda t}e^{-\lambda t} = \lambda \quad (15)$$

where we substituted our previous result (9) for $P(0;t)$. Integrating equation (18) gives

$$e^{\lambda t}P(1;t) = \int \lambda dt = \lambda t + C \quad (16)$$

Now the probability to find one event in zero time must be zero, i.e., $P(1;0) = 0$ and therefore $C = 0$ and

$$P(1;t) - \lambda t e^{\lambda t} \quad (17)$$

this result can be generalized to arbitrary n by induction. then the probability to find n events in a time t is

$$P(n;t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t} \quad (18)$$

3.0 Results and Discussion

3.1 Traffic Volume and Composition

The traffic volume data collected for the two locations MAR and COR for Monday is presented in Table 1.

Table 1

Traffic volume for MAR and COR on Monday

	MAR		COR	
Vehicle	Morning	Evening	Morning	Evening
Motorcycle	521	421	614	768
Tricycle	445	411	564	506
Passenger Cars	453	507	511	499
Bus/Pick Up	671	788	768	877
2-Axle	54	48	101	66
3-Axle	21	25	27	19
Total	2165	2200	2585	2735

The total number of vehicles counted for the MAR location for Monday morning and evening are 2165 and 2200 respectively. COR has 2585 and 2735 vehicles for morning and evening respectively. The percentage of tricycle counted in relation to the total vehicle counted for MAR and COR for morning and evening are 20.55%, 18.68%, 21.82% and 18.50% respectively. This is an indication that tricycle as a paratransit mode of transportation is responsible for moving a sizeable percentage of passengers on daily basis. Table contains the traffic volume for MAR and COR on Tuesday.

Table 2

Traffic volume for MAR and COR on Tuesday

	MAR		COR	
Vehicle	Morning	Evening	Morning	Morning
Motorcycle	256	324	321	312
Tricycle	345	397	456	399
Passenger Cars	413	312	389	461
Bus/Pick Up	912	819	445	687
2-Axle	47	61	55	49
3-Axle	18	21	25	29
Total	1991	1934	1691	1937

The percentage of tricycle counted on in relation to the total vehicle counted for MAR and COR for Tuesday morning and evening are 17.33%, 20.53%, 26.97% and 20.60% respectively. The traffic volume count for Wednesday is presented in Table 3.

Table 3

Traffic volume for MAR and COR on Wednesday

	MAR		COR	
Vehicle	Morning	Evening	Morning	Morning
Motorcycle	331	299	423	306
Tricycle	438	356	525	515
Passenger Cars	413	396	407	561
Bus/Pick Up	833	761	711	987
2-Axle	33	44	41	38
3-Axle	31	18	44	51
Total	2079	1874	2151	2458

The percentage of tricycle as compared with the total volume of vehicles counted indicated that MAR and COR are 21.07%, 19.00%, 24.41% and 20.95% respectively for Wednesday Morning and evening. The total volume of vehicle counted on Thursday is presented in Table 4.

Table 4

Traffic volume for MAR and COR on Thursday

	MAR		COR	
Vehicle	Morning	Evening	Morning	Morning
Motorcycle	294	244	311	334
Tricycle	349	315	431	419
Passenger Cars	290	219	318	305
Bus/Pick Up	654	876	908	843
2-Axle	12	18	77	81
3-Axle	22	9	40	51
Total	1621	1681	2085	2033

The result presented in Table 4 showed that the percentage of tricycle as compared with the total volume of vehicles counted indicated that MAR and COR are 21.53%, 18.74%, 20.67% and 20.61% respectively for Thursday morning and evening. The traffic volume for Friday is presented in Table 5.

Table 5

Traffic volume for MAR and COR on Friday

	MAR		COR	
Vehicle	Morning	Evening	Morning	Morning
Motorcycle	512	467	653	694
Tricycle	499	522	516	663
Passenger Cars	541	415	459	465
Bus/Pick Up	1324	1543	867	951
2-Axle	55	61	71	66
3-Axle	31	21	64	36
Total	2962	3029	2630	2875

From Table 5, the percentage of tricycles counted as compared with the total volume of vehicles counted indicated that MAR and COR are 16.85%, 17.23%, 19.62% and 23.06% respectively for Friday Morning and evening.

From the result of traffic volume count for the MAR and COR locations presented in Tables 1-5, it can be seen that the percentage of tricycles relative to the total number of vehicles counted ranges between 16.85% and 26.97%. This is an indication that tricycle as a paratransit mode of transportation constitutes a reasonable percentage of vehicle available to transport passengers on daily basis to and from the study locations.

3.2 Socio-Economic Data of Respondents

Slovin's formula and the 2006 census demographic data were used to determine the sample size of the study locations. The Population, population growth, calculated population in 2021 and the sample size calculated based on Slovin's formula are presented in Table 6.

Table 6

Determination of Sample size from Slovin's formula

Location	Local Government Area	Population in 2006	Population Growth Rate	Projected Population as at 2021	Error Margin	Sample Size Slovin's Formula
MAR	Ibadan North	432,900	3.5%	660,173	5%	400
COR	Ibadan South East	374,400	3.5%	570,960	5%	400

Based on the sample sizes calculated from Slovin's formula, 400 questionnaires were distributed at each study locations. The responses obtained from the well-structured questions designed to collect socio-economic data from commuters and tricycle riders is presented in Table 7.

Table 7

Responses from Commuters and Tricycle Riders.

S/N		Strongly Agree (%)	Agree (%)	Uncertain (%)	Disagree (%)	Strongly disagree (%)	Total (100%)
1	I have seen a tricycle before	70	20	6	2	2	100
2	I have used/entered a tricycle before	66	18	4	11	1	100
3	Tricycle is comfortable compared to other modes of transportation	45	27	3	2	23	100
4	Tricycle is cheap compared to other modes of transportation	43	16	15	22	4	100
5	Tricycle is fast compared to other modes of transportation	40	35	11	6	8	100
6	Tricycle is safe compared to other modes of	14	24	19	33	10	100

S/N		Strongly Agree (%)	Agree (%)	Uncertain (%)	Disagree (%)	Strongly disagree (%)	Total (100%)
	transportation						
7	Tricycle as a paratransit mode of transportation has reduced accident	37	23	6	11	23	100
8	Tricycle as a paratransit mode of transportation does not contribute to traffic congestion	15	29	13	18	25	100
9	Tricycle as a paratransit mode of transportation has provided a means of employment to people	56	24	2	6	12	100
10	The startup capital for tricycle is cheap compared to other mode of transportation	39	11	5	29	16	100
11	Tricycle as a paratransit mode of transportation is cheap compared to other modes of transportation	11	61	1	13	14	100
12	The maintenance cost of tricycle is cheap compared to other modes of transportation	48	21	7	22	2	100
13	Tricycle has functioned effectively as other major modes of transportation	64	18	2	12	4	100
14	Tricycle can be used to travel a long distance	21	11	23	12	33	100

From Table 7, a total of 90% of the respondents have seen a tricycle, 6% are uncertain to have seen a tricycle while a total of 4% have not seen a tricycle. A total of 72% agreed and strongly agreed that tricycle is convenient, 3% are uncertain while 25% disagreed that tricycle is convenient. Furthermore, 75% of the respondents agreed and strongly agreed that tricycle is fast, 11% are uncertain while 14% disagreed and strongly disagreed that tricycle is fast. A total of 72% agreed that tricycle is a cheap mode of transportation, 1% are uncertain while 27% disagreed that tricycle is a cheap mode of transportation. It can be deduced from the respondents that a high percentage of them agreed that tricycle as a paratransit mode of transportation is effective, cheap, fast and efficient and this further validate the earlier findings.

3.3 Poisson Distribution of Vehicle Inter-Arrival Time

The interarrival time of tricycles were measured to determine the rate of arrival and distribution at the study locations. The arrival time, observed frequency, theoretical or calculated frequency and Poisson distribution (probability of a time interval occurring) for COR and MAR from Monday to Friday were determined. Table 8 shows these typical data for MAR and COR on Monday

Table 8

Poisson Distribution of Inter-Arrival Time for MAR and COR on Monday.

MAR				COR			
Arrival Time (t) (minute)	Observed Frequency	P(t)	Theoretical Frequency	Arrival Time (t) (minute)	Observed Frequency	P(t)	Theoretical Frequency
1	4	0.0044	2.0	0	2	0.0011	0.45
2	5	0.0165	7.3	1	1	0.0073	3.00
3	20	0.0408	18.2	2	7	0.0249	10.23
4	41	0.0757	33.7	3	24	0.0568	23.34
5	41	0.1123	50.0	4	40	0.0972	39.95
6	74	0.1389	61.8	5	53	0.1332	54.75
7	61	0.1472	65.5	6	53	0.1520	62.47
8	67	0.1365	60.7	7	67	0.1488	61.16
9	44	0.1126	50.1	8	61	0.1274	52.36
10	32	0.0835	37.2	9	36	0.0969	39.83
11	31	0.0563	25.1	10	27	0.0664	27.29
12	12	0.0348	15.5	11	18	0.0414	17.02
13	6	0.0199	8.9	12	9	0.0236	9.70
14	2	0.0105	4.7	13	7	0.0124	5.10
15	3	0.0052	2.3	14	5	0.0061	2.51
16	2	0.0024	1.1	15	1	0.0028	1.15
	445	1.00	443.9		411	1.00	410.30

The interarrival time of tricycle observed for MAR and COR on Monday ranges between 1 and 16 minutes. The total tricycle observations for MAR is 445 and 411 was observed for COR. The tricycle arrival rate for MAR and COR are 27.81 and 25.69 respectively. The probability that 61 tricycles arrives in 7 minutes has the highest observed frequency with the probability of 14.72% for MAR while the probability that 53 tricycles arrives in 6 minutes has the highest observed frequency with the probability of 15.20% for COR.

Along with other similar data for Tuesday to Friday, the arrival rates of tricycles at the two study locations are increasing with a corresponding increase in their probability of arrival rates, this indicates that tricycles have been efficient with high arrival rates and corresponding high probability of occurrence. Therefore, tricycle as a paratransit mode of transportation has provided an alternative mode that is cheap, efficient and effective for the movement of both goods and commuters to and from the study locations. The Poisson probability distribution functions of MAR and COR from Monday to Friday are presented in Figures 2 and 3.

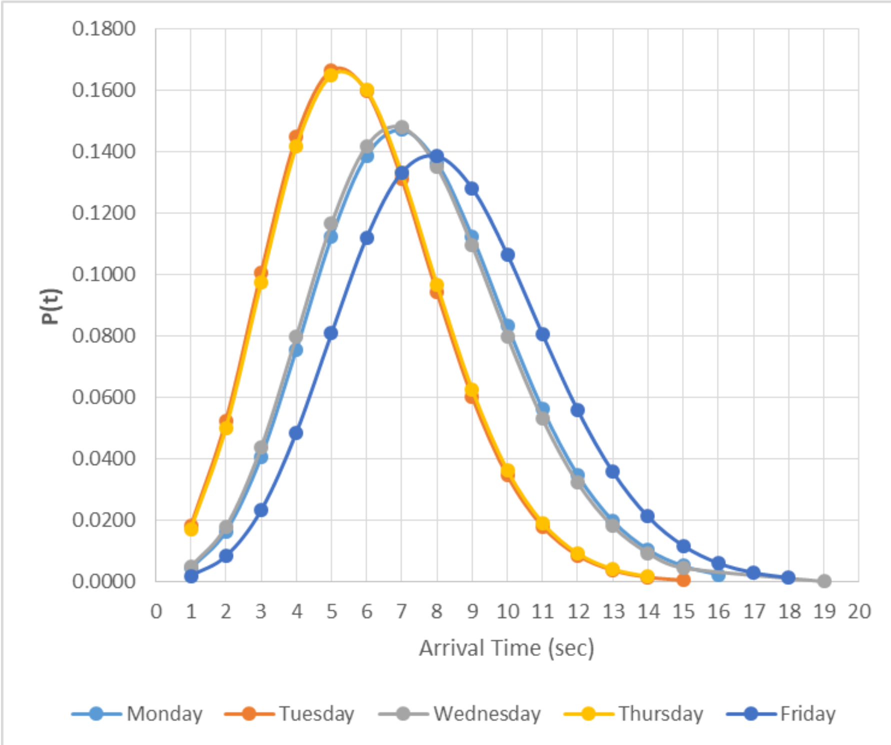

Figure 2: Poisson Distribution function for MAR.

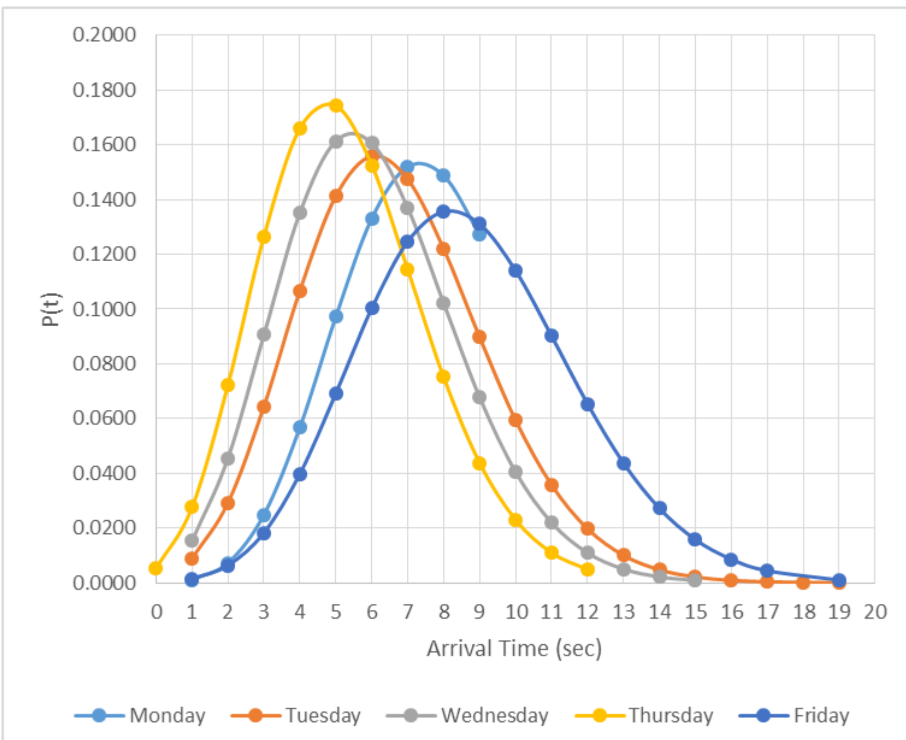

Figure 3: Poisson Distribution function for COR.

4.0 Conclusion

This research has focused on the stochastic analysis of the efficiency of tricycles as a public transportation mode in an urban city of Ibadan. Traffic volume and traffic composition data were collected at selected routes where the use of tricycles were prominent.

From this research, the percentage of tricycles compared to other modes of transportation is 16.85% and 26.97%. This affirms that the use of tricycle as a paratransit mode of transportation has increased in number and is acceptable to passengers. Tricycle occupancy measured ranged between 20% and 23% which affirmed that tricycles have been effective in moving a sizeable number of passengers and goods along the selected route. Respondents affirmed that tricycles have provided a cheap, effective and efficient alternative mode of transportation. The arrival rates of tricycles at the two study locations increases with a corresponding increase in the probability of arrival rates, this indicates that tricycles have been efficient with high arrival rates and correspondingly high probability of occurrence.

The use of tricycle has been effective and efficient as a paratransit mode of transportation, it is therefore recommended that government should monitor and regulate the activities of the tricycle operators. Adequate training should be given to the operators to boost their capacity. Special routes and parks should be created for tricycles where their operations will not interfere with the operations of other transportation modes and boost their service delivery.

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Environmentally friendly technique for making high-strength geopolymer concrete reinforced with animal fibers as food industry waste

Tehnică ecologică de producere a unui beton geopolimeric cu rezistență înaltă armat cu fibre animale ca deșeuri ale industriei alimentare

Lucian Păunescu[1], Adrian Ioana[2], Bogdan Valentin Păunescu[3]

[1] Cosfel Actual SRL
95-97 Calea Grivitei street, M4 room, sector 1, Bucharest 010705, Romania
E-mail: lucianpaunescu16@gmail.com

[2] University „Politehnica" of Bucharest, Faculty of Science and Materials Engineering,
313 Independence Splai, sector 6, Bucharest 060042, Romania
E-mail: adyioana@yahoo.com

[3] Consitrans SA
56 Polona street, sector 1, Bucharest 010504, Romania
E-mail: pnscbogdan@yahoo.com

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Abstract. *Applying the method of reinforcing cement-concrete with chicken feather fibers was extended to fly ash-based geopolymer concrete. Four manufacturing recipes were used, in which the fiber amount was modified between 6-9 kg·m^{-3} and NaOH molarity in the alkaline activator varied from 8M to 10M. Curing process of the fresh geopolymer was performed with 80 ºC-steam for 24 hours and then at room temperature for 36 hours. The specimen mechano-physical characterization was made after 7 and 28 days and the results showed obtaining high values of compression strength of 45.1 and 47.8 MPa and flexural strength of 14.5 and 15.6 MPa.*

Key words: *geopolymer concrete, chicken feather fiber, fly ash, alkaline activator, mechanical strength.*

Rezumat. *Aplicarea metodei de armare a betonului din ciment cu fibre din pene de pui a fost extinsă la betonul geopolimeric pe bază de cenușă zburatoare. Au fost utilizate patru rețete de fabricare , în care cantitatea de fibre a fost modificată între 6-9 kg·m^{-3}, iar molaritatea NaOH în activatorul alcalin a variat de la 8M la 10M. Procesul de îmtărire a geopolimerului proaspăt a fost efectuată cu abur la 80 ºC timp de 24 ore și apoi la temperatura camerei timp de 36 ore. Caracterizarea mecano-fizică a probei a fost făcută după 7 și 28 zile, iar rezultatele au arătat obținerea unor valori mari ale rezistenței la compresiune de 45,1 și 47,8 MPa și rezistenței la încovoiere de 14,5 și 15,6 MPa.*

Cuvinte cheie: beton geopolimeric, fibră din pene de pui, cenușă zburătoare, activator alcalin, rezistență mecanică.

1. Introduction

Cement-based concrete has long been considered the most used construction material, the change in its hierarchical position being due to the ecological and energy crisis that our planet is currently facing. Portland cement is the concrete component that generated to a great extent this serious crisis and, starting from the end of the last century, it seems that geopolymer concrete [1] has become the replacement material.

Traditional concrete had some disadvantageous features including low values of tensile strength, ductility, and energy absorption. The low level of tensile strength was explained by low toughness as well as structural defects and microcracks of concrete. The solution considered optimal for increasing toughness was the incorporation of reinforcing fibers [2].

The first mention in the literature of the use of fibers in the composition of concrete in the modern age of technology was in 1963 [3]. The first fibers were wires in a metal reinforcement placed into the concrete mass, having the role of avoiding the internal cracks propagation. Since from the 1960s, the reinforcement method with steel fibers dispersed in cement-based concrete has seen a wide development in construction. The decrease of shrinkage and implicitly, shrinkage cracking of fresh concrete during the curing process is one of the advantages of using fibers in the concrete structure. Theoretically, this crack type appears in the unreinforced material when the evaporation rate of water on the surface of concrete is greater than the rate of water migration from the inside to the surface. The shrinkage gradient causes the appearance of surface cracks, which can be counteracted for example by a very low volume of added steel fibers [2].

Other mechanical properties of concrete such as wear resistance, durability, and fatigue resistance have been improved by applying the fiber reinforcement technique not only in the field of buildings, but also in bridges, highways, airport runways, etc. In load-bearing applications, the use of steel fiber reinforcement is a frequently encountered procedure [2].

Normally, the concrete reinforcing fibers should be easily embedded in the volume of the material mixture, to be resistant in the cementitious medium and to develop a good mechanical strength. The main disadvantage of the use of steel fiber reinforcement still remained the high cost of corrosion-resistant steel fibers [4]. Except steel, other materials such as glass, natural cellulose, carbon, nylon, polyethylene, etc. are already known in the form of concrete reinforcement fibers [5, 6].

Different solid wastes such as rubber, paper, plastic, textiles, etc. present special interest of researchers for their use as concrete reinforcing fibers. Thus, the role of fibers recovered from residual tires on the concrete shrinkage was researched in [2] and recycled fibers from paper waste coming from used journals were analyzed for cement reinforcement [7]. Steel shavings have been tested as fibers in concrete [8] and food packaging waste has provided usable fibers in concrete subjected to extreme climatic conditions of successive freeze-thaw [9].

Various natural fibers coming from sisal, jute, coir, bamboo, hemp, flax, and others were experimentally investigated for their using in concrete structure. The results showed that sisal and coir fibers have the most important contributions to improving the mechanical features of concrete [10].

Among the natural fibers tested in concrete reinforcement, the use of animal fibers is obviously less frequent. Previous research has revealed that the protein called "keratin" identified in wool [11], mulberry silkworms, and poultry feathers [12-14] plays a major role in concrete reinforcing. According to the mentioned literature, chicken feather fiber is an excellent substitute for synthetic fibers. Feather barbs have a unique peculiarity regarding its cross-section, which is no longer found in other natural fibers based on protein (wool and mulberry silkworm).

By adding animal fibers to the initial material mix, higher durability and mechanical resistance have been experimentally proven in recent decades. Poultry feathers are still largely considered food industry waste and are thrown into landfills, harming the environment health in the respective areas. The qualitative influence of some mechanical properties of concrete due to poultry feathers embedded in its structure was tested [15]. Mainly, the flexural strength is favoured, while the material density decreases by comparing with ordinary concrete based on Portland cement. It was found that the flexural strength was improved after 14-56 curing days in the case of 1% of chicken feathers addition, while this mechanical effect was observed only after 56 curing days in the case of concrete with 2% of feathers addition. Increasing the proportion of feathers above this limit contributed to the decrease in flexural strength.

The present work aimed at the application of a still untested solution for manufacturing the fly ash-based geopolymer concrete using residual chicken feathers as an addition of natural animal fibers for the geopolymer reinforcement. In this situation, the components of the mixture have completely ecological features. Adopting the recent remarkable invention of the French researcher J. Davidovits [1], the geopolymer is manufactured on the basis of waste or industrial by-products consisting of alumino-silicate materials with pozzolanic properties, which have the ability to completely replace ordinary Portland cement. The conditions for manufacturing cement using the actual technology are totally inadequate to current ecological and energetic requirements, while coal fly ash used as a raw material in the geopolymer concrete composition is a by-product of the energy industry. In the experiment presented in this paper, the technique of activating the alumino-silicate waste indicated by the inventor was adopted, i.e. its contact with very alkaline aqueous solution consisting of NaOH and Na_2SiO_3 capable of developing the geopolymerization reaction. This complex reaction leads to the transformation of alumino-silicate waste into a geopolymer with excellent mechano-physical properties. The originality of the work is the use of natural animal fibers (particularly, chicken feather fibers) in the process of reinforcing the geopolymer concrete. Animal fibers have previously been applied in the case of cement-based concrete, but they have not been tested so far in the case of geopolymer concrete, practically the substitute of traditional cement-based concrete.

2. Materials and methods

So-called "barbs" of the chicken feather are the keratin-rich lateral parts, which start from the main branch of the feather. Several previous investigations presented in the literature on the chicken feather embedded in the concrete structure, showed the possibility of modifying mechanical and physical features of the traditional cement-based concrete. Barbs of the chicken feathers were cut with scissors at maximum lengths of 15 mm in preparing process for their use as reinforcing fibers in this experiment. Compared to other natural fibers (natural cellulose and wool), the density value of chicken feathers is significantly low (below 0.8 $g \cdot cm^{-3}$) [16]. According to the literature [17], chicken feather contains 82.36 % crude protein, 2.15 % crude fibers, 0.83 % crude lipid, 1.49 % ash, 12.33 % moisture. Its chemical composition includes 64.47 % carbon, 10.41 % nitrogen, 22.34 % oxygen, and 2.64 % sulphur. Processing feathers for their use in experiment included the following operations. First, the feathers were washed and sterilized with water deionised mixed with 6 % NaOH solution and detergent to remove dirt. Then, they were freely dried at room temperature (22-25 ºC) in conditions of relative humidity of 65 %, according to some recommendations taken over from [14, 16].

The basic recipes of making fly ash-based geopolymer concrete both in variants of making porous products and in variants of high-strength products are generally known from the literature.

According to the paper [18], in the manufacturing process of geopolymer concrete, it is indicated to use class F-fly ash characterized by the low content of CaO (below 5 %), because higher weight proportions can affect the geopolymerization reaction and the microstructure of the final product. Class F-fly ash represents the ash resulting from burning anthracite or bituminous coal. The ash used in the experiment was part of the batch of fly ash provided by Paroseni-Thermal Plant (Romania) in 2016, when the power plant used anthracite in the combustion process. The chemical composition of fly ash from Paroseni plant included 54.4 % SiO_2, 26.5 % Al_2O_3, 4.8 % Fe_2O_3, 3.5 % CaO, 2.5 % MgO, 1.5 % TiO_2, 0.4 % Na_2O, 0.6 % K_2O, 1.7 % SO_3, and 2.3 % LOI. The particle size of fly ash used during the experiment was below 60 µm obtained as a result of supplementary grinding, the initial size of ash being below 200 µm.

Alkaline activator adopted by authors was composed of 8M NaOH or 10M NaOH in form of solid flakes dissolved in deionized water and 38 %-Na_2SiO_3 aqueous solution. Na_2SiO_3/NaOH ratio had values in the range of 1.43-2.50.

The usual aggregates (fine and coarse) were also introduced into the composition of solid mixture. Silica-rich quartz sand was the fine aggregate (560 $kg \cdot m^{-3}$) having 98.9 % SiO_2. Its grain dimension was below 2 mm. Gravel (87.5 % SiO_2 and 6.1 % Al_2O_3) constituted the coarse aggregate, the grain size varying within the limits of 4-14 mm. Over 75 % of the amount of coarse aggregate (1290 kg·m^{-3}) had the grain size between 4-8 mm. The amounts of the two aggregate types were kept constant during the experiment.

The water addition amount was in the range of 5-15 kg·m^{-3}, being influenced by the NaOH molarity between 8M and 10M.

To make the geopolymer concrete reinforced with animal fibers, four testing versions were adopted according to the data in Table 1.

Table 1

Composition of the testing versions

Composition	Version 1 (kg·m^{-3})	Version 2 (kg·m^{-3})	Version 3 (kg·m^{-3})	Version 4 (kg·m^{-3})
Fly ash	410	410	410	410
Fine aggregate (sand)	560	560	560	560
Coarse aggregate (gravel)	1290	1290	1290	1290
Chicken feather fiber	6	7	8	9
8M NaOH solution	40	50	-	-
10M NaOH solution	-	-	60	70
Na_2SiO_3 solution	100	100	100	100
Water addition	5	5	15	15

The volumetric proportion of chicken feather fibers was tested in the range of 0.75-1.12 %, avoiding approaching the upper limit of the 2 % that affects the geopolymerization process [16]. Taking into account the fiber density value, their quantities were calculated at 6-9 kg·m^{-3}.

The first condition for processing geopolymer concrete is the separate preparation of the two types of mixtures (liquid and solid) in separate vessels. NaOH flakes (commercially available) dissolved in deionized water with molarities of 8M and 10M, respectively, were mixed with Na_2SiO_3 aqueous solution (also available on the market). Mixing was performed by stirring at a rate of 500 rpm for 5 min. Finely ground fly ash together with fine sand and coarse aggregate were mixed in another container for 3 min, then chicken feather fibers were added. Mixing was continued for another 3 min. The second step of the preparation process was pouring the liquid mixture containing the alkaline activator over the homogenized solid. Their mixing by stirring with a speed of 300 rpm for about 5 min took place until the formation of the gel. It was poured into several metal molds protected with thin plastic film. Introduced into a thermally insulated and sealed room, the fresh geopolymer was subjected to the curing process, first with steam at 80 ºC for 24 hours and then at room temperature for 36 hours. After completing this treatment, the hardened specimens removed from molds were also kept at room temperature until their characteristics were investigated, for variable periods of 7 and 28 days, respectively.

The investigation methods adopted for determining geopolymer concrete sample features are presented below. The density was measured based on the regular shape of the material by weighing it with an electronic balance and dividing this value to the calculated sample volume [19]. Apparent porosity was determined using the ISO

15901-2:2022 standard. The method of immersing the concrete specimen under water (ASTM D570) was used to evaluate the water volume absorbed by the material during 24 hours. 100 kN-compression fixture Wyoming Test Fixture was used for the identification of compression strength value of the geopolymer concrete [20]. The flexural strength measuring was carried out according to SR EN ISO 1412:2000. Biological Microscope MT5000 model (1000 x magnification) was used for analyzing the microstructural configuration of geopolymer concrete samples.

3. Results and discussion

Preparing the four testing versions of fly ash-based geopolymer concrete reinforced with chicken feather fibers was performed in laboratory conditions. After the curing treatment made in two stages, the first with 80 ºC-steam blowing for 24 hours and the second at room temperature for 36 hours, the cured products were investigated by usual mentioned methods for determining their mechanical and physical features after free storage at room temperature for 7 and 28 days, respectively.

Table 2

Main features of cured geopolymer concrete samples reinforced with chicken feather fibers

Feature	Version 1	Version 2	Version 3	Version 4
Density ($kg \cdot m^{-3}$)				
- after 7 days	2420	2406	2392	2384
- after 28 days	2435	2415	2398	2388
Apparent porosity (%)				
- after 7 days	23.1	23.3	23.4	23.5
- after 28 days	22.9	23.2	23.3	23.4
Compression strength (MPa)				
- after 7 days	44.8	45.0	45.1	45.1
- after 28 days	47.1	47.4	47.6	47.8
Flexural strength (MPa)				
- after 7 days	14.0	14.5	14.8	15.0
- after 28 days	14.5	14.9	15.3	15.6
Water uptake (vol. %) after 28 curing days	4.1	3.5	3.1	2.8

Changing the quantity of feather fibers from version 1 to version 4 between 6-9 $kg \cdot m^{-3}$ allowed to observe the structural modification of geopolymer influencing its density. It decreased from 2420 to 2384 $kg \cdot m^{-3}$ after 7 curing days as well as after 28 curing days from 2435 to 2388 $kg \cdot m^{-3}$. By increasing the keeping time of geopolymer concrete specimens from 7 to 28 days, a normal slight increase of the material density was observed.

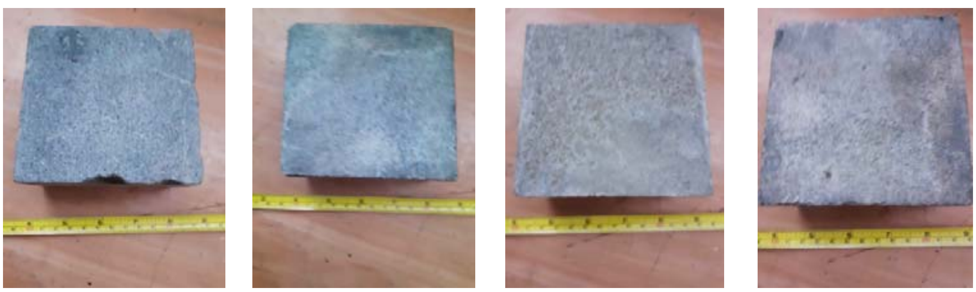
Normally, the apparent porosity is inversely influenced by the density value. In this experiment, the increase of porosity was insignificant both after storing the specimens for 7 days and after 28 days.

The use of animal fibers combined with the traditional technique of curing the fresh material led to reaching very high values of compression strength both after 7 days (44.8-45.1 MPa) and after 28 days (47.1-47.8 MPa). The increasing amounts of fibers in testing versions 1-4 influenced this strength, especially in the fiber amount range of 6-7 $kg \cdot m^{-3}$ and less in the range of 8-9 $kg \cdot m^{-3}$, in case of fresh products stored for 7 days and in the whole range in case of geopolymers stored for 28 days. Thus, the highest value of the compression strength (47.8 MPa) was reached by the specimen containing 9 $kg \cdot m^{-3}$ of chicken feather fibers (i.e. about 1.12 vol. %) stored for 28 days before measuring this mechanical strength type.

The influence of animal fiber addition on the flexural strength was beneficial keeping low enough volumetric proportion (below 2 %) not to cause the beginning decreasing trend of flexural strength experimentally found in [18]. According to the data in Table 2, the strength increased from 14.0 to 15.0 MPa after 7 curing days and from 14.5 to 15.6 MPa after 28 curing days. Flexural strength values were higher compared to other values of geopolymer concrete without natural fiber reinforcing.

Water uptake of geopolymer concrete specimens measured by immersion under water showed that volumetric proportions within the limits of 2.8-4.1 % were obtained. Increasing the amount of chicken feather fibers allowed lowering the level of absorbed water below 3 % in case of using 9 $kg \cdot m^{-3}$ of fibers. Almost similar results were obtained in case of manufacturing fly ash-based geopolymer concrete (without reinforcing fibers addition) presented in [21].

Appearance images of geopolymer concrete specimens reinforced with animal fibers are presented in Fig. 1.



a b c d

Fig. 1. Appearance images of geopolymer concrete specimens reinforced with animal fibers
a – testing version 1; b – testing version 2; c – testing version 3; d – testing version 4.

Microstructural pictures of specimens made with fly ash as alumino-silicate waste and reinforced with chicken feather fibers as animal fibers are shown in Fig. 2.

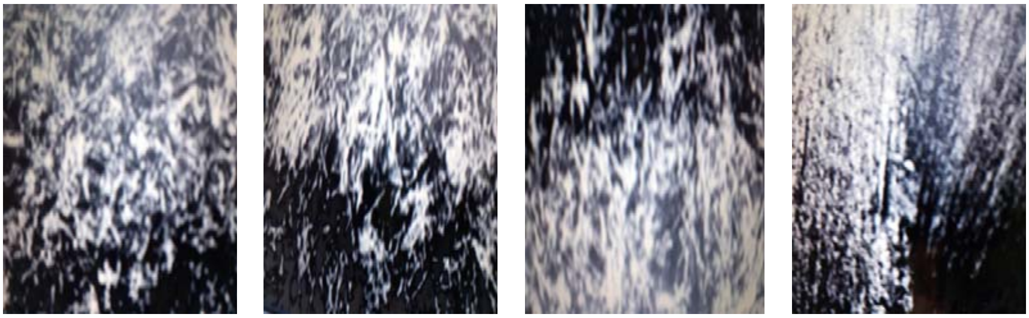


Fig. 2. Microstructural images of geopolymer concrete samples reinforced with animal fibers
a – testing version 1; b – testing version 2; c – testing version 3; d – testing version 4.

Images in Fig. 1 shows macrostructural compactness and robustness of all testing versions indicating very high mechanical strength of the made geopolymer samples. Fig. 2 indicates the presence of fibers in the microstructure of geopolymer samples composition in increasing volumetric proportion from version 1 to version 4.

The main concern of research in the field of manufacturing high-strength geopolymer concrete is to obtain high mechanical strength, especially compression strength. The addition of different fiber types applied to ordinary cement-concretes has proven to be effective. The best mechanical results were obtained with corrosion-resistant steel fibers. Recently, similar research on the use of steel fibers was also extended on geopolymer concretes [22, 23] and mechanical strength results were promising. Although the workability of the fresh geopolymer decreased with the increase in the content of fibers and the decrease in their diameter, the mechanical strength increased significantly, being reached extremely high values of compression strength (up to 180 MPa) in the particular case of slag-based geopolymer reinforced with steel fibers [24].

Geopolymer concrete is known as an inexpensive and environmentally friendly construction material using alumino-silicate waste and by-products. In the world, stainless steel fibers are very expensive products, their production involving high energy consumption. For this reason, in the current paper a type of animal fiber (poultry feathers) was chosen, which is practically a waste of the food industry in the field of poultry meat processing. The raw material is widely available, although the experiment presented above required only a very low amount of feathers supplied from a small private farm in Romania.

Except for the technical advantage of incorporating feather fibers in the manufacturing process of geopolymer concrete to increase its mechanical strength, the use of this animal waste contributes to regional environmental protection reducing the large amounts of feathers thrown into landfills.

It should be mentioned the important role of the curing process of fresh geopolymer (also applied in the case of ordinary cement concrete) on mechanical characteristics of the final product. Although, in principle, relatively similar steps are used, this process is adopted by the manufacturer having its own particularities. In the current experiment, authors applied their own curing mode, also used in other experiments with some changes. Considering the wide variety of mixture types used for the production of concrete, geopolymers or other similar construction materials the role of material type, amounts, processing degree before mixing, nature of admixtures, etc., on the one hand and the parameters of the curing process of fresh mixture, on the other hand, has not been precisely determined.

4. Conclusions

The main objective of the work was to test the reinforcement of a fly ash-based geopolymer concrete with chicken feather fibers. The volumetric proportion of these animal fibers was kept within a limited range between 0.75-1.12 % (i.e. 6-9 kg·m^{-3}) in order not to affect the efficiency of the geopolymerization reaction of transforming the alumino-silicate waste (fly ash) into a geopolymer. The principle of fly ash activation was achieved through the method recommended by the remarkable Davidovits' invention, using aqueous solution of NaOH and Na_2SiO_3. Chicken feathers are residual materials of the food industry containing over 85 % keratin protein. The paper originality consists in the use of poultry feathers, non-tested in the world for reinforcing in the manufacturing process of geopolymer concrete. The own technique adopted for curing the flesh geopolymer concrete consisted of treatment by blowing steam at 80 ºC for 24 hours, followed by room temperature-curing for 36 hours. The investigation of physical and mechanical features of specimens was performed after their freely keeping at room temperature for 7 and 28 days, respectively. The feature values after 7/28 days corresponding to the optimal version (with 9 kg·m^{-3} of chicken feather) were: 2384/2388 kg·m^{-3} for density, 23.5/23.4 % for apparent porosity, 45.1/47.8 MPa for compression strength, 14.5/15.6 MPa for flexural strength, and 2.8 vol. % after 28 curing days for water uptake.

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Modernization of the district heating system in Timisoara through the integration of RES in heat points. Case study

Modernizarea sistemului de termoficare din Timisoara prin integrarea RES in punctele de caldura. Studiu de caz

Daniel Muntean, Adriana Tokar, Dănuț Tokar, Alexandru Dorca

[1]Politehnica University of Timisoara, Faculty of Construction
Str. Traian Lalescu Nr. 2, 300 223, Timişoara, Jud. Timiş, România
daniel-beniamin.muntean@student.upt.ro, adriana.tokar@upt.ro, daunt.tokar@upt.ro, alexandru.dorca@upt.ro

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Abstract. *The increase in global temperature and the current energy context have brought the district heating system in Timișoara (partialy renovated) to the brink of collapse. Therefore, major investments and orientation towards the integration of renewable energy sources (RES) are required. The article analyzes, by exemplifying a case study, the integration of photovoltaic technologies at a heat point that supplies the buildings of the Faculty of Construction (CT) in Timișoara. The study was carried out with the help of Polysun software. The results obtained indicate a reduction in thermal and elctrical energy costs of 38.51% by installing a number of 1095 photovoltaic (PV) panels on the roof of 4 building bodies (ASPC, Deposit, CT and Metal).*

Key words: *heating system, RES*

1. INTRODUCTION

In Romania, heating systems represent one of the most polluting public services through the large amounts of CO_2 emissions per Gcal [1], [2], [3], [4]. By particularization, regarding the heating system in Timișoara (completely unrenovated), the problems of the global context related to the increase in global temperature and the current energy crisis have brought this system to the brink of collapse. The abandonment of heating systems cannot be questioned because the main energy supply networks (electrical and thermal) in Romania (the electricity supply network and the combustible natural gas supply network) cannot take over the provision of thermal energy, not being dimensioned for such a high consumption, a fact that requires the upgrading of heating systems [5].

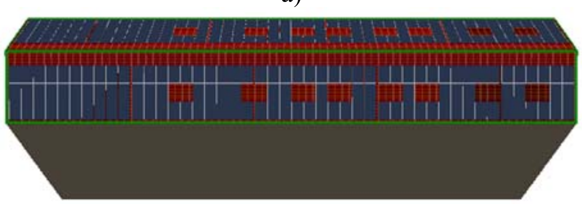
So, overcoming the crisis in which the district heating system in Timișoara is, and not only, requires major investments and orientation towards the integration of renewable energy sources (SRE).

Therefore, the article presents a case study applied to a heat point that supplies thermal energy to the heating installations related to the building bodies (Main Building, Warehouse, Metal Building and ASPC) of the Faculty of Construction in Timișoara. The heat point is connected to the centralized heating system in Timișoara through the secondary thermal network to the final consumers [4], [6], [7]. The energy efficiency solution consists in the installation of photovoltaic panels on the roof of the buildings that are part of the Faculty of Construction, in order to reduce thermal and electrical energy costs.

2. SIMULATION OF THE PHOTOVOLTAIC SYSTEM. CASE STUDY

The ensemble of buildings within the Faculty of Construction (Faculty of Construction main building body (CT), warehouse building body (W), Metal building body (M) and ASPC building body (ASPC) that were the subject of the study and the positioning of the photovoltaic panels (PV) on the roof of the 4 building bodies are shown in Figure 1 [8].

a)



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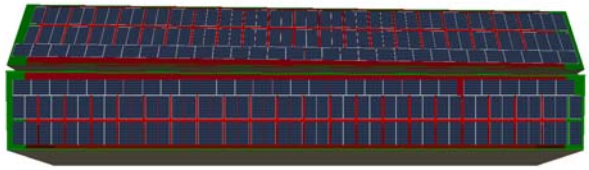

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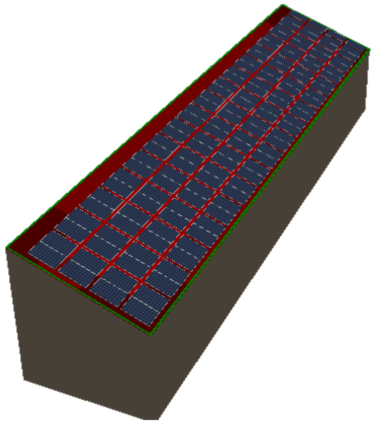

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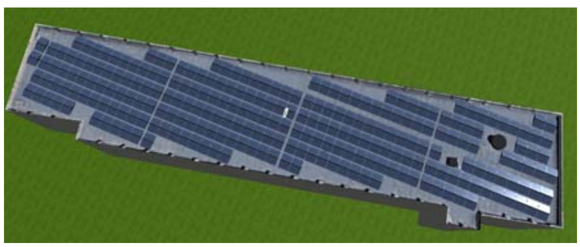

e)

Figure 1. The ensemble of buildings of the Faculty of Construction
a) Overview, b) PV positioning on CT body, c) PV positioning on Metal body, d) PV positioning on Warehouse body, e) PV positioning on ASPC body

To carry out the study, with the help of Polysun SPTX Constructor [8] and Polysun Designer [9] programs, the possibility of installing a 200kW air-water heat pump and a photovoltaic system to supply electricity to the heat pump was simulated. In the existing situation, the four building bodies are supplied with thermal agent for heating and domestic hot water from the heat point which is connected to the secondary circuit of the heating network of the city of Timișoara.

Table 1 presents the input data on the basis of which the simulation was performed.

Table 1 Input data – available surfaces, consumption and heat demand (existing situation)

Building	Roof surface [m^2]	Electricity consumption [MWh/an]	Electricity consumption from NES [MWh/an]	Thermal requirement for heating [MWh/an]
ASPC	1850	60	57,3	58,50
M	660	25	23,88	19,15
D	420	10	9,55	3,50
CT	600	120	114,60	95,73
Total	3530	215	205,325	176,87

According to Table 2, the simulation showed that it is possible to install a photovoltaic system with a total installed power of 194.4 MW by mounting 1095 EvoloCells 400 MIB 400W photovoltaic panels covering a total surface of 3530m2 of roof. Four SMA Sunny Tripower CORE2 STP 110-60 inverters (maximum efficiency of 98.6%) and 20 REACT-3.6TL 6kWh type storage batteries were chosen for the photovoltaic system.

Table 2 Output data – photovoltaic system [8], [9]

Building	Number of panels [buc]	Installed power [MW]	The amount of electricity produced [MWh/an]
ASPC	486	194,4	64,50
M	233	52,8	17,52
D	132	93,2	30,92
CT	244	97,6	32,38
Total	1095	438	145,32

The principle diagram of the existing heat supply system of the building complex is presented in Figure 2, and that of the proposal for the modernization of the thermal point, in Figure 3.

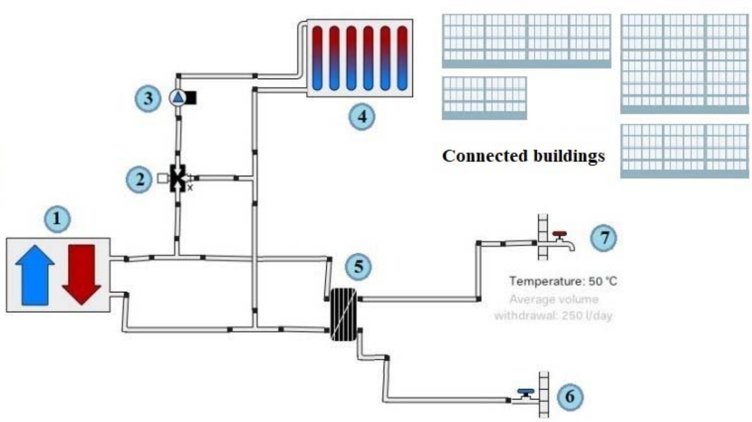

Figure 3. Principle diagram of the existing system [9]
1 – Heating network, 2 – Mixing valve, 3 - Circulation pump, 4 - Internal heating installation, 5 - Hot water heat exchanger, 6 - Cold water supply, 7 - Hot water consumers

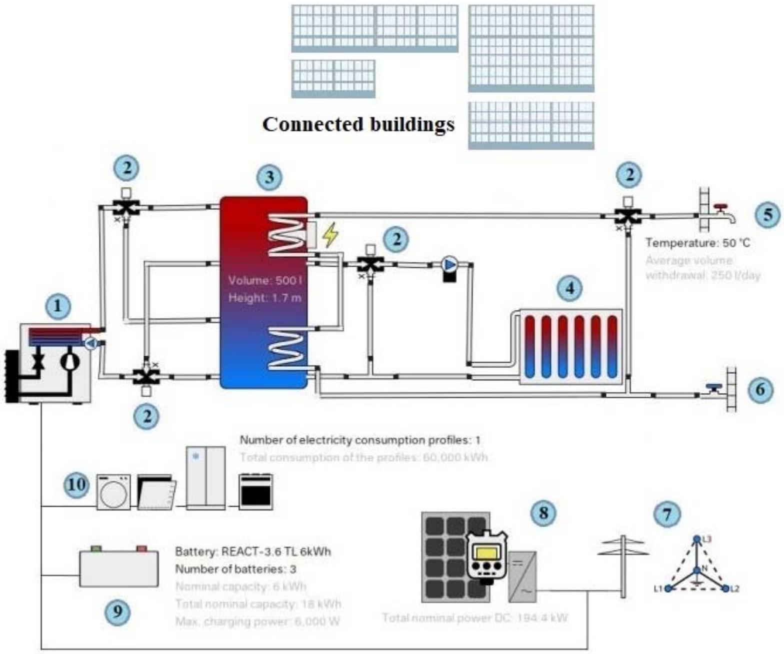

Figure 3. Principle diagram of the proposed system [9]
1 - Heat pump, 2 - Mixing valve, 3 - 1000 liter storage tank, 4 - Indoor heating system, 5 - Hot water consumers, 6 - Cold water supply, 7 -NES, 8 - PV system, 9 - Storage batteries, 10 - Electricity consumers

3. COMPARATIVE ANALYSIS OF COSTS. EXISTING SITUATION VS. MODERNIZATION

For the comparative analysis between the two situations of the system (existing vs. modernized), the consumption of thermal energy from the local heating system and the consumption of electricity from the SEN were taken into account for all four buildings considered (Table 3).

For the calculations, a price of 1008.65 lei/MWh (205.85 Euro/MWh) was considered for thermal energy and respectively 1500 lei/MWh (306.12 Euro/MWh) for electricity.

Table 3 Total costs existing system vs. modernized

Type and source of energy	System status	Consumption [MWh]	Price [Euro]	Total cost [Euro]
ASPC building				
From district heating	E	58,50	12.042,05	30.409,39
Electricity from NES		60	18.367,35	
From district heating	M	0	0,00	17.540,82
Electricity from NES		57,3	17.540,82	
Metal building				
From district heating	E	19,15	3.941,03	11.594,09
Electricity from NES		25	7.653,06	

Type and source of energy	System status	Consumption [MWh]	Price [Euro]	Total cost [Euro]
From district heating	M	0	0,00	7.308,67
Electricity from NES		23,88	7.308,67	
Warehouse building				
From district heating	E	3,50	720,46	3.781,69
Electricity from NES		10	3.061,22	
From district heating	M	0	0,00	2.923,47
Electricity from NES		9,55	2.923,47	
CT building				
From district heating	E	95,73	19.705,17	56.439,86
Electricity from NES		120	36.734,69	
From district heating	M	0	0,00	35.081,63
Electricity from NES		114,60	35.081,63	

Note: E - Existing, M - Modernized

From the cost analysis presented in Table 3, it can be seen that a reduction in energy costs is obtained, of 42.32% for the ASPC building, 36.96% for the M body, 22.69% for the D body and 37.84% for the body CT, which will represent a reduction of 38.51% for the heat point feeding the four building bodies.

Also, for the proposed photovoltaic system, an electricity flow diagram was generated (Figure 4) based on the monthly electricity consumption/surplus of the proposed photovoltaic system for installation.

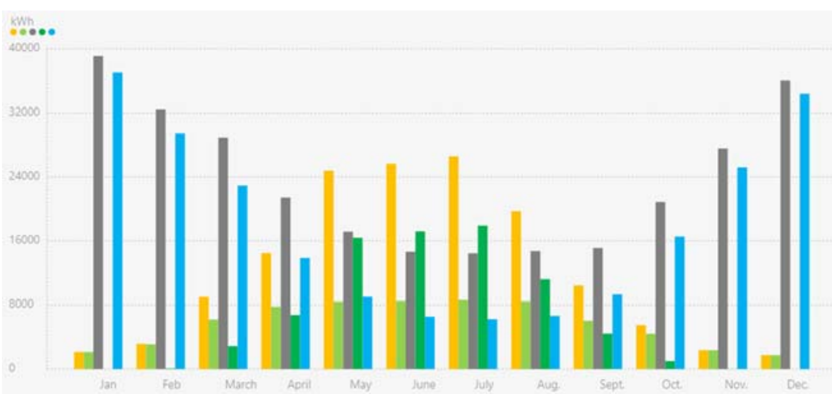

Figure 4. Annual energy flow diagram for the photovoltaic system [8]

	Energy production [kWh]
	Total consumption [kWh]
	Consumption from NES [kWh]
	Consumption from the PV system [kWh]
	Injection into NES [kWh]

From the analysis of Figure 5, it can be seen that during the summer months the energy surplus generated by the photovoltaic system is considerable.

Considering the injection problems in the SEN, as a future research direction, an analysis of the use of the surplus for cooling the spaces or use for other purposes is proposed, considering that in these spaces, during the summer, the activity is restricted.

4. CONCLUSIONS

The proposed measures aim at the sustainable rehabilitation of heating networks, in accordance with the policy of reducing energy consumption and CO_2 emissions.

The solutions analyzed through the case study have as main conclusions:

- SRE integration at the level of heat points, which is a necessity for the rehabilitation of heating systems;

- the hybrid system: heat pump and photovoltaic panels, is a viable system for the rehabilitation of heat points considering the reduction of annual costs by 38.51% obtained through simulation.

- expanding the prosumer concept, respectively the hot water supplier concept, as a storage solution for the surplus of captured photovoltaic energy.

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For a better definition of 'quality' in construction projects

Pentru o mai bună definire a „calității" în proiectele de construcții

Hadi Ghorbani Aghbolaghi[1], Prof. Constantin Militaru[2]
[1]Politehnica University of Bucharest
Splaiul Independenței, no. 313, District 6, Bucharest, Romania
Arh_hadi@yahoo.com

[2]Politehnica University of Bucharest
Splaiul Independenței, no. 313, District 6, Bucharest, Romania
Prof_militaru@yahoo.com

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Abstract. *As quality becomes a more and more weighty concept in the field of construction, as a general client expectation on the one hand, as well as a constructor/developer commitment and claim, on the other hand, we have found that there is no such thing as a specific definition of it. As such, in the present paper we have sought to put together a clearer and more practical perspective on what 'quality' actually means – or should mean – in construction projects, in addition to coming up with recommendations for establishing and meeting such requirements throughout the duration of a project.*

Key words: *Construction Project, Quality Definition, Stakeholders, Design, Project Requirements*

1. Introduction

The notion of quality refers to how good or bad something is, a characteristic or feature that something (or someone) has.

On a first try, quality can be defined as meeting the legal, aesthetic and functional requirements of a project. These requirements may be simple or complex, or they may be stated in terms of the expected end result or as a detailed description of what is to be done. However expressed, though, (a general standard of) quality is considered to be achieved if the completed project conforms to the initial requirements, but also if these requirements are adequate.

Law defines quality in terms of professional liability, a legal concept that requires all professionals to know their trade and practice it responsibly. Every architect and engineer who offers his or her expertise to owners is subject to professional liability laws.

Some design professionals believe that quality is measured by the aesthetics of the facilities they design. According to Stasiowski and Burstein [1], this traditional definition of quality is based on such issues as how well a building blends into its surroundings, a building's psychological impact on its inhabitants, the ability of a landscaping design to match the theme of adjacent structures, and the use of bold new design concepts that capture people's imaginations. Because aesthetic definitions of quality are largely subjective, major disagreements arise as to whether quality has been achieved or not. Since objective definitions of aesthetic quality do not exist, design professionals generally take it upon themselves to define the aesthetic quality of their designs.

Quality can also be defined from the view point of function, that is by how closely the project conforms to its requirements. Using this definition, a high quality project can be described by such terms as ease in understanding drawings, the level of conflict in drawings and specifications, the economics of construction, the ease of operation, ease of maintenance and energy efficiency.

In the construction industry, quality can be defined as meeting the requirements of the designer, constructor and regulatory agencies, as well as the owner. According to an ASCE study [2], quality can be characterized as follows:

• Meeting the requirements of the owner as to functional adequacy; completion on time and within budget; life-cycle costs; operation and maintenance.

• Meeting the requirements of the design professional as to the provision of a well-defined scope of work; the budget to assemble and use a qualified, trained and experienced staff; the budget to obtain adequate field information prior to design; the necessary time for making decisions, for the owner and design professional; the contract to perform the required work, at a fair fee and with an adequate time allowance.

• Meeting the requirements of the constructor as to the provision of contract plans, specifications and other documents prepared in sufficient detail in order to allow the constructor to prepare the pricing proposal or competitive bid; timely decisions of the owner and design professional in regards to the authorization and processing of change orders; fair and timely interpretation of contract requirements from field design and inspection staff; contract for performance of work on a reasonable schedule, which will yield a reasonable profit.

• Meeting the requirements of regulatory agencies (the public) as to public safety and health; environmental considerations; protection of public property, including utilities; conformance with applicable laws, regulations, codes and policies.

A modern definition of quality can be derived from Juran's "fitness for intended use", which basically says that quality is "meeting or exceeding customer expectations" [3]. So, who is the customer? Firstly, customers may be either internal or external. Satisfying their needs and requirements is an essential part in the process of delivering a quality product to the final external customer.

Secondly, Juran claims that each of the three parties involved in a process (supplier, processor, and customer) has a "triple role". Figure 1 shows Juran's "triple role" concept applied to construction. The designer is the customer of the owner because the former needs to receive the project requirements from the latter in order to provide a feasible design. Further on, the designer supplies the plan and specifications to the constructor; in this case the constructor is the designer's customer, because the constructor uses the designer's plans and specifications, then conducts the construction process and finally supplies the completed building to the owner. The owner is now the constructor's customer. Quality in each phase is affected by the quality in the preceding phases. Therefore, customer service in each phase is important for the overall quality performance of the process.

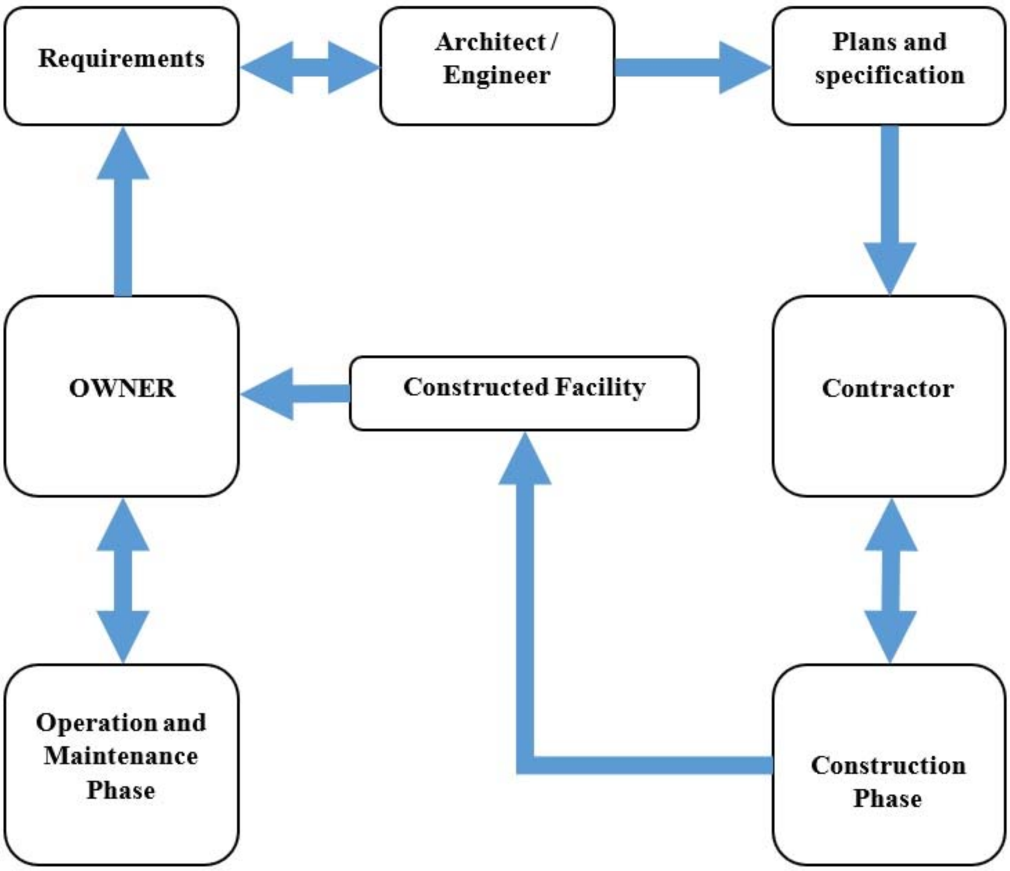

Fig. 1. Phases of the Construction Process

2. Quality in the designing process

The standard of design quality required of a project should be defined by the client. It must be noted that design quality is not always the primary objective for the client, as time or saving costs may be more important to him. Furthermore, it is realistic to specify and expect very high standards of design quality only if the budget to achieve these standards is available.

Design quality too can have a number of different meanings, so it needs to be defined in a clear-cut way, that is measurable and testable – and can also be prioritized. An important recommendation in this respect is that the client should appoint an internal senior design expert to take on the responsibility of ensuring the design achieves the required design quality.

The aspects of a design that might be assessed are various are include the following:

- How well the design represents the client's values.
- How well the design creates places for entry, reception, breaks, catering and so on.
- The impact on the local community and environment.
- Whether the design is accessible and welcoming.
- Accessibility for people with disabilities.
- Quality of views and outlook.
- The internal environment: lighting, heating, air quality, acoustics etc.
- The comfort provided by furniture.
- Use of color, texture, light and architectural features to enliven the environment.
- Overall standard of materials and finishes (including life-span and maintenance issues).
- Sustainability of materials.
- Build quality and robustness of systems, finishes and fittings, furniture and equipment.
- Energy consumption and pollution, both during construction and use of the building.
- Whether the design promotes reduction, reuse and recycling of materials.
- Whether the design exploits opportunities for standardization and prefabrication.

If the client has little experience in design and construction projects, they may wish to appoint an independent client adviser.

3. Contract documentation

The contract documentation describes the design that the contractor is being paid to build. It will include a series of specifications describing the materials and workmanship required.

The various aspects of the works are generally specified by:

- Products (defined by standard, a description of attributes, naming (perhaps allowing equivalent alternatives) or by nominating suppliers.

- Workmanship (defined by compliance with manufacturers' requirements, by reference to a code of practice or standards or by approval of samples or testing).

It should be possible to verify standards of products and workmanship by testing, inspection, mock-ups, samples and documentation such as manufacturers' certificates. These requirements need to be set out in the contract documentation.

4. Construction process

The contractor's obligation is to carry out and complete the works in a proper and workmanlike manner, as indicated in the contract documents. This means that the contractor must carry out the works with reasonable skill and care, to the reasonable satisfaction of the contract administrator.

The quality of materials and standard of workmanship might be controlled by the contractor on site, by implementing a quality plan. The plan establishes the resources required and associated documents (lists, purchasing documentation, machinery, equipment etc.) and the control activities (verification of compliance with specifications, validation of specific processes, monitoring of activities, inspections and tests). These activities can be carried out by inspection, testing plans, action plans and, where applicable, specific tests (for example, load tests for structures).

The standard of workmanship can be improved by providing adequate training, appropriate instructions and clear checklists, as well as ensuring there is on-site supervision and monitoring, as well as an ongoing process of feedback between the parties, to allow for continuous improvement.

In addition to the contractor's own quality control measures, site inspectors working on behalf of the client will inspect the works as they proceed, in order to verify the compliance with the requirements of the contract documents. Site inspectors may be based on site permanently or may make regular visits. Specific inspections may also be carried out during the construction phase, as part of the general contract administration process.

5. Design control

This activity calls for the development of procedures for the control and verification of the design of the product, in order to meet the specified requirements, for the identification of design activities, the definition of user/customer specifications (design input), the expression of design output in terms of requirements and its verification in meeting user specifications and, similarly, for the control of design changes. Goulias [4] addressed the development of pavement quality assurance specifications and defined criteria for selecting the best specification to be used in different construction processes, for a particular product or project, by assessing the suitability of the types of each specification. The Mallon and Mulligan [5] approach considered quality function deployment (QFD) as a methodology during the design phase to allow for better decisions, focus project budgets, define project quality and meet customer's needs. QFD consists of expressing customer requirements (e.g., security) into quality characteristics (e.g., exterior door), and deploying a series of relationships (e.g., correlation) between them to develop a design quality. QFD has been widely addressed in the construction industry – Sikorsky [6], Diaz-Murillo [7], Ahmed [8], Oswald [9] – as a model to understand and develop priorities for customer requirements. East et al. [10] adopted a case-based reasoning in developing a prototype computer-based system as a tool to assist design reviewers in capturing, documenting, and retrieving design-review comments and thus providing lessons to be learned. This approach improves the design-review process, which requires reviewers to examine plans and specifications, identify potential errors and deficiencies based on a culmination of past experience and references, and list review comments for designers and other reviewers.

Among the identified challenges were the segregation of functional aspects best performed by human or machine and the appropriate representation and structure of data. Case representation, indexing mechanism, storage and retrieval means and method for case adaptation have been tackled by exploiting a relational database system for implementation. A prototype expert critiquing system has been developed and implemented for the assistance of both designers and reviewers in the design and review processes, of flat and low-slope structure roof [11].

The support environment for design and review (SEDAR) derives its supporting functional duties from error prevention, error detection, design review critiques and design suggestion critiques. Its method for structuring its critiques was induced from the way roof designers break the roof design into smaller subtasks related to the layout of roof subsystems. It provides a flexible means of tracking the progress of roof designers and advising at appropriate intervals during the design process. The user interface was channeled in a design environment built on a CAD system and offers a direct manipulation of the design and textual/graphical display of critiques derived from condition-action rules about constructability – compiled partly in East et al. [11].

6. Review and further discussion

Construction projects are a balance between cost, time and quality. One of these will almost always be presented as a type of constraint by the sponsor or client, so that it may be possible to have high quality and low cost, but at the expense of time, and, conversely, to have high quality and a fast project, but at a cost. If both time and money are restricted, then quality is likely to suffer. High quality is not always the primary objective for the client; time or cost may be more important. A very high standard of quality can be achieved only if the necessary budget to achieve it exists.

When defining quality objectives, the client should consider:

- Available funding and time.
- Existing corporate policies (such as environmental policies).
- Key requirements of the business.

- Key requirements of stakeholders.
- The views of external organizations, such as the local planning authority.
- Local and national legislation (for example, the local planning requirements for energy use).

As quality in construction has yet no universally accepted definition, it is vitally important that briefing documents in the planning phase of a project set out clearly the quality requirements that are to be met. Specific standards of quality can generally be defined, prioritized and measured quite precisely and criteria weighting can help in the appraisal of design options, in particular where conflicting views exist amongst stakeholders.

7. Conclusions

In conclusion, quality in construction projects refers to the level of performance, reliability and durability of the end product, as well as to the safety and satisfaction of the end user. The definition of quality in construction projects is that the work meets or even exceeds the expectations of stakeholders.

Quality should always be a priority in any construction project, as it is essential for its successful outcome. In general, quality is considered to be achieved when the project is completed on time, within budget and with minimal risks – but also when the project meets the stated goals and objectives of the stakeholders.

In addition to clarifying what quality in construction means – or should mean –, in the present paper we have shown that quality assurance processes and procedures must be in place in order to confirm these standards are met and maintained throughout the project. This is an essential requirement for the successful completion of any construction project.

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Using VR to explore the 3D city model obtained from LiDAR data

Folosind VR pentru a explora modelul de oraș 3D obținut din datele LiDAR

Anca Patricia Grădinaru[1,*], Ana-Cornelia Badea[1], Petre Iuliu Dragomir[1]

[1]Surveying and Cadastre Department, Faculty of Geodesy, Technical University of Civil Engineering Bucharest, Romania
Bulevardul Lacul Tei, nr. 122-124
**E-mail: anca-patricia.gradinaru@utcb.ro*

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Abstract. *3D city models are tridimensional representations of cities, focused on buildings that can be used as a base for numerous analyses such as heat demand estimation, solar radiation estimation, visibility analyses, noise analyses, or for urban and emergency situations planning. Geospatial data used to develop such models can be acquired through different methods, one of them being using a LiDAR point cloud. Virtual Reality can be a useful tool in exploring these 3D city models and may offer a better understanding of the different situations that need to be analyzed. The aim of this paper is to investigate the possibilities of exploring the 3D model of Baia Mare city in a VR environment.*

Key words: *3D City Model, LiDAR, Virtual Reality*

1. Introduction

A 3D city model is a tridimensional representation of the built environment. A semantic 3D city model contains, additionally to the geometric information, other elements of urban knowledge, attributes of the represented objects and spatial relationships between the objects [1]. These city models are used in various applications such as underground land administration [2], life cycle assessment of building energy systems [3], city-scale ventilation analyses [4] and life cycle assessment of building stocks [5]. 3D city models can also be used to assess the energy demand of an urban area [6], [7], to calculate the amount of sun exposure of a building, in order to predict the efficacy of installing solar panels [8], to estimate the seismic damage [9], to plan the response in case of emergency situations [10] and in many other applications, synthesized in a study by Biljecki et al. [11]. 3D city models can be a tool to increase the energy efficiency and mitigate the effects of the climate changes [12]. Therefore, the

Smart City concept was introduced and it represents a solution to mitigate the impact that rapid urbanization and population growth have on the environment [13].

3D city models can be generated from different types of geospatial data, obtained through various techniques, such as TLS (terrestrial laser scanning) [14], [15], MLS (mobile terrestrial laser scanning) [16], [17], [18], ALS (airborne laser scanning) [19], [20], photogrammetry [21], [22], or a combination of ALS and photogrammetry [23].

While many papers focus on the data acquisition and 3D modelling of the buildings, they don't seem to address the visualization issue, which is essential for a better understanding of the various analyzed situations. In a study by Li et al., 2022 [24], a non-photorealistic visualization of 3D city models in a VR (Virtual Reality) environment was proposed. While this representation can be useful for experts in numerous fields, it may be difficult to comprehend for the general population. In this article, we aim to investigate the possibilities of exploring a 3D city model obtained from LiDAR (Light Detection and Ranging) data in a VR environment.

2. Materials and methods

Laser scanners use opto-mechanical assemblies that utilize an emitted laser beam and a received portion of the beam to determine the distance between the sensor and the object [25] by measuring the time of propagation [26].

ALS (Fig. 1) is one of the most used methods of geospatial data acquisition that allows collecting a large volume of data from platforms such as UAVs (Unmanned Aerial Vehicles), planes or helicopters. The main components of an airborne laser scanner are [26]:

- ✓ Scanner assembly, composed of laser, scanning mechanics and optics;
- ✓ Airborne GNSS (Global Navigation Satellite System) antenna;
- ✓ Inertial measurement unit (IMU), that records acceleration data and rotation rates;
- ✓ Control and data recording unit;
- ✓ Operator laptop;
- ✓ Flight management system.

Additionally, a GNSS ground station is required, to serve as a reference station.

The result of airborne laser scanning is a LiDAR point cloud, such as the one in Fig. 2 that represents a collection of object points with a known and accurate 3D position.

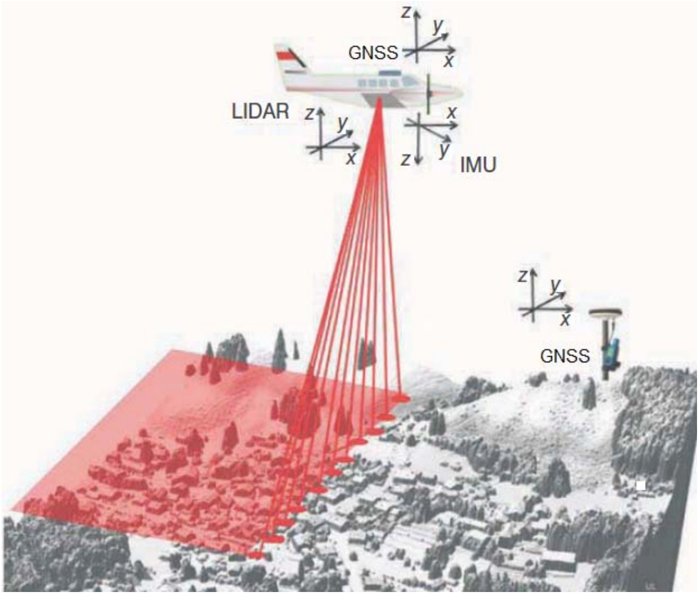

Fig. 1. Principle of airborne laser scanning [26]


Fig. 2. LiDAR Point Cloud

3D city modelling from a LiDAR point cloud involves point cloud classification, in order to determine the class that each point belongs to (ground, building, low vegetation, medium vegetation or high vegetation) and buildings footprint extraction. To generate the 3D city model of an area in Baia Mare City, we classified the point cloud in Fig. 2, each point being assigned one of the classes from Fig. 3 and we extracted the buildings footprints (Fig. 4) using a trained Deep Learning model. CGA (Computer Generated Architecture) rules were applied in CityEngine to generate the 3D models of the buildings. The rules included generating the streets, extruding the buildings footprints to a certain height derived from the LiDAR point cloud, modelling of the floors, windows and doors and adding textures to the surface. We obtained the 3D model of an area from Baia Mare city (Fig. 5) [27].

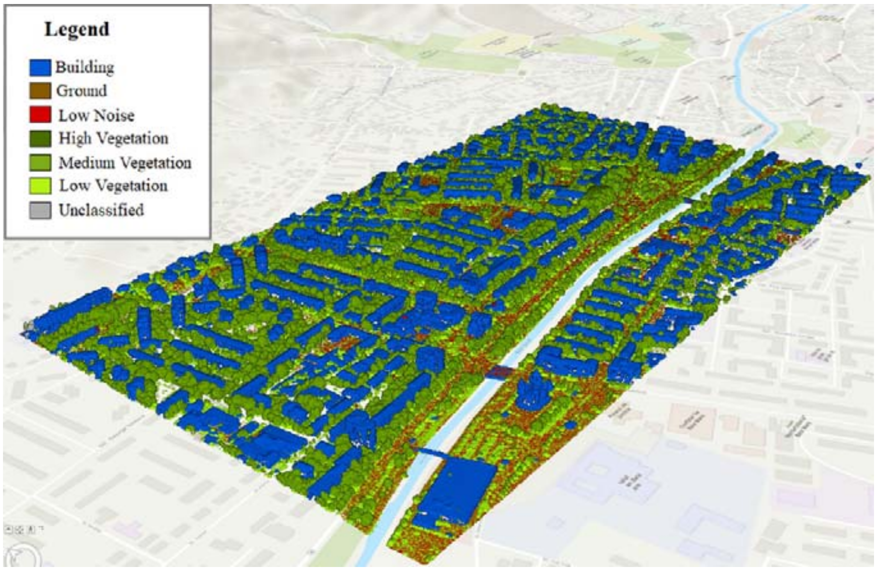

Fig. 3. Classified LiDAR point cloud

Fig. 4. Buildings footprints

Fig. 5. 3D model of an area in Baia Mare city

3. Creating a virtual reality application

In order to create the virtual reality application, we used ArcGIS 360 VR Experience.

We added the bookmarks in Fig. 6, which are used to navigate the virtual model on a desktop application (Fig. 7), on a mobile application (Fig. 8) or in a VR environment, using a VR headset. On the desktop application, the view can be changed by using the mouse cursor, while on mobile, the view can be changed by tilting and moving the device. When using a VR headset, the user can change the view by moving around.

Fig. 6. Bookmarks

Fig. 7. Virtual model of the city on a desktop app

Fig. 8. Virtual model of the city on a mobile application

Unreal Engine is a 3D computer graphics engine, used to create visuals and immersive experiences [28]. While it is mostly used for videogames, it can also be used to enhance the visualization and exploration of 3D city models.

In this regards, we exported the model in a *.udatasmith format, a file standard used to import 3D scenes into Unreal Engine projects [29]. Then we imported the model in Unreal Engine (Fig. 9) for further editing. We added realistic textures of the sidewalks, soil, building walls and roofs, and other objects such as the total station in Fig. 10. We also edited the lighting, sun brightness and cloud opacity to achieve a more realistic view of the area.

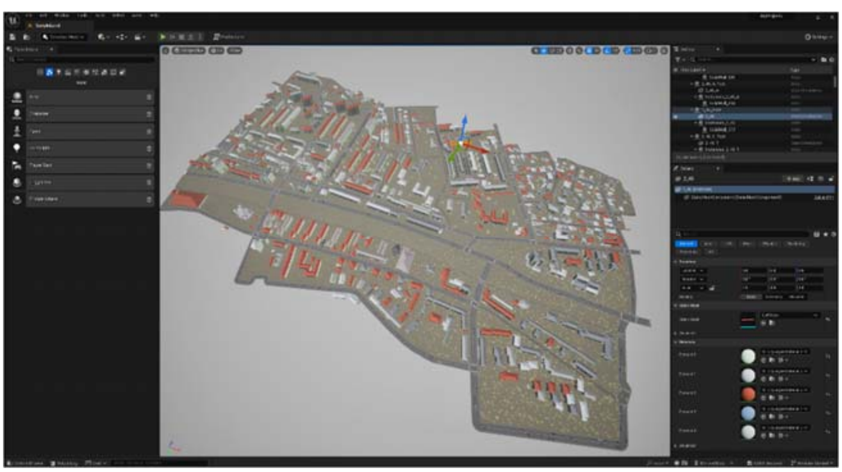

Fig. 9. 3D city model in Unreal Engine

4. Results and conclusions

3D city models can serve as a base for numerous analyses that support decision making and urban sustainability. The accuracy of these models depends on the data used to generate them and ALS is an efficient solution to acquire large amount of data in a short time.

Deep Learning models that use convolutional neural networks are the actual standard for LiDAR point cloud classification and building footprint extraction and can lead to accurate 3D city models.

By applying CGA rules to the buildings footprints, the buildings can be modelled in detail, with elements such as windows and doors.

VR visualization of the city model allows a better understanding of the analyzed situations and can lead to more efficient decisions. When comparing the models obtained in CityEngine and the models obtained in Unreal Engine, we noticed that by importing and editing the 3D model in Unreal Engine, we obtained a more photorealistic representation that can describe the reality more accurately than CityEngine alone (Fig. 10).

Fig. 10. Comparison between the CityEngine model and the Unreal Engine model

Therefore, we propose the following workflow for using VR to explore the 3D city model obtained from LiDAR data (Fig. 11):

a. LiDAR point cloud acquisition and classification and building footprint extraction;
b. Applying CGA rules to obtain the 3D models;
c. Data export in *.udatasmith format;
d. Editing the 3D city model in Unreal Engine;
e. Realistic model visualisation;
f. VR exploration of the model.

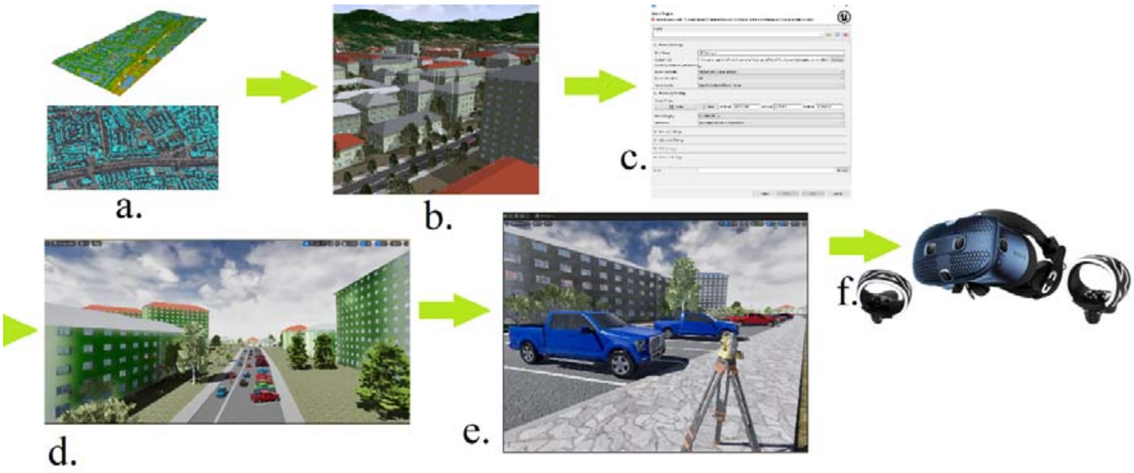

Fig. 11. Workflow for exploring the 3D city model obtained from LiDAR data

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