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The influence of filters in the structure of air treatment plants units (ATP) on energy efficiency

Influența filtrelor din componența CTA-urilor asupra eficienței energetice

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Abstract. *The paper aims to analyze the major influence of filters on the consumption of electricity in ventilation systems, especially in air treatment plants in accordance with ISO EN 16890. On-site measurements are made with the help of the air treatment plant within the HVAC laboratory, with a flow rate of 2700 m3/h, on two filters with dimensions of 287 mm x 592 mm x 500 mm. The results indicate an energy class C for the analyzed filter. As future directions of study for the achievement of energy efficiency within an HVAC system, simulation with the help of the TRNSYS software can be used, for different scenarios.*

Key words: air handling unit, filters, energy efficiency, HVAC.

1. Introduction

People spend on average up to 90 % of their life indoors. Not only at home, but in various places such as offices, schools, restaurants, shopping malls or cinemas. It goes without saying that having a clean air indoor is crucial for the health of the population as a whole and in particular vulnerable groups such as babies, children or elderly people [1].

The energy consumption of air filters in general ventilation systems has become the focus of attention as energy prices increase, and as demands to reduce CO_2 emissions get tougher.

All air filters can be graded from A+ to E. Grade A+ stands for the lowest energy consumption and E for the highest. The classification, based on the filter test method **EN ISO16890**, will give you a better understanding of annual energy consumption, average efficiency and minimum efficiency [2].

Classifying the air filters based on the new test standard will be more precise. Deciding the filter efficiency based on the indoor requirements is the first step in choosing the best energy efficient filter.

2. Energy consumption evaluation of air filters for general ventilation purposes

The energy consumption of a fan in an air handling unit can be evaluated as a function of the volume flow rate supplied by the fan, the fan efficiency, the operation time, and the difference of the total pressure (static plus dynamic pressure) after the fan and the static pressure of the ambient air (assuming that the fan sucks in air from a static reservoir).

Typically, the volume flow rate supplied by the fan and the pressure difference the fan has to overcome, are related to each other by the characteristic fan curve. The efficiency of the fan is a function of the fan speed [3]. The actual fan efficiency also strongly depends on the design and the layout of the fan and can be in the best case as high as 0,80 or even higher, and in the worst case as low as 0,25 or even lower. The portion of the total yearly energy consumption which is related to the filters' pressure drop can be calculated using Eq. (1):

$$W=\frac{q_v \cdot \Delta p \cdot t}{\varepsilon \cdot 1000} \quad (1)$$

where: W – total yearly energy consumption [kWh], q_v – air flow volume [m^3/h], Δp – the pressure drop [Pa], t – operating time [h], ε - fan efficiency [%]. If fan efficiency and/or operating time are not known, the default values can be used as a substitute: t = 6.000 h/y, ε = 0,5

In case filters are changed when they have reached the final pressure drop, the average pressure drop is not time dependent (as long as the time interval for calculating the average pressure drop always considers full filter lifetime intervals), and the only variable to determine the average pressure drop is the shape of the pressure drop curve as a function of the time. In this case, the average pressure drop can be estimated by using Eq. (2):

$$\Delta p = \tfrac{2}{3}\Delta p_0 + \tfrac{1}{3}\Delta p_{final} \quad (2)$$

where: Δp_0 is the initial point and Δp_{final} is the predefined final pressure drop at which filters are changed.

3. Case study and results comparison

We started this research from the example according to EN ISO 16890, and the calculation method shown based on test results for a panel filter rated as ISO ePM1 50% at 0,277 m^3/s. We also used as a point of reference the data from Figure 1, presented in the code of good practice of Eurovent 4/24, where the red line marks the average pressure drop, for a filter with dimensions 592 mm x 592 mm x 50 mm and an accordingly fitted volume flow rate of 0,556 m^3/s.

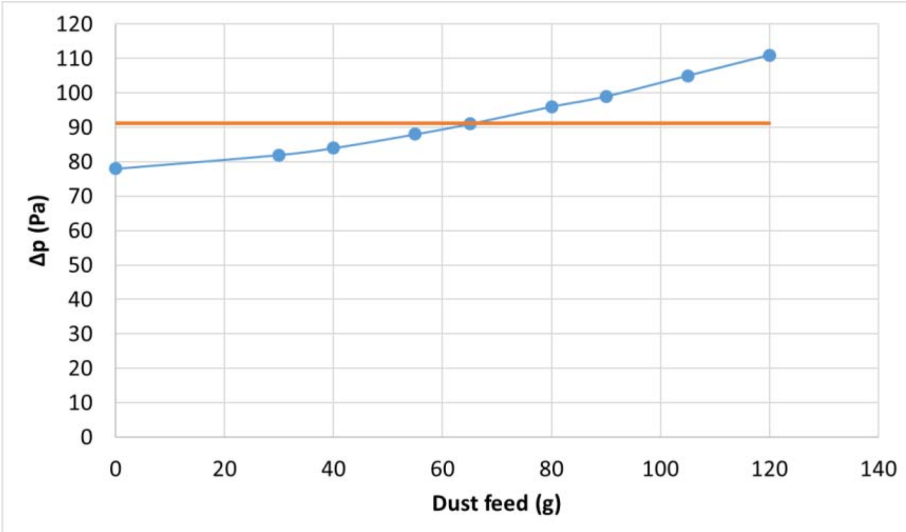

Fig. 1. Pressure drop as a function of dust loading at 0,944 m^3/s according to EN ISO 16890-3.

In our research laboratory we have an experimental stand composed of an air handling unit with an air flow of 2700 m^3/h including a filtration area with 2 filters with size of 287 mm x 592 mm x 500 mm. The values measured, according to the methodology presented in EN ISO 16890-3, are centralized in table 1.

Table 1

Test data for the pressure drop

Step	Dust feed [g]	Pressure drop [Pa]	Dust increment [g]	Av. Pressure drop [Pa]t
0	0	81		
1	35	84	35	70,1
2	45	88	10	72,8
3	55	91	10	72,9
4	70	95	15	75,6
5	80	98	10	76,5
6	95	102	15	79,3
7	110	107	15	80,5
8	125	113	15	83,5

By using Eq. (1) with the data given in Table 1, the average pressure drop calculates to $\overline{\overline{\Delta p}}$ = 92,4 Pa and the yearly energy consumption to W = 831,6 kWh/a.

According to these results, the filter G4 is classified in energy class C.

6. Conclusions

Following the results obtained, it is possible to observe the major influence of the filter on the consumption of electrical energy within an AHU (air handling unit).

To reduce energy consumption, it is recommended to use filters that are part of energy class A, they will generate a value for *W* less than 600 kWh/a.

As a future research directions, we propose to carry out a comparative study on several types of filters through real-time simulations with TRNSYS software, regarding the energy consumption within an AHU in different scenarios, using the interconnection scheme between modules according to Figure 2.

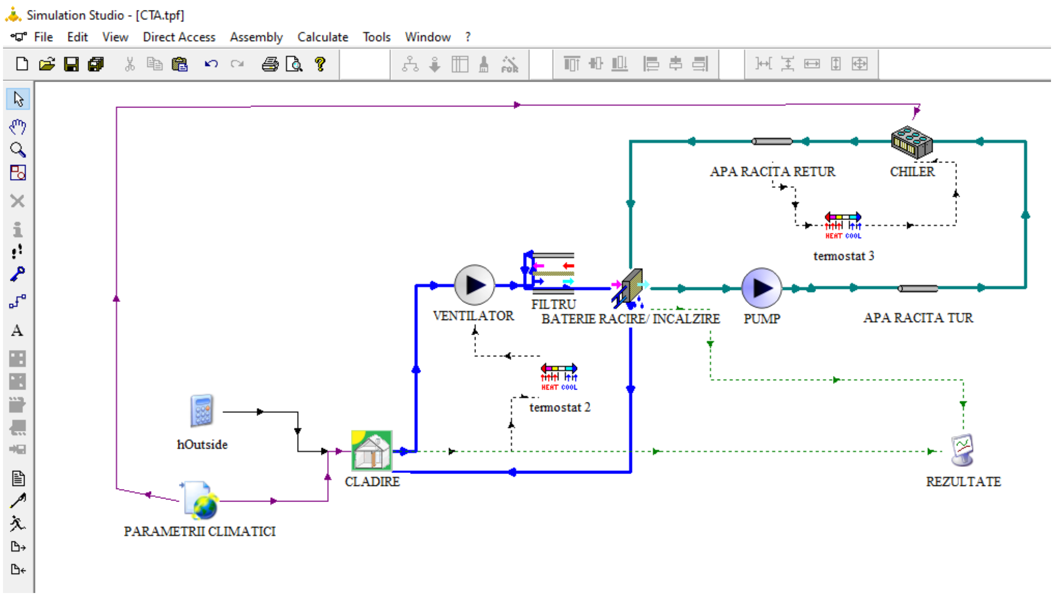

Fig. 2. TRNSYS scheme for simulate the yearly energy consumption in AHU

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Reduction of energy consumption by replacing surface aerators with fine bubble aeration in Slobozia Wastewater Treatment Plant, Romania

Reducerea consumului de energie prin înlocuirea aeratoarelor de suprafață cu aerare cu bule fine în Stația de Epurare a Apelor Uzate Slobozia, România

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Abstract. The biological process in a conventional wastewater treatment plant is one of the largest consumers of energy in wastewater treatment technology. The biological process can use from about 50% to 90% of the electricity used by a treatment plant (depending on its size and technological solutions used), while the cost of energy used can be up to 15–49% of the total costs of an installation. In Slobozia Wastewater Treatment plant, the energy consumption and operational costs were very high, due to the use of surface aerators in the biological tanks. In order to optimize the biological treatment and energy consumption, the present paper analyses the replacement of surface aeration with a fixed grid aeration system with membrane diffusers. By using a fine bubble aeration – lobe blower system, optimized regarding number of diffusers, aeration grids sizing, membrane material, membrane perforations size, blower motor power, the energy consumption in a wastewater treatment plant was considerably reduced and the oxygen transfer efficiency (SAE kgO2/kWh) was increased.

Keywords: wastewater treatment plant, optimization

1. Introduction

While evaluating an aeration system with regard to performance, one must take into account the total energy cost for system operation over its life span. The challenge in calculating these costs is to reliably include efficiency data that reflects the performance we would expect to measure on site.

The performance of any aeration equipment depends on the specific site conditions inherent in the installation. Liquid depth, aeration grid configuration, tank geometry, air flow, air piping placement, and other parameters have a direct impact on oxygen transfer efficiency.

The calculation equation for the economic coefficient is as follows[1]:

$$E = \left(\frac{V}{P_C}\right)\left(\frac{dC}{dt}\right) = aK_L(C_S - C)\frac{V}{P_C}, in\ \frac{kgO_2}{kWh} \quad (1)$$

- Pc = power required for gas compression

The evaluation of aeration systems performance is based on the criteria developed by the American Society of Civil Engineers[3], together with other groups.

Fine bubble aeration systems, with flexible membranes, are the most energy efficient equipment. Membranes made using high-tech technologies can ensure an oxygen transfer efficiency of up to 10-12% oxygen transfer per meter of depth, which translates into approximately 5.50 kgO_2/kWh[2].

Mechanical surface aerators are generally limited to liquid depths of up to 3.5 m to optimize oxygenation and mixing. The area of influence of this type of aerator is significantly reduced for lower depths, due to decreased air circulation capacity and oxygen transfer efficiency. This type of oxygenation requires an increased energy consumption, exceeding 0.7 kWh/m^3 of wastewater.

The energy efficiency of the mechanical oxygenation systems is found in the range of 1.5 - 2.1 kgO_2/kWh.

Table 1

Aeration systems – Energy efficiency comparison[2]

Mechanical aeration	
Surface aerator	1.82 – 2.13 kgO_2/kWh
Diffused air aeration	
Fine bubble aerator	
Membrane diffuser (disc, tube, panel)	3.04 – 4.26 kgO_2/kWh

Fine bubble aeration systems offer energy consumption saving regardless of the depth and geometry of the tank or type of application.

The optimal sizing of the aeration system influences the rate of oxygen transfer and energy consumption. Figure 2 shows 6 different aeration system designs, for a tank with fixed dimensions and the same submersion depth. Oxygen transfer efficiency increases as the number of diffusers increases and the total air flow per tank decreases, thus decreasing the air flow per diffuser membrane.

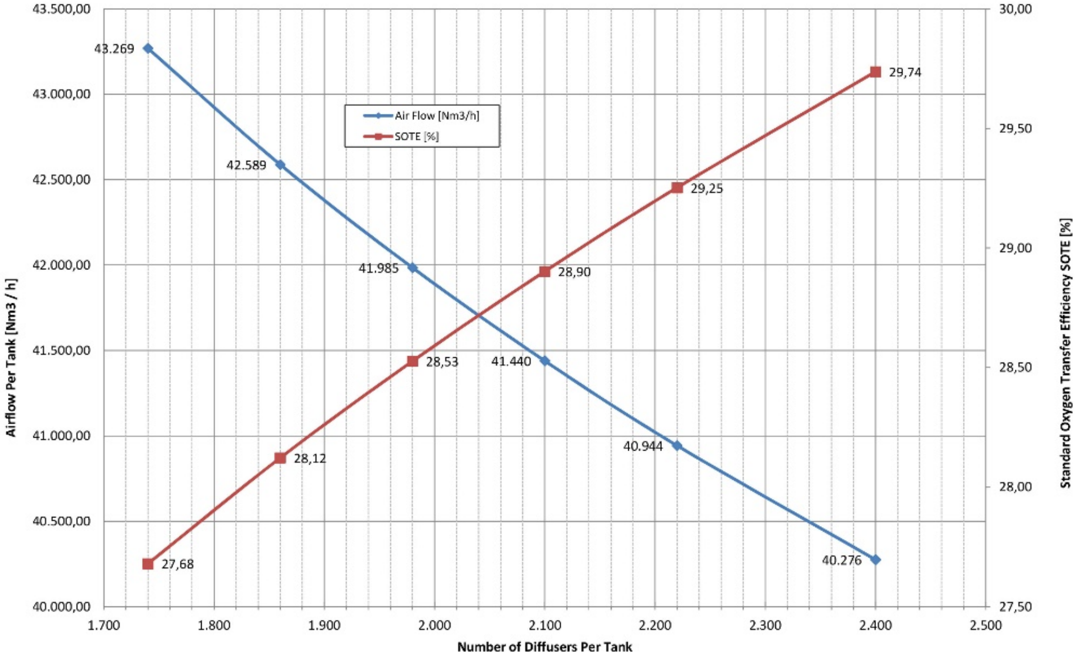


Figure 1 – Optimization of fine bubble aeration system – Oxygen Transfer (own graph)

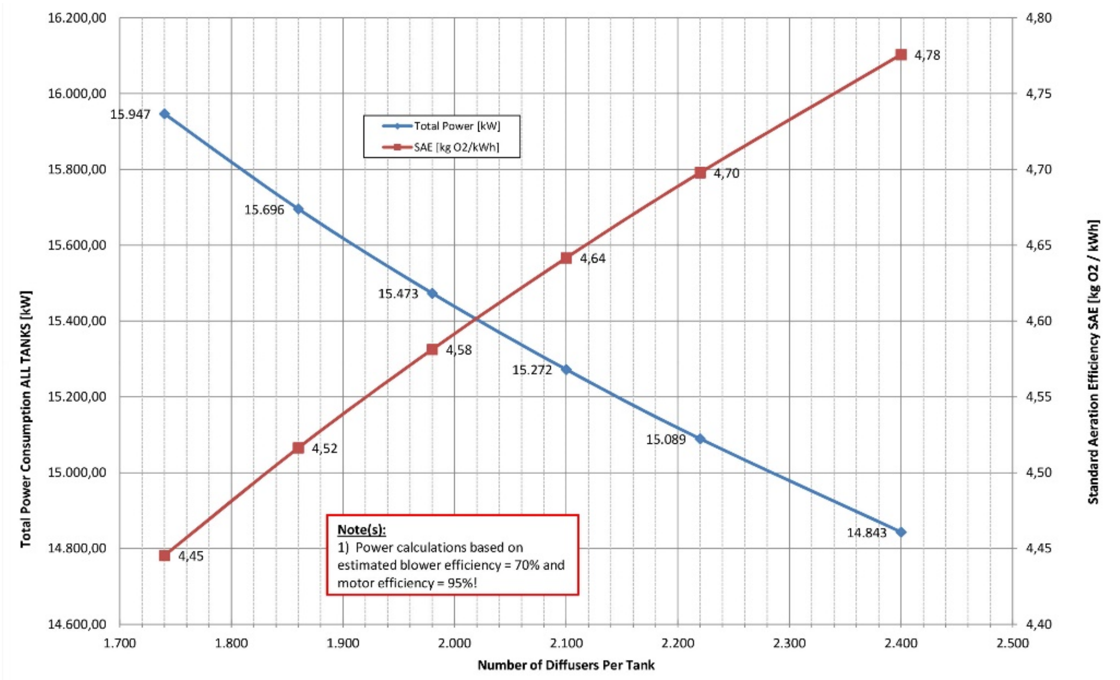


Figure 2 – Optimization of fine bubble aeration system – Energy Consumption (own graph)

2. Current situation – Slobozia WWTP

The Wastewater Treatment Plant serving Slobozia County in Romania was designed for a population equivalent of 60.000 people and a maximum daily water flow of 11.520 m^3/day.

The process is conventional wastewater treatment with activated sludge.

Figure 3 – Slobozia WWTP (Google Earth)

Inlet data and results (Appendix 1) to be taken into account in the development of this article have been corrected according to the requirements mentioned in the Government Order GD 188/2002 (technical norms NPTA-011/2002, NPTA-002/2002 and NPTA-001/2002), with reference to the water temperature in the General Project Requirements ($T_{water} = 20^0$C).

The biological treatment consists of 2 aeration tanks, with the following characteristics:

- Active units 2
- Tank aerated area surface 687,50 m^2
- Total aerated surface area 1.375,00 m^2
- Liquid depth 5,00 m
- Liquid volume 3.437,50 m^3
- Total liquid volume 6.875,00 m^3

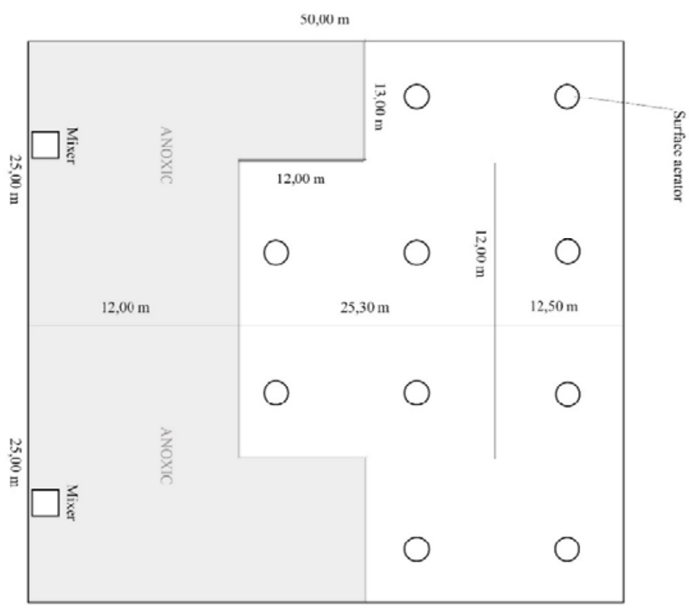


Figure 4 – Biological tank layout (own layout)

For aeration, the plant uses surface aerators type FB 80 (Appendix 2). There are 5 aerators operating per tank.

The FB surface aerator is an open-type impeller, suitable for working with solids of various sizes. It is basically composed of a tubular shaft, an inverted cone and a certain number of driving blades, which are tangential to the central tubular shaft. The impeller is made of electro-welded steel. The impeller of the aerator, when rotating, evacuates with its blades the existing fluid around it. The evacuated fluid is continuously replaced by the fluid that occupies the base of the aerator, generating a suction from the bottom of the tank and combining a toroidal and circular movement of the entire liquid mass. In this way, a renewal of the tank surface is achieved, and speed gradients keep the activated sludge in suspension. (http://www.filtramas.com/en/catalog/biological-treatment/fb-surface-aerators/)

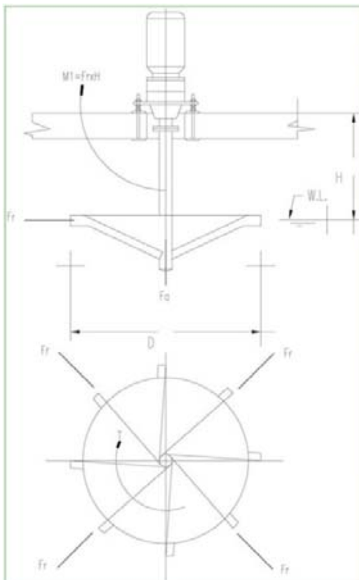


Figure 5 – Surface aerator

3. Theoretical considerations

For the dimensioning of the aeration system with pneumatic equipment, the following aspects must be taken into account:

a. Biologic tank sizing

For the analyzed application, we have 2 biological tanks, with the following dimensions per tank:

- Tank aerated area surface 687.50 m^2
- Liquid depth 5.00 m
- Liquid volume 3,437.5 m^3

b. Oxygen demand

SOR (standard oxygen transfer rate) is defined as the mass of oxygen per time unit, dissolved in a volume of liquid, produced by an oxygen transfer system operating under standard conditions of temperature, pressure, power, gas rate and DO concentration. The defined value is expressed in kgO_2/h - under normal/standard conditions, in clean water. The standard conditions for measuring oxygen transfer are defined as 1 bar ambient pressure, 20^0C water temperature, 0 mg/l dissolved oxygen and clean water.[3]

It is extremely difficult to calculate the rate of oxygen transfer in wastewater, in real conditions, due to the variety of factors impossible to control: actual temperature of the wastewater, wastewater loading, concentration of suspended solids, etc.

The efficiency of aeration systems under standard conditions is hereinafter referred to as SOTE (standard oxygen transfer efficiency).

In order to convert the measured efficiencies in standard conditions to real conditions, the SOTE value must be reduced by means of a correction factor. This factor is generally defined as the ratio of[4]:

$$AOR/SOR \tag{2}$$

- AOR = real oxygen transfer rate
- SOR = standard oxygen transfer rate

Typical AOR/SOR adjustments range from 0.3 to 0.6. Analyzing this range, it results that the actual oxygen transfer is only 30% - 60% of the measured efficiency under standard conditions.

c. Oxygen transfer efficiency from the air bubble to the liquid volume

The efficiency of an aeration system can be discussed from two perspectives:

i. Percentage of oxygen in a flow of injected gas, dissolved under given conditions for temperature, pressure, gas rate and DO concentration. The oxygen transfer efficiency per time unit is known as:
   - SOTE [%], representing the total percentage of oxygen transferred from the bubble to the water.
   - SSOTE [%/m], representing the percentage of oxygen transferred from the bubble to the water, per 1 m immersion depth
   - SSOTR [$gO_2/m^3/m$], representing the amount of oxygen transferred from the bubble to the water, per 1 m3 liquid volume and 1 m immersion depth

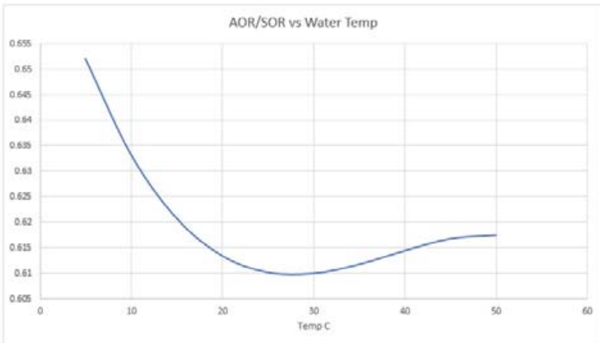
In the next chapter we will conduct various calculation to show the aeration efficiency of a floor mounted, fine bubble aeration system for the given tank dimensions and required oxygen demand.

ii. Amount of oxygen transferred to the water per 1 kWh, known as OTR [kgO_2/kWh]: This particular type of energy efficiency is the purpose of the present article.

After sizing the floor mounted, fine bubble aeration system, and the blowers required to supply the air flow for aeration, we will compare the energy consumption between the two types of aeration systems, that is surface aerators versus fine bubble aeration system.

d. Available air flow, supplied by blowers, in [Nm^3/h] – under normal conditions
e. Wastewater temperature, in [^0C]

The AOR/SOR ratio is also dependent on wastewater temperature, as shown in the below estimates.



	INPUTS	
alpha	0.8	
beta	0.98	
depth	2.70	m
elevation	0	m
depth correction	0.4	
DO	2	mg/l

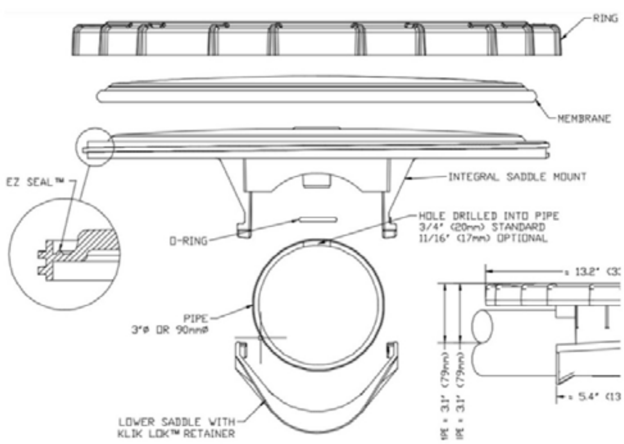
Figure 6 – AOR/SOR ratio dependent on wastewater temperature

For the present application, the fine bubble aeration system will be designed at a maximum wastewater temperature of 20^0C.

f. Organic load in the tank, as presented in the “Inlet data” table above.
g. Aeration system geometry in the biologic tank
h. Type of pneumatic aeration equipment:

The type of oxygenation equipment is chosen depending on the application, process, aeration efficiency. Fine bubble aeration equipment is applicable for high aeration efficiencies. In the case of this equipment, the air bubbles have small diameters, thus increasing the total oxygen transfer area and the oxygen transfer efficiency.

For the replacement of surface aerators in this application, fine bubble disc diffusers were chosen (Appendix 3).



Diffuser type: EDI FlexAir^{TM} Disc 12”
Design air flow: 0-16.0 Nm^3/h
Diameter: 336 mm
Active surface: 0.059 m^2
Weight: 1.2 kg
Membrane material: EPDM
Membrane perforation: 1.0-3.0 mm

Figure 7 – Disc diffuser 12” build

4. Design of the fine bubble aeration system:

The performance capabilities of aeration systems including mechanical and diffused air systems are commonly quantified using standard methodologies under clean water conditions. In order to quantify the field performance characteristics of these systems, process water conditions must be incorporated. We employed the following methodology to determine field performance.

a. Oxygen Demand:

Oxygen demand is ultimately determined based on the mass loading of the system, originating from BOD, COD, and NH_3 coming into the influent of the plant. Part of this demand may or may not be treated upstream of the reactor by solids separation or pre-treatment (such as primary clarifiers or trickling filters). Once the remaining influent characteristics are defined, an actual oxygen demand or oxygen transfer rate (AOR) for the aeration system is determined.

b. Standardized conditions:

Once an AOR is determined, conditions must be normalized to a standard value. Standardization for oxygen transfer is defined by the following parameters:

- Clean (potable) water
- New Diffusers
- 0 mg/L operating DO
- Standard water temperature, 20^0C
- Standard pressure, 1atm

To correct for these conditions, the following equation is used based on calculations followed in the WEF Design of Municipal Wastewater Treatment Plants[4]:

$$\frac{AOR}{SOR} = \alpha * \theta^{T-20} * \frac{\tau * \beta * \Omega * C_{20}^* - C}{C_{20}^*} \tag{3}$$

- α = Alpha. Ratio of process water oxygen transfer rate to clean water oxygen transfer rate
- Θ = Theta. temperature correction factor
- for oxygen transfer rate
- T = Wastewater temperature in ^{0}C, calculated both for winter and summer conditions
- τ = Tao. Temperature correction factor for DO saturation ($\frac{C_{st}^*}{C_{S20}^*}$)
- C_{st}^* = tabular value of dissolved oxygen surface saturation at field temperature, 1atm and 100% RH
- C_{st20}^* = tabular value of dissolved oxygen surface saturation at 20^0C, 1atm, and 100% RH
- β = Beta. ratio of dissolved oxygen saturation in process water to clean water
- Ω = Pressure correction factor for DO saturation, (P_b/P_s)
- P_b = Barometric pressure under field conditions
- P_s = Barometric pressure under standard conditions, 1atm
- C_{20}^* = average steady state DO saturation at 20^0C and 1atm
- C = process water operating DO concentration

C_{20}^* can either be measured by field tests or calculated using a depth correction factor. The equation to calculate C_{20}^* is as follows[4]:

$$C_{20}^{*} = C_{S20}^{*} \frac{P_b + d_e}{P_b} \quad (4)$$

- d_e = effective saturation depth, d_e = 0.4 * air release depth for fine bubble

c. Diffuser sizing

Required efficiency of the selected diffuser system is determined from the following equation[4]:

$$SOTE = (\frac{SOR}{Q_S})(\frac{1}{\rho})(\frac{1}{23.17\%}) \quad (5)$$

- SOTE = Standard oxygen transfer efficiency
- Q_s = Standard flow rate at 20^0C, 1atm, and 35% RH
- ρ = density of air at 20^0C, 1atm, and 35% RH
- 23.17% = percentage of oxygen in air at 20^0C, 1atm, and 35% RH

The selected diffuser system should match these performance conditions in order to supply the correct amount of oxygen, using the available amount of air supplied. The performance of the system is dependent on multiple variables.

- Diffuser Submergence – the available depth of water above the centreline of the diffuser.
- Diffuser Density – commonly expressed as AT/AD (Area of Tank per Area of Diffuser).
- Airflow Rate per Diffuser
- System Configuration

Using the site-specific conditions previously listed, the value for SOR was calculated at 118.01 kgO_2/h per each tank.

For the design, we used an in-house developed Excel calculation sheet.

As input data, we took into account the given design information (Appendix 4):

The design sheet calculated a number of 568 pieces 12” disc diffusers per tank, which we now have to place in the tank layout, having in mind operational requirements, piping material and economical aspects.

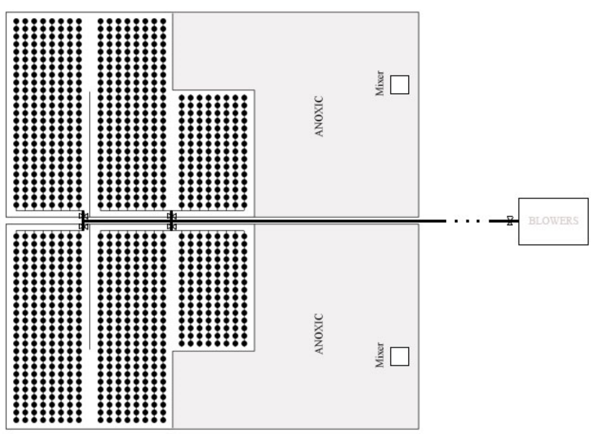


Figure 8 – Aeration system layout in biologic tanks (own design)

The figure above shows the diffused aeration system in the two biological tanks.

Aeration system is fixed on the tank bottom, being sized as two aeration grids per tank. Each aeration grid has a stainless-steel drop pipe, DN160mm, supplying air to the aeration diffusers. Each drop pipe has a valve, adjusting the air flow according to changes in loadings, wastewater temperature, etc.

The aeration system layout shows two types of grids. Grid type 1 has a main sub header pipe, DN160mm, connected to the air drop pipe. There are 8 diffuser support pipes, DN90mm, on which the disc fine bubble diffusers are installed. Grid type 2 also has a DN160mm sub header pipe, the difference being the diffuser support pipes, DN90mm. There are 16 such pipes, with different lengths.

d. Blower sizing

Based on the air requirements for diffusers system, 1087 Nm^3/h at 500 mbar(g), per aeration tank, 2 tanks in total, Atlas Copco proposed following equipment:

- Total 2+1 blowers
- Lobe blower
- With soundproof case 75 dB
- Q/blower = 1220 Nm^3/h at 500mbar(g) operating pressure
- Motor power = 22kW
- With integrated Inverter within the canopy
- With integrated controller onto the canopy, full monitoring and possibilities for remote control, Smart link available also
- Compact design 1m x 1.15m footprint

As standard Scope of supply for ZL (VCA type) lobe blowers, the following are included:

Inlet pulsation damper
Oil free 3-lobe element
Safety valve for ZL1-ZL2(DN80)
Combined start-up and safety valve for ZL2-DN100 -ZL3-ZL4
Check valve
Discharge pulsation damper
Outlet compensator (stainless steel)
Outlet air flange DIN or DIN+ANSI
Supplied with oil for 1st fill
IE3 Induction motor
TEFC IP 55
Pulley & Belt
Automatic belt tensioning system
Sound attenuating canopy
Package vibration isolators
Cubicle including:
Elektronikon® controller
VSD Inverter
Sensors discharge pressure and temperature
Flow control via 4-20 mA (external source)

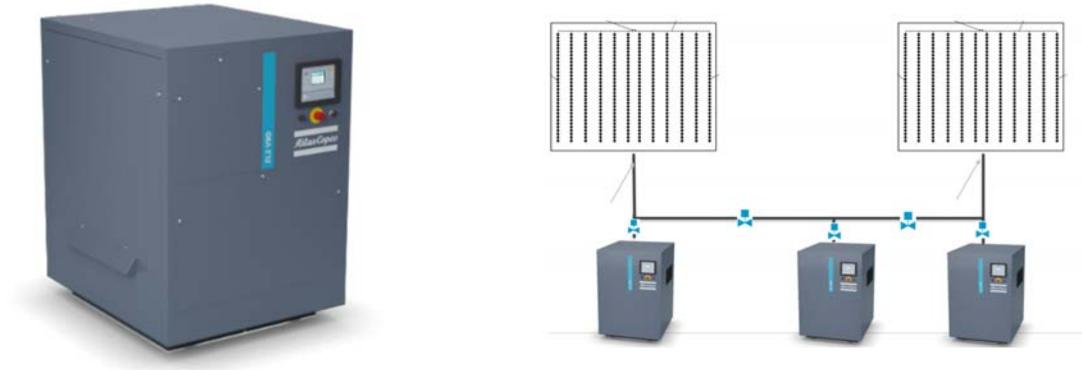


Figure 9 – Installation proposal ZL (VCA type) lobe blower

The yearly energy savings of this system versus original surface aerators system are presented in the following table, considering that cost of kWh is 0.10€.

Table 2

Yearly savings (own calculations)

Surface aerators		
Manufacturer		Filtramas S.A.
Model		FB80
Quantity	pcs	10
Package power kW	kW	25
Running hours/year	h/year	8,760
Total kWh/year	kWh (package)	219,000
Electricity cost/kWh	€/kWh	0.1
Total cost electricity €	€ (package)	219,000
Blower		
Manufacturer		Atlas Copco
Model		ZL2VSD 22K 500 lobe
Quantity	pcs	3
Inlet flow	Nm^3/hr	1,078
Outlet pressure	bar	0.5
Shaft power	kW	19.9
Package power	kW	21.9
Running hours/year	h/year	5,840
Total kWh/year	kWh (shaft)	116,216
	kWh (package)	127,896
Electricity cost/kWh	€/kWh	0.1
Total cost electricity €	€ (package)	38,369
Savings/ year:	**€**	**180,631**

As shown, the calculated yearly energy savings are 180,631.00 €.

5. Conclusion

By using a fine bubble aeration – lobe blower system, optimized regarding number of diffusers, aeration grids sizing, membrane material, membrane perforations size, blower motor power, the energy consumption in a wastewater treatment plant was reduced with 85%, the oxygen transfer efficiency (SAE kgO2/kWh) was increased 2.8 times and energy costs were reduced with 180,631.00 €.

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Appendix 1 – Inlet data Slobozia WWTP

Table 1

Inlet data

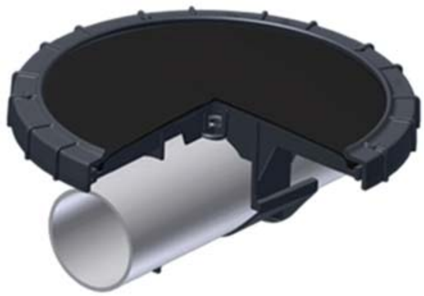
Inlet data		
Temperatures:		
Average water temperature	^0C	20
Air temperature	^0C	5
Flows		
Daily	m^3/day	11,520.00
Hourly	m^3/day	480.00
Loads		
Average BOD_5	mg/l	312.50
Maximum BOD_5	mg/l	468.75
Average COD	mg/l	625.00
Maximum COD	mg/l	937,50
BOD_5/COD ratio	%	50
Average TDS	mg/l	468.75
Maximum TDS	mg/l	703.75
TDS/ BOD_5 ratio	%	150
Average TKN	mg/l	62.50
Maximum TKN	mg/l	93.75
Total N	mg/l	62.50
Total P average	mg/l	15.63
Total P maximum	mg/l	23.44
Outlet data		
Maximum BOD_5	mg/l	25.00
Maximum COD	mg/l	125.00
Maximum TDS	mg/l	35.00
Maximum TKN	mg/l	15.00
Maximum Total P	mg/l	2.00

Appendix 2 – Technical Data Sheet surface aerator FB 80

Figure 1 – Surface aerators type FB 80

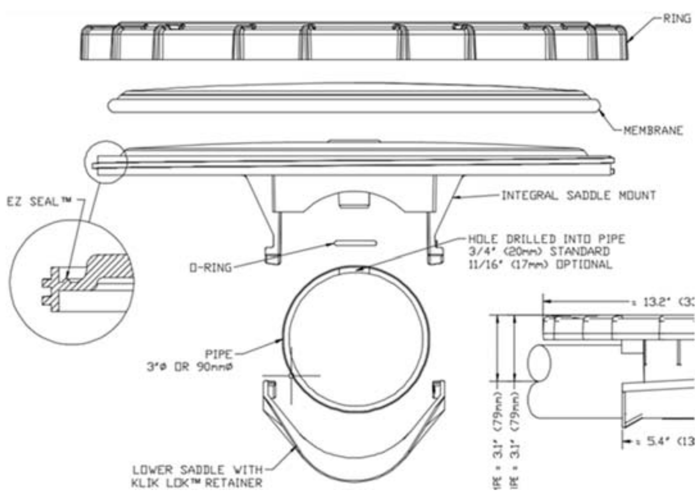
Producer		Filtramas S.A.
Type		FB80
No. aerator	pcs	10
No. impeller	pcs	8
Pallet height	mm	115
Rotation speed	rpm	60.5
Container dimensions	m	12.52 x 11.62 x 4.3
Specific oxygen transfer	kgO_2/kWh	1.94
Nominal oxygen transfer	kg O_2/h	23.60
Total oxygen transfer per tank	kg O_2/h	118.01
Installed power	kW	29.44
Total installed power per tank	kW	147.20
Absorbed power	kW	25
Motor speed	rpm	1470
Outlet speed	rpm	60

Appendix 3 – Technical Data Sheet EDI FlexAir Disc Diffuser



- Glass-fiber-reinforced polypropylene body for maximum chemical, temperature, and UV resistance
- Premium quality membrane materials available: EPDM, silicone, urethane, PTFE MATRIX™, specialty polymers
- High-capacity membrane option available for maximum airflow and low operating pressure
- Triple-check valve design minimizes entry of liquid/solids into piping. Ideal for on / off applications

- Integral Saddle Mount provides ease of installation and maintenance with maximum mechanical strength
- Mounts on any pipe material (PVC, ABS, CPVC, SS, etc.)
- 12" disc available to fit 3" and 90 mm pipe sizes; 9" disc available to fit 3", 4", 90 mm, and 110 mm pipe sizes
- Patented EZ-Seal™ for quick membrane installation



Metric					English				
Diffuser Type	Design Airflow m^3_N/h	Overall Diam. mm	Active Surface m^2	Dry Weight kg	Diffuser Type	Design Airflow scfm	Overall Diam. in	Active Surface ft^2	Dry Weight lb
9" Nano	0-4	273	0.038	0.85	9" Nano	0-3.0	10.7	0.41	1.9
9" Micro	0-9.5	273	0.038	0.85	9" Micro	0-6.0	10.7	0.41	1.9
9" High-Cap	0-16.0	273	0.038	0.85	9" High-Cap	0-10.0	10.7	0.41	1.9
12" Nano	0-6.0	336	0.059	1.2	12" Nano	0-4.0	13.2	0.64	2.6
12" Micro	0-16.0	336	0.059	1.2	12" Micro	0-10.0	13.2	0.64	2.6
12" Macro	0-29.0	336	0.059	1.2	12" Macro	0-18.0	13.2	0.64	2.6

Appendix 4 – Technical Data Sheet EDI FlexAir Disc Diffuser

Table 3

Input data

Basin Information			
Tank / Zone	M.U.	Bio. Tank	Total (2 tanks)
Water Depth	m	5.00	
Aeration Depth	m	4.75	
Aerated Tank Floor Area (AT)	m^2	687.5	1,375
Aerated Tank Volume (VT)	m^3	3,438	6,875
Mixing			
Tank / Zone	Unit	Bio. Tank	Total (2 tanks)
Specific Airflow Rate for Mixing	$m^3_N/h/m^2$	1.50	
Volumetric Airflow Rate for Mixing	$m^3_N/h/m^3$	0.30	
Diffuser Information			
Tank / Zone	Unit	Bio.	Total (2 tanks)
Diffuser Assembly Type			
Perforated Membrane Area per Diffuser Membrane	m^2	0.059	
Oxygenation			
Tank / Zone	Unit	Bio. Tank	Total (2 tanks)
Standard Oxygen Requirement (SOR)	kgO_2/h	118.01	236.02
Specific Standard Oxygen Transfer Rate (SSOTR)	$gO_2/m^3_N/m$	22.87	

Based on the input data above, we ran the Excel design calculation sheet and obtained the results below:

Table 4

Fine bubble aeration system design calculations

Basin Information			
Tank / Zone	Unit	Bio.	Total (2 tanks)
Water Depth	m	5.00	
Aeration Depth	m	4.75	
Aerated Tank Floor Area (AT)	m^2	687.5	1,375.0
Aerated Tank Volume (VT)	m^3	3,438	6,875
Mixing			
Tank / Zone	Unit	Bio.	Total (2 tanks)
Specific Airflow Rate for Mixing	$m^3_N/h/m^2$	1.50	
Volumetric Airflow Rate for Mixing	$m^3_N/h/m^2$	0.30	
Airflow Requirement for Mixing (Q_{mix})	m^3_N/h	1,031	2,063
Diffuser Information			
Tank / Zone	Unit	Bio.	Total (2 tanks)
Diffuser Type		12in Disc	
Number of Diffuser Membranes Required	1	568	1,136
Number of Diffuser Assemblies Required	1	568	1,136
Perforated Membrane Area per Diffuser Membrane	m^2	0.059	
Perforated Membrane Area per Diffuser Assembly	m^2	0.059	
Total Perforated Membrane Area Requirement (AD)	m^2	33.8	67.5

Design Density - Floor Coverage (AD / AT)	1	4.9%	
Design Density (AT / AD)	1	20.36	
Diffuser Density, Number of Diffuser Units per AT	$1/m^2$	0.83	
Diffuser Density, AT per Diffuser Unit	m^2	1.21	
Layout Information			
Tank / Zone	Unit	Bio.	Total (2 tanks)
Number Diffuser Assemblies per Tank / Zone	1	568	1,136
Number of Grids per Tank / Zone	1	2	
Airflow for System Pipe Sizing	$m^3{}_N/h$	1,087	2,173
Number of Grids per Tank / Zone	1	2	
Average Airflow per Grid = per Drop Pipe	$m^3{}_N/h$	543	
Recommended Drop Pipe Diameter	mm	160	
Average Airflow per Sub-header	$m^3{}_N/h$	543	
Recommended Sub-header Diameter	mm	160	
Airflow per Lateral	$m^3{}_N/h$	-	
Recommended Lateral Diameter	mm	90	
Oxygenation			
Tank / Zone	Unit	Bio.	Total (2 tanks)
Standard Oxygen Requirement (SOR)	kgO2/h	118.01	236.02
Airflow Requirement for Process (Q_{oxy})	$m^3{}_N/h$	1,087	2,173
System Determining Airflow (Q_{mix}or Q_{oxy})	$m^3{}_N/h$	1,087	2,173
Specific Airflow per Aerated Tank Floor Area	$m^3{}_N/h\ /m^2$	1.58	
Airflow per Diffuser Membrane	$m^3{}_N/h$	1.91	
Diffuser Membrane Flux Rate	$m^3{}_N/h\ /m^2$	32.17	
Standard Oxygen Transfer Efficiency (SOTE)	%	36.35	
Specific Standard Oxygen Transfer Efficiency (SSOTE)	%/m	7.65	
Specific Standard Oxygen Transfer Rate (SSOTR)	$gO_2/m^3{}_N/m$	22.87	
SOTR per Diffuser Membrane	kgO_2/h	0.21	

Building Materials and the Future of Alternative Solutions

Materialele de construcție și viitorul soluțiilor alternative

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Abstract: While conventional materials like hemp could be employed as a lowcost, low-carbon method of reinforcing concrete, building intelligent materials are the future of efficient manufacturing.A new breakthrough in the industry is currently being promised by at least 10 novel construction materials, including plastic that is stronger than steel and 3D-printed mushroom columns.A lot of effort was put into developing biochar cladding, carbon-fiber reinforced concrete, super-strong plastic, and 3D-printed mycelium with the goal of preventing issues like corrosion and fire as well as prolonging the lifespan of concrete structures.Additionally, materials like green charcoal loofah make it possible for the bricks to serve as a habitat for both plant and animal life, boosting the biodiversity of cities.

Keywords: building materials, alternative solutions

1. Introduction

The incorporation of sustainable solutions into architectural design is one of the essential elements in achieving the shift to sustainability. The variety of structural components, the availability of sustainable materials, and the diverse tastes of clients, architects, and structural designers make the decision-making process difficult [1]. All across the world, alternative building materials and methods are used. Soil is the most basic building material, other than wood and stone. Soil, which may be recycled, can be used to build structures. Soil is the best form of passive air conditioning since it can adapt to any environmental factor.

While using less energy, employing dirt as a building material can benefit the environment. Mud houses are used often all around the world [2].

The Building Research Establishment Environmental Assessment Method (BREEAM), the Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), the Leadership in Energy and Environment Design (LEED) and Green Globes in the United States, the Building Environmental Assessment Method (BEAM Plus) in Hong Kong, and the Comprehensive Assessment System for Built Environment Effi. These, however, take a long time to implement and don't take the economic side into account, which goes against the fundamental tenet of sustainable development. The investor aspires to pursue cost-effective projects while also pursuing ecologically friendly solutions with low energy usage and waste output [3]. Due to the documented flaws in sustainability evaluation tools, it may be concluded that sustainable product design tools are still in their infancy [4]. Numerous scientists have proposed theoretical developments in sustainable design and construction, but more research, including testing, is required. Before investors find the green project financially appealing, this area requires a lot of development. The observed flaws in design and sustainability assessments led researchers to the conclusion that quick, easy, and trustworthy methodologies were required to evaluate the sustainability of structural solutions at the outset of design [1].

2. Methods

Numerous studies have been carried out by the scientific community worldwide in pursuit of low-tech and alternative sustainable building materials, which results in a more sustainable and affordable construction meeting comfort standards. Using environmentally friendly building materials is a fantastic way to accomplish this. The least harmful to the environment construction materials can be employed because of their importance in a nation's sustainable development [5]. Choosing environmentally friendly building materials and reusing and recycling trash as or to generate construction materials are effective ways to improve a building's performance and decrease its detrimental effects on the environment and human health [6].

Buildings are the world's largest energy consumers, according to the United Nations Environment Program [7]. Residential energy use makes up a sizeable share of overall national energy use in the majority of countries [8]. International activities have increasingly centered on reducing building carbon emissions [9]. Operational energy reduction has been the industry's top focus since it has a bigger impact on carbon emissions over the course of a building's lifetime and is easier to predict than embodied energy [10]. Typically, the building performance research should be carried out while taking into account the construction documents and the architectural blueprints [11]. Access to specific data, such as material quality, U-values, and technical systems, is required for early design stage energy performance study of a building. This information is one of the elements influencing a building's energy efficiency [12]. The geometric information of buildings is often extracted from architectural drawings. An energy analyst can then, based on their knowledge, expertise, and experience, define the thermal perspective of the building utilizing this information [13].

Affordable green roof designs, the use of alternative building materials for liners and substrates, the integration of solar energy generation with green roofs, and the establishment of multipurpose recreation areas have all seen an increase in interest recently (Figure 1). Many cities are adopting the EU Research and Innovation policy agenda, which promotes renaturing cities and territorial resilience for communities that are socially and environmentally responsible (EU 2015). Each city, however, has a different vision for the application and promotion of green roofs, depending on regional circumstances. Subject to the accomplishment of a set of sustainable development goals, policies are necessary to encourage the use of green roofs by law or financial incentives (such as a reduction in water or property costs). This is because green roofs are sustainable over their full life cycle [14].

Figure 1 The Praça de Lisboa in Porto, Portugal, has a green roof as an example of how cities and vegetation coexist (photo: Cristina Calheiros).

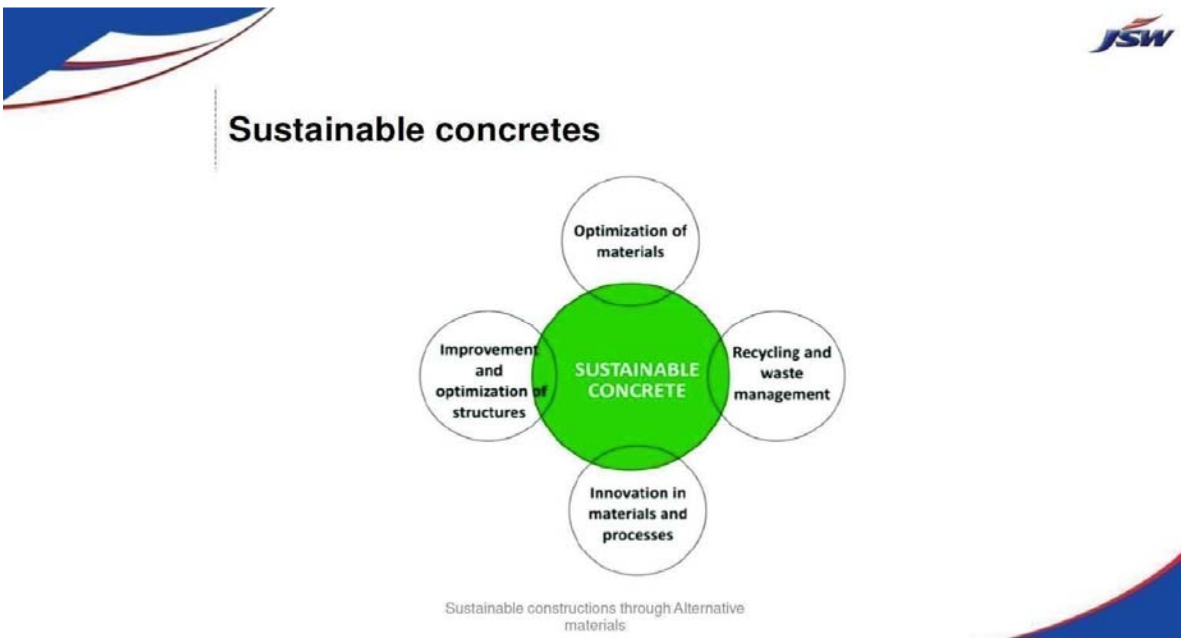
3. Results

The chosen building and city models are no longer useful and practical because they were built 50 years ago disregarding nature. Finding ways to deal with urban issues and adapt to or mitigate the consequences of rising temperatures is essential. The building industry in most countries is responsible for between 30 and 40 percent of both energy use and carbon emissions. Reducing the carbon footprint of the building sector by creating sustainable, energy-efficient structures is the main goal of worldwide environmental policy. Utilizing zero-impact or at the very least low-impact technological solutions, the building envelope should be built.

In addition to the numerous social, economic, public health, and environmental advantages, green roofs can also help to improve building thermal performance, especially in the summer, and to optimize urban stormwater management, which could play a significant role in the field of green infrastructures as a whole. This is significant because space is often an issue in cities. In order to combat climate change, green roofs must be adapted to local conditions and incorporated into urban green infrastructure plans. However, these components continue to be subject to constraints that affect energy modeling and environmental and economic evaluations [15].

The appropriate and contextual use of a sustainable building material is necessary for any community development. In addition to lowering material prices, carbon emissions, and transportation costs by using sustainable building materials, doing so also gives local residents job and training opportunities. As an alternative criterion, functional, technical, and financial considerations are frequently utilized to choose sustainable construction materials.

The environmental impact of building materials has, however, grown in importance as a vital factor as sustainability has become a significant issue in recent years, particularly in industrialized nations. Construction accounts for 22% of annual environmental damage, hence it has a duty to identify more ecologically friendly building and construction techniques in order to promote sustainable growth. Some of the approaches for discovering solutions include the usage of new material applications, recycling and reuse, the production of sustainable products, or the utilization of green resources [16].



Sustainable Constructions through Alternative Building Materials - copyright © Dr. L. R. Manjunatha BE, MBA, PhD, Associate Vice President - Direct Sales JSW Cement limited, India [17].

It is common knowledge that the building's perimeter walls make up the building's envelope, which serves as a barrier between the interior and outer climates. Conduction, convection, and radiation are three heat transfer mechanisms that work together on location to move heat from a building's interior to its exterior [18]. Three crucial material factors define the thermal insulation capacity of building materials:

1.the coefficient of thermal conductivity (W/mK), which measures how much heat moves through a material having a surface area of 1 m2 and a thickness of 1 m over the course of an hour with a temperature difference between the two surfaces of 1 K (or 1ºC see [19]).

The density and humidity of the substance have a clear link with this variable. It has been shown in steady state experiments that the lower the thermal conductivity and the drier the material, the better it functions as a thermal insulator (other parameters are constant).

2. **R** - resistance to heat transfer by conduction in a steady condition, as per [20-21] .

$$R = \sum \left(\frac{d}{\lambda} \right) \left[m^2 k / W \right] \tag{1}$$

3. $\mathbf{R_0}$ - global thermal resistance, [m2k/W], for global heat transmission at the element's external and interior surfaces by convection and radiation, as well as over the thickness of the element by conduction. global thermal resistance, [m^2k/W], for global heat transfer, over the thickness of the element, by conduction, as well as at the external surface of the element (Rse) and the internal surface of the element (Rsi) by convection and radiation [2021].

$$R_0 = Rsi + \sum \left(\frac{d}{\lambda} \right) + Rse \left[m^2 k / W \right] \tag{2}$$

In order to maintain an indoor environment that adheres to the passive home concept, the corrected thermal resistance is computed using the correction coefficients stated in the C1073/2005 and C107-5/2005 regulations [22].

The building industry is among Europe's top resource consumers in terms of both material and energy use during all stages of a construction project. Actually, one-third of the waste created in Europe comes from materials from construction and demolition waste (CDW see [23]). To fully comprehend, it's critical to keep in mind that the European Union generates roughly 3 billion tons of waste every year. Construction and demolition activities account for about 1 billion tons of this, with a considerable amount of CDW materials ending up in landfills with little possibility of recovery or reuse [24]. As a result, the building industry is a top priority of the EU's plan to reduce waste production and decarbonize the European economy [25]. Innovation in end-of-life material management must be in line with the Waste Framework Directive 2008/98/EC's mandate that 70% of CDW be ready for reuse, recycling, and other types of recovery by 2020 [26]. The efficiency of the current quality assurance and control systems for recycling construction materials (as the European Quality Association for Recycling see [27]) creates a product of excellent quality with possibilities for sale [28].

4. Discussion

Alternative Building Materials (ABM) are defined differently by different researchers in the construction business, who also employ distinct terminology and definitions of ABM.

ABM is a generic term that, without being particularly precise, refers to a class or group of building materials.

It includes building and construction materials and supplies that go by a variety of names in literature, including alternative materials, local building materials, unusual building supplies, alternative residential construction supplies, sustainable building supplies, indigenous building supplies, vernacular building supplies, green building supplies, environmentally responsible building supplies, eco-friendly building supplies, etc. The study's methodology included a systematic examination of the literature and content analysis to compile and assess all the crucial information. In order to reduce costs, address environmental concerns, or deal with a lack of conventional materials, "alternative building materials" are defined as "building materials that are an alternative to conventional building materials in the form of total or partial substitution of the materials or its constituents" (working definition, operational). According to research, the qualities of ABM include, among others, low or no chemical emissions that can lead to poor indoor air quality, recycled content (post- and preconsumer), a lack of CFC, HCFC, or other ozone depleting substances, low embodied energy, local production, the capacity to repair and replace the product using local resources, and social acceptability. Some benefits of using ABM include ease of construction, wide availability, low cost, and low embodied energy (which typically results in lower greenhouse gas emissions see [29]). In the construction industry, recycling waste materials not only reduces project costs but also safeguards the environment by reducing the amount of waste dumped in landfills, the consumption of natural resources, and carbon emissions [30].

In this age, energy conservation and economic energy use have become complicated issues. It is one of the main causes of the high inflationary tendencies seen around the world and developed nations have already begun to take effective conservation measures. India, meanwhile, appears to be falling behind in this area. Today, coal, nuclear power, oil, and natural gas are the primary energy sources. Alternative energy sources must be developed quickly while also conserving and expanding the current energy supply to the greatest extent possible due to the global depletion of oil and natural gas reserves [31].

Using environmentally friendly materials may not always result in sustainable building. The pursuit of sustainability cannot be effective by concentrating only on environmental issues. It is necessary to balance the former with the economic and social problems [32]. Adopting sustainable practices necessitates the participation of all accountable stakeholders and the integration of all sustainable principles throughout the project life cycle [33]. When designing sustainable buildings that comply to the many sustainability categories, the job of the structural engineer is especially important. Structural engineers hardly ever consider the environmental dimension in the conventional approach to building design, in contrast to the new integrated building design process, which acknowledges it as one of the most important factors [34]. Decisions made on structural engineering have a substantial impact on environmental emissions, water use, energy use, and waste generation [35]. By incorporating sustainable construction principles into the design process, projects can become more sustainable [36]. However, major barriers were found, including greater costs, longer wait times, and a lack of information and suppliers for green goods [37]. Making choices can be challenging due to the availability of a large variety of sustainable construction materials, client preferences, architectural styles, and structural designs, as well as the wide range of sustainable structural components [38]. Sustainability is a complex phenomenon with many conflicting objectives [1].

5. Conclusions

The incorporation of sustainable solutions into architectural design is one of the essential elements in achieving the shift to sustainability. Due to the variety of structural elements, the availability of sustainable materials, and the diverse tastes of clients, architects, and structural designers, the selection process is difficult. Choosing environmentally friendly construction materials and reusing and recycling trash as or to manufacture building materials are fantastic ways to increase a building's performance and lessen its detrimental impacts on the environment and people's health. Buildings are the world's largest energy consumers, according to the United Nations Environment Program. Interest in developing more economical green roof designs, using alternative building materials for substrates and liners, combining green roofs with solar energy production, and developing multipurpose recreation areas has recently increased. All responsible parties must be involved in adopting sustainable practices, and all sustainable principles must be used throughout the project life cycle. Energy conservation and wise energy use are complex concerns in the modern world. One of the key reasons for the high inflationary tendencies observed globally, industrialized countries have already started to implement efficient conservation measures.

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Tourism supply chain post covid-19 change management: the case of tour operators

Managementul schimbării lanțului de aprovizionare în turism după Covid-19: cazul operatorilor de turism

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Abstract. The relevance of this paper is that that covid-19 outbreak, which has been announced by WHO (World Health Organization) on the 30th of March, 2020 and two years later still has continuous effect over most of the world, has caused blockages in all economic sectors, but tourism and its supply chain has been affected the most. The conducted research explores inner-organizational alterations within the tourism supply chain (TSC) management, though the prism of tour operators, in times and post pandemic. Tourism supply chain management strategies have already been adopted by many large tourism service providers, such as hotels and airlines. Therefore the article‘s main focus is on successful tour-operator change management within the chain, addressing the key elements. Study results present the impact caused by the outbreak on tour-operators in Lithuania and accordingly suggest the template for resilience. Furthermore, an interview based systematic crisis resilience model for tourism supply chain management is introduced.

Keywords: tour operators, Covid-19, tourism supply

1. Introduction

The effectiveness of Tourism supply chain (TSC) management depends on the targeted actions of the participants within the chain (Pomponi, Fratocchi and Tafuri, 2015). Innovative tourism supply chain management approach is needed to positively impact its business and ensure its continuation (Guan, et al 2020; Gossling, Scott, & Hall, 2020), also to achieve productive performance indicators such as customer satisfaction, profit and profit margin, flexibility, liquidity, reliability, productivity, transparency, sustainability, and risk resilience. A properly functioning TSC is the optimal balance between two opposite poles - efficiency and sensitivity, which represent customers' satisfactory level. This balance is dictated by the adopted tourism supply chain participant performance and governing strategy. The supply chain is as strong as its weakest link, as achievements depend on the entire chain (Long and Chen, 2021).

As circumstances, such as constraints imposed by public administrations, change consumer behavior, business organizations must respond and adjust their supply chain management strategy, considering the region, size and nature of the business. Given the nature of the Covid-19 outbreak, it is useful to provide additional insights into how TSC management strategies change during crisis: from operational efficiency to favorable conditions, changes in employment relationships, ways to retain and attract customers, to liquidity in the event of disruption and finally resilience against long-term negative consequences.

Tourism has become increasingly subjected to risks that threaten the whole tourism industry itself (Vargas, 2020). Those together with globalization and increasing competitive challenges are encouraging tourism business leaders to seek modern solutions to achieve resilience in the tourism supply chain (TSC), preserving their continuity in adverse economic situations such as Covid-19 epidemic outbreak (Baum and Hai, 2020; Venkatachalam and Raja, 2020). Global developments in recent years have shown that global crises, which require change management models, should be considered as adverse situations.

The aim: After analyzing the importance of the tour-operator in promoting the effective integration of the tourism chain network that supplies the different components of tourism products and services, to justify the need for post-pandemic change management of tour-operators, to disclose their restructuring principles and to provide the change management model for the tourism development chain with measures to be implemented after the pandemic.

The research methodology consists of scientific literature, documentary and statistical data, regarding the effects of the coronavirus pandemic on the tourism supply chain, analysis, as well as qualitative research of 6 largest tour operators in Lithuania. The findings are presented accordingly.

2. Tour operator importance as advocating effective integration of the tourism chain network that supply different components of tourism products and services

Tourism has, over the last half century, emerged as one of the world's largest and fastest-growing economic sectors. Consequentially, it has also become one of the most widely adopted development strategies at the national, regional and international levels, representing an effective and, for many countries, the only realistic means of achieving social and economic development (Soratana, Landis, Jing and Suto, 2021). Tourism supply chain (TSC) management is a set of functional methods for effective coordination of the relationships between participants in the tourism supply chain itself (Zhang, Song, and Huang, 2019; Wongsurawat and Shrestha, 2018; Vsrk and Sriniv, 2016). In order for all participants in the supply chain to work together and for information to flow smoothly between chains, companies must effectively manage business; synchronize, integrate and optimize key supply, production, warehousing, inventory, purchasing, and sales processes (Wilujeng, Nikmah and Sarwoko, 2021). The fragmented but closely interrelated nature of the components of the tourism industry forces tourism companies to engage with many industrial participants - suppliers, distributors, competitors, governmental and private companies - which determine the continuity of TSC business (Eckardt, Font and Kimbu, 2020).

The tourism supply chain is a very broad concept. According to X. Guo and L. He (2012), TSC is an industry that combines various services and professions and is related to many areas of economic activity. It includes the customer in the center, then such service providers as accommodation, catering, transport, sightseeing, entertainment industries, as well as outbound, domestic and inbound tourism providers, and all related services (Song, 2011). Among the latter - organization and sale of personal and business trips, search and sale of boat, ferry, bus and plane tickets, orders for transportation, insurance, money back guarantee services, bookings of attractions, even organization of weddings in another country, etc. TSC's are an important catalyst for the economic development and integration of each country (Mirakzadeh, Karamian, Khosravi and Parvin, 2021). TSC is also a very flexible industry and, unlike other areas, is often closely intertwined with other industries such as fashion, aviation, cinema, music, crafts, gastronomy and the media, including blogging. Furthermore, all services are unconditionally interconnected. Any shock to one part of the chain affects others (Barua, 2020). The chain reaction disrupts all TSC operations, which undermines corporate performance and profitability and can cause irreparable damage to tourism companies (Larin, Tarasov, Mirotin, Rubliov and Kapski, 2021).

Evidently, tourism supply chain is a complex phenomenon and should be analyzed and managed from an integrated perspective, through the prism of demand, which is best known by the main tourist product provider – the tour operator (Long and Chen, 2021). Demand structures the development in particular tourism destination; it also implies value creation processes, which are usually shaped by a variety of operations, main TSC participants, that play key roles within the TSC system, such as the tour operators, and tourist interests. Key participants of the tourism value chain encompass a range of processes linked to the tourism sector, such as policymaking and integrated planning; product development, promotion, and marketing; distribution and sales, also destination operations and tourism services (Mariani, Czakon, Buhalis, and Vitouladi, 2016). The tour operator is considered to be the largest retailer in the field of TSC. It is like a producer of an organized tourism and has a special place in shaping the whole tourism supply chain (Phillips and Mountinho, 2014). According to authors, tour operator outsources every TSC participant by creating tourist routes, abounding them with services, organizes advertising, calculates and sets prices for travel on those routes, sells travel directly to consumers or smaller travel agencies (2014). Tour operators are settling down for the consumers to whom they provide their services and at the same time expanding the system of the tourism supply chain. Tour operators are a key factor in the success of the whole chain (Guo and He, 2012).

Summarizing, it can be stated that tourists count on tour operators to turn their dream vacations into realities. Booking an outsourced, full packaged, time checked or brand new tour is an easy way for a traveler to explore and experience a foreign land and make sure they hit the best spots. A well-equipped package of services brings a lot of profit to the tour operator and value to the TSC.

3. Justification of the need for post pandemic tourism supply chain change management based on the analysis of statistical and scientific literature

Tourism supply chain change management is a consistent and systematic process aimed at the smooth transition of the organizations to the desired state. Successful tourism supply chain change management is a process that requires the multifaceted preparation of organizations, managers with different competencies, and the willingness of employees to change.

An innovative tourism supply chain management approach is needed to positively impact businesses and ensure continuation, also to achieve productive performance indicators such as customer satisfaction, profit, profit margin, flexibility, liquidity, reliability, productivity, transparency, sustainability, and resilience. While implementing change during a pandemic is different for every organization, managing it becomes necessary in a volatile environment.

Tourism is a highly adaptive and rapidly changing industry, it depends on many external and internal factors (Mariani, Czakon, Buhalis and Vitouladi, 2016). Despite the recognition of tourism as a priority sector with a contribution to GDP of 15-35% (Hungary, Czech Republic, Austria, Sweden, Italy, France, Spain, Portugal) (Буценко and Кулакова, 2017), post pandemic development rates indicate slow recovery (Gossling, Scott and Hall, 2020).

As the tourism supply chains experienced chaos - in 2020 and 2021 Covid-19 pandemic, the tourism sector in Lithuania shrank by 70-80% (Statista, 2022). According to A. Livina, G. Bukovska, I. Abols and M. R. Gavinolla, tour operators in Lithuania suffered € 9.5 million loss during the year of 2020 (2021). Their income fell by an average of 58%, as it was impossible for tour operators to plan future work due to the daily changing extent of the pandemic and the changing quarantine conditions, hence it was not possible to objectively assess future travel conditions and risks. Lack of government support and communication played a significant role in the financial situation of tour operators, which was also aggravated by the need to reimburse customers for their travel expenses due to quarantine or emergency declarations, as some of those funds were already frozen at destinations.

In order to maintain liquidity, the tourism sector was covered partially by state-guaranteed loans, a downtime system and subsidies for small and medium-sized enterprises, rent and interest compensation measures, negotiations with creditors and partners, and partial restructuring.

Up to today, the omicron variant of Covid-19 pandemic continues to be a global concern. So much so, that the centers for Disease Control and Prevention (CDC) has added more countries to its highest-risk category for travel including Japan, Cuba and Israel. The CDC's Level 4 classification now includes 134 destinations, meaning that more than half the countries in the world are on the agency's "avoid travel" list (UNWTO, 2022). For their part, tour operators made every effort to improve operational efficiency and reduce costs. Summarizing the data about the business of tour operators affected by Covid-19 and modulating the metamorphoses of their long-term planning strategy, principles of success and the future of tourism, it is possible to make a statement that the tour operator business had to adopt change.

German researchers A. Thams, N. Zech, D. Rempel, and A. Ayia-Koi (2020) studied the survival strategy of the travel business after the Covid-19 pandemic and the relationship between business organizers and service users. The paper emphasizes the importance of timely adaptation to change and new working conditions. The fundamental purpose is to increase organizational performance levels and to maintain these improvements.

Addressing the post-pandemic period in 2021, the problem of tour operator restructuring and the tourism supply chain system industry in Spain was also addressed by T. Gonzalez-Torres, J.L. Rodriguez-Sanches and E. Pelechano-Barahona (2021). The survey conducted by the method of qualitative interviews approached 9 respondents and examined the financial statements and documents of selected companies. Conclusions were reached on various company change management processes, such as the maximum use of state support, coordination of financial and fiscal activities, cooperation with other tour operators, attractiveness management, etc.

The analyzed literature showed a tendency to focus on the importance of change management models' implementation in the tourism supply chain structures, as well as the adaptation to changing business conditions' techniques, the potential for change in corporate governance strategies, and the analysis of changes in corporate governance models and consumer travel habits. Although the impact on the tourism supply chain structures is similar, the organizational aspects of chain participants were divergent. In order to substantiate the aim of this article, it is useful to analyze several specific examples of tour operators in Lithuania and the methods of change management implementation. A qualitative study was selected for this analysis.

4. Methodology

The method of qualitative research has been systematically chosen in order to examine the principles of activity of a certain group (in this case tour operators) under certain conditions in their natural environment (pandemic impact) to understand the experiences of the subjects and provide an interpretive, holistic evaluation. The strategy of the in-depth semi-structured interview of the phenomenological approach was chosen. The in-depth interview strategy focuses on the experiences of the subjects (Nunkoo, 2018). The semi-structured interview method is based on specific questions provided in advance in the interview plan, but it is likely that in the course of the research the researcher may ask additional questions not included in the plan if he/she thinks it could enrich the research (Tribe, 2015). Qualitative research will help to generalize the defense, gain insights, examine the perspectives of tour operators and refine concepts.

The representativeness of a qualitative research sample is determined by flexible theoretical criteria (Dann, Nash and Pierce, 2018). When conducting a qualitative in-depth semi-structured interview, each case is investigated in detail, therefore a smaller number of cases may provide a sufficient amount of data to achieve the purpose of the study (Tribe, 2015). During the research, the target numbers were chosen accordingly: a total of 6 informants – largest tour operators in Lithuania (4 respondents - X1, X2, X3 and X4) and medium (2 respondents - X5 and X6). Senior employees or managers, with no less than 5 year experience, were addressed, hereinafter referred to as experts in the survey. The field-of-work status of the X5 and X6 experts is defined as a travel agency, but both experts confirmed that in addition to the packages sold, they themselves organize bus tours (X5) as well as leisure, business trips and conferences (X6). All interviews were performed during March and April, 2021. A total of 8 questions were planned for the experts, but during the validation of the questionnaire with one of the interviewed experts, one question was abandoned and a total of 7 questions remained. The questions were divided into blocks of 2 sections, which were accordingly split up into several subsections. As in qualitative research with phenomenological approach, due to the much closer relationship between the researcher and the respondent, special attention was paid to ethics. Participants did not belong to vulnerable groups, so ethical principles were not difficult to implement.

5. Change management principles of tour-operators on the basis of the research results

Performed qualitative expert study of tour operators showed that the activities of tour operators were significantly affected by the Covid-19 outbreak, which led to many challenges in the organizational processes of their operations. As one of the most serious challenges in the history of the travel business, all respondents note the beginning of pandemic, when the movement between the countries was stopped, planes were landed and borders were closed. The tourism supply chain performance is based on people's travels, and when their demand for forced quarantine around the world ceased, not only did sales stop, but it was impossible to recover the contributions paid to intermediaries, making it difficult for travelers to return their booked trips. Analyzing the experts' responses in table 1, there was a consensus that employees were the greatest asset, and no one was forcefully fired. The number of employees decreased due to natural change or the choice of the employee, as the business has gone to standstill.

Table 1.

The impact of Covid-19 on tourism business.

Section 1. Opinion on the impact of covid-19 on tourism business	
Subsection 1.1	*Change of activity after the onset of outbreak*
Quotations: „The main challenge was the period of operating restrictions. The company has decleared downtime... as long as we had an opportunity to work from home, we kept going"-(X1). "It is difficult to say exactly how the coronavirus will affect our business. The company has sufficient funds to operate in the next financial year, therefore the risk of termination is low ..." - (X2). "…The biggest crisis in the company's history..." - (X3). "… We did not lay off employees, but suspended operations, employees were on downtime and ballots. At that time, the preservation of businesses and jobs was being addressed. 2020 the summer travel season was very short and particularly difficult for the entire tourism sector. We were limited in our activities. In an effort to take advantage of all opportunities, we organized flights, created conditions for partners to work and earn income. If the travel agency did not take advantage of this and did not participate in sales, then it is not active as a partner…"-(X4). "…Affected one hundred % directly; March, April and May of last year were a time of handling, keeping customers in touch, trying to retain and reassure them. Everyone in the dark ... we did not dismiss the old employees, only those accepted for a probationary period, and a few people left themselves ... " - (X5); „One of the main goals is not to hurt the service, the second is the staff. We tried not to lose people so that people had downtime to work partly with us, partly elsewhere. State benefits are not enough to pay full salary. It will soon be a year as we barely survive. All resources are exhausted, both the human factor and the company"- (X6).	

Subsection 1.2	*Loss assessment*
Quotations: „...The total turnover of all last year is 82% lower compared to 2019" - (X1). "... The company has suffered significant losses, but taking advantage of the opportunity, we will operate a specially purchased aircraft for our own needs, with which we hope to control the most important passenger logistics process without intermediaries ..." - (X2); "… 88% losses compared to 2019…" (X3). "At the moment, we cannot estimate all the losses incurred by the company; it will be seen when this situation is resolved and the flights will be resumed. In any case, the impact of this pandemic on the company's financial performance and the company's overall operations will undoubtedly be significant… " - (X4). "... Losses over 50 %...", "... everything stopped ..." - (X5). "... Income has fallen by 77%, there is no profit and so far the results are not visible ..." - (X6).	
Subsection 1.3	*Cost reduction factors*
Quotations: "…The company has optimized costs; costs have been reduced by more than half…salary compensation has been used…we have agreed on a loan…to settle with travelers…working on distribution channels so that we are stronger than ever after recovering from travel " - (X1). "... We received ... subsidies from investors and European funds, until 2023 we plan to significantly reduce costs ..." - (X3). "… The company has declared downtime and the salary funds have been halved. During this difficult period, the company strived to maintain its business and jobs, and we have optimized our costs to the maximum. The company to receive a soft loan with a state guarantee ..." - (X4). "... We are in partial downtime ... we used the help with the rent of offices, if the owner reduces the rent by 30%, 40% is paid by the state, and the rest by the agency. We gave up one office in Vilnius ..." - (X5). "... The state paid for downtime. We did not receive a grant. State aid is delayed, hopefully the money will reach as soon as possible. The number of offices has not changed ..." - (X6).	

Source: compiled by the authors based on the results of interviews.

The responses in the second subsection show that the travel business has almost come to a halt with the onset of the pandemic. The losses were 77-88% (X1, X3, and X6). Comprehensive state aid was needed. It can be argued that the state would spend much more on redundant workers by paying benefits to fund their reorientation; therefore it is more beneficial to subsidize the tourism sector so that people are not laid off. Respondents in both 1st and 3rd subsections mention that the aim was to save the workforce by using state support for downtime. According to the X5 expert, only those employees who were hired for the probationary period were laid off. New reorganization solutions were also sought to support operations: according to the X2 expert, several well-thought-out strategic merger and acquisition decisions were made in the wake of the pandemic to expand expertise and competencies and provide better customer service when tourism recovered.

The analysis of the responses provided by tourism experts shows that many tour operators have taken similar steps to maintain the liquidity of businesses. In terms of management practices, companies have focused on three key performance factors in order to enable uptime: retaining employees, stabilizing customer relationships, and securing business operations. State support was used during downtime to retain employees; companies invested in staff training. In order to meet the needs of customers, as well as to avoid bankruptcy, applications for soft loans were submitted and the accumulated funds of companies were used without paying dividends for the previous year. However, not all organizations had the same strategy in this regard. While some companies were looking for survival methods, optimizing costs and liquidity, controlling financial flows, managing liabilities, others were intensively and strategically preparing for the future and market recovery: reviewing portfolios, contractual terms, improving information distribution channels, investing in equity development, new technologies and reservation systems, expanded the range of services to be "stronger than ever" after the end of quarantine and the release of travel restrictions (X1). The small number of agencies exploiting this niche could be explained by the fact that many of them lack a clear vision, trust, technological, financial and competent human resources to optimize the performance of companies during the pandemic. However, it is also worth examining what changes companies implemented, trying to remain the most attractive after recovering, all of which are reflected in table 2.

Table 2.

The change management implementation

Section 2. Opinion on the change management implementation	
Subsection 2.1	*Establishing innovations through ASIT (Agency for Scientific Innovation and Technology) applications*
Quotations: "Yes, tourism innovations have been introduced in the travel business…" - (X1). … Did not participate. – (X2); Did not participate – (X3). "… We have created and integrated an electronic claims register ..." - (X4). "... We did marketing IT project that will launch in April. Updating the website, implementing the principles of gift voucher sales and concentrating on domestic travel ..." - (X5). "... Implemented and improved the CRM (customer relationship management) system and SEO (search engines optimization), also Google awards training ..."- (X6).	
Subsection 2.2	*Principles of avoiding levelling*
Quotations: "... We focus on increasing operational efficiency and are currently improving customer service ... customers are guaranteed warranty insurance ... all their money for future travel is insured ..."- (X1). "... Since the spring we have been traveling on a more modern aircraft and in more convenient times. These are our market advantages… "-(X2). "... The company received the award as a favorite tour operator ... long-term cooperation with regular customers, security of employees and customers - a priority, new security procedures at airports, ships, ... faster, cheaper and more efficient synergy; ...restructuring, digitization of activities, airlines and orders ... "-(X3). "... It is very important to have the right expectations ... and a personal connection…. and to offer what is relevant to the client.... focus on advertising ..." - (X5). "… Customer service ..." - (X6).	
Subsection 2.3	*Reservation automation processes*
Quotations: "... Sales have been automated for a long time, customer service centers work well and when offices are open - older people visit or those who find it harder to use the Internet ..." - (X3). "... Online travel is cheaper, so online shopping is encouraged ..."- (X4). "100 % online. Some come to the office if they want to pay in cash ... exotics need more details, ... and maybe people are more confident when they see us live ... " - (X5). "... During pandemic, consumer confidence in online tickets has declined due to a lack of service or difficulty in contacting ... - (X6).	
Subsection 2.4	*Model for successful business*
Quotations: "...The advantages are flexibility in planning activities, pricing system, the possibility to quickly change the direction of destination, the range of products offered and to adapt to market changes ..."-	

(X1). "This year is a year for customers, so we will make every effort to break established market standards, not only to open new destinations, but also to offer extended travel products" - (X2). "... Flexibility, customer satisfaction and loss of ownership, operating in a synergy model - adapting to market changes, speed and efficiency ..." - (X3). "... Flexibility and adaptation to changing conditions ..."- (X4)."... Faith in travel ..." - (X5). "... Be flexible ..." - (X6).

Source: compiled by the authors based on the results of interviews.

Most of the companies requesting financing have developed and improved their services - implemented new innovative information systems, travel reservation systems, online services. Others created various augmented presentations of their services and virtual video tours. It can be assumed that the remaining companies did not participate in the innovation tender due to the short deadlines for the implementation of innovations - only a few months gap was given for implementation. The choice of innovation may depend on other reasons. It is worth calculating what added value the new product or service will provide to the target customers, whether it will be the most useful and attractive. Of course, the potential for added value must also be taken into account, as every innovation requires investment, in this case, time and staff resources, and the economic benefits or payback will only happen in the future. New products for the tourism business, in turn, encourage fundamental changes in the motives of tourists to choose a particular nature, route and destination.

The importance of avoiding leveling in the company was examined by N. Dev (2020). According to him, the attitude of consumers to the company through the flexibility of the organization itself directly affect the financial indicators of the organization, the change of which can be a serious signal to managers and owners that the business strategy and methods need to be reconsidered and avoided (2020). Almost all the experts interviewed emphasized that close personal contact with customers (X2), analysis of their needs (X4, X5, X6), image of company reliability, customer safety during travel (X3), as well as increasing operational efficiency and quality of customer service (X1) are the basic principles for avoiding leveling. But if all tour operators follow the above principles, then what makes them exceptional? What methods do organizations seek to be visible? The answer to this question was given by expert X5 - marketing and online advertising. The digitalization is a great tool for implementing various marketing strategies, but it requires a lot of human, financial resources and systematic work, as confirmed by expert X6 in the first category, that the prolonged pandemic and quarantine required much more effort to attract customers than before.

Rapid ability to adapt to market changes is an essential factor for the survival of tour operators (Gretzel, et al, 2020). Technological advancement poses challenges for both the organization and the service user. Authors confirm that services online will only increase with time. In the wake of the pandemic, prolonged quarantine and the closure of tourism businesses, consumers have been encouraged to buy packages online. In the 2.3 sub-category, experts say that there are no major barriers to buying online (X3, X4, X5), but direct contact is still sought by elderly customers or exotic trip buyers, who may need more details from personal experiences of employees on particular destination (X5). The X1 expert says that traveling online is cheaper, which is why the interest in buying a trip online is high. Summarizing the opinion of tourism experts about online bookings, it can be stated that this factor affects all tour operators in a similar way, as the number of direct contacts in companies is decreasing. The European Commission is actively promoting the digital switchover, but it is worth noting that, as in the 2.1 sub-category, both innovation and online technologies are an excellent tool for implementing various marketing strategies, but also require significant human, financial and systematic resources.

Balance is important in every organization. A balanced solution at the right time is the basis for a successful business (Kopczuk, 2020). When the tourism business came to a standstill during the pandemic, tour operators had to balance between survival and the belief that, as the epidemiological situation improved, it would be possible to continue operating on an adequate scale. According to some experts, companies have given up loss-making assets, as well as cooperation with non-performing agents, while others have invested in property, redesigned travel routes to offer customers exceptional services when borders open. However, it can be assumed that during the pandemic, the maximum effort for staying “on board” was put into flexibility (X1, X3, X4 and X6), adaptation to market changes (X1, X4), belief in travel (X5) and development of new products (X2).

The measures analyzed during the expert interview for the successful change management/restructuring of the tour operators post-pandemic are: investments in employees and innovations, digitalization and automation of processes, correctly established customer expectations, cost optimization, maximum use of public funds, flexible sales conditions, continuous cooperation and improvement with service providers, return of deposits from partners in tourism supply chain, focus on future sales, caring for existing customers, expanding destinations to secure areas and full flexibility.

6. Change management model presentation

Restructuring means change, and in the event of a crisis caused by a pandemic, these changes become forced. A smooth and timely restructuring process allows organizations in temporary difficulties to reshape their operations, change the company's strategy, abandon unprofitable forms of activities, and focus on the most efficient ones. The difficulties are successfully overcome by those tourism supply chains that proactively monitor and evaluate key performance indicators - if the indicators are not satisfactory, they take all possible measures to improve their performance, that is, to implement the change. So in order for this sector to remain viable in the future, comprehensive change management was needed to retain competent staff and repay deposits for undelivered services, while funds were frozen at various foreign partners. Change management solutions are traditionally focused on improving the state of the tourism supply chain to implement change. The use of change (crisis) management models does not bring quick results, as decisions to manage them are made late, after the crisis has begun (Figure1).

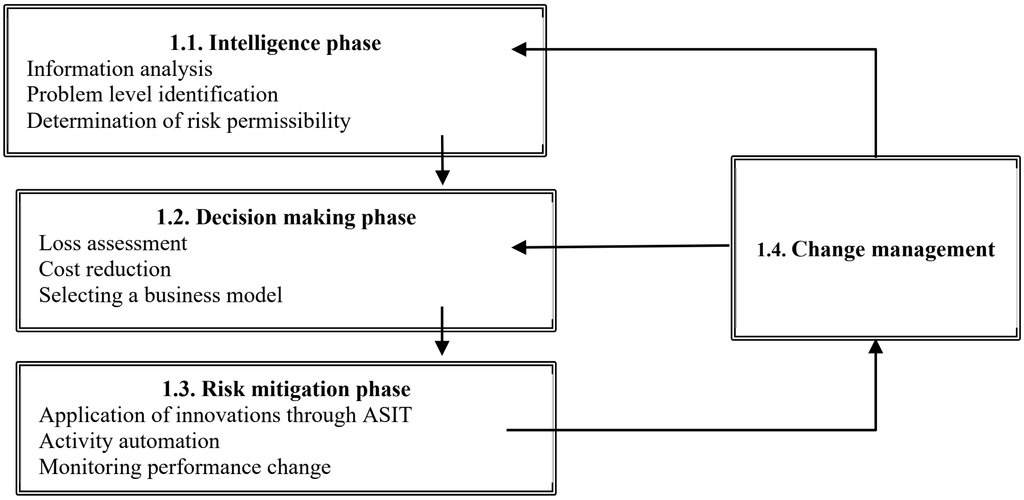

Figure 1. A model for management of change in tourism supply chain after Covid-19

Source: compiled by the authors.

The tourism supply chain change management model consists of the four phases listed above in figure 1. Each of the four stages of model are important in its own right, and requires careful conduct to ensure that it contributes towards the successful delivery of change.

1.1. Intelligence phase.

The necessary internal and external information must be collected and analyzed. Emerging risks must be identified, addressed, and monitored. Risk analysis is based on examining all past losses, a forecast of their occurrence for specific customers, and a justification of the methods used to predict or reimburse potential losses. Such information may be collected using formal methods. For example, external information is market analysis, and internal information is analysis of tour-operator businesses' financial statements, management interviews, and a survey of management consultants and employees. Information is also collected through informal methods - by observing or discussing the situation. It is important to distinguish between relevant and inappropriate information when analyzing. Information is the basis for decision-making and it is natural to aim for it to be as accurate as possible and relevant to the problem. The source information received by the manager usually contains a large amount of data that is not directly related to the problem being addressed. In order to focus on a specific problem, it is necessary to exclude from the source data provided information that is not related to the problem under consideration.

1.2. Decision making phase.

The importance of threat analysis is determined by the fact that its results will be used by decision-makers when planning security and risk reduction measures and the resources needed to implement them. Most of the management decisions made in companies are based on cost information. In order to successfully use cost information, it is necessary to clearly define the objectives that are being pursued and to select those types of costs that would be suitable for the implementation of a specific objective. The goal is focused on reducing the losses incurred by the tour-operator and increasing the efficiency of activities through separate operational processes. This phase allows to assess which risks could potentially have the greatest negative impact. The measurement of risk anticipates changes, anticipates and evaluates the risks to specific tour-operator. The significance of these risks is assessed, as is the risk position and the impact of market changes on a service-by-product basis. Loss assessment allows the tour-operator to assess the extent to which potential risks affect the achievement of its goals, and also allows assessing which risks can potentially have the greatest negative impact. All information received is used in choosing a further business model.

1.3. Risk mitigation phase.

This phase is intended to create and implement security and/or risk reduction measures in order to prevent possible emergency situations and/or reduce their impact, and mitigate possible consequences. It is one of the most important processes in the risk reduction phase, as the prediction and prevention of situations depend on its results. A risk management policy is a means of ensuring risk management in any tour-operator business. It is important that the selected risk mitigation measures are suitable for curbing the risk, and their cost is not higher than the potential losses. It is necessary to evaluate what is more useful (cheaper) for the tour-operator: whether they are losses due to risk realization or costs for risk reduction measures.

1.4. Change management.

The goal and objectives of a change management strategy are determined by the ever-changing tourism business environment in which the tourism supply chain has to operate, let alone the Covid-19 pandemic. In assessing the operational risk of such a tourism supply chain, it is important to break down the entire management process into appropriate systems and their elements. There are following elements of the change management system: management strategy, risk measurement system, information system, and control system. They examine change management as a system that integrates all its inherent elements. Elements of systemic risk management must be analysed through principles of their effective operation; the most characteristic connections between them must be categorized; the purpose of the system and the variables of the objective function must be determined (system results), emphasizing the importance of reducing the potential negative effects of the forces of the tourism business environment.

The presented model covers all the most important phases (functions) of change management in the tourism supply chain, considering the ever-changing post-pandemic environment. In the light of what is set out in this section, it can be assumed that large tour operators are currently leading the market, actively adapting to changing operating and market conditions during the pandemic, maintaining customer confidence, maximizing costs and automating, investing in human capital - the professional knowledge and personal qualities required for quality human resources. All these listed factors allow stating that the tour operators in Lithuania had to restructure, which has been proven by the research conducted.

7. Conclusions

The rapid spatial diffusion of the covid-19 epidemic outbreak has resulted in the total economic disruption of the tourism supply chain, causing a significant reduction in revenue and creating liquidity issues for all agents. All participating organisations in tourism supply chain are linked to each other in complex patterns. Any shock from one quickly spreads to others, producing cascading effects on the TSC. Considering the objectives of the different organisations, effective management within the supply chain is a key issue in achieving and maintaining competitiveness for the entire supply chain and its individual agents, especially those ones that largely represent customers' satisfactory levels. The tour operator is considered to be the largest retailer in the field of TSC, therefore tour-operators are the key factor in the success of the whole tourism supply chain, which justifies the aim of this article and further investigation into tour-operator post-pandemic change management options. After analysing the scientific literature, the tour-operator sector was identified as the most affected part of the tourism supply chain throughout the covid-19 pandemic. Due to the implementation of various restrictions, consumer fears, and worldwide efforts to stop the spread of the virus, the travel industry has fallen back to the level of thirty years ago as a result of the pandemic and has had a direct impact on the key tourism supply chain participants - the cruise, aviation, accommodation industries and consequentially - tour operator businesses. According to various scientists and given literature analysis, the change management process offers the greatest potential for growth and further development.

Tourism supply chain change management is one of the guarantors of the organizations', such as tour operator business, survival and factors that increase competitiveness. Although the impact on the tourism supply chain structures is similar, the organizational aspects of chain participants were divergent. Foremost components of the tourism supply chain encompass a range of processes linked to the tourism sector, such as policymaking and integrated planning; product development, promotion, and marketing; distribution and sales, also destination operations and tourism services. The main focus of the article is on successful tour operator change management, addressing key elements. Change management depends on an appropriate strategic planning and implementation process within the framework of organisations. Very important enabling sub-factors of tour operator change management are employee empowerment and business flexibility. Managers who want to make major changes in their organisations to remain competitive must work with HR to gain the support of key employees. In addition, the innovations, digitalization, and automation of processes, correctly established customer expectations, cost optimization, maximum use of public funds, flexible sales conditions, continuous cooperation and improvement with service providers, return of deposits from partners in the tourism supply chain, focus on future sales, caring for existing customers, and expanding destinations to secure areas were identified as crucial elements for post pandemic tour operator business resilience.

The fundamental changes caused by Covid-19 have forced tour operators to implement change management fast. The created model becomes an instrument for initiating and implementing tourism supply chain changes and managing pandemics. A smooth and timely change management process allows tourism supply chains in temporary difficulties to reshape their operations, change their strategy, abandon unprofitable forms of activity and focus on the most efficient ones.

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Energy efficiency of educational buildings using photovoltaic panels and air-water heat pumps. Case Study

Eficientizarea energetică a clădirilor de învățământ utilizând panouri fotovoltaice și pompe de căldură aer-apa. Studiu de caz

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Abstract. *Considering the current energy context, with the increase in the price of natural gas and electricity, the use of renewable energy has recently had an increasing trend. In this sense, the article presents a case study for the energy efficiency of educational buildings, through the installation of photovoltaic systems and air-water heat pumps. The simulation was carried out with the help of the Polysun calculation program, analyzing the energy consumption of the ASPC building of the Faculty of Construction in Timișoara, in the existing situation and in the proposed efficiency stages. The results show that in the first stage of efficiency in which the photovoltaic PV system and the air-water heat pump are installed, a decrease in costs for the necessary thermal and electrical energy is achieved, by 42.36%. In the second stage, in which it is proposed to decrease the return/return temperature regime of the indoor installation from 60/40 °C to 40/30 °C, the result is a decrease in the electricity consumption from the national network by 7.94%.*

Key words: *energy efficiency, photovoltaic panel, heat pump*

1. Introduction

Energy, regardless of its form, represents an indispensable resource for contemporary life. Currently, approximately 40% of the energy demand in the European Union (EU) is used in buildings, of which 80% represents the energy required for thermal needs (heating and water preparation in the building), and the energy demand for cooling increases every year. Taking into account the requirements related to energy economy through the sustainable use of human resources, the energy efficiency of buildings represents an increasingly current problem and of increased interest [1,2].

Another important aspect that must be taken into account is the increase in the price of natural gas, something that pushes us more and more towards the use of renewable energy sources, as evidenced by the measures taken by the EU, regarding the increase in energy efficiency from 9 to 13% and at the same time to reduce gas demand by 15% until the end of March 2023 [3-6].

A safe and sustainable source of energy is the solar one, which together with improving the energy efficiency of buildings, can contribute both to achieving the measures taken by the EU and to the reduction of greenhouse gas emissions and to the prevention of dangerous climate changes.

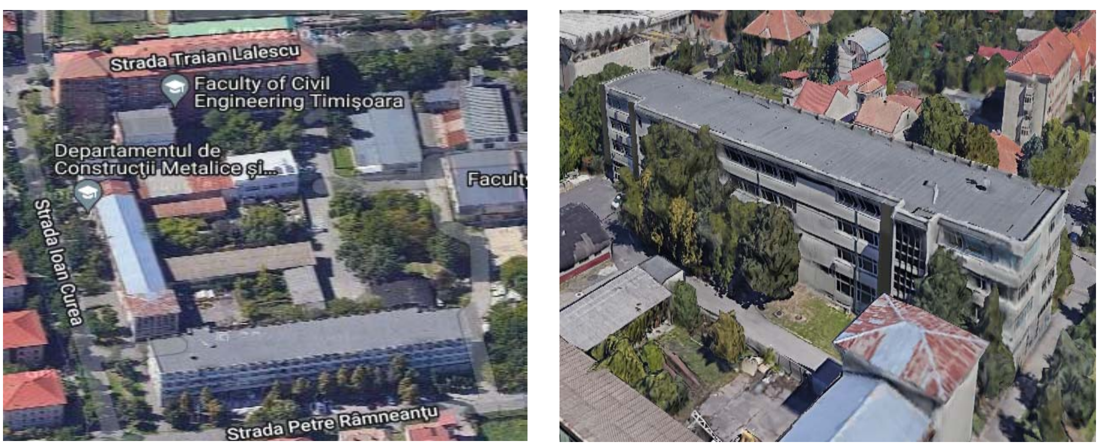
On the other hand, the agglomeration of buildings with different heights in urban areas, generates partial shading or uneven distribution of light intensity on the photovoltaic modules, causing considerable negative effects on the efficiency and integrity of the photovoltaic systems [3,7].

The article proposes, on the one hand, a study related to the shading of photovoltaic panels (PV) that affects the output power of the PV system and, on the other hand, the use of the energy produced to meet the thermal needs of the studied building, using an air-water heat pump.

2. Simulation of the photovoltaic system for the ASPC building. Case Study

To carry out the simulations, the simulation programs Polysun SPTX Constructor [8] and Polysun Designer [9] were used, a comparative study was carried out regarding the performance of the building's heating system, between the current situation and the proposed modernization solution.

The studied ASPC building, where teaching activities are carried out, is part of the building complex of the Faculty of Construction in Timișoara, has a height of 13m (P+3E), and the roof is of the terrace type with a perimeter attic of 50 cm high and 30 cm wide (Fig. 1).



a) b)

Fig. 1 ASPC building of the Faculty of Construction in Timișoara [9]

In the existing situation, the building is supplied with thermal agent for heating and preparing hot water for consumption from the public heating network of the city of

Timisoara. The basic diagram of the power supply system of the studied building is presented in Fig. 2.

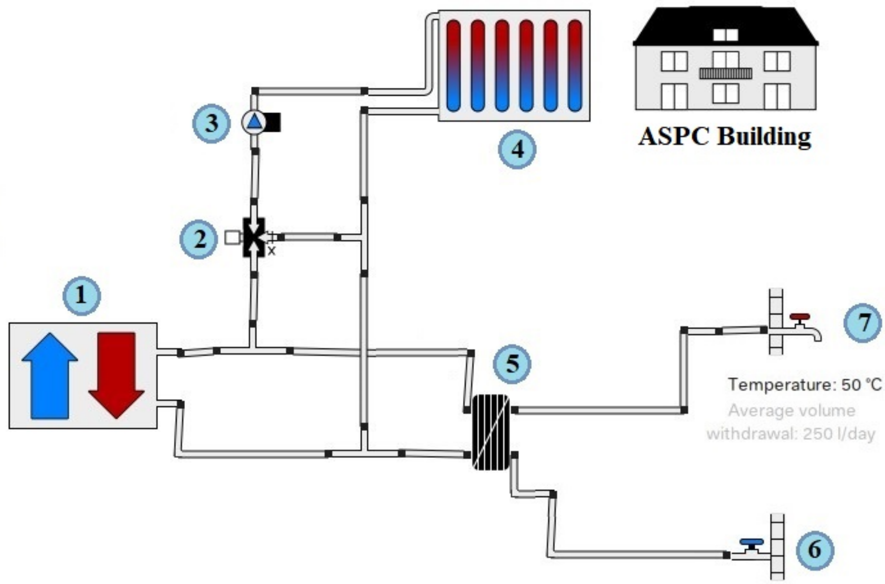


Fig. 2. Diagram of the heating and ACC installation in the existing situation [9]
1 – Heating network, 2 – Mixing valve, 3 - Circulation pump,
4 – Internal heating system, 5 – Heat exchanger,
6 - Cold water supply, 7 - Hot water consumers

The proposed modernization solution for the studied educational building involves, in the first phase, the installation of a PV system on the terrace of the building, designed to produce the electricity needed for its own consumption, following which the surplus energy produced will be transferred to the national energy system (NES).

Considering the previous studies carried out, we found that the ASPC building, from the point of view of the energy production of the PV system, its optimal orientation is East-West, the production compared to the orientation of the system on the South, being 5.58% bigger. We also found that of the total of 72.5 MWh of electricity produced by the PV system, 59.85% is transferred to NES [3].

For this reason, we proposed that the first stage of energy efficiency of the building should also include the installation of an air-water heat pump, which, using part of the surplus energy produced by the PV system, would ensure the thermal energy required for heating and water production hot housekeeper The basic diagram of the power supply system of the studied building is presented in Fig. 3.

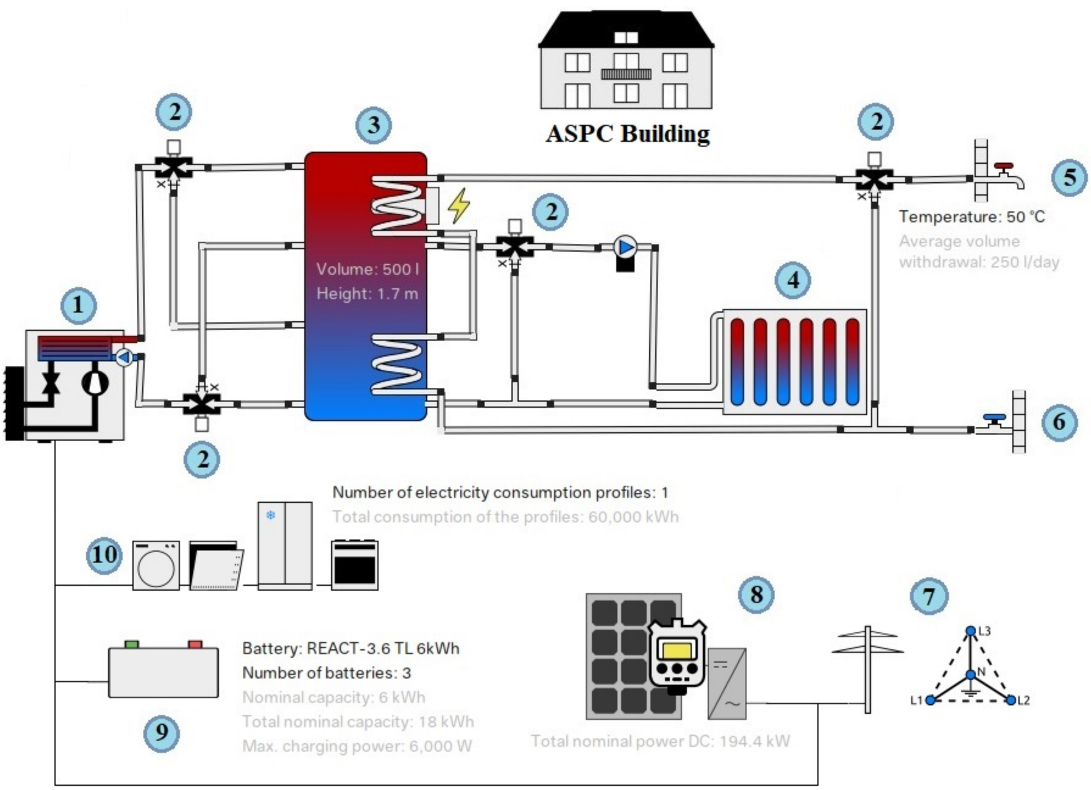


Fig. 3. Basic diagram of the installation after the proposed modernization [9]
1 – Heat pump, 2 – Mixing valve, 3 - Accumulation tank,
4 – Internal heating installation, 5 – Hot water consumers,
6 - Cold water supply, 7 - NES, 8 - PV system, 9 - Storage batteries, 10 - Electricity consumers

The PV system is composed of 486 EvoCells 400 MIB modules with a maximum production power of 400 Wp, with a total installed power of 194.4 MWp. The distance between the rows is 18.3 cm and a passageway of 40 cm is provided for a group of 10-12 rows, positioning distances determined by the shading of the PV modules by the attic of the building (Fig. 4) The PV system is also provided with 3 energy storage batteries, each of 6 kWh [3].

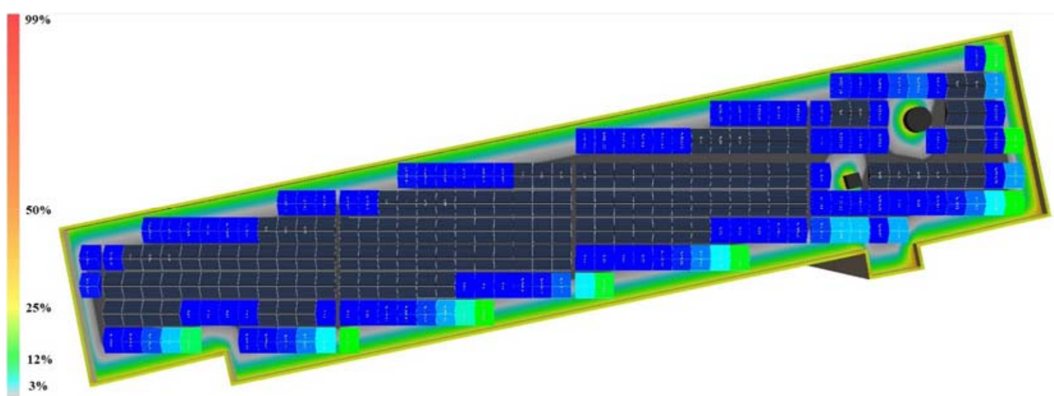


Fig. 4 Placement of PV modules on the ASPC building [1]

Considering the fact that the existing installation of the building contains radiators as well, the temperature regime chosen for the round and return is 60/40 °C. It is well known that the efficiency of air-water heat pumps is related both to the temperature the outside air as well as the temperature of the thermal agent that it must achieve. In order to increase the efficiency of the heat pump, we must lower the temperature of the heating agent, which leads us to the need to intervene on the existing heating bodies.

Thus, the second stage of efficiency proposed involves the replacement of radiators with fan coil units and thus reducing the temperature regime of the thermal agent to 40/30 °C.

3. Results and discussion

Following the simulations carried out, it can be seen in Table 1, in comparison, the annual consumption of electricity from the national energy system (SEN), and the consumption of thermal energy from the centralized heating network, both for the existing situation and for the two stages of efficiency proposed .

A calculation of the necessary costs for the energy consumed from the network was also made, at the currently estimated prices of 205.85 EUR/MWh for thermal energy and 306.12 EUR/MWh for electricity.

Table 1

Annual energy consumption

The type of energy	Stage	Consumption MWh	Price EUR	Total costs EUR
District heating consumption	Existing situation	58.58	12,059.13	30,442.40
Electricity from NES	Existing situation	60.05	18,383.27	
District heating consumption	Stage 1	0	0.00	17,546.94
Electricity from NES	Stage 1	57.32	17,546.94	
District heating consumption	Stage 2	0	0.00	16,154.08
Electricity from NES	Stage 2	52.77	16,154.08	

In Fig. 5, the monthly electricity consumption from the national network for the two proposed efficiency stages is presented and a decrease in energy consumption is observed due to the reduction of the temperature regime of the indoor installation from 60/40 °C to 40/30 °C.

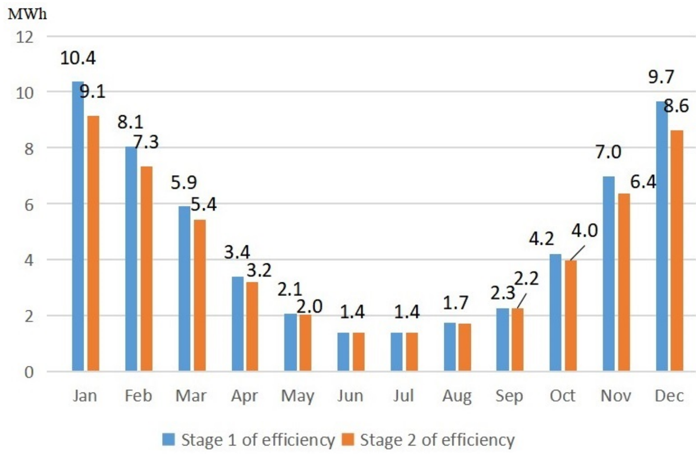


Fig. 5. Electricity consumption from NES for the 2 stages of efficiency

4. Conclusions

In conclusion, through the efficiency proposed for the studied educational building, it is observed for the first stage in which the photovoltaic PV system and the air-water heat pump are installed, a decrease in the costs for the purchased energy by 42.36% compared to the existing situation in which the building is supplied with thermal energy from the city's heating network.

Also, for an even greater increase in the efficiency of the air-water heat pump, a decrease in the temperature regime of the indoor installation is proposed, thus resulting in a decrease in the consumption of electricity from the national network by 7.94%.

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Alternative thermal insulation building material manufactured by expanding the glass waste with anthracite under the effect of microwave radiation

Alternativ material de construcție termoizolant fabricat prin spumarea deșeului de sticlă cu antracit sub efectul radiației microundelor

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Rezumat. *Sticlă celulară cu excelente proprietăți termoizolante (densitate de 0,27 g/cm³ și conductivitate termică de 0,053 W/mK) și rezistență acceptabilă la compresiune (2,7 MPa) a fost produsă din deșeu de sticlă, fosfat disodic (5,7 %) ca agent de stabilizare a spumei și antracit (0,9 %) ca agent carbonic de spumare, prin sinterizare cu microunde la 793 ºC. Antracitul a fost folosit pentru prima oară în cuptoare cu microunde într-un proces original. Eficiența energetică a procesului (0,66 kWh/kg) a fost remarcabilă față de procesele convenționale datorită vitezei de încălzire semnificativ mai înaltă față de vitezele utilizate în procesele convenționale, fără afectarea microstructurii omogene a produsului. Acesta este adecvat utilizării ca material termoizolant in construcții.*

Cuvinte cheie: sticlă celulară, microunde, antracit, agent de spumare, fosfat disodic, material termoizolant.

Abstract. *Cellular glass with excellent thermal insulation properties (density of 0.27 g/cm^3 and thermal conductivity of 0.053 W/mK) and acceptable compressive strength (2.7 MPa) was produced of glass waste, disodium phosphate, (5.7 %) as foam stabilizing agent and anthracite (0.9 %) as carbonaceous expanding agent by microwave sintering at 793 ºC. Anthracite was used for the first time in microwave ovens in an original process. The process energy efficiency (0.66 kWh/kg) was remarkable compared to the conventional processes due to the heating rate significantly higher than the rates used in conventional processes, without affecting the product homogeneous microstructure. This is suitable for using in building as a thermal insulation material.*

Keywords: cellular glass, microwave, anthracite, expanding agent, disodium phosphate, thermal insulation material.

1. Introduction

The last decades have been marked by a growing concern of the world community for the recycling of waste and industrial by-products. Annual waste generation rates from metal, plastic, glass, textiles, etc. or also coal fly ash, metallurgical slag, oil shale, different sludge and other by-product have excessive dynamics, so their storage in landfills has become insufficient to protect the environment. According to [1], continuing the current trend of waste recycling would be insufficient and the environment would be suffocated by them. Taking 2015 as a benchmark, the global amount of recycled waste should increase by 2030 from 363 Mt to 740 Mt.

Given that the glass is a material with relatively short life-time, large amounts of waste are annually generated (25.8 Mt in 2007 only in EU countries) [2]. In addition, the different types of glass as a chemical composition make it difficult and costly to sort waste for the reintroduction into the industrial production circuit of the new glass. In the last 3-4 decades, it has been found that recycled glass waste could be an excellent raw naterial for the manufacture of building materials similar to existing ones. The energy consumption for their production (about 500 kJ/kg) is significantly lower compared to the energy consumption required to make the glass (about 1500 kJ/kg) [3].

Several companies (Misapor Switzerland, Pittsburgh Corning, Glapor Werk Mitterteich, Geocell Schaumglas, etc.) focused their production activity in Europa, the United States, and China [4] on manufacturing cellular glasses with variable characteristics, but incorporating remarkable physical, thermal and mechanical properties (light weight, low density, low thermal conductivity, at least acceptable mechanical strength, resistance to fire, moisture, insects, rodents and bacteria aggression, resistance to corrosion and frost, high durability, chemical and physical stability, etc.) [5]. Due to this combination of properties, the cellular glass is especially attractive for the construction sector, being a thermal insulation material with load bearing capacity, usable both inside and outside the building for insulation and as a light filler for building foundations or for road and railways construction, drainages, sports fields, swimming pools, insulation for underground heating pipelines and storage tanks, etc. [6, 7].

Except the industrial production, worldwide scientific research in the field of making various cellular glass types by improved techniques, use of various raw materials, expanding agents and additives is very active, numerous works being published in the literature.

The main method of foaming the powder mixture based on glass waste applied by all industrial manufacturers is the incorporation of a solid or liquid expanding agent and sintering the mixture at a temperature equivalent to its softening point. The expanding agent must be selected so that at the temperature mentioned above it releases a gas (or a gaseous compound) into the viscous mass of raw material. The gas generates bubbles, which are blocked inside the viscous material and by cooling the bubbles turn into pores (cells) forming the specific structure of the cell glass [5].

Generally, the gaseous products result through decomposition (e.g. calcium carbonate) or redox (e.g. oxidation of carbonaceous materials) reactions [5]. The main carbonaceous materials used as an expanding agent are: coke, graphite, anthracite, carbon black, glycerol, etc. In industrial processes the most commonly used are carbon black (Pittsburgh Corning, Misapor) and glycerol (Glapor).

The advantage of using carbon-based expanding agents is the lower cost and ability to oxidize at lower temperatures (750-850 ºC) compared to other expanding agents. From this point of view, it is considered that this agent type is suitable for the processes of foaming the glass, the obtained porous products having cells with small size. According to [5], the carbonaceous agent is used in weight proportions between 0.2-2 %.

The disadvantage of using carbonaceous materials in ovens that operate with an oxidizing atmosphere is the danger of premature oxidation of carbon particles. To avoid this disadvantage, the coating of fine carbon particles with a protective layer is necessary [8]. According to the literature [9], the optimal solution is an addition to the starting mixture of sodium phosphate (Na_3PO_4) or potassium phosphate (K_3PO_4) as a foam stabilizer. The temperature of the foaming process of the glass waste was reduced with the increase of the alkaline phosphate content.

The carbon black as a carbonaceous foaming agent (in proportion of 1 wt. %) was chosen by the authors of the paper [10] to produce a high mechanical strength cellular glass, using borosilicate glass waste, antimony oxide (Sb_2O_3) between 0-1.2 wt. % and disodium phosphate (Na_2HPO_4) as an additive (6 wt. %). The finely ground mixture was sintered at 750-800 ºC for 30 min in a graphite crucible placed in a conventional oven. Due to the presence of Sb_2O_3 in the glass mass, the viscosity and surface tension of the melt were diminished, also reducing the value of the sintering temperature. Also, the pore size was reduced and the density of the foamed material increased. Higher Sb_2O_3 ratios block the premature oxidation of carbon black during heating, but can lead to structural inhomogeneity. At the optimum sintering temperature of 775 ºC the compressive strength reaches 3.6-4.6 MPa, while at 800 ºC the mechanical strength decreases to 1.8-2 MPa. The samples sintered at 775 ºC had the density of 0.408 g/cm^3, porosity of 84.6 %, compressive strength of 4.4 MPa and water absorption of 1.6 %.

According to [11], an analysis of the sintering/expanding process of borosilicate glass waste showed that by increasing the heating rate there is a tendency to reduce the pre-oxidation of carbon black, resulting an inhomogeneous distribution of pores in the foam structure. The optimum heating rate was determined experimentally at 8 ºC/min and the grain size of carbon black was considered optimal at 150 μm to obtain uniform pore size.

Charcoal (a lightweight carbon black residue) has been used as a carbonaceous expanding agent in the process of foaming the panel glass of an expired life-time cathode-ray-tube (CRT) [12]. Manganese oxide (MnO_2) between 5.4-7.2 % was added to the starting powder mixture as an oxygen-supplying agent for the release of carbon dioxide (CO_2). The grain size of charcoal and MnO_2 had values between 15-27 μm. The sintering temperature varied between 800-840 ºC. The optimum sample was obtained by sintering at 800 ºC using 1 % charcoal and 7 % MnO_2. The apparent density of the sample was very low (0.13 g/cm^3) as well as the thermal conductivity (0.042 W/mK).

It should be noted that the processes of expanding glass waste with carbonaceous agents both industrial and small-scale mentioned above have been carried out by conventional heating methods. Unlike these, the group of Romanian companies Daily Sourcing & Research and Cosfel Actual Bucharest (including the main authors of the current paper) have developed in the last 4-5 years an experimental program to test the production of cellular glasses exclusively using electromagnetic wave radiation.

According to [13], experiments aimed at foaming borosilicate glass waste included, among others, a carbonaceous expanding agent (activated carbon). The powder mixture included 92.8 % glass waste, 1 % activated carbon, 6.2 % Na_2HPO_4 and 10 % water addition. The sintering/expanding temperature was 820 ºC, the average heating rate being 15.3 ºC/min. The porous product had the following features: apparent density of 0.34 g/cm^3, porosity of 84.5 %, thermal conductivity of 0.055 W/mK, compressive strength of 2.5 MPa and pore size between 1-2.5 mm.

The paper [14] reports the foaming of borosilicate glass waste in a 800 W-microwave oven using in the optimal variant carbon black (1 %) as a carbonaceous foaming agent, Na_2HPO_4 (5.9 %) as a foam stabilizing agent, Sb_2O_3 (0.8 %) as an oxygen supplying agent and water addition (10 %) as a binder. The optimal sintering temperature was 790 ºC and the heating rate was 24.8 ºC/min, unlike the conventional heating techniques with hearing rate around 10 ºC/min [15]. The main characteristics of the cellular product were: 0.34 g/cm^3 apparent density, 84.5 % porosity, 0.06 W/mK thermal conductivity, 2.2 MPa compressive strength and 0.4-0.7 mm pore size. The energy efficiency of the process (0.68 kWh/kg) was below the consumptions level reached in the industrial cellular glass conventionally manufacturing processes.

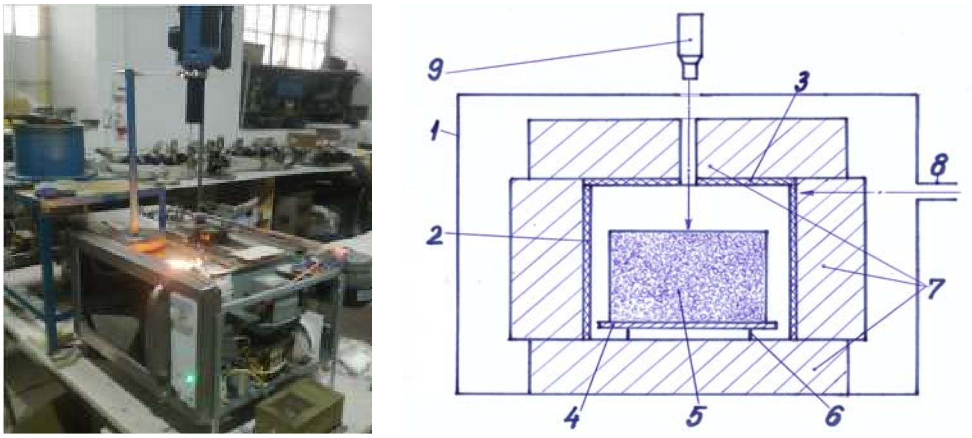
The current paper keeps the own original method of predominantly direct microwave heat treatment developed in the latest experiments of the Romanian group of companies and presented in the literature [16]. In addition, the originality of this paper is the choice of the type of carbonaceous expanding agent (anthracite) which has not been previously tested in unconventional heating processes.

2. Methods and materials

The first experiments aimed at direct microwave heating of recycled soda-lime glass (commercial glass) powder, i.e. post-consumer drinking bottle and clear flat glass from demolition, showed that the core structure of the glass sample suffers serious damage due to the excessive contact intensity between the microwave field and the glass. The original solution adopted by the authors was to protect the material with a ceramic tube covered with a lid made of a mixture of SiC and Si_3N_4 (both components being excellent microwave susceptible materials) placed between the microwave source and the glass. The ceramic tube with an outer diameter of 125 mm, a height of 100 mm and a wall thickness of 2.5 mm purchased from China proved to be the optimal solution ensuring predominantly direct and partially indirect (by thermal radiation) microwave heating [16].

The experimental equipment shown in Fig. 1a is composed according to the scheme in Fig. 1 b of a microwave oven (1) equipped with a single 800 W-magnetron (8) of the kind used in household adapted for high temperature operation (up to 1200 ºC), inside which is placed at the oven base a thermal insulation bed of ceramic fiber mattresses (7), on which a metal plate (4) is placed on a metal support (6), which will support the pressed powder mixture (5) prepared from the previously dosed materials. Above the pressed mixture is placed the ceramic tube (2) provided with a lid (3), supported on the thermal insulation bed. The outer surface of the tube and lid are protected with thick layers of ceramic fiber mattresses (7) to avoid the heat loss from the inside to the outside. The control of the heating process is performed with a radiation pyrometer (9) mounted above the oven on a support at about 400 mm, which visualizes the heated material through the holes provided in the upper wall of the oven and the ceramic lid.

The direct microwave heating (predominant in this case) is initiated in the core of the irradiated material, the microwave power being converted into heat. The heat thus generated volumetrically propagates throughout the mass of the material from the inside to the outside. Another characteristic of direct microwave heating is selectivity, which means that only the microwave-sensitive material is heated, not other massive components of the oven. Thus heating is done quickly and efficiently in terms of energy, being completely different compared to the conventional heating [17, 18].



a b

Fig. 1. Experimental microwave equipment
a – overal image of the equipment; b – constructive scheme of the equipment:
1 – microwave oven; 2 – ceramic tube; 3 – ceramic lid; 4 – metal plate;
5 – pressed powder mixture; 6 – metal support; 7 – thermal insulation;
8 – waveguide; 9 – pyrometer.

The foaming process of glass waste using carbonaceous materials as an expanding agent is based on the oxidation reactions of carbon with formation of CO_2 or CO according to the following ecuations.

$$C + O_2 = CO_2 \qquad (1)$$

$$C + 0.5O_2 = CO \qquad (2)$$

The gas bubbles containing CO_2 and/or CO are spread into the viscous mass of glass forming by cooling a fine porosity structure [5]. Only an excessive increasing of the process temperature would create a structure with semi-open pores due to the increase of gas presure inside the bubbles and increasing the glass volume.

According to [5], the glass foaming with carbonaceous materials occurs in the range 800-900 ºC and the gaseous products are strongly influenced by the type of carbonaceous materials and by the glass composition (mainly, the sulfate content). Except the reaction with atmospheric oxygen existing in the oven and in the spaces between the glass particles, carbon can react with some constituents of the glass (alkalis, sulfates and water).

As noted above, the carbonaceous expanding agent adopted in the experiment presented in this paper was anthracite, a hard sort of coal having the highest carbon content (between 86-97 %) [19]. Chemically, anthracite may be considered as a transition stage between common bituminous coal and graphite. Its standard features (maximum limits) are: 15 % moisture, 20 % ash, 10 % volatiles, 73 % fixed carbon and 1 % sulfur. This carbonaceous expanding agent was ground in a ball mill and sived at the grain size of 15 μm.

The basic raw material used in the experiment was recycled post-consumer drinking bottle (green, colorless, and amber in approximately equal ratios). The oxide composition of the three soda-lime glass types [20] is presented in Table 1.

Table 1

Oxide composition of the glass types

Glass type	Oxide composition (wt. %)								
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	Na_2O	K_2O	Cr_2O_3	SO_3
Green	71.8	1.9	11.8	-	1.2	13.1	0.1	0.09	-
Colorless	71.7	1.9	12.0	-	1.0	13.3	-	0.05	-
Amber	71.1	2.0	12.1	0.2	1.1	13.3	0.1	-	0.05

Processing the glass waste used in esperiments consisted in washing, color selection, breaking, grinding and sieving. These operations were performed in the Romanian company Bilmetal Industries SRL Popesti-Leordeni, Ilfov and led to the final granulation below 80 μm.

The composition of the starting material mixture was supplemented with the addition of Na_2HPO_4 as a foam stabilizing agent and distilled water as a binder. As mentioned above, the role of Na_2HPO_4 is to prevent the premature oxidation of anthracite before reaching the foaming temperature by enveloping its fine particles with a protective layer, under the conditions that the process takes place in an oxidizing environment. Na_2HPO_4 with a purity of 95 % was purchased from the market as a Chinese crystalline product and was ground in an electrically operated laboratory device at a grain size below 30 μm.

Three experimental variants of the starting mixture components were adopted including recycled glass waste (between 92.7-93.3 wt. %), Na_2HPO_4 (between 5.7-6.3), anthracite (between 0.9-1.1 wt.%) and water addition (12 wt. %) having the weight proportions shown in Table 2.

Table 2

Composition of the starting mixture

Variant	Recycled glass waste (wt. %)	Na_2HPO_4 (wt. %)	Anthracite (wt. %)	Water addition (wt. %)
1	93.3	5.7	0.9	12.0
2	93.0	6.0	1.0	
3	92.7	6.3	1.1	

Similar methods to characterize the foamed products used in all previous experiments performed in Daily Sourcing & Research and Cosfel Actual companies were also applied in the current work to determine the apparent density by gravimetric method [21], porosity by comparison of apparent density and „true" density [22], compressive strength with a TA.Xtplus Texture Analyzer, thermal conductivity by the guarded-comparative-longitudinal heat flow (ASTM E1225-04), water absorption by water immersion method (ASTM D570) and microstructural investigation of the cellular glass samples with an ASONA 100X Zoom Smartphone Digital Microscope.

3. Results and discussion

The parameters of the testing process of manufacturing the cellular glass by the unconventional technique presented above are shown in Table 3.

Table 3

Parameters of the manufacturing process of cellular glass

Variant	Dry raw material amount (g)	Process temperature (ºC)	Process time (min)	Average rate (ºC/min)		Cellular glass amount (g)	Specific energy consumption (kWh/kg)
				Heating	Cooling		
1	470	793	31	24.9	5.2	486	0.66
2	470	801	33	23.7	5.3	485	0.69
3	470	810	35	22.6	5.3	487	0.75

The dry raw material amount was kept constant at 470 g for the three experimental variants. As a characteristic of the foaming processes of glass waste which use carbonaceous expanding agents, the sintering/foaming process temperature had low values (between 793-810 ºC). The microwave heating rate (between 22.6-24.9 ºC/min) significantly exceeded the usual values of this parameter in conventional processes (around 10 ºC/min) and contributed to achieving very economical specific energy consumption (0.66-0.75 kWh/kg) without influencing the cellular glass quality.

The cross section of the cellular glass samples obtained after the heat treatment is presented in Fig. 2.

a b c

Fig. 2. Cross section of the cellular glass samples
a – variant 1; b – variant 2; c – variant 3.

According to the images in Fig. 2, the fineness of the porosity of samples decreases from variant 1 made at 793 ºC with 5.7 % Na_2HPO_4 and 0.9 % anthracite to variant 3 made at 810 ºC with 6.3 % Na_2HPO_4 and 1.1 % anthracite. Therefore, a slightly higher proportion of anthracite as an expanding agent increases the temperature of the foaming process and leads to more coarse macrostructures.

Table 4 presents the main physical, thermal, mechanical and microstructural characteristics of the cellular glass samples determined accordind to the methods of analysis mentioned above.

Table 4

Characteristics of cellular glass samples

Variant	Apparent density (g/cm^3)	Porosity (%)	Thermal conductivity (W/mK)	Compressive strength (MPa)	Water absorption (vol. %)	Pore size (mm)
1	0.27	87.1	0.053	2.7	1.6	0.1-0.5
2	0.25	88.1	0.049	2.2	1.4	0.2-0.8
3	0.22	89.5	0.046	1.8	1.4	0.3-1.0

The data in Table 4 show that the unconventional method of predominantly direct microwave heating using anthracite as an expanding agent favors obtaining cellular glasses with good thermal insulation properties (apparent density between 0.22-0.27 g/cm^3, thermal conductivity between 0.046-0.053 W/mK and porosity between 87.1-89.5 %) and at the same time with sufficiently high compressive strength (1.8-2.7 MPa). The water absorption is low with values below 1.6 vol. %. These characteristics indicate that the cellular glass manufactured under the conditions presented in the paper is suitable to be used as thermal insulation material in building, being able to replace the existing materials.

Examination of the microstructural characteristics of the cellular glass samples (Fig. 3) indicates that the best dimensional uniformity of the pores is achieved in the case of variant 1 (pore size between 0.1-0.5 mm), the microstructural homogeneity decreasing in the case of variants 2 and 3. The sample corresponding to variant 3 tends to have a more coarse distribution of pores, which are in the range of 0.3-1.0 mm.

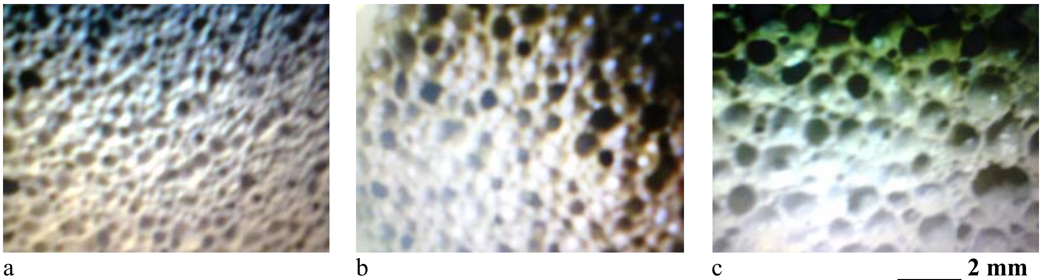


Fig. 3. Microstructural configuration of the cellular glass samples
a – variant 1; b – variant 2; c – variant 3.

Centralized analysis of information on microwave field cell glass manufacturing with the use of anthracite as a carbonaceous expanding agent including physical, thermal, mechanical, microstructural characteristics and functional process parameters (temperature, heating rate and specific energy consumption) led to establishing variant 1 as optimal. The cellular glass corresponding to this variant sintered at 793 ºC with heating rate of 24.9 ºC/min reached a minimum value of energy consumption (0.66 kWh/kg) being a very economical process compared to the other two experimental variants, but also to the consumption achieved in conventional industrial processes (0.75-1.15 kWh/kg [23]). As a peculiarity of the unconventional foaming process, it was observed that, despite the significantly higher heating rate compared to conventional processes, the microstructural characteristics of the porous product are not affected.

The comparison of the characteristics of the foamed products obtained in this experiment with those previously made with different carbonaceous expanding agents (carbon black, charcoal, activated carbon) showed generally a good similarity, especially in the case of applying the unconventional method [13, 14]. By using the anthracite, adopted in the experiment presented in the current paper, a cellular glass with apparent density (0.27 g/cm^3) and thermal conductivity (0.053 W/mK) was produced, even slightly lower than the results of applying the unconventional technique mentioned above, thus increasing the thermal insulation properties of the final product. In addition, the specific energy consumption was kept at a very low level.

4. Conclusions

The aim of the research that formed the basis of this paper was to test anthracite as a carbonaceous expanding agent in a process of manufacturing cellular glass from recycled glass waste (post-consumer drinking bottle) by microwave heating using the own original heating method predominantly direct. This method has already been successfully applied by authors in several previous experiments and presented in the literature. The main originality of the paper is the testing for the first time in the world of foaming glass waste with anthracite as an expanding agent embedded in the starting powder mixture, which also contains Na_2HPO_4 as a foam stabilizing agent, under the conditions of applying the microwave irradiation technique. Three experimental variants were tested including glass waste (92.7-93.3 %), Na_2HPO_4 (5.7-6.3 %), anthracite (0.9-1.1 %) and water addition (12 %) as a binder. The powder mixture was microwave sintered at 793-810 ºC using heating rates between 22.6-24.9 ºC/min, significantly higher than the rates used in conventional processes. The very low level of specific energy consumption (0.66-0.75 kWh/kg) is remarkable. Heating rates did not affect the physical, thermal, mechanical and microstructural characteristics of the products. The values of these features were: apparent density between 0.22-0.27 g/cm^3, thermal conductivity between 0.046-0.053 W/mK, porosity between 87.1-89.5 %), compressive strength between 1.8-2.7 MPa, water absorption below 1.6 vol. % and pore size below 1 mm. All variants had properties suitable for use as alternative thermal insulation building material, but variant 1 which used 0.9 % anthracite, 5.7 % Na_2HPO_4 and sintering temperature 793 ºC was chosen as the optimal variant. It had the highest apparent density of 0.27 g/cm^3, but the other characteristics were excellent (thermal conductivity of 0.053 W/mK and compressive strength of 2.7 MPa). Very fine porosity with pore size between 0.1-0.5 mm represented the appearance of the cross section of this foam sample.

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Characterization of Calcined Clay Blended Self Compacting Concrete-Correlation between Super-plasticizer dosage and Self-Compacting Concrete Properties

Caracterizarea betonului autocompactant amestecat cu argilă calcinată - corelația dintre doza de super-plastifiant și proprietățile betonului autocompactant

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Abstract. *Sustainability in the construction industry is essential to economic development and can be achieved by the use of locally available construction materials. This research work, thus, uses locally available materials –calcined clay and Sandcrete SPR-300 superplasticizer in the production of Self Compacting Concrete (SCC) by investigating the correlation between the superplasticizer dosage and the fresh and hardened states properties of a grade 30 SCC made by incorporating a Calcined Clay (CC) – Portland Limestone Cement (PLC) blend as the cementitious material at 15% replacement of PLC with CC and using CC as filler. The superplasticizer dosage was varied from 0.0 to 3.0% by weight of cementitious material and the fresh state properties - measured using slump flow tests, v-funnel time test and L-box test – as well as strength parameters investigated. The result shows a positive correlation between the increased dosage of the superplasticizer and the fresh and hardened states properties of the SCC up to 2% dosage of the SCC. The* J_{Spread}, t_{500J}, *Slump flow, L-box* H_2/H_1 *ratio and strength, all increases with SP dosage while the V-funnel flow decreased with SP dosage. Overall, SP ratio of 1.5 and 2.0% by mass of cementitious material can be used in improving the properties of SCC produced using calcined clay both as filler and SCM. However, because of the volume of clay used and the nature thereof, the target strength could not be reached. It is therefore recommended that SP dosage of Sandcrete SPR-300 of between 1.5 and 2.0% be used with calcined clay as SCM but different filler, like limestone powder, be used.*
.

Keywords: Calcined Clay, Compressive Strength, Fresh-state Properties of SCC, Self-Compacting Concrete, Superplasticizer dosage.

1. Introduction

Concrete is the life-wire of the construction industry and it has been described as the most utilized construction material in the world [1]. Globally, the annual concrete consumption stands at over ten billion metric tons and is the second most utilized material on earth, second only to water [2] Thus, the importance of this material to humanity cannot be overemphasized. Basically, concrete is a heterogeneous material consisting of a binder (Cement), aggregates (Fine and Coarse), water and sometimes some mineral admixtures and is characterized by its strength at 28 days and its durability. Concrete is said to be durable if it can maintain a reasonable amount of its mechanical properties, especially its compressive strength, over a period of time known as its service life. Other properties of concrete considered under durability include its resistance to chemical attacks, freezing and thawing, cracking, corrosion resistance of the embedded reinforcement, etc. [3].

To ensure that concrete satisfies its intended use during its lifetime as well as satisfy the evolving needs of the construction industry, various improved forms of this product have been invented/ developed, especially in the last century that architects and construction engineers have ventured into otherwise impossible ambitious designs and constructions. One of such revolutionary concretes is Self-Compacting Concrete (SCC) also known as self-consolidating concrete. [4] defines Self-consolidating concrete (SCC) as highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation. In general, SCC is concrete made with conventional concrete materials and, in some cases, with a viscosity-modifying admixture (VMA). SCC has also been described as self-compacting concrete, self-placing concrete, and self-leveling concrete, which all are subsets of SCC. SCC involves the use of large amounts of secondary cementatious materials (SCM) and fillers which reduces the cost of concrete production. Also, the use of SCMs optimizes two of the three most important fresh properties of SCC, namely segregation resistance and flowability.

Despite the many advantages inherent in the use of SCC, there is no limit to improvements that can be brought about on this very important construction material. For instance, when compared to NVC, SCC has different mix composition due to the presence of high quantities of fine particles and paste but lower coarse aggregate content which can lead to a change in the pore structure of SCC and alter some of its properties like its fracture behavior [5,6]. Thus, concerns are raised about the fracture behavior of SCC because the lower coarse aggregate content can lower its energy absorption capacity and hence its ductility [7]. Other properties of SCC that can be improved upon include its strength, pore characteristics and durability characteristics. However, the properties of SCC in the hardened state are mostly influenced by its fresh state properties, which are a function of the rheology of the SCC [8]. The rheology of SCC and its workability is in turn affected by the use of admixtures like super-plasticizers (SP) and viscosity modifying admixtures (VMA) [9]. Thus, research is ever ongoing aimed at improving the properties of SCC at the fresh and also hardened state by either altering the mix composition of its ingredients, incorporating new environmentally friendly materials into SCC to produce a more sustainable SCC.

This research investigates the effect of varying the quantity of a local super-plasticizer, SANDCRETE SPR-300, on the fresh and hardened state properties of a Calcined clay blended Self-compacting concrete.

Self-compacting Concrete is concrete that can flow under its own weight alone without external vibration. [10] states that SCC should not only be able to flow and compact under its own self weight but also be able to fill all parts of the duct, reinforcements, etc. and still maintain its homogeneity. It can thus be inferred that a good SCC must meet the criteria of passing ability, flowability and segregation resistance.

Flowability refers to the ability of SCC to flow under its own weight and fill all parts of the formwork without any form of external vibration. This property is sometimes referred to as the filling ability and basically has to do with the deformability of SCC. There are two distinct aspects of deformability, namely; the deformation capacity - which is the maximum ability of SCC to deform and it depends on the yield stress - and the deformation velocity; which is the time taken from the start to the end of flow of SCC. [11] citing Khayat & Tangermsirikul (2000) states that the deformation capacity of SCC can be increased by lowering the inter-particle friction between the solid particles.

Passing ability is the ability of SCC to pass through heavy reinforcing steel bars without the blocking and separation of its particles and at the same time maintaining the suspension of coarse particles in the Cement Matrix. The passing ability of SCC is affected mostly by the risk of blocking, which depends mainly on the size, shape and content of the coarse aggregates in the concrete, as well as the paste volume (Aggarwal et al. 2008). The yield stress of concrete has a far greater effect on its passing ability than its plastic viscosity.

Segregation resistance describes the ability of SCC to maintain homogeneity without separation of its larger constituents. Segregation can occur between water and solid particles in the SCC, paste and aggregates and between mortar and coarse aggregates in both the static and flowing states. It is known as dynamic segregation if it occurs during placing of SCC and static segregation if it happens after placement of concrete [12]. The resistance of SCC to segregation depends largely on the viscosity of the SCC [13]

The flowability and filling/ passing ability of SCC are key properties of SCC in the fresh state and are greatly influenced by the cement paste properties [14]. The use of super-plasticizer helps to ensure that these workability properties are achieved without compromising the segregation resistance of SCC. [15] stipulates the SP dosage as a percentage of the cementitious material content but the exact quantity is most times determined on a trial-and-error basis.

Various researchers have investigated the relationship between SP dosage and different properties of SCC, the most recent being [16] who studied the rheological properties of modified self-compacting cementitious paste and concluded that the fresh state properties impact on the properties of SCC in the hardened state. [17] studied the correlation between rheology and strength when SP dosage is varied, while [18] studied the combined effect of water-powder ratio and SP dosage on the Rheology and strength of SCC. [19-20] variously studied the effect of SP dosage and mixing time on rheology and strength of SCC. All the researchers were unanimous on the correlation between rheology of SCC and the hardened state properties as well as the influence of SP dosage.

2.0 Materials and Methods

2.1 Materials

Portland Limestone Cement, grade 42.5N was used in the and tests were carried out to determine its properties in accordance with the provisions of BS 12 (1991).

The grading and particle shapes of fine aggregate are significant factors in the production of SCC. Thus, the aggregates were carefully chosen to fit into the specifications for aggregates for SCC. Consequently, River sand from river Benue and crushed rocks of maximum particle size 10mm was used as fine and coarse aggregates respectively. The aggregates were characterized at the Civil engineering laboratory of the Joseph Saawuan Tarka University Makurdi in accordance with the provisions of BS 812 (1985) and ASTM C 127 and 136.

Super plasticizer (polycarboxylic fiber) by the trade name of Sandcrete SPR-300, was used for this study, manufactured by WAFA group of companies. The specific gravity, pH and chloride content of the SP is 1.08, 6.5 and less than 0.1% respectively.

2.2 Fresh state properties of Self-Compacting Concrete

The slump flow tests were carried out to determine the flow time, time taken to reach a diameter of 500mm and the flow diameter in line with [15, 21] while the V-Funnel test was carried out in accordance with the procedures of [22].

The L box and J rings were used to determine passing and filling ability of the SCC with the procedure set out in [15, 23-24] used for the J-ring tests; while methods given in [25] were used for the L-box tests.

2.3 Permeation and Strength properties

The permeation properties of the SCC were determined in accordance with [26] and [27, 28] for sorptivity and water absorption respectively. The test for sorptivity was carried out at 28 and 56 days for each mix to evaluate the effects of the SP dosage on the rate of water absorption through interconnected capillary poles. Three numbers diameter 100mm by 50mm discs, cut from 100mm by 200mm concrete cylinder specimens, were used for each test and the average result calculated, while the water absorption test was carried out at 7, 14, 28 and 56 days to monitor the change in water absorption capacity of the SCC with changing quantities of SP. For each test, three 50mm x 50mm x 50mm cubes were used and the average value taken. The effect of varying the SP dosage on the tensile strength was determined using diameter 100mm by 200mm cylinders at 7 and 28 days in line with the provisions of [29], while the compressive strength of the SCC was determined using 100 cubic millimeters concrete cubes cured at 7, 14, 28 and 56 days in accordance with the provisions of [30].

3.0 Results and Discussions

3.1 Materials Characterization

The materials used for the study were characterized for their physical properties, oxide composition and morphological properties. Tables 1 and 2 and figs. 1 to 3 shows the result of materials characterization.

Table 1:

Tests on Materials

Property investigated	Material tested				
	PLC	CC	PLC-CC	Fine Aggregates	Coarse Aggregates
Specific gravity	3.15		-	2.60	2.40
Setting Times Initial (final)	150 (195)	-	180 (230)	-	-
Consistency (%)	30	-	31.5	-	-
Soundness(mm)	2	-	2	-	-
Moisture Content (%)	-	-	-	3.0	-
Fineness modulus	-	-	-	3.45	-
Agg. Crushing value	-	-	-	-	21.73
Agg. Impact value	-	-	-	-	24.5

Table 2:

Result of Oxide composition of PLC and CC

Oxide	CaO	Fe_2O_3	Al_2O_3	SiO_2	TiO	K_2O	Na_2O	SO_3	BaO	P_2O_5	V_2O_5	Cr_2O_3	MnO	TiO	LOI
CC	1.5	7.7	25.1	61.2	0.36	1.8	0.03	0.2	0.11	4.32	0.1	0.03	0.04	1.8	-
PLC	65.57	6.83	5.60	16.20	0.20	0.48	0.78	2.51	0.12	-	-	-	-	-	0.09

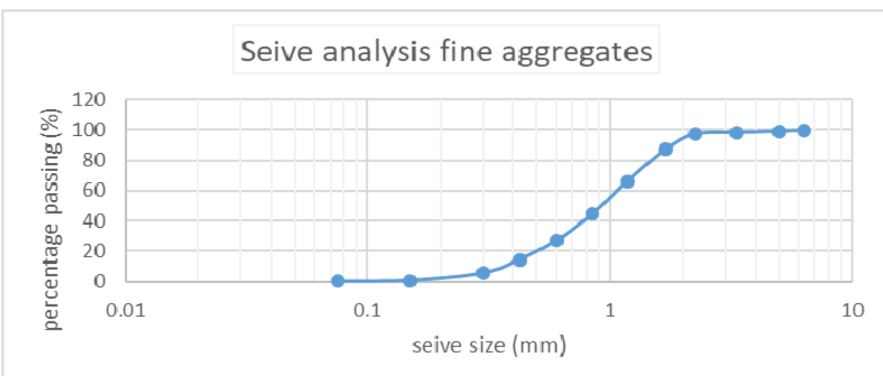

Fig. 1: Gradation curve for fine aggregates

Fig. 1 shows the gradation curve for fine aggregates. It can be seen from the curve that the sand is well graded and thus suited for SCC application.

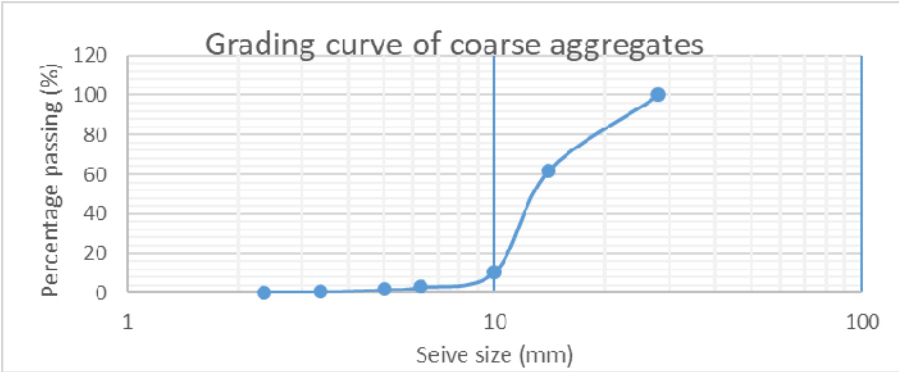

Fig. 2: Grading curve of coarse aggregates

The coarse aggregates are well graded and have a maximum aggregates size of less than 20mm as recommended in EFNARC 2005 for SCC aggregates and is thus suitable for SCC production. The result of XRF analysis presented in table 2, shows that Calcined clay contains more than 70% of SiO_2+Al_2O_3+Fe_2O_3 and so meets the ASTM C618 for a class F pozolan. The cement also contains more than 50% CaO as stipulated in BS 12.

Fig 3 gives the sieve analysis of calcined clay.

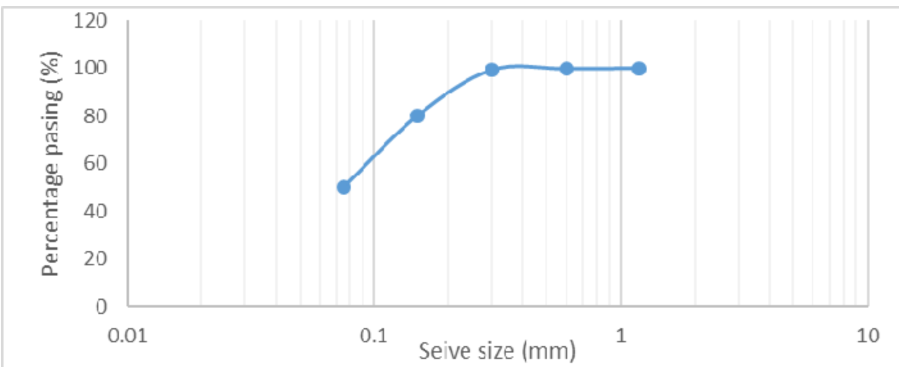

Fig. 3: Grading curve of Calcined Clay

The sieve analysis of the clay shows 50% passed through the 75µm sieve and over 99% of the clay particles are finer than 300µm. The clay particles have a large surface area for reactivity and can also fill the pore spaces between the aggregates in the concrete matrix.

The result of XRD analysis, quantitative and qualitative is presented in figures 4 and 5 respectively.

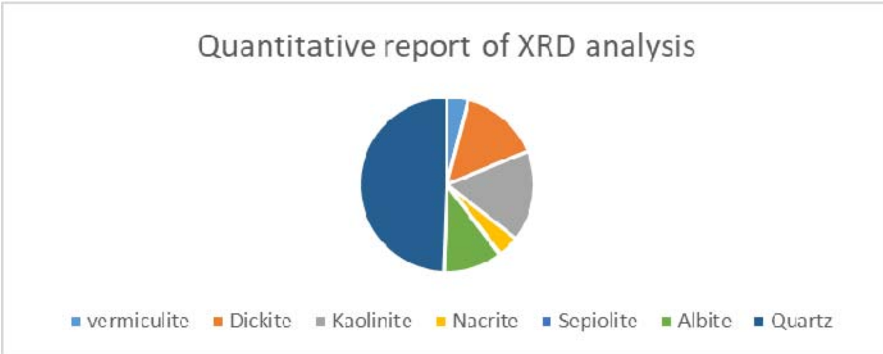

Fig. 4: XRD analysis of Calcined clay (Quantitative)

It can be seen that the CC is made up principally of quartz (50% by total mineral volume)- SiO_2 which indicates pozzolanicity and can be used as a secondary cementitious material. The result of the grading of the calcined clay also shows that more than 50% of the material is finer than 75μm and can make a good filler material.

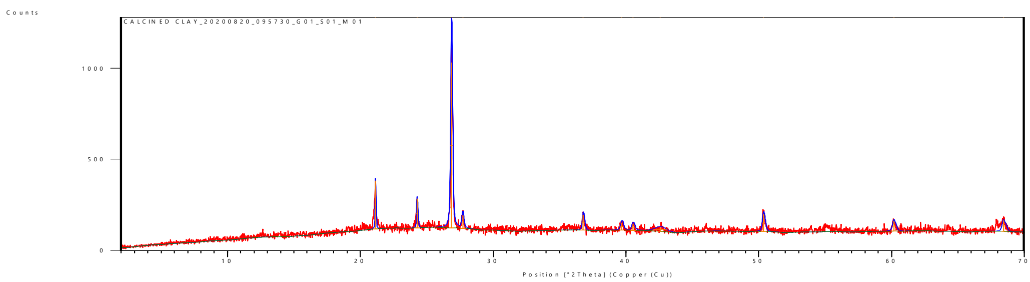

Fig. 5: Result of XRD analysis on calcined clay (Qualitative)

Fig. 6 gives the FTIR analysis of calcined clay. In the IR studies of the clays, Si-O stretching vibrations were observed at 773.3cm^{-1} (775.3 cm-^{1}); 909.5 cm^{-1} (913.2 cm^{-1}), 998.9 cm^{-1} (1028.7 cm^{-1}), for clay (and calcined clay), showing the presence of quartz (Mansor et al 2016; Manu & Dinaka 2015). A strong band at 3693.3 cm^{-1} (3697.5 cm^{-1}) and 3649.1 cm^{-1} (3623.0 cm^{-1}) indicate the possibility of the hydroxyl linkage (Messaoud et al, 2018), while the interlayer hydrogen bonding is assigned by the characteristic band of 3620 cm^{-1} (Messaoud et al, 2018). Most of the bands present in the clays shows the presence of the Kaolintes (Witkowski et al, 2018).

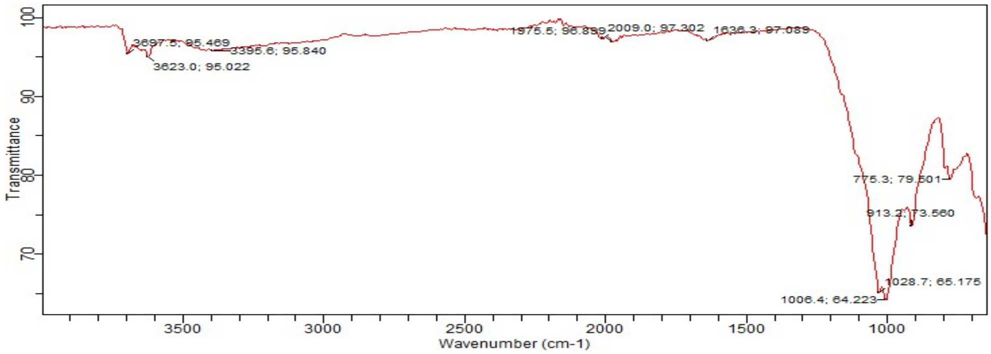

Fig. 6: FTIR Spectroscopic analysis of Calcined Clay

3.2 Mix proportioning

The mix is designed based on the principle of the plastic viscosity of the SCC mix; which was first proposed by Kharihaloo & Ghanbari (2012) and it exploits the expression for the determination of the plastic viscosity of a heterogeneous material like SCC from the known plastic viscosity of the homogenous component (in this case the cement paste). It is based on the micromechanical procedure developed by Ghanbari & Kharihaloo (2009).

Al-Rubaye (2016) and Abo-Dhaheer (2016) used this principle to develop mix design charts for SCC. The mix design chart for SCC grade 30 was used in the design of the mix to determine the quantities of the constituent materials incorporating 15% CC as SCM and using CC as the filler. The chart is presented as fig. 7 and the mix parameters are presented in table 3. The target plastic viscosity chosen is 11PaS.

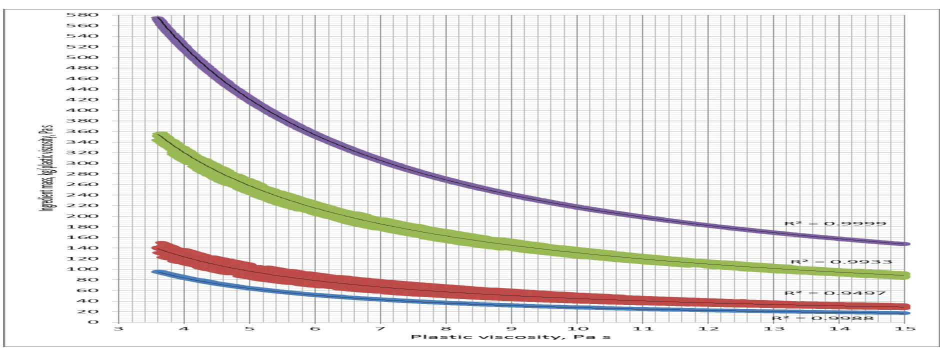

Fig 7: Design Chart for SCC grade 30 based on target plastic viscosity. (Source: Al-Rubaye, 2016)

Table 3 gives the quantities of materials calculated and used for the research.

Table 3:

Mix quantities for SCC testing

% of SP	Quantities in Kg						
	C	CC	W	SP	F	FA	CA
0	11.25	1.25	7.2	0.0	4.1	25.9	28.3
1.0	11.25	1.25	7.2	0.123	4.1	25.9	28.3
1.5	11.25	1.25	7.2	0.185	4.1	25.9	28.3
2.0	11.25	1.25	7.2	0.247	4.1	25.9	28.3
2.5	11.25	1.25	7.2	0.309	4.1	25.9	28.3
3.0	11.25	1.25	7.2	0.371	4.1	25.9	28.3

3.3 Fresh state properties

3.3.1 Flowability testing

The slump flow and V-funnel tests were used to measure the flowability of the SCC and the result is presented in table 4.

Table 4:

Flowability testing results

ID mark	Sp %	t_{500} (s)	Viscosity class	t_{flow} (s)	d_{1-} (mm)	d_{2-} (mm)	SF (mm)	SCC class	V_{funnel} time (s)
S0	0	0.44	VS1/VF1	1.36	536	538	537	-	3.86
S1	0.5	0.42	VS1/VF1	1.18	550	540	545	SF1	2.83
S2	1.0	0.60	VS1/VF1	1.29	570	575	572.5	SF1	3.24
S3	1.5	0.63	VS1/VF1	1.32	670	660	665	SF2	4.00
S4	2.0	0.53	VS1/VF1	2.10	740	740	740	SF2	3.50
S5	2.5	0.59	VS1/VF1	1.17	780	780	780	SF3	2.32
S6	3.0	0.82	VS1/VF1	1.12	810	810	810	SF3	2.06

The result shows that the mix belongs to viscosity class VS1/ VF1 based on the $t_{500\ test}$ and V_{funnel} time tests respectively for all SP dosages. However, the flow diameter shows that the mix without SP does not have the required slump flow and hence low workability. This is due to the shortage of water which could be enhanced by the use of SP since the water demand of calcined clay is high. Samples S1 to S6 all show good slump flow and workability. However samples S5 and S6 showed segregation and bleeding due to the high dosage of SP which made the workability to be too high. S3 and S4, containing 1.5 and 2.0% of SP by mass of cementitious material belongs to SCC class SF2 and showed good workability without bleeding and segregation which is an indication of low yield stress and good deformability (EFNAC 2005). The European guidelines for SCC (EGSCC 2005) states that the slump flow value gives the flowability of a fresh SCC. SF2 is suitable for most normal applications whereas class SF1 has limited applications.

3.3.2 Filling and Passing Ability tests

The L-Box and J-ring Tests are a measure of the filling and passing abilities of an SCC batch respectively and indicates how well a specific batch of SCC will flow through restricted spaces without blocking. The filling ability, determined using the L-box, gives an idea of how well an SCC mix batch can flow into and fill formwork under the action of gravity alone. The result is presented in table 5.

Table 5:
Test results for filling and passing ability

L-Box Test results							J-Ring Tests results			
ID mark	SP %	H_1	H_2	H_2/H_1	T_{200} (s)	T_{400} (s)	d_{Jx} mm	d_{Jy} mm	SF_J	Passing ability rate
S0	0.0	7.7	6.0	0.78	0.80	1.86	460	465	462.5	2
S1	0.5	7.5	6.6	0.84	0.73	1.68	500	490	495	1
S2	1.0	7.4	6.6	0.89	0.67	1.40	530	532	531	1
S3	1.5	8.2	7.6	0.93	0.68	1.04	640	640	640	0
S4	2.0	8.4	7.6	0.93	0.57	0.84	730	730	730	0
S5	2.5	8.0	7.8	0.98	0.47	0.78	770	772	771	0
S6	3.0	7.3	7.2	0.99	0.40	0.73	805	805	805	0

According to EFNARC 2005, for proper filling ability the ratio, $0.8 \le H_2/H_1 \le 1.0$ must hold. It can be seen from table 5 that the ratio holds true for all mixes except for S0 which contains no superplasticizer. More so all mixes met the stated criterion and visual inspection showed no signs of segregation or blockage except S0.

Similarly, from table 5, and comparing with the provisions of EFNARC 2005, sample S0, containing no SP shows noticeable to extreme blockage due to the low workability while S1 and S2 shows low passing ability with minimal to noticeable blockage and S3 to S6 sows no visible blockage due to their high workability.

3.4 Strength Characterization

Fig. 8 gives the result of compressive strength tests at 7 and 28 days.

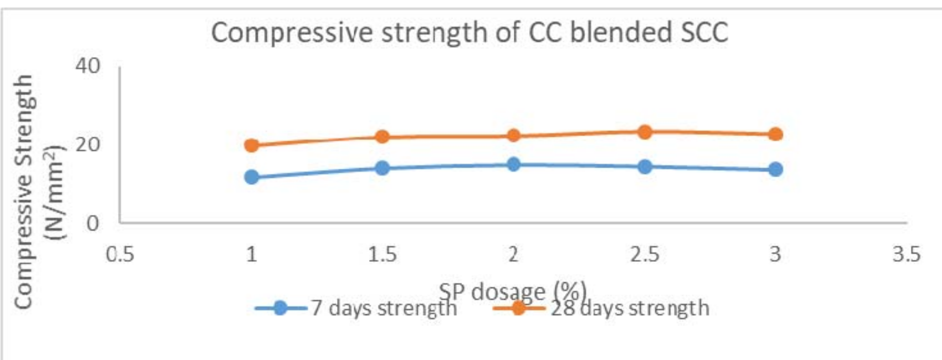

Fig 8: relationship between Compressive Strength and SP dosage

The result shows that the strength increases with curing age for all superplasticizer dosages. This is expected, as the cement hydration process is time dependent. The rate of strength increase with age, however, is higher with the SP dosage. This is because the increasing SP dosage provides for more workable concrete and hence more water is available for the hydration reaction without causing bleeding of the concrete.

3.5. Durability Characterization

The rate of ingress of water and other substances into an SCC gives a measure of the durability and is a function of the pore structure of the concrete. The two basic measures employed here are the water sorptivity that is a measure of the rate at which water ingress through interconnected pore spaces while water absorption gives a measure of the general water ingress through all kinds of pore spaces. The result of percentage reduction in water absorption is presented in fig 9 while fig. 10 shows the Sorptivity characterization.

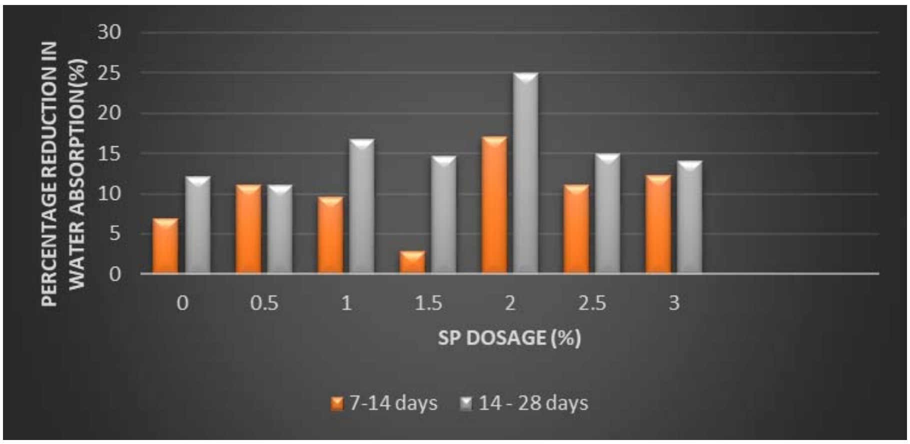

Fig. 9: Change in water absorption with age

It can be seen from fig 9 that the rate of decrease in water absorption varies with age and SP dosage with sample with 2% of SP showing the best water absorption behavior with age.

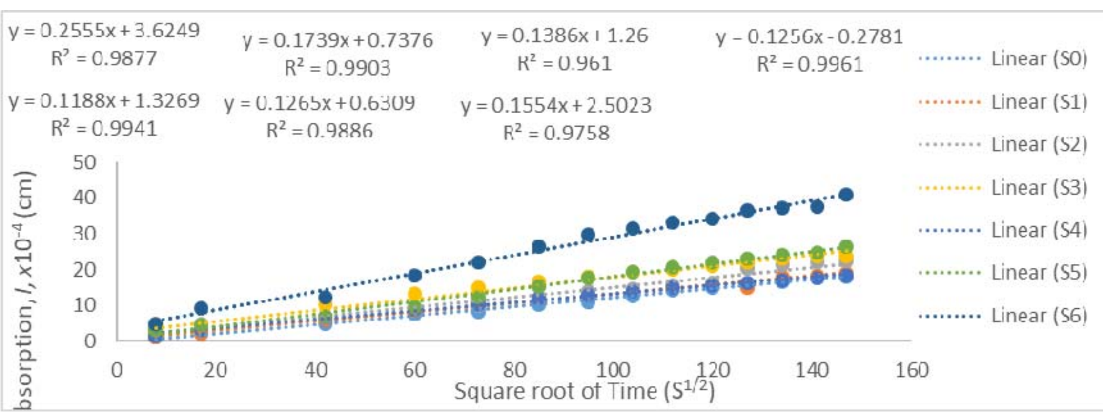

Fig 10: Sorptivity performance of CC blended SCC at 28 days curing

It can be seen that samples S3 to S5 shows better sorptivity performance, while the sample without SP (S0) shows the worst sorptivity performance at 28 days curing.

4.0 Conclusion

It is concluded from this research work that SP ratio of 1.5 and 2.0% by mass of cementitious material improves the properties of SCC produced using calcined clay both as filler and SCM. However, because of the volume of clay used and the nature thereof, the target strength could not be reached. It is therefore recommended that SP dosage of between 1.5 and 2.0% be used with calcined clay as SCM but different filler, like limestone powder, be used.

Author Contributions

The lead author (Taku Kumator) designed and supervised the entire work with the assistance of Engr Dr. B. Amartey. The experimental works were carried out by Gondo George and Eze Chinedu while Avre provided logistics and technical support.

Conflict of Interest

Declaration of conflict of interest. There is no conflict of interest

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Procedura simplificata de evaluare a sistemelor fotovoltaice

Simplified PV panels system energy evaluation procedure

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Rezumat: Lucrarea prezentată reprezintă o metodologie simplificată de evaluare a sistemului fotovoltaic în ceea ce privește energia generată, acoperirea globală a cererii de energie a sistemului analizat, energia suplimentară necesară din rețea și performanțele sistemului la modificarea parametrilor de montaj. Ecuații propuse și legătura cu metodologia națională MC001 și anexele acesteia, lucrarea propune o evaluare rapidă a aspectelor economice și a perioadei de rambursare. S-a demonstrat că investițiile în astfel de sisteme sunt rambursate rapid în perioade de la 4 până la 5 ani pentru consumatorul obișnuit cu un consum mediu zilnic de 11,15 kWh. În ultima parte a procedurii, a fost definit un parametru de suprafață specific consumatorului, util în calculul rapid a suprafeței solare nete totale a sistemului pentru a satisface un consumator cunoscut. În final, a fost studiată locația Bucureștiului, iar parametrii propuși de ecuațiile date au fost supuși unei evaluări de optimizare.

Cuvinte cheie: Energie regenerabilă, panou fotovoltaic, MC001, SEN

Abstract: Presented paper represent a simplified methodology for evaluation of PV system with regards to generated energy, overall energy demand coverage of the system analyzed, supplementary energy required from the grid and performances of the system when mechanical parameters are changed. Proposed equations and link with Romanian national methodology MC001 and its annexes the paper proposes a quick evaluation for economic aspects and refund period. Was shown that investments in such systems are rapidly reimbursed in periods of 4 to 5 years for common household appliances consumer with a daily average consumption of 11.15kWh. In last part of the procedure, it was defined a specific consumer specific surface parameter, useful in rapid return of system total net solar surface to satisfy a known consumer. In the end, location of Bucharest was studied, and the parameters proposed by this paper equations where subjected to an optimization evaluation.

Keywords: Renewable energy, PV panel, MC001, SEN

1. Introduction

The use of PV panels system for residential building electrical energy demand is more and more an adopted solution of customers to household energy bills increase. Solar radiation is a constant waveform that heats the Earth. The PV panels technologies known a wide development in terms of transforming surface materials or increased efficiency.

Due to their easy installation and low exploitation costs, usage of such technology is only an energy balance question, with focus on overall cost reduction and electrical energy generation. To evaluate such systems, a simplified procedure is the best approach when decision of implementation required an easy approximation of yearly energy coverage of a specific consumer energy. Not being so simple to distinguish an average energy demanded in residential sector for example, a specific evaluation per unit of kWh consumed, may be a good choice when the daily or monthly energy consumption is known or can be approximated based on several previous months consumption. This paper will propose several energy and qualitative parameters together with their specific equations to reflect the impact of several PV panels geographical position installation based on known specific horizontal solar irradiation from national normative.

2. Methodology description

The method described below evaluates overall electrical energy obtained by PV panels systems, in monthly intervals, for one year.

First step is to evaluate a PV panel system using the methodology described in MC001. In the methodology, horizontal solar radiation is presented as daily average for each month of the year and for several Romanian cities. The same methodology presents a set of correction factors, depending on azimuth and tilt angle of PV panels, to calculate the corresponding tilt radiation shown by equation 1.1.

$$I_{tilt} = I_{T,Oriz} \cdot c_c \qquad 1.1.$$

In Standard Test Conditions, PV panels efficiency is evaluated based on the maximum power, $P_{max,1000}$ obtained on its surface when the PV panel is tested with equivalent tilt surface equal 1000W/m^2. Based on net solar PV panel surface A_{pan}, representing the net area that will transform the radiation on electrical energy without the case and boundary frame of it and with Standard Test Condition radiation can be expressed efficiency. This efficiency is calculated with maximum power presented in PV panel datasheet with equation 1.2 or can be given as a specific parameter by some of PV panel manufacturers. In both cases, efficiency represents same indicator and can be used with same meaning during evaluation. This efficiency is a separate indicator of solar PV panels depending on each manufacturer and materials used in production. In worm environments, PV panels functionality depends on external conditions, such the air temperature, their thermal efficiency being a known parameter that harms overall energy production (η_t).

$$\varepsilon_{PV} = \frac{P_{max,1000}}{A_{pan} \cdot I_{1000}} \qquad 1.2$$

PV panels electrical energy is produced in DC type due to semiconductor material characteristics with junction based that allowed to circulate only the current in one direction from its Anode to Cathode when photons from solar radiation affect the electron- hole pairs. DC current produced cannot be used in residential building were household appliances, TV and all types of electrical devices work with AC type current. To commute from DC to AC current, inverters are used. Those devices use the technique of switching the DC poles with a frequency of 50-60HZ and thus creating an alternate current useful in residential electrical energy applications. Being electronical devices inverters introduce their own efficiency (η_{inv}) in the system.

For a specific system with several installed PV panels, the monthly energy it is expressed as sum of all daily energy produced. Using the tables from the MC001 methodology, correction coefficient from Annex A1 based on azimuth and tilt angles, and thermal efficiency, some examples can be found in Annex A2, monthly electrical energy obtained by the system is calculated with equation 1.3 were index i represents the month number in the year for which the evaluation is performed.

$$E_{l,i} = \frac{1}{1000} \cdot 24 \cdot N_{zl} \cdot A_{tot} \cdot I_{tilt} \cdot \eta_{t,i} \cdot \eta_{inv} \cdot \varepsilon_{PV} \qquad 1.3$$

$$E_{tot} = \sum_{1}^{12} E_{l,i} \qquad 1.4$$

Total energy produced by the system is easily found as the sum of all monthly energies obtained over the year, given by equation 1.4 were Nzl is month days number.

3. Procedure steps frame

The evaluation procedure frame consists in several useful steps to determine each parameter, calculate the specific efficiency, and evaluate overall energy produced by the PV panel systems. Firstly, are assessed PV panel system components such total net solar surface, tilt and azimuth angles and inverter type and its efficiency. After this step can be evaluated corresponding horizontal solar radiation for the location where system is installed based on charts in MC001. Third step is selection of right correction coefficient, based on physical characteristics found at first step, from Annex A1 and PV panel thermal efficiency from Annex A2. Finally, the total energy produced is calculated as the sum of all monthly energies. Bellow a frame of the steps is presented.

First step:

a. Count and note the number of PV panels, Np;
b. Measure and note the tilt angle of PV panels as the angle with horizontal line;

c. Measure and note azimuth angle, as the angle that surface of PV panels and South imaginary line forms.

d. Extract from the datasheet the maximum power of PV panel for Standard Test Conditions;

e. Calculate the efficiency in case the maximum power in Standard test Condition is presented inside datasheet;

f. If efficiency of PV panel is given by manufacturer, use it and ignore steps d and e;

g. Extract from datasheet the equivalent net surface of PV panel;

h. Search the inverter efficiency on its case as a declared parameter or found it on manufacturer datasheet.

Second step:

i. Select from Annex A1 the corresponding correction coefficient;

j. Select the corresponding table with horizontal solar radiation from MC001, annex A.9.6 based on location;

k. Calculate total surface of all PV panels;

l. Calculate tilt solar radiation using equation 1.1;

m. Calculate PV panel efficiency using equation 1.2 or select it from datasheet;

n. Calculate and memorize all monthly electrical energy using equation 1.3;

o. Sum all of energies using equation 1.4 and find the overall energy obtained.

Using data of systems and following the procedure steps frame the evaluation of PV panels system is an easy task, data presented in MC001 helps the designers of such systems to answer the energy demands of the final consumer.

4. Application example:

Following procedure steps frame from chapter 3, it was evaluated a system described by components in table 1.

Table 1

Ui	45	[º]
Ua	0	[º]
Np	9	[-]
$P_{max, 1000}$	375	[W]
Location	Bucharest	[-]
η_{inv}	0.96	[-]
Apan	1.92	[m^2]

System proposed for application example is composed by nine PV panels with 1.92 m^2 net solar surface each. Tilt angle is 45º and the azimuth angle is 0º which represent its orientation towards South. Inverter which makes the conversion from DC current produced by PV panels to AC current used by household electrical devices has a good efficiency of 0.96. Total net surface counts 17.28 m^2 and equivalent efficiency calculated by equation 1.2 is 0.195. Thermal efficiency is 0.8 during hot period of the year, with 0.85 for transition periods in spring and autumn and 0.9 on cold period. Monthly thermal efficiency can be seen in table 2. Maximum PV panel power is 375 W obtained from the manufacturer datasheet.

Table 2

	Jan.	Feb.	Mar.	Apr.	Mai.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
η_t	0.9	0.9	0.85	0.8	0.8	0.8	0.8	0.8	0.8	0.85	0.9	0.9

Corresponding values of correction coefficient were selected from Annex A1 of MC001 methodology as can be seen in table 3.

Table 3

	Jan.	Feb.	Mar.	Apr.	Mai.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
c_c	1.76	1.45	1.25	1.05	0.94	0.88	0.90	1.03	1.22	1.45	1.62	1.67

For Bucharest, horizontal solar radiation and corresponding corrected tilt radiation are presented on figure 1 as an average hourly solar radiation on each month during the year.

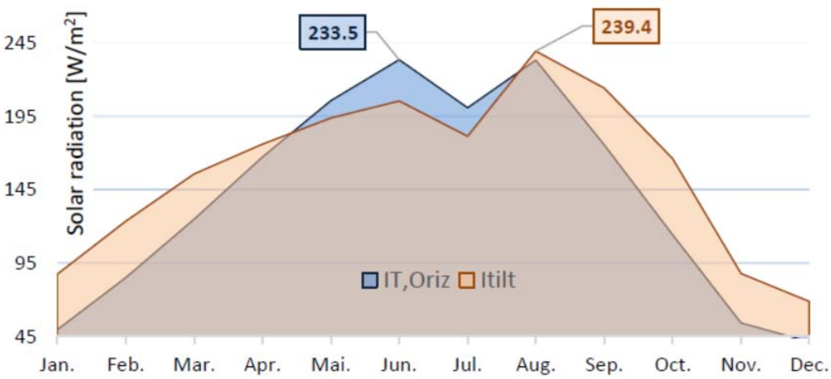

Figure 1

Solar radiation on horizontal and tilt surface are plotted as surfaces with their maximum values marked in bold for each corresponding type inside the flags with same colors. Can be easily observed that corrected tilt radiation based on tilt angle is increased comparing with horizontal solar radiation during cold periods, the 45^{0} values bringing an advantage in the system. Despite period between May and July when corrected solar radiation is below horizontal radiation values, the overall obtained energy is higher than demanded energy, shown further in the paper, for the mentioned period of the year. Therefore, the best angle of tilted surface is a key parameter to respond to optimization question always asked in PV panel system design.

Using equation 1.3 monthly electrical energies are calculated, results being plotted in figure 2. Values represent the total electrical energy generated by the PV panels system during each month of functionality.

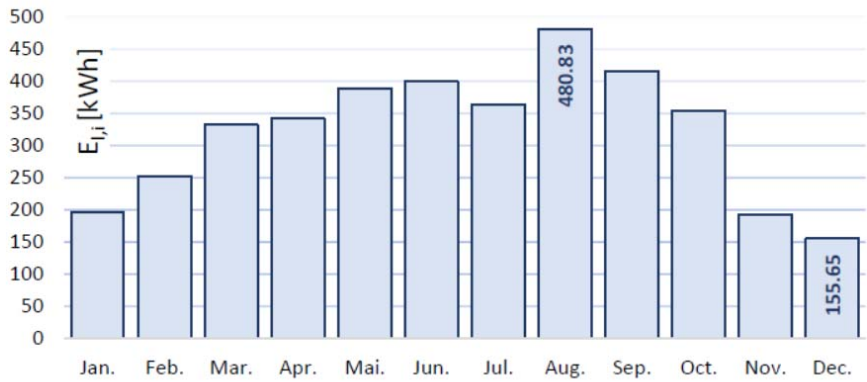

Figure 2

For Bucharest, the location studied by this example, the maximum generated energy was obtained during August when the system can generate approximatively 480 kWh with all 9 PV panels representing ±890Wh per day from each squared meter of PV panels system surface and a corresponding minimum generated energy of ±290.5Wh/m^2 each day in December.

For a given specific consumption of a residential consumer can be evaluated the overall energy balance between demanded and generated energy from the solar system. Thereby, using an average consumption, by equation 1.5 can be evaluated monthly electrical energy demand.

$$C_{m,i} = N_{zl,i} \cdot E_{d,d} \qquad 1.5$$

Inverter ON grid technology used in European Union give the advantage of discharging the additional energy generated by the PV panels in the grid, when there is more than demanded available energy that can be produced in system. This energy can be used by other customers of same Electrical power companies connected to same power grid system. Thus, the energy surplus is introduced in National Electrical Energy System (SEN) not being lost when consumer don’t use it. A simple calculation between generated energy and demanded energy can be done using equation 1.6, its results being positive when is extracted energy from the grid respectively negative when PV panel solar system produce energy in excess and discharge it inside grid.

$$E_{SEN,i} = C_{m,i} - E_{l,i} \qquad 1.6$$

For the example of this application, a consumer with average electrical energy demand of 11.15kWh per day, and using equations 1.5 and 1.6, figure 3 is plotted with each energy corresponding values.

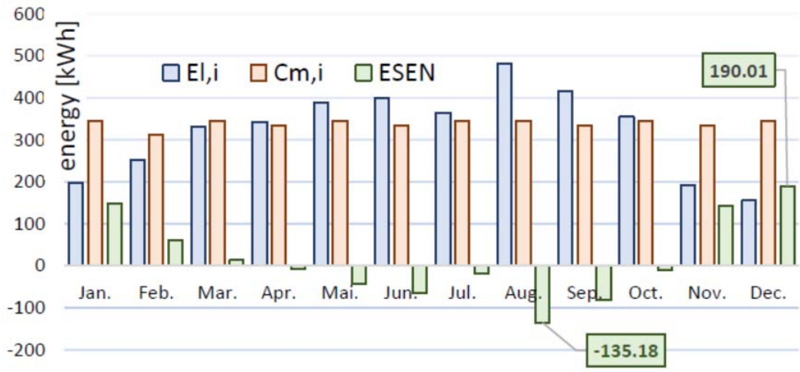

Figure 3

Figure 3 shows in one graph all 3 specific energies that characterize the functionality of system composed by PV panels, consumer, and Energy grid. Green labels show maximum energy injected in the grid in August and extracted from the grid during the cold month with low solar radiation in December. PV panel system has the capacity to satisfy consumer demand in 8 months during the year, even that as a plus it will inject energy in the grid for same period making such systems being relevant for residential application in which electrical energy from renewables is requested as primary type of electrical energy used.

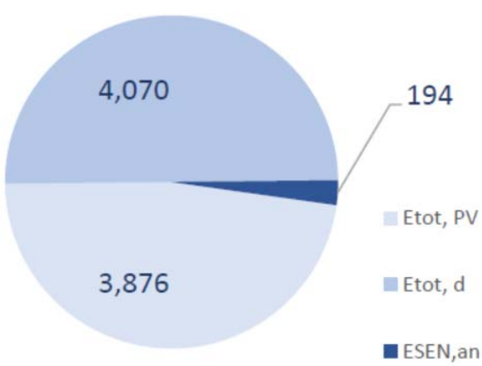

Figure 4

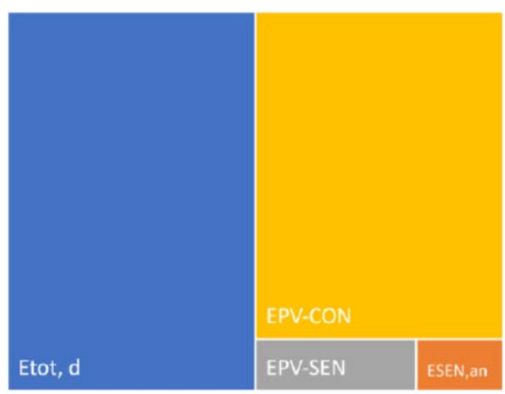

Figure 5

During the year, total energy demanded by the consumer, and total energy injected in the grid by the system, are evaluated with equation 1.7 respectively 1.8. Over the year, PV panel generated energy is directly used by the household electrical devices and appliances named PV to consumer energy symbolized EPV-CON, but in same time can be injected on National Electrical Energy System named bellow PV to SEN energy and noted EPV-SEN. PV to consumer energy and PV to SEN energy are both evaluated with equations 1.9 respectively 1.10

$$E_{tot,d} = \sum_{1}^{12} C_{m,i} \qquad 1.7$$

$$E_{tot,SEN} = \sum_{1}^{12} E_{SEN,i} \qquad 1.8$$

$$E_{PV-CON} = E_{tot,PV} - E_{PV-SEN} \qquad 1.9$$

$$E_{PV-SEN} = \sum abs\left(E_{SEN,i}\right)\Big|_{E_{SEN,i}<0} \qquad 1.10$$

Total energies and their distribution are shown in figure 4. Values are expressed in kWh with 4070 kWh total energy demanded over the year. From this value, 3876 is generated with PV panels system and only 194 is required from National Electrical Energy System, representing 4.77% from the total demanded.

Energy injected in SEN is the sum of absolute values of all monthly negative energies representing the flow from PV panel system to National grid. In figure 5 the blue rectangle represents total demanded energy over the year with distributed energies from PV and supplementary energy extracted from the grid. PV to SEN energy is symbolized with grey rectangle and represent the energy that is sent to the grid but, when required, is extracted from the grid, over the months when PV panel system cannot generate the total demanded energy.

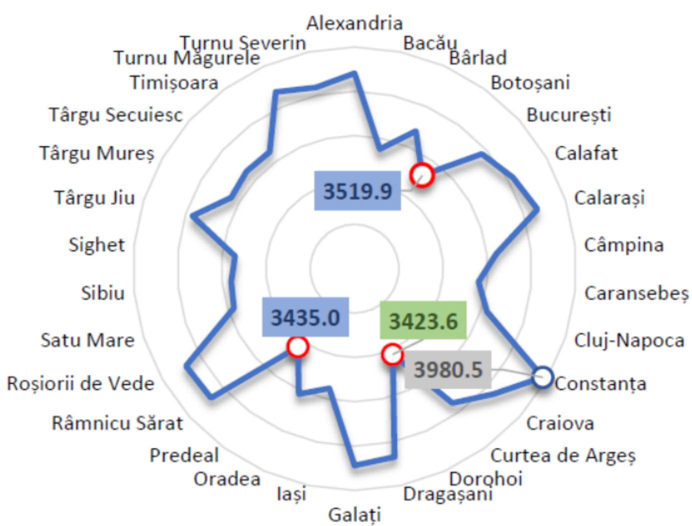

Figure 6

The analyze was extended to other 29 cities of Romania, which cover major of different specific climate over its territory. Romania consists in 5 distinct climatic zones, as described in Methodology MC001, with warm environment over the year in South-East coast area near Black Sea till the coldest zone in the Middle Carpathian area, where temperatures can degrease bellow -25ºC. In figure 6 can be observed generated energy of the PV panel system for all 30 cities in same configuration as previously example.

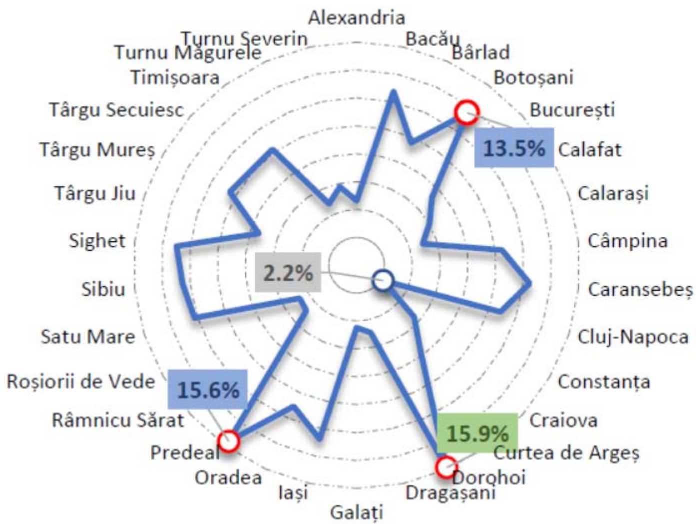

Figure 7

Due to warm climate and higher solar radiation, in Constanta, a city located on the Black Sea coast, the total generated energy of 4980,5 kWh with the biggest benefits for the same system. As can be seen in Figure 7, the percent of required energy from the field ESEN, Constanta offer the best location of all 30 where only 2,2% of supplementary energy is required from the grid. The situation is opposite for 3 cities like Predeal, Dorohoi and Botoșani, marked in red circle on Figure 7.

A short economical analyze was done for all the cities to evaluate the recovery period of the investment in such a system, based on prices of electrical energy as the drawback parameter. Therefore, the investment is refund with the total generated energy over the year. The annual economy consists of EPV-CON energy which will not be paid anymore by the consumer. Both energy and tax prices being a refund cost per kWh of generated energy as can be seen on equation 1.11.

$$p_{ref,year} = E_{PV-CON} * (p_{kWh} + p_{tax}) \quad 1.11$$

Table 4

Pv panel nb	PV panel	Inverter	Installation	Battery	Total Investment
9	1200	5500	5000	4004	25304.32

The refund period is evaluated with number of years necessary for the investment to be paid by the annual economy. In Figure 8 are presented the results for all cities evaluated in terms of refund period where the initial investment consists in all components prices according to table 4, prices being shown in RON.

Chart from figure 8 shows the refund period, in years, for all 30 cities. With Constanta on the lowest investment recovery period all the other cities are not too far from it. The most disadvantaged city Dorohoi, need approximatively half of year more to refund all the investment.

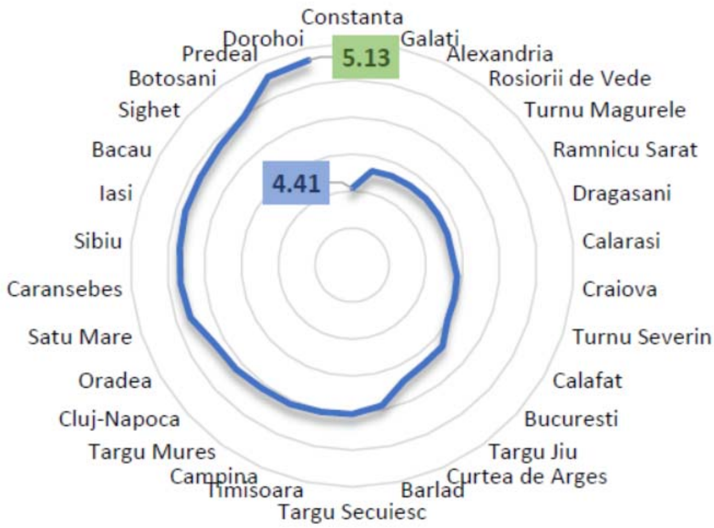

Figure 8

The question on the table of PV panel system designer is what system is needed to satisfy the consumer. For a specific energy demand this question can be resolved by a numerical evaluation based on What-If Analysis commonly used nowadays.

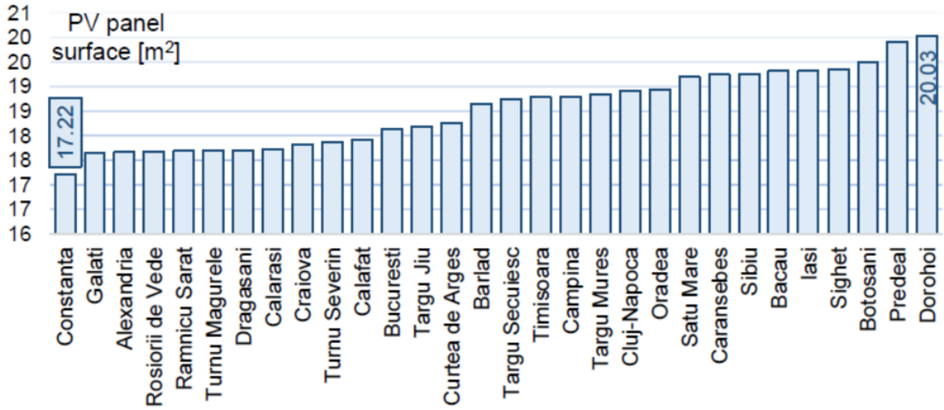

Figure 9

Goal-seek is useful for such approach, just by request of what is the total net surface of PV panels to satisfy the total demand of energy over the year. Using equation 1.3 and 1.4 with the error is established by difference between demanded energy $E_{tot,d}$, and annual PV Panel solar energy generation $E_{tot,PV}$. With a difference of 16.3% towards Constanta, Dorohoi required 4.81m^2 more PV panel surface to satisfy annual energy demanded by consumer. In figure 9 can be observed all cities necessary surface for the system to generate the entire energy necessary by the consumer.

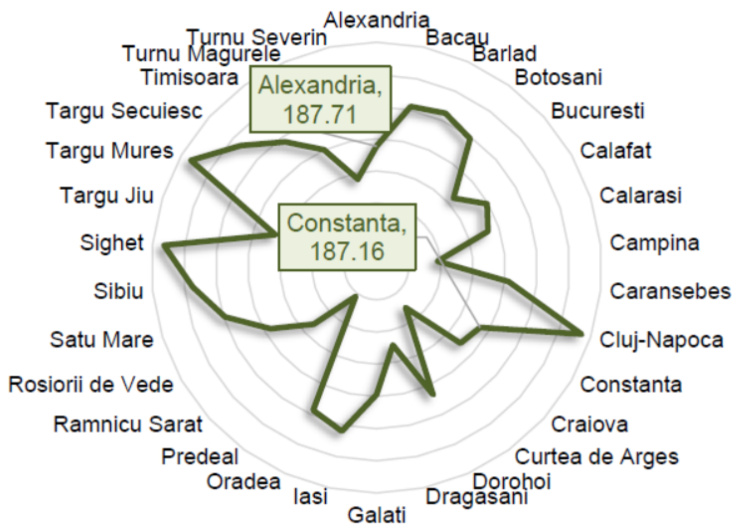

Figure 10

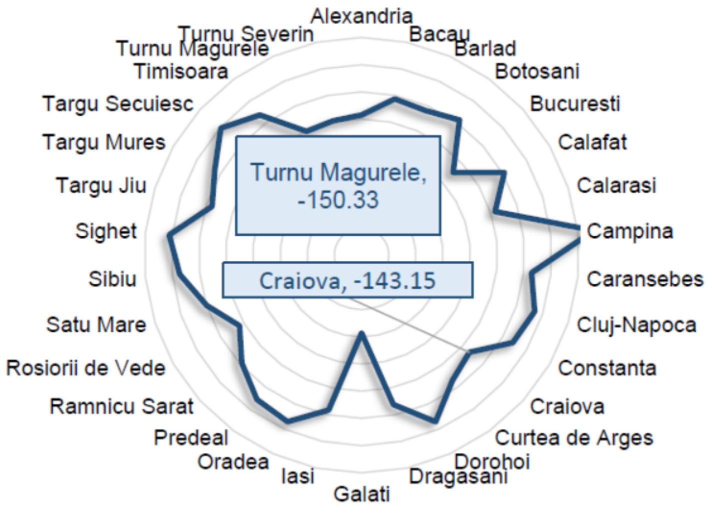

Figura 11

In figure 10 can be observed the maximum supplementary energy, ESEN, required for each location in the worst month solar radiation conditions. Predeal and Curtea de Arges requests maximum of supplementary energy from the grid even the overall energy obtained from PV panel system is sufficient for consumer demand. The total energy extracted from the grid will be delivered during the year back into SEN when solar radiance will be higher. In the same analyze data, where studied the values of maximum injected energy in the grid, plotted in figure 11. Negative values symbolize the flow of the energy from PV panel system towards the grid. Even in Constanta the solar radiation is at its maximum on studied locations, the maximum injected energy is obtained at Galati. This is possible by the group “solar radiation” – “total PV panel surface”. Because Galati required $0.4m^2$ more surface, and different solar radiation, during August the total energy delivered in the grid, 192.67, is higher comparing with value from July in Constanta where is injected 121.4kWh in the grid, at its maximum.

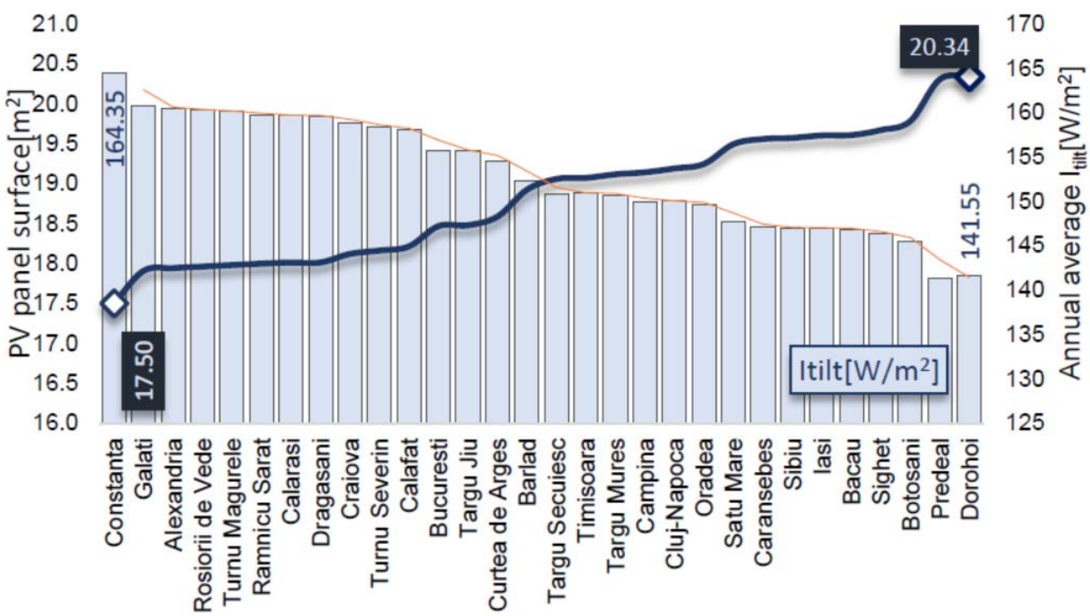

Figure 12

In figure 12 is plotted the annual average tilt solar radiation together with minimum surface to cover the total energy demand by each city. Can be observed on the graph that average tilted radiation over the year is a good indication of the PV panels amount required to satisfy the consumer energy needs.

When the net total solar surface of the PV panel, Atot, is reported towards daily demanded energy Ed,d, by equation 1.12 is obtained an important specific indicator defined by authors Consumer Specific Surface (CSS).

$$CSS = A_{tot}/E_{d,d} \qquad 1.11$$

Values of CSS are observed in figure 13, example of Constants stats is needed $1.61m^2$ for each kWh of daily demanded energy. The parameter is obtained by a fixed value of demanded daily energy of consumer. The methodology proposes to be used an average daily consumption of the consumer during the year. In case consumer data is available for this period, using annual average of the daily consumption and with CSS from figure 13 the total net PV panels surface will be obtained. Therefor CSS is a quick method parameter to approximate each consumer needs by its location and by its daily demanded energy.

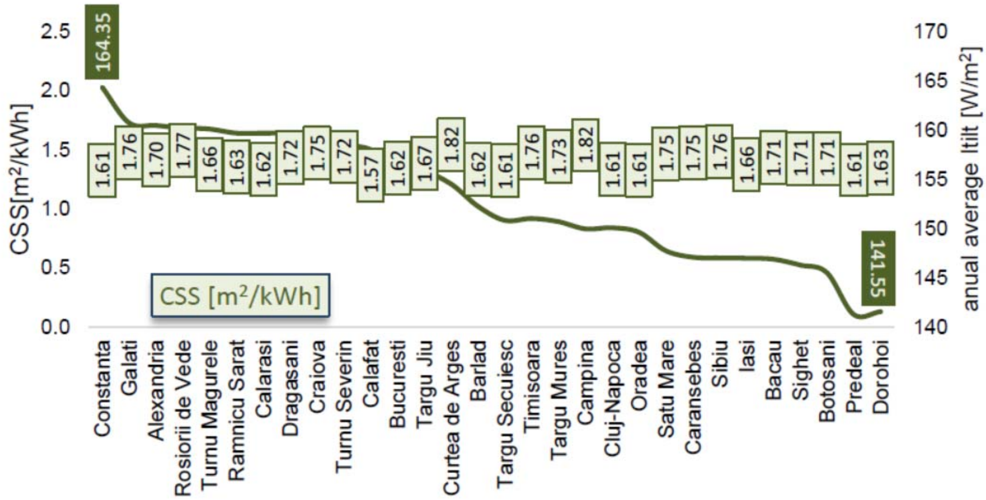

Figure 13

This study was extended to optimization of the system towards different tilt and azimuth angles. Thus, for azimuth angle between -90º and 90º with a 30º step, and for tilt angle from 30º to 60º with 5º step.

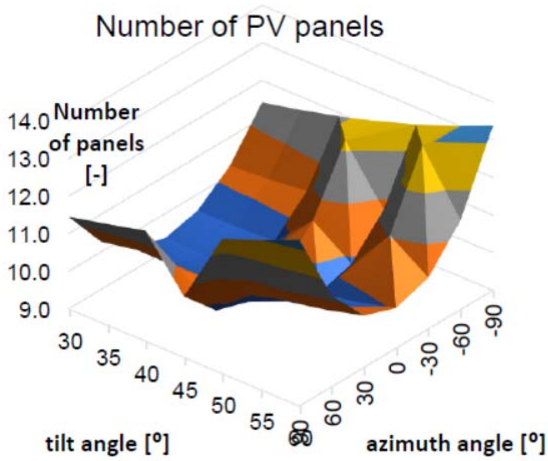

Figure 14

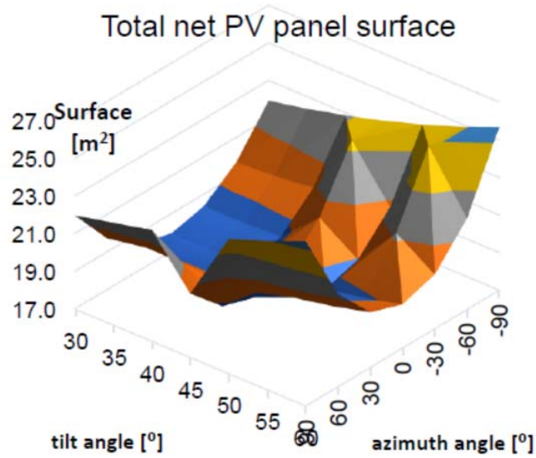

Figure 15

All the parameters proposed in this paper was evaluated for Bucharest location using the same horizontal solar radiation but with recalculation of each tilt solar radiation with above proposed values.

Both figures 14 respectively 15, number of PV panels and their net surface indicate the best mechanical installation with 30º tilted angle and 0º azimuth angle. Based on position of the building, impact on investment cost can be drastically high in case the azimuth angle cannot be reduced to South orientation, corresponding to 0º on the charts.

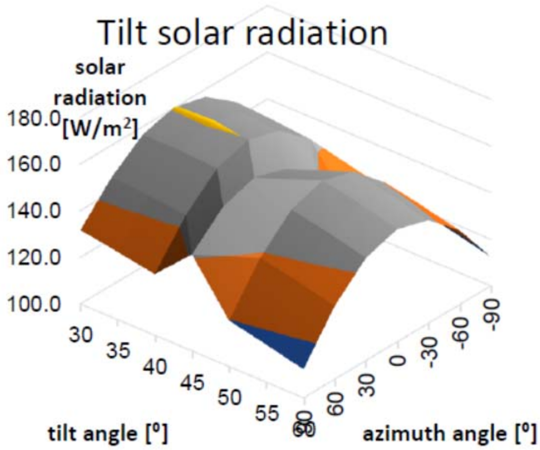

Figure 16

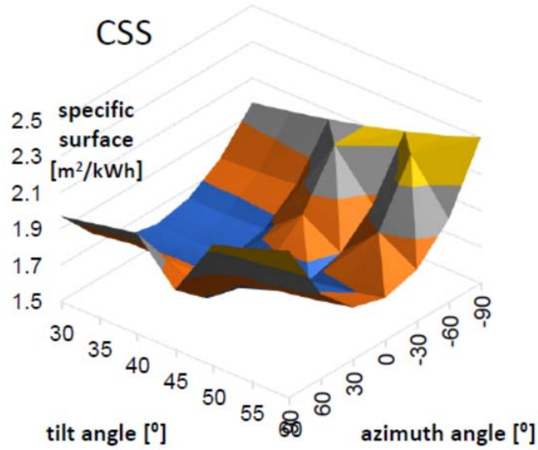

Figure 17

Tilt solar radiation represented in figure 16 denotes the values of annual average of tilted solar radiation when azimuth and tilt angles are changed. The chart help designers to extract an average tilt solar radiation based on mechanical characteristics of solar panels installation. With same distribution, the best installation respect same values above mentioned for azimuth and tilt angles. Figure 17 shows the distribution of CSS with angles change. With this chart, can be seen for Bucharest what is the consumer specific surface and easily calculation of required total net surface of PV panels based on equation 1.11, questioning the value of A_{tot}.

7. Discussions

Presented paper represent a simplified methodology for evaluation of PV system with regards to generated energy, overall energy demand coverage of the system analyzed, supplementary energy required from the grid and performances of the system when mechanical parameters are changed. Proposed equations and link with national methodology MC001 and its annexes, simplify the way a new system or an installed one can be analyzed. Thus, with charts values of thermal efficiency from Annex A2 and correction coefficient from Annex A1, using the horizontal solar radiation can be calculated the energy generation of the system for a specific location from Romania. Apparently, if horizontal or tilted solar radiation is available for other cities or location outside Romania, this simplified methodology can be successfully applied.

The paper proposes a quick evaluation for economical aspects too. Therefore, based on generated energy and energy prices, a refund period is possible to be calculated based on equation 1.11. Can be noted nowadays that with rise of energy prices, investments in such systems are rapidly reimbursed in periods of 4 to 5 years for common household appliances consumer.

Nomenclature

Latin symbols:
U_i – solar PV panel tilt angle, [º];
U_a – solar PV panel azimuth angle, [º];
A_{tot} – total net solar PV panels surface, [m^2];
$I_{T,\ Oriz.}$ – Horizontal solar irradiation established by Romanian Methodology MC001-volume I, annex A.9.6, [W/m^2];
I_{tilt} – Corrected tilt radiation based on horizontal radiation and correction factor. [W/m^2];
$P_{max,1000}$ – maximum PV Panel power, expressed for a solar irradiance 1000W/m^2, [W];
A_{pan} – net solar PV panel surface, [m^2];
I_{1000} –Standard Test Condition irradiance for PV panel efficiency evaluation [1000W/m^2]
ε_{PV} – PV panel efficiency, [-];
N_{zl} – month days number, [day];
N_p – number of PV panels used in evaluation, [-];
c_c– solar radiation correction coefficient, MC001 - annex A1, [-];
$C_{m,i}$ – monthly demanded energy, [kWh];
η_t – thermal efficiency of PV panel, MC001 - annex A2, [-];
η_{inv} – inverter efficiency, [-];
$p_{ref,year}$ – annual economy. [RON];
p_{kWh} – energy price, [RON];
p_{tax} – taxes for one kWh of consumed energy, [RON]
$E_{l,i}$ – monthly PV panel solar energy generation, [kWh];
$E_{PV\text{-}SEN}$ – PV energy injected in SEN over the year, [kWh];
$E_{PV\text{-}CON}$ – PV energy used by consumer over the year, [kWh];
$E_{tot,\ PV}$ – annual PV panel solar energy generation, [kWh];
$E_{d,d}$ – daily demanded energy, [kWh];
$E_{tot,\ d}$ – total demanded energy by consumer, [kWh];
$E_{tot,\ SEN}$ – total injected energy in the grid, [kWh];
E_{SEN} – supplementary energy required from the National Electrical Energy System, [kWh];

Greek symbols:

η_{inv}, inverter efficiency, [-];
$\eta_{t,\ PV}$ panel thermal efficiency, [-];
$\varepsilon_{PV,\ PV}$ panel efficiency, [-];

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Considerations for limiting the contribution of buildings to climate change through efficient energy use

Considerații privind limitarea contribuției clădirilor la schimbările climatice prin utilizarea eficientă a energiei

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Abstract. *The incontestable evidence of climate change and extreme weather events has brought the entire world to the brink of a red code alert, which determined the need to establish targets for limiting greenhouse gas emissions and the other actions that can be taken to solve them. The paper presents aspects of limiting the contribution of buildings to climate change through energy efficiency measures with an emphasis on the importance of the nZEB concept. The need to reduce the consumption of energy from fossil sources and increase the contribution of energy renewable sources is discussed, in a realistic context.*

Key words: efficient energy, climate change, renewable sources, buildings

1. Introduction

Climate change, being one of the most alarming global problems, has determined the establishment of actions to limit global warming. As energy production and consumption are considered to be the main contributors to climate change, reducing energy demand and increasing energy efficiency are seen as key factors in solving this problem [1], [2], [3]. The worldwide concern regarding this subject has led to the appearance of various studies related to the increase in global temperature of which a study conducted in 2018 draws attention to the seriousness of the problem, a fact highlighted in Fig.1 [4], [5]

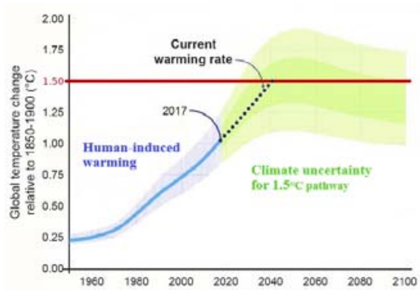

Fig. 1. Global temperature increase relative to the period 1850-1900 [5].

In Fig.1 the blue continue line corresponds to the actual observed temperature which continues dotted with black suggesting the predicted increase for the coming decades. This forecast is analysed under the impact of two trends marked by coloured bands: keeping CO_2 emissions at current levels and respectively decreasing them to the value 0. It is noted that at the current rate of global temperature increase, the alarmed value of 1.5 °C would be reached around 2040, and by stopping CO_2 emissions, a global temperature of about 1 °C could be reached by 2100 C. On the other hand, data published by Eurostat highlight the fact that in 2022 the civil residential buildings sector is the main responsible for greenhouse gas emissions - (24%), followed in relative similar percentages by the electricity and gas production and supply sector (21%) and respectively 20% - manufacturing industry [6]. What is worrying is that the residential building sector maintains a constant level of greenhouse gas emissions (about 245 million tons of CO_2-eq.) [6] compared to previous years (Fig. 2). This aspect highlights the fact that the effects of the transition to green energy are not observed in the main sector responsible for the highest percentage of greenhouse gas emissions.

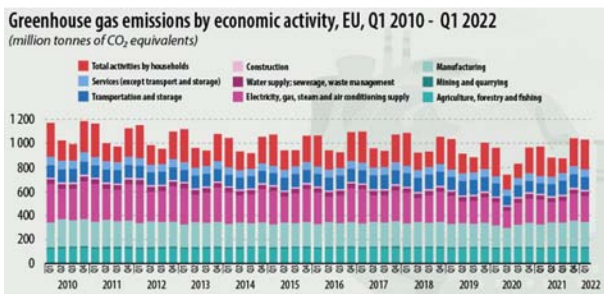

Fig. 2. Greenhouse gas emissions by economic activity in UE [6]

Therefore, immediate stopping measures are necessary, measures that involve reducing energy consumption simultaneously with the application of energy efficiency measures in the context of an energy mix with an increased weight in the direction of renewable energy sources (RES) [2], [6], [7], [8], [9], [10]

For this reason, the paper addresses aspects of limiting the contribution of buildings to climate change through the efficient use of energy, emphasizing the principles of nZEB (near zero energy building) buildings in terms of annual energy consumption (during operation). An important aspect, in this context, is the lack of a link in the design-execution-exploitation-post-use chain, namely the training of building operators. In principle, they are responsible for ensuring efficient energy consumption. No matter how efficient the design and execution phase is, the interaction between technology and users is not completed, and in this way the correct management and maintenance possibilities are not clarified [11], [12], [13]. Clearly, these aspects are much more visible in the non-residential sector, where building occupants are not directly affected by the costs of inefficient exploitation of systems that ensure environmental comfort [11], [12], [13]. If for this type of buildings there is staff dealing with building maintenance, for the residential sector, currently, there are no clear regulations [14]. Also under this aspect, the issues regarding the direction in which the construction sector is heading towards energy efficient buildings are addressed.

Even if there are regulations by which all new buildings must be built under nZEB principles, the decision makers in Romania do not make enough efforts to support their actual realization. On the other hand, the specialized literature shows that the implementation of these principles is very varied both at European level and at country levels or even in different areas within the same country [12].

2. Forecasting the evolution of RES integration to stop climate change

Reducing the consumption of energy from fossil sources is possible by integrating RES into the buildings services systems. According to the current legislation, the concept of nZEB buildings is closely related to this aspect, as it is mandatory to ensure a certain percentage of RES, from consumption. So, in the future, in order to keep the global temperature below the limit of 1.5°C, it is desired to limit and finally eliminate fossil fuel use. A forecast of the global evolution of the required energy sources is presented in Fig. 3 [15]. In order to keep the global temperature below this limit, it is observed that in the 2030s the percentage of RES energy should reach approximately 56%, 88% in 2040 and 100% by 2050 [15], [16], [17].

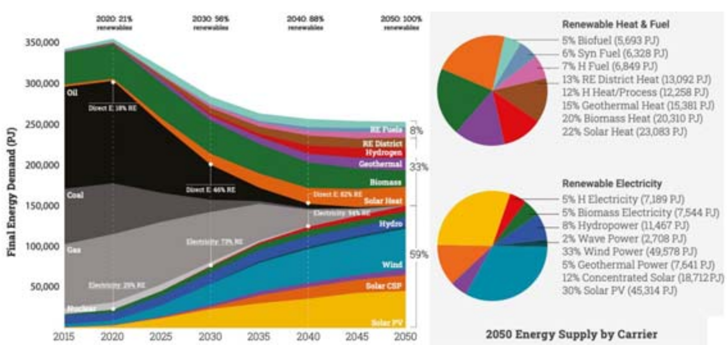

Fig. 3 Global evolution of energy sources regarding total energy demand [9]

The scientific specialized literature provides information regarding the upper limits of RES potential (solar and wind) and the maximum possible capacities to be installed (in GW) for global temperature limitation in the scenarios: 1.5°C and 2.0°C. [18]. In Europe, utility-scale solar photovoltaic sites (Fig. 4) are relatively small due to the density of buildings, and also relatively low solar radiation. As favourable areas stand out: southern Spain, southwestern Italy, the Asian part of Turkey, but also the southern part of the Alps (areas marked in red and yellow on the map in Fig. 4) [17]. However, suitable roof surface for installing solar panels is available in almost all of Europe, even in the northern parts.

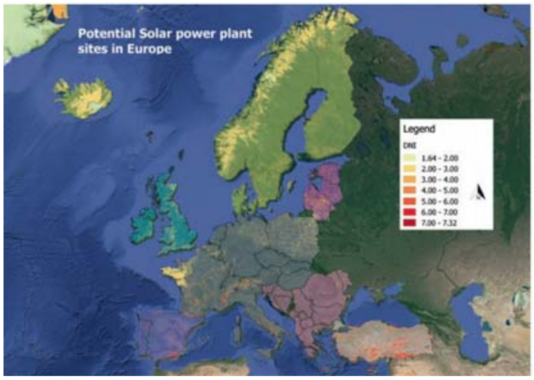

Fig. 4 Europe's potential for utility-scale solar power plants [18]

The data available in the scientific specialized literature for the solar capacities that can be installed are established, taking into account the space requirements shown in Table 1 [18].

Table 1

Space requirements for calculating installed capacities

Type of renewable energy system	Installed capacity (MW)	The required surface (km^2)
Solar photovoltaic	1	0.04
Concentrated solar power	1	0.04
Onshore wind	1	0.2

3. Targets of increasing energy efficiency at UE level

The new EU objectives in terms of energy efficiency, proposed through the "Fit for 55" package, establish an 11.7% higher reduction for final energy consumption for 2030 compared to the targets set for 2020, increasing the minimum quota ford RES, by 2030, from 32% (Renewable Energy Directive-RED I [19]) to 40% (Renewable Energy Directive-RED II [20] and recently to 45% (REPowerEU 2022) [21]). The target of reducing greenhouse gases by at least 55% by 2030 compared to 1990 levels, set by the "Fit for 55" package, can be reached by respecting the RES share of at least 38-40% by 2030, which in the long term (at the level of 2050), will ensure climate neutrality. In this context, accelerated energy efficiency efforts by all countries are needed. Thus, updates were needed to both the minimum performance requirements for existing buildings and for new buildings in order to bring them into the near-zero energy category (nZEB). In Romania, the calculation methodology regarding the energy performance of buildings Mc 001-2022 [22] introduced flexibility and realistic targets in terms of ensuring the percentage of renewable energy in relation to nZEB standards. All these changes were necessary because, at the level of methodologies, the variety of approaches did not lead to uniform criteria regarding the implementation of nZEB buildings. So setting minimum performance requirements for existing buildings and new buildings with near-zero energy consumption (nZEB) is one of the requirements covered by the new regulation Mc 001-2022 [22].

Currently, for Romania, the Mc 001-2022 methodology [22] defines the nZEB building as the building whose consumption is covered by RES in a proportion of at least 30%, which is not consistent with the "Fit for 55" package of measures regarding compliance with the RES share of at least 38-40%. On the other hand, a study carried out in 2012 proposes for the year 2020, as a share of RES, a percentage higher than 40% for individual, collective and office buildings, and for public administration buildings a percentage higher than 50 is proposed % yet from the level of 2019 [23] .

4. Challenges of designing nZEB buildings in Romania

Even though the European Union has set targets for the new build sector to be carbon neutral by 2030, economic challenges and other equally important factors prevent the renovation of the existing residential building stock and the addition of high-performance buildings for newly built ones. From 2021, all new buildings in the EU should have been built as near-zero energy buildings (nZEBs), but many countries in Europe are still struggling to implement this concept. [24].

Practically, the nZEB building is characterized by low consumption of energy from fossil sources and using RES, in proportions established by minimum thermal and energy performance requirements, adopted for each country. For Romania, the Mc001/2022 methodology established these criteria for the categories of residential and non-residential buildings: new nZEB and existing renovated ones [22].

Although the "Fit for 55" package specifies that in order to limit climate change, a RES share of at least 38-40% is necessary until 2030, Mc001/2022 sets a realistic target of at least 30% for Romania, with the remark that after 2031 is necessary update the minimum proportion of energy from RES.

Depending on the climate zone, the maximum allowed values of total primary energy consumption (renewable and non-renewable) are established for nZEB buildings, which vary for collective residential buildings from 99.1 kWh/m^{2}y to 113.1 kWh/m^{2}y and respectively from 120.1 kWh/m^{2}y to 147.9 kWh/m^{2}y for buildings [22]. Thus, in order to obtain a high level of energy performance that to place the building within the nZEB consumption limits, must be met, in terms of design and execution the requirements regarding: compact geometry (ratio between surface and volume as small as possible), advantageous orientation of the building both on the site and in relation to the cardinal points, lighting strategies to ensure an adequate level of the proportion of natural light, strategies for adequate and efficient natural ventilation of the space, efficient constructive solutions for the building envelope (optimal level of thermal insulation) with the approach of minimizing the effects of thermal bridges, external windows with high thermal performance, properly adapted heating/cooling systems, energy storage systems for energy produced from RES (thermal/electrical), ecological materials conformable with to the principles of the circular economy or materials with phase change.

At the design stage, special attention must be paid to the optimal combination of different energy saving measures. Cost-optimal integration, control, and scheduling strategies of hybrid energy systems are crucial for improving the overall performance of nZEBs. The nZEB buildings subsequently connected to smart networks will play an important role in future smart cities.

Energy demand in buildings varies greatly depending on countries and climate zones, variation influenced by factors whose future evolution is uncertain (climate, income, user behaviour) [25] and therefore, practically, the great challenge of designing nZEB buildings requires a bold approach and clear actions. A series of studies they analysed x the evolution of energy demand in buildings in developing countries showed that in the long term an increase in consumption is expected despite the application of energy efficiency measures [25], [26], [27], [28], [29], [30]. However, these studies have not assessed the global implication of socio-economic uncertainty in a coherent framework.

As the construction sector in Romania still has a considerable percentage of buildings with high energy consumption, more attention should be paid to these categories of buildings through energy efficiency actions. Therefore, information that can be collected through continuous monitoring is needed in order to fully understand the key factors that influence the energy use of buildings.

Through the regulations and methodologies adopted at the level of each country, it is proven that the decision-makers are aware of the fact that one of the main ways to reduce energy consumption and CO_2 emissions is the increase in energy efficiency in the construction sector, which implies the acceleration of the implementation of the nZEB concept both for newly built and existing buildings, despite economic, social and political barriers [31].

5. Conclusions

Awareness of climate change and the evolution of greenhouse gas quantities has focused attention on energy efficiency in buildings in all sectors of activity. The medium and long-term objectives, but also the immediate priorities, will have to reflect actions on how energy is produced and the profiles of final consumers, with an emphasis on those actions that have the greatest impact at the level of each country.

On the other hand, in order to limit and finally eliminate carbon emissions, the transition to renewable sources in terms of energy production will not be sufficient, but measures and solutions aimed at reducing energy consumption will have to be adopted, which can achieve through energy efficiency, especially in the field of construction. And, on the other hand, even if energy efficiency can bring the construction sector very close to achieving sustainable development goals, it will not be able to solve some of the challenges of climate change without the transition to renewable sources and changing final consumers' lifestyle behaviour.

At the same time, financing schemes to support the buildings construction of nZEB standards should be more accessible.

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The influence of the vertical temperature gradient on working conditions in industrial halls heated with radiant tubes. Case Study

Influența gradientului vertical de temperatură asupra condițiilor de lucru în hale industriale încălzite cu tuburi radiante. Studiu de caz

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Abstract. *The article analyses the variation of the vertically temperature gradient, in an industrial space heated with radiant tubes. Data monitoring was done with a workstation equipped with 5 high-performance temperature sensors. The temperature measurement was carried out in 5 distinct points inside/outside the production space, selected in different hypotheses, and a thermovision camera was used at the floor level. The values of the indoor air temperature measured at the level of the ankles, at the level of the work plane and at the level of the head of the people in the productive space fall within the normal limits.*

Key words: temperature gradient, working conditions, industrial halls, radiant tubes

1. Introduction

The heating of industrial spaces generally raises problems in the choice of the heating system [1] due to high energy consumption (over 50% of global energy consumption is due to industrial sector) [2]. For this reason the interest in radiant heating systems has increased in recent years, as these systems have been shown to be energy efficient compared to hot air heating systems [3].

For industrial buildings and the heating systems that serve them, the energy efficiency of the system must be correlated both with ensuring working conditions and with ensuring inside parameters specific to technological processes [4], [5], [6], [7], [8], [9], [10], [11]. On the other hand, only the thermal justification for a heating system related to industrial buildings is not enough to decide whether an investment is economically efficient. Practically, from an energy point of view, the options for choosing the heating system can be compared based on the following criteria [5]:

- annual cost;
- updated total costs;
- payback.

Thus, in order to evaluate the provision of working conditions from the point of view of thermal comfort, the study carries out the verification by in situ measurements of the air temperature at 4 representative heights for the activity carried out in the production hall (at the level of the floor, the ankle, the work plane and at human head level) considered for the case study. The obtained experimental data were monitored and collected for a period of 5 days (February 2023).

2. Description of the space where the temperature is monitored

The monitored production space with an area of 573m^2, and a free height of 5.33m, is set up in a hall with a metal structure, side closures from 40mm sandwich panels, no false ceiling, roof closures from 60/100mm sandwich panels, PVC windows with insulating glass 4x18x4 (52.5 sq m), finished concrete floors without insulation (directly on the ground). The monitored production space (the wing building J1) has a common wall to the North with the wing building H1 production space, it has a common wall with the production space J2 and has 2 external walls to the East towards the inner courtyard and to the West towards the wing building D.

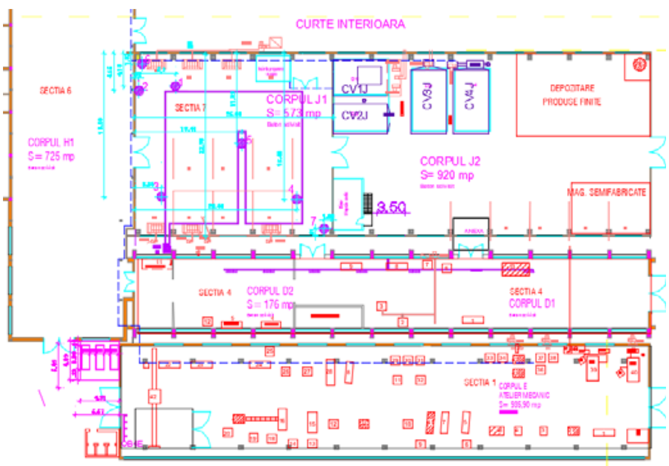


Fig. 1. Site plan

The space is heated with an OHA 20-100 radiant system, with a thermal power of 100kW, powered by natural gas from the public network. The heating system must ensure a temperature of at least 18ºC, at the height of the work surface 1.15-1.25m.

3. Description of the temperature measurement procedure

The temperature monitoring station was executed within the "Automation Laboratory" at the Faculty of Construction in Timișoara, it uses 5 high-performance temperature sensors DS18B20, with a resolution from 9 to 12 bits, with a conversion time of 750 ms to 12-bit, connected to an ARDUINO UNO development board. The measurement of the on vertically temperature in the production space, and of the outside temperature was carried out with the help of the measuring station (at an interval of 5 minutes). 4 temperature sensors (S1, S2, S4, S5) are installed inside the production hall, and one temperature sensor (S3) was used to measure the outside temperature. The sensors inside are placed on a metal pole at the elevations shown in (Fig. 2), the sensor S3 is taken outside the building through a hole made in the outer wall.

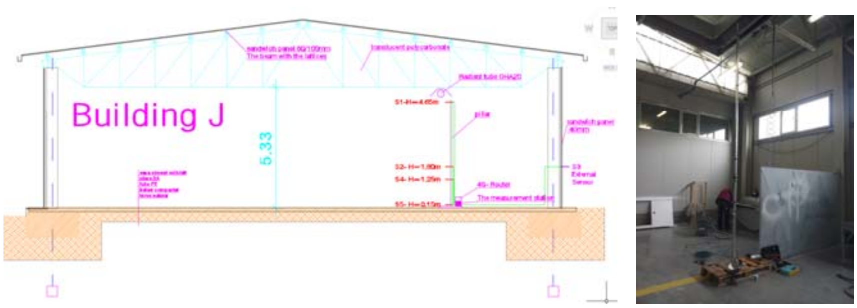


Fig. 2 The measurement station

The vertical temperature measurement was carried out in 5 distinct points inside the production space (P1, P2, P3, P4, P5) which are indicated in Fig 3.

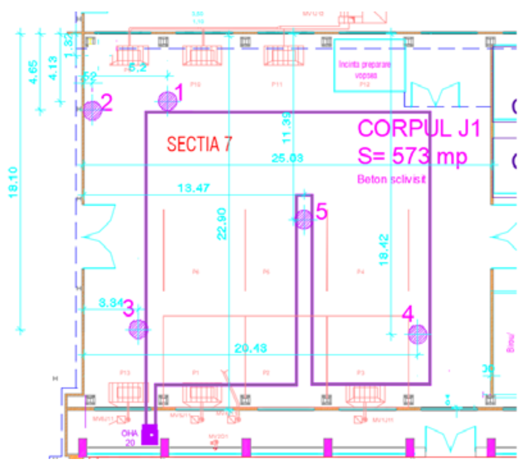
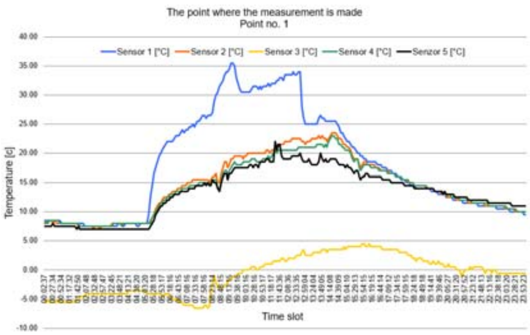


Fig. 3. Location plan of the measuring station

The temperature measurement at the floor level was carried out with a FLIR thermovision camera, which is in the equipment of the Installation Measurements Laboratory at the Timişoara Faculty of Construction. The transmission of the measured values is done in real time with the help of a 4G 300Mbps Wireless TP-Link router. Internet access is provided with a SIM card, data (measured temperatures) are stored on a server through the Google Docs application.

4. Results

The results of the measurements were represented graphically by following the variation of temperature on vertically at the points Pi (i=1...5), where the measuring station was mounted Fig. 4. a), b), c), d), e).



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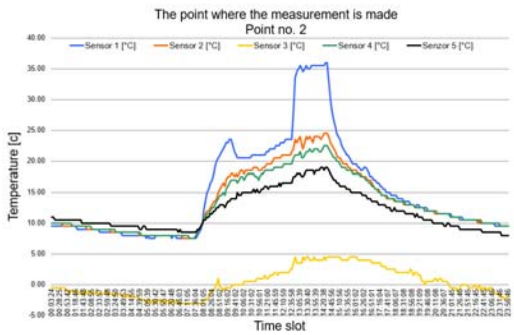

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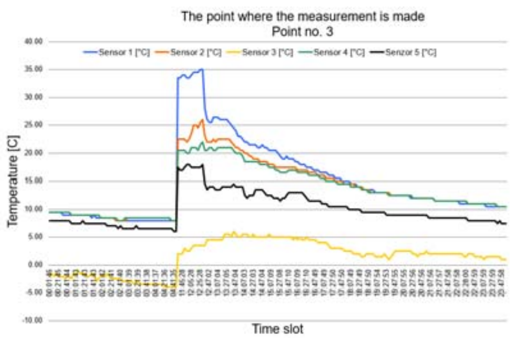

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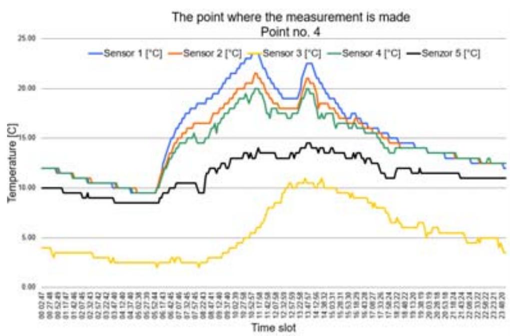

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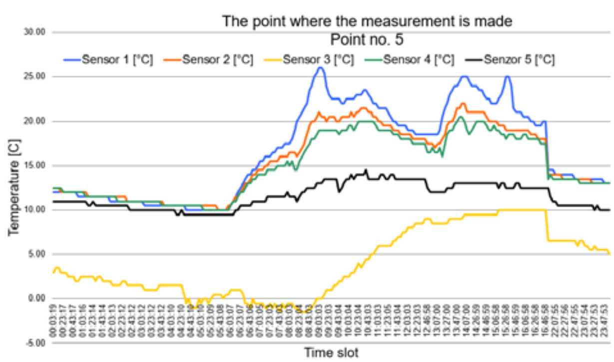
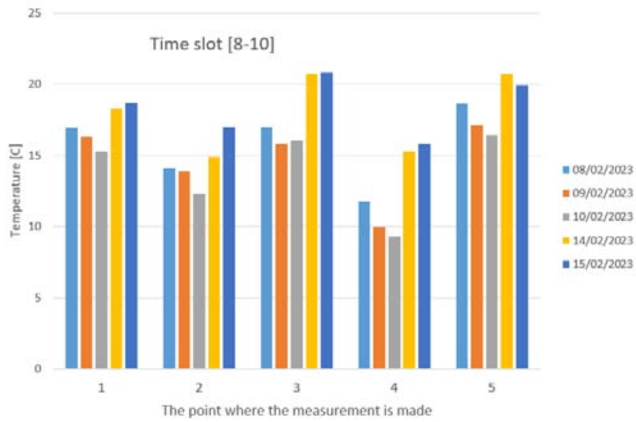


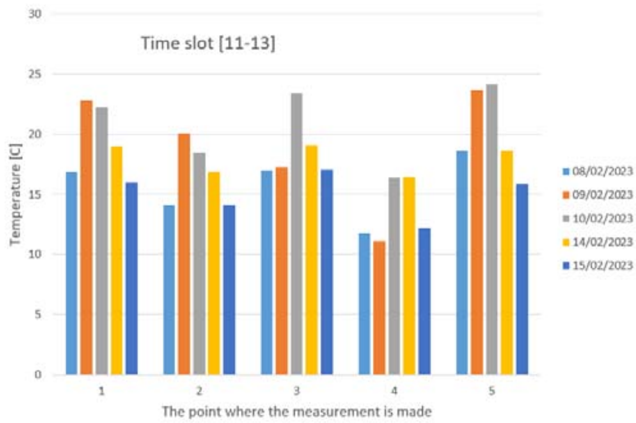
e)

Fig. 4. Temperature measurement in the Pi points
a) Point 1, b) Point 2, c) Point 3, d) Point 4, e) Point 5.

The results of the temperature measurements at the floor level (3 time intervals were targeted, between 8-10, 11-13, 15-17) are represented in Fig. 5.



a)



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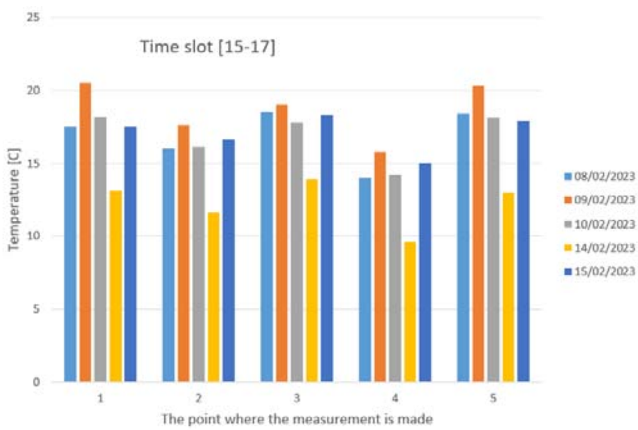
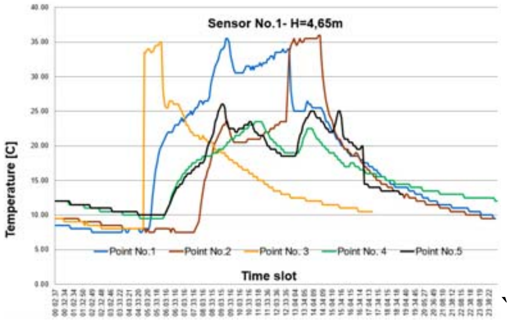


c)

Fig. 5. The temperature measured on the floor
a) time slot 8-10, b) time slot 11-13, c) time slot 15-17

The temperatures recorded by each sensor in the measurement points Pi (i=1...5) were also represented.



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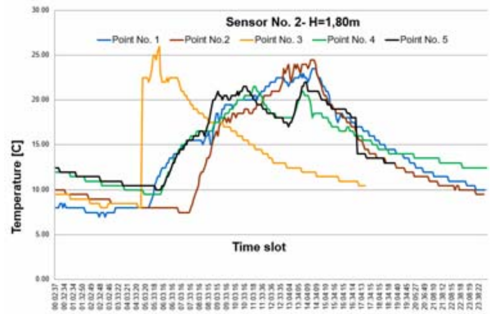

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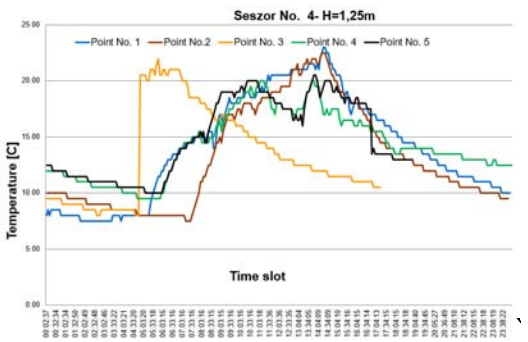

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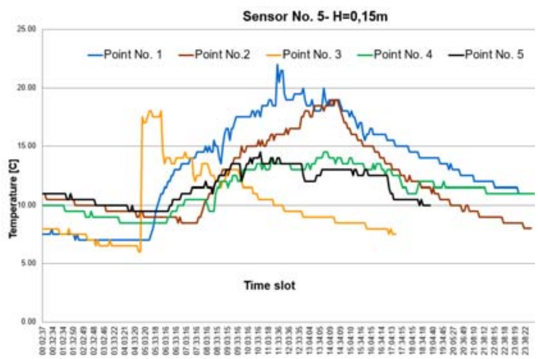


d)

Fig.6. Variation of temperatures in measuring points
a) Temperature measured by sensor S1, b) Temperature measured by sensor S2,
c) Temperature measured by sensor S4, d) Temperature measured by sensor S5

4. Conclusions

The paper analyzes the temperature of the indoor, outdoor air and the finished floor at various points in Section 7 wing building J1, according to Fig.2, equipped with a heating system with radiant tubes. The air temperature is measured during a period of one day, in each mentioned point on 4 levels of height related to the height of the finished floor, namely: h=0.15 m; h=1.25 m; h=1.80 m and h=4.65 m (near the radiant tubes).

The measurement points were selected considering the following working assumptions:

• point P1, near the point of intersection of the longitudinal radiant tube with the transverse one;

• point P2, near the inner wall that separates section 6 from 7 at a distance of 3.25 m from the intersection point corresponding to location 1;

• point P3, under the transverse radiant tube at a distance of 5.5 m from the burner of the radiant tube;

• point P4, on diagonal from location 1, for the configuration of the radiant tube;

• point P5, exposed to thermal radiation in 3 directions, 2 transverse and one longitudinal.

The temperature values at the established points and at the rates previously specified, during the productive period, are given in Table 1, Table 2, Table 3, Table 4 and Table 5.

Table 1

Punctul P1 temperatura exterioară t_e=0 - 4°C

Sensor	Elevation H [m]	Temperature t [°C]
1	4.65	30 - 35
2	1.8	18 - 23
4	1.25	16,5 - 22
5	0.15	14 - 21

Table 2

Punctul P2 temperatura exterioară te=0 – 4,5°C

Sensor	Elevation H [m]	Temperature t [°C]
1	4.65	24 - 36
2	1.8	16,5 – 24,5
4	1.25	15 – 22,5
5	0.15	13 - 19

Table 3

Punctul P3 temperatura exterioară te=2 – 5°C

Sensor	Elevation H [m]	Temperature t [°C]
1	4.65	18 - 35
2	1.8	17 – 26
4	1.25	16 – 21
5	0.15	13 - 17

Table 4

Punctul P4 temperatura exterioară te=0 – 4,5°C

Sensor	Elevation H [m]	Temperature t [°C]
1	4.65	20 - 23
2	1.8	16,5 – 24,5
4	1.25	15 – 22,5
5	0.15	13 - 19

Table 5

Punctul P4 temperatura exterioară te=1 – 9°C

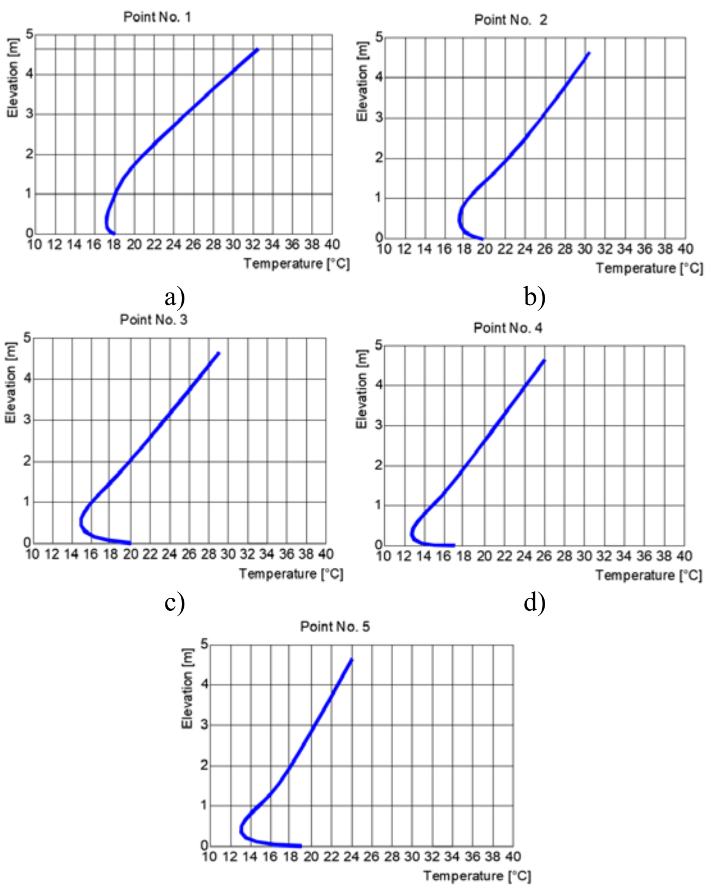
Sensor	Elevation H [m]	Temperature t [°C]
1	4,65	20 - 26
2	1,8	18 – 22
4	1,25	16 – 20
5	0,15	12 - 16

It can be seen from the diagrams presented in Fig. 6, that the lower temperature values are found at the beginning and end of the productive period, when the heating systems starts and stops.

The heating installation works with indoor air temperature control, in which case certain temperature variations occur that generate the minimum and maximum values during the working program period.

The graphs of the temperature gradient corresponding to the average values of the air temperature in the time interval 8 – 16, considering the work schedule of the productive personnel in the mentioned locations, were built. Air temperatures at heights h=0.15 m are taken into account; h=1.25 m; h=1.8m and h=4.65m; as well as the average temperature of the finished floor.

From the temperature gradient graphs in Fig. 7 a), b), c), d), e), it is observed that the shape of the temperature variation curve on the height of the analyzed productive space is similar with the difference that there are changes in the indoor air temperature in the vicinity of the floor, respectively at a height above 4.5 m.



e)

Fig.7. The temperature gradient corresponding to the average values of the air temperature in the 8 – 16 time interval
a) Measurements in P1, b) Measurements in P2 , c) Measurements in P3, d) Measurements in P4, e) Measurements in P5

The value of the floor temperature for the 5 specified points are in the range of 17 - 20ºC, a suitable temperature for the productive space. In all cases analyzed, it was observed that the temperature of the floor is higher than that of the air at a height of h=0.15 m, a phenomenon that is due to the radiant system that has the effect of heating the floor during the period of work, a fact that leads to a secondary radiation at the level of the finished floor.

Indoor air temperature at ankle level, at approx. 0.15 m from the finished floor, varies by location in the range of 15 – 19ºC.

At the level of the working plan, at approx. h=1.25 m, the temperature is in the range of 17.5 – 19.5ºC.

The temperature at the people head level, in the production space is also it has been verified, this being 16.5 - 26ºC, which falls within the normal limits regarding thermal radiation at the head level.

Practically, the air temperatures on the height of the analyzed productive space, in the specified locations, have values that fall within the parameters corresponding to the productive process, considering the high heat losses of the industrial building that is not properly thermally insulated.

A decrease in the internal temperature is observed in case of non-operation of the heating installation, due to the insufficient thermal insulation of the analyzed industrial hall, which leads to lower temperatures in the morning at the beginning of the work schedule, especially at the level of the ankles (h=0.15 m) as well as during the night.

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Contributions to the passive house concept through the usage of photovoltaic blinds

Contribuții la conceptul de casă pasivă prin utilizarea panourilor fotovoltaice

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Abstract. *The paper presents a study on the efficiency of installing photovoltaic blinds in a didactic laboratory with large glased surfaces, in order to ensure the shading of the interior spaces and to avoid the use of air conditioners during warm periods of the year, as a contribution to the passive house concept.*

Key words: photovoltaic bilds, passive house, thermal comfort, solar energy

1. Introduction

In the moment. the construction sector accounts for 35% of global energy consumption, respectively 40% , in the case of the European Union (buildings account for 80% of this consumption The European Commission, Commission Recommendation (EU) 2019/1659 of 25 September 2019 on the content of the comprehensive assessment of the potential for efficient heating and cooling under Article 14 of Directive 2012/27/EU, Official Journal of the European Union, 2019, https://eur-lex.europa.eu/legal-content]), with a corresponding share of CO2 emissions of 38%

At the national level, the final energy consumption in the construction sector their 42% of the total final energy consumption, of which 34% residential areas, and the rest (about 8%) commercial and public buildings.

The residential sector has the largest share of consumption (about 81%), while all buildings together (offices, schools, hospitals, commercial spas and other non-residential buildings) account for the remaining 19% of total energy consumption. the final. [1, 2].

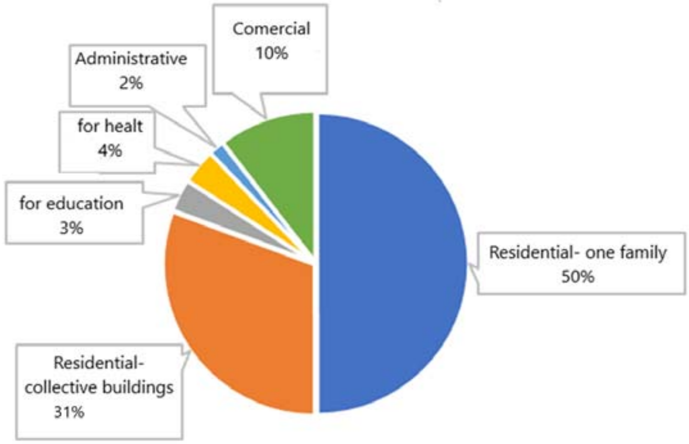

Fig. 1. Energy consumption in the residential sector [3].

The urbanization that is in continuous growth affects and modifies the ecosystems of urban areas, ultimately causing the Urban Heat Island (UHI) effect [4]. . The Urban Heating Island Effect represents the cause of the increase in soil temperature which further generates a series of ecological and environmental effects, such as: changes in soil properties, urban climates, atmospheric environment, energy metabolism that negatively affect people's health (Fig. 2).

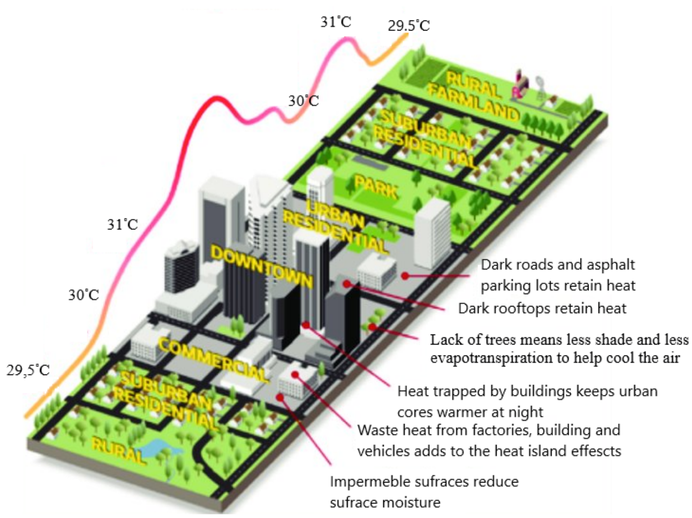

Fig. 2. Urban Heat Island Effect.[4]

The problem of global temperature increase generated by the increase in energy consumption and implicitly by the intensified urbanization, must be mitigated without having a negative impact on the general indoor comfort [5-8].

From the point of view of indoor thermal comfort, it was found that the energy demand for cooling in very hot and arid areas, but also in those with a temperate-continental climate with hot summers, has increased considerably, especially in the case of buildings with very large glazed areas [9].

The Urban Heating Island Effect could be significantly mitigated by several methods including: the construction of green roofs, the use of materials with high reflectivity, the cultivation of green land, the efficiency of the urban landscape and of course the improvement of the energy efficiency of buildings, which corresponds, at least, to the concept of passive house (Fig. 3) [10-11].

Fig. 2. Pssive green house.[4]

Recent scientific research proposes as measures to solve these problems, on the one hand, the adoption of energy-efficient materials and systems, which implies the transition from fossil fuels to renewable sources, and on the other hand, the design of buildings in house concepts passive or nZEB (netzero-energy) [12].

The Passive House concept is clearly defined and is applicable to all types of buildings and all climate zones, having as a common point the high level of comfort and energy efficiency.

The passive house standard brings to attention the increase in health and well-being of the building's occupants, thermal comfort at the same time as increasing indoor air quality. Limitation of the building heating requirement and the total demand for primary energy was also taken into account. [13-15].

The passive house is defined in terms of five criteria: airtightness, thermal insulation, elimination of thermal bridges, ventilation with heat recovery and windows with reduced heat loss (Fig. 4) [16].

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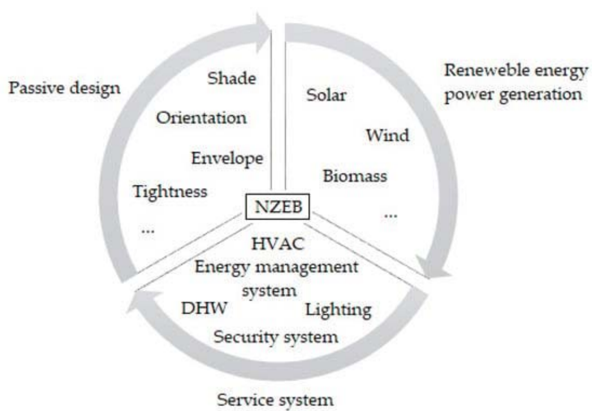


Fig. 4. Urban Heat Island Effect [16]

The article makes a study of these aspects as a contribution to the passive house concept, addressing in parallel the effects on the natural lighting of buildings which, concretely, represents a passive strategy for reducing energy consumption in buildings.

On the other hand, the European directive on the energy performance of buildings stipulates that starting with the year 2020, all newly constructed buildings should fall within the standard of building with almost zero energy consumption (nZEB) [9, 11, 17, 18].

In this article, an analysis of the criterion referring to the glazed superface is proposed. This criterion was addressed because the problem of overheating of buildings, during the warm periods of the year, generates high energy consumption, even for passive houses. On the one hand, solar radiation is beneficial in cold periods, and on the other hand it creates problems in warm periods. So, radiation control can be a key to the optimized design virtually for any type of building, especially with regard to the glazed surface [16]. Heat loss/input through glazed surfaces is greater than through walls, so it can be said to be a critical point for any type of building. That is why, in addition to the quality of the glass and profiles, an important criterion is the establishment of the optimal dimensions in relation to the size and destination of the space, but also the orientation and the materials used for assembly and sealing. The overheating of buildings, during the warm periods of the year, generates high energy consumption, even for passive houses. The increased use of insulation and the demand for greater building air-tightness have unintentionally combined to produce a growing number of buildings that suffer from “overheating”. The nZEB standard or buildings with net zero energy consumption were defined around 2010 as buildings that achieve a balance between energy consumed and delivered, also having a reduced energy requirement for the operation of HVAC (heating, ventilation, and air conditioning installations), through the integration of renewable energy sources (RES) and the use of state-of-the-art technologies in order to recover heat. [19]. Even if this goal seems far away, the progress made in the design of buildings with the aim of reducing carbon emissions or even storing carbon suggests that this building sector can become climate neutral at some point. Research shows that the key to achieving the nZEB standard is maximizing the energy efficiency of buildings, using the energy resulting from different processes to which is added the energy produced from local renewable sources. All these strategies include a variety of activities and steps to be followed as can be seen in the Fig. 5 [5. 19].

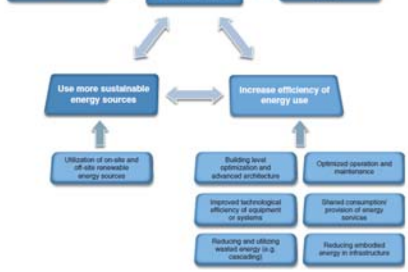


Fig. 5. Activities to achieve the objectives of the nZeb standard [5],

Although interest in residential overheating has been popular, the challenges extend across the whole built environment, including commercial and institutional buildings.

In this sense, a solution is photovoltaic blinds that exploit solar energy in both seasons (cold and warm) and provide shading of glazed surfaces in the warm season, in order to maximize energy efficiency.

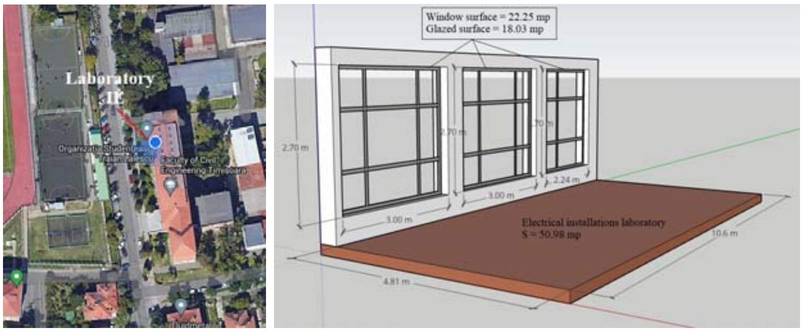
2. Background research

The interrelated effects between buildings and climate change begin to manifest once the building is in use. Buildings contribute to global warming by emitting greenhouse gases (GHG) in order to provide heat and cold. Therefore, over the lifetime of a building (which has conventional energy as its primary source of energy), the higher the outside temperature, the more energy the buildings will consume to cool the spaces, which will again contribute to GHG increase and will respectively accelerate global warming [9, 20]. For these reasons, it is estimated that the construction fund is responsible for a significant percentage of energy consumed and CO_2 emissions [19-21]. For this reason, the article addresses the context of buildings located in areas with considerable solar potential that have generous glazed surfaces. An analysis of the efficiency of the installation of photovoltaic blinds in a laboratory of the Faculty of Construction in Timisoara is proposed in order to ensure the shading of the interior space and to avoid the use of air conditioners during the warm period of the year.

The Electrical Installations (IE) laboratory of the Faculty of Construction in Timisoara was chosen for the study, where teaching activities are carried out (Fig. 6) and which raises problems in terms of ensuring thermal comfort conditions during the summer.

Fig. 6. Laboratory of Electrical Installation

From the study of the specialized literature, it was concluded that large glazed surfaces facing south and small glazed surfaces facing north correspond to the passive house concept from the point of view of space heating, compared to the cooling requirement for the warm period of the year, this concept becomes unfavorable. Practically, the influence of the dimensions of the glazed surfaces, in the current conditions of the energy performance of the windows, on the heating of the spaces is not as important as in the case of their cooling. This conclusion is also valid in the case of the IE laboratory. The laboratory has a maximum capacity of 20 places, and during the warm periods of the year (June-August) the indoor temperature exceeded the ambient comfort limit. For this reason, two air conditioners were installed to ensure a comfortable temperature during the warm periods of the year. The laboratory has a volume of 178.45m^3, with a window area of 22.25m^2 and a glazed area of 18.08m^2 facing West (Fig. 7 b). The percentage of glazed surface in the west-facing wall is 48.6%. The entire building of the Faculty of Construction has generous glazed surfaces and spaces with the same orientation as that of the IE laboratory. It has no tall buildings in front of the west-facing facade (Fig. 7a).



a) b)

Fig. 1 Civil Engineering Faculty

a) Orientation of glazed surfaces, b) Detail of glazed surfaces

In order to facilitate the installation of photovoltaic blinds, the need for large sizes of glazed surfaces was analyzed by evaluating the luminosity coefficient. The luminance coefficient given by the glass/floor ratio for the IE laboratory is 0.355, falling into the category of laboratory-type spaces that require precision (0.25-0.5). Although the luminance coefficient of the IE room is beyond the limits required for educational spaces (0.166-0.25), it is considered correctly chosen because laboratory work is carried out in this space, which requires precision in making experimental measurements. Therefore, the surface of the existing glazing, which is currently shaded with textile blinds, is necessary. Although the west orientation of the windows is seen as an advantage because it benefits from more time of natural sunlight, in the case of the IE laboratory it creates both the effect of overheating and the appearance of unwanted reflections on the screens of measuring devices and computers. The overheating effect is accentuated by the significant increase in temperature in recent years (Fig. 8) [22].

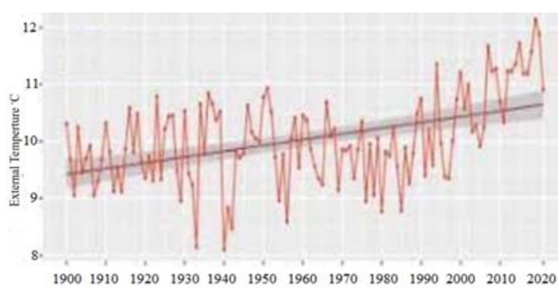


Fig. 8. Climate changes in Romania in the period 1900-2021 [12]

The overheating effect in Romania is accentuated by the significant increase in temperature in recent years (Fig. 8), a fact also confirmed in Timisoara in the period 2021-2022 (Fig. 9)

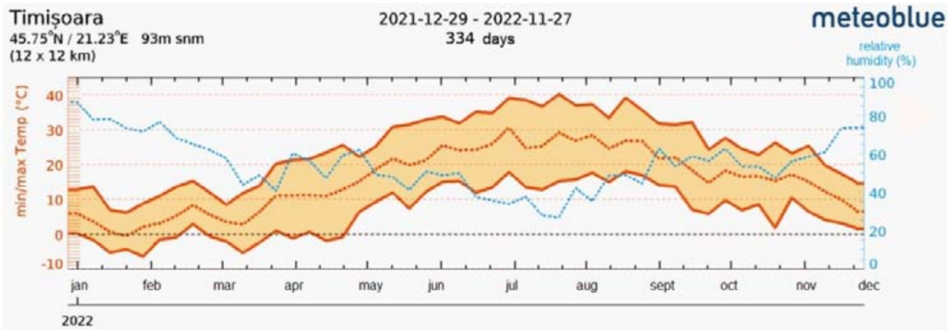


Fig. 9. Climate changes in Romania in the period 29.12.2021- 27.11.2021 [13]

In the Fig.9, it can be seen that in the absence of shading and/or air conditioning systems, in the laboratory, a greenhouse effect would be produced, making teaching activity impossible.

The proposal to replace them with photovoltaic blinds will contribute, on the one hand, to the reduction of energy consumption for cooling and, on the other hand, to the integration of solar energy as an energy source for supplying consumers in the laboratory. Thus, the installation of photovoltaic blinds will contribute to the transition of existing buildings with large glazed surfaces to the passive house concept, as is also the case with the Faculty of Construction.

Two installation options are analyzed (Fig.10):

- Outside the glazed surface – solar radiation is captured before coming into contact with the glazed surfaces;
- Inside the space – solar radiation is captured after passing through the glazed surfaces;


Fig. 10. Blinds installation options

In this regard, a data acquisition station using KNX equipment was installed for the proposed study:

- outside a pyranometer (Fig. 11. a) for monitoring the intensity of solar radiation. The monitored data were stored and processed using a Logic controller (Fig. 11. b). The monitoring of the intensity of solar radiation was also carried out in order to analyze the opportunity of installing photovoltaic panels on the facade of the building, an analysis that was the subject of previous studies by the authors [23-24].

- inside (in the laboratory), a sensor for monitoring temperature and solar radiation (Fig. 11.c)

a) b) c)

Fig. 11. Acquisition station

For the experimental measurements regarding the photoelectric conversion, the following were used: MI 3109 Eurotest PV Lite, METREL, a sensor for measuring the temperature of photovoltaic cells, a probe for measuring solar radiation , a variable resistance and two multimeters for measuring voltage and current intensity DC/AC, (Fig.12).

Fig. 12. Solar radiation measurement

3. Results and discutions

The study addresses three directions, namely:

- Reducing the energy needed to cool the space consumption;
- Space shading;
- Production of electricity through photovoltaic effect.

Measurements were made for short periods of time, both in the warm season (June) and in the cold season (November).

To reduce the greenhouse effect, the paper proposes the creation of a shading system with photovoltaic cells.

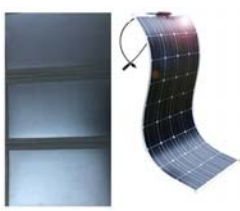


Fig. 13. Shading system with photovoltaic cells

Using PVGIS, the photovoltaic potential was evaluated for a 2KW(peak) photovoltaic system, installed vertically on the building facade. The proposed system can produce 1182 kWh/year, estimated with help of PVGIS

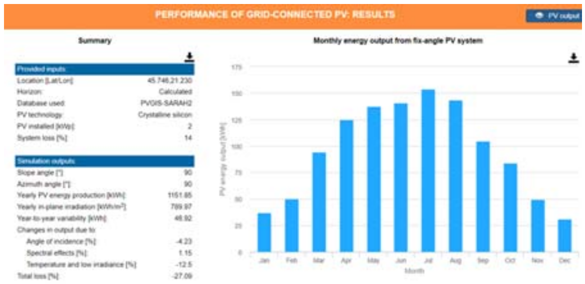


Fig. 13. Estimation of energy production with PVGIS [23]

Table 1 shows the data on energy consumption during the teaching period, for the two air conditioning units installed in the LE laboratory, and in the Fig. 14 compares the electricity consumption required for cooling with the electricity production during the absence of teaching activity.

Table 1

The energy requirement for cooling the space

Month	Week	Day	Hour	Total hour/month	Consumption / unit [kW]	No unit
May	3	5	8	120	0.31	2
June	4	5	8	160		
July	25	5	8	80		
Total hour/ year				360		
Total comsumtion/ year [kWh/year]					446.4	

Estimation of the amount of energy during the period when there is no teaching activity (total shading 556 kWh/year) and consumption for cooling (223 kWh/year), resulting in a benefit of 333kW/year.

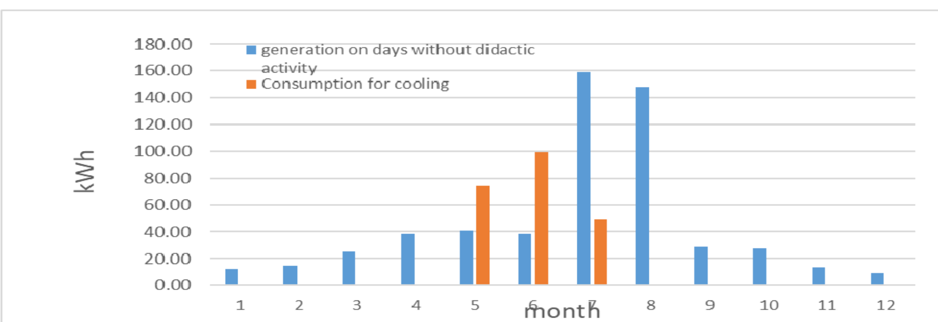


Fig. 14. Compares the electricity consumption and electricity production

4. Conclusions

Starting from the problem of the effects generated by global warming on energy consumption in buildings, especially during the warm period of the year, the luminance coefficient related to the didactic laboratory-type educational space was evaluated, which was calculated at the value of 0.355, which places the space in the category of precision laboratories. It started with this idea because during the warm period of the year the space overheats due to solar radiation and the orientation of the glazed surfaces.

The shading of the glazed surfaces with the textile blinds mounted on the inside is not sufficient, both from the point of view of overheating the space, and from the point of view of shading.

Even if there is the possibility of reducing the glazed surface needed for the natural lighting of the space, in order to maintain the luminance coefficient in the range of 0.166-0.25, it was decided to analyze the installation of photovoltaic blinds for the benefit of solar inputs during the cold period of the year.

The study was also carried out in order to make a contribution to the passive house concept, a concept that should also be adopted in existing buildings.

As solar radiation is beneficial in cold periods, but creates problems in warm periods, it can be said that a key to solving the problems of overheating of the analyzed space is radiation control. Practically, the influence of the dimensions of the glazed surfaces, in the current conditions of the energy performance of the windows, on the heating of the spaces is not as important as in the case of their cooling. For the warm period of the year, the installed air conditioners consume 0.31 kW/h/unit and it is necessary to operate during the entire period of occupation of the space.

Since solar radiation is beneficial in cold periods but creates problems in warm periods, it can be said that a key to solving the problems of overheating of the analyzed space is radiation control. Practically, the influence of the dimensions of the glazed surfaces, in the current conditions of the energy performance of the windows, on the heating of the spaces is not as important as in the case of their cooling. For the warm period of the year, the installed air conditioners consume electricity and it is necessary to operate during the entire period of occupation of the space.

The proposed installation of photovoltaic blinds will contribute, on the one hand, to the reduction of energy consumption for cooling and, on the other hand, to the integration of solar energy as an energy source for supplying consumers in the laboratory. Extrapolating, the installation of photovoltaic blinds will contribute to the transition of existing buildings with large glazed surfaces to the passive house concept.

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Comparative study of two heating/cooling systems for an office building using Design Builder software

Studiu comparativ a două sisteme de încălzire/răcire pentru o clădire de birouri utilizând software-ul Design Builder

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Abstract. *The buildings sector is responsible for the largest percentage of total energy consumption, especially for heating and cooling. For this reason, the paper compares two heating/cooling systems (multisplit VRF and respectively chiller, central heating and fan coil units) for an office building. Energy consumption for heating/cooling, domestic hot water preparation and lighting, expressed in MWh/year, was analyzed. Following the simulation, the VRF air-conditioning system, which registers a global consumption of 70.23 MWh/year, compared to the system with a chiller, thermal plant and fan coil units, which registers a global consumption of 81.25 MWh/year, was found more advatageous.*

Key words: global energy consumption, heating, cooling, building

1. Introduction

Energy consumption has become a global issue in recent years. Of the total energy consumption of the European Union member states, approximately 40-45% is used in residential and commercial buildings, which means that the building sector is responsible for approximately 36% of total carbon dioxide emissions [1], [2], [3], [4], [5], [6], [7].

The Kyoto Protocol emphasizes improving energy efficiency and also solving major problems that can affect the environment, mainly through efficient management of resources and costs and reduction of carbon dioxide (CO2) emissions [8].

The existing building stock in Europe represents approximately 35,000,000 square meters of built-up area, i.e. a large part of this area (more than 80%) was built before 1975. In addition, 18% of the existing building stock was built after the 1990s. This fact explains the very high consumption of European buildings, 60% of these buildings being residential characterized by an energy consumption of primary energy around 190 kWh/(m^2an year).

Taking into account the current context of sustainable development and the most efficient use of energy worldwide, it was proposed to construct buildings in which energy consumption is as low as possible or almost equal to zero, a requirement in the course of mandatory implementation starting from December 31, 2018 for public buildings and 31 December 2020 for all types of buildings.

Thus, by reducing consumption in buildings, a nation can reduce its dependence on imported energy and strengthen its strategic position at an international level. The "energy efficiency" criterion is understood by the European Union to be a good way of establishing long-term energy security.

2. The description of the analyzed building

The studied building was constructed in 2014, and falls into the category of open space office buildings, with a S + GF + 4F height regime and a total area of each floor of 229 sqm (Fig.1).

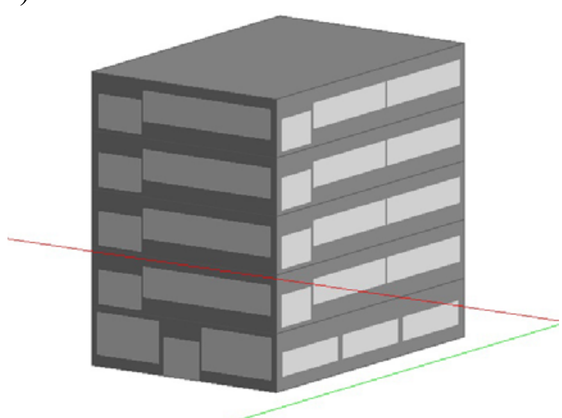


Fig.1. Analyzed building

The constructive structure is of the reinforced concrete frames type, the masonry is made of brick plastered with lime and cement mortar, thermally insulated. The terrace is passable with gravel, thermally insulated and waterproofed with bitumen cardboard. The interior walls and floors are made of reinforced concrete. The exterior carpentry is made of PVC, wood and metal.

3. Simulation of air conditioning systems with the help of Design Builder

Solution 1 – VRF air conditioning system

For indoor spaces that require air conditioning, a multisplit VRF system will be provided, operating with ecological refrigerants. The indoor units are non-encased and will be mounted buried in the false ceiling, for all areas of the building. The outdoor units will be mounted on the terrace of the building. The air conditioning system will work both in the cooling system (up to outside temperatures of +43ºC) and in the heating system (up to minimum temperatures of -25ºC). The connections between the indoor units and the outdoor units are made of Cu pipe and insulated with Armaflex.

Solution 2 - Water-based air-conditioning system, air-cooled chiller and unheated 4-pipe fan-coil indoor units

The air conditioning system designed is of the heating/cooling type with ceiling fan coil units with reversible battery, with condensate pump with supply pipes with thermal agent cooling and heating. The thermal heating agent hot water with temperature parameters 75°C -55°C will be provided from the boiler through the heating installation and as a cooling agent cold water with temperature parameters 7°C -12°C, provided by coolers external water chiller type, through supply pipes that will be connected to the level distributors.

The box type fan coil units will be mounted in the decorative ceiling, and are without fresh air intake, considering the fact that a ventilation installation with fresh air intake has been provided (in both solutions). The supply of thermal heating and cooling agent to the fan convectors will be done with an internal distribution installation with polyethylene pipes joined with cold-pressed fittings, insulated and mounted in the decorative ceiling. The distribution of the heating/cooling agent will be made from level distributors, mounted in the decorative ceiling. Adjustment/separation valves and a three-way valve are mounted on the connection pipes from the fan coil units.

For the comparative study of the two systems, the simulation program Design Builder [9] was used. After choosing the air conditioning solution, the model created with the help of Design Builder software was simulated and the output data was analyzed. The program automatically generates the heating requirement related to the created model and allows the creation of graphs between the parameters of interest (temperatures, heat inputs, energy consumption, etc.).

Thus, the two systems proposed for analysis were simulated:

- *Solution 1 - Air conditioning installation in direct expansion with VRF type equipment - centralized, having uncased DUCT type indoor units*

The first step of the simulation involves the creation of the model (Fig.1) [9] based on which the software automatically generates the heat requirement for heating (Fig.2) and cooling (Fig.3) [9].

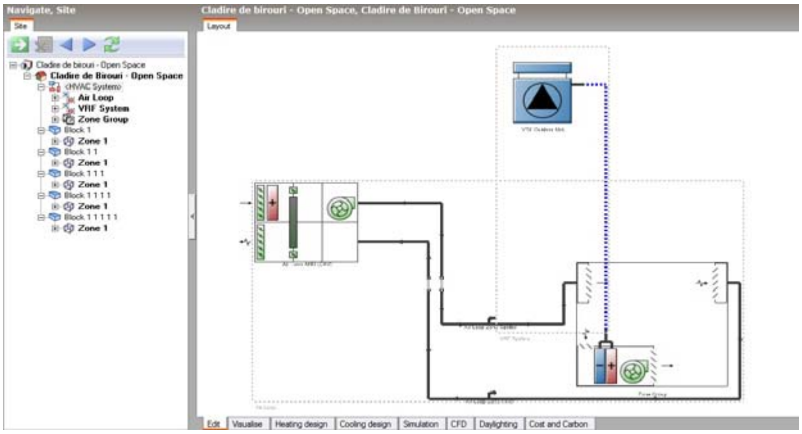
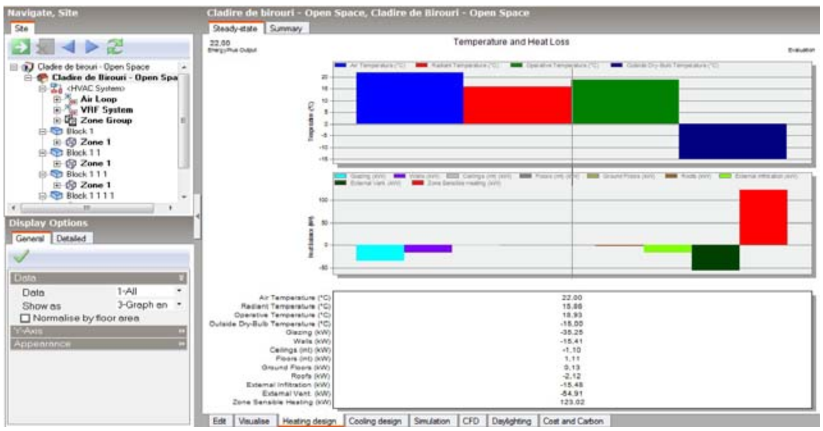


Fig.1. The creation of the model – Solution 1



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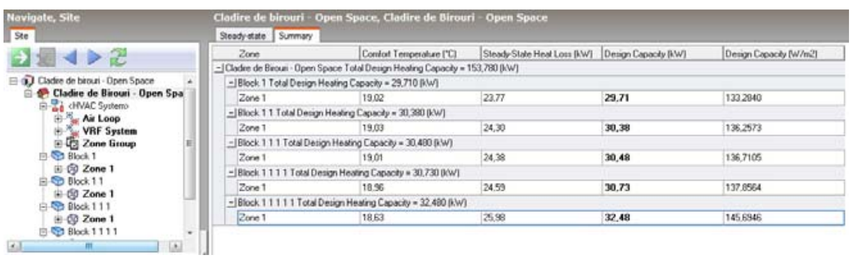
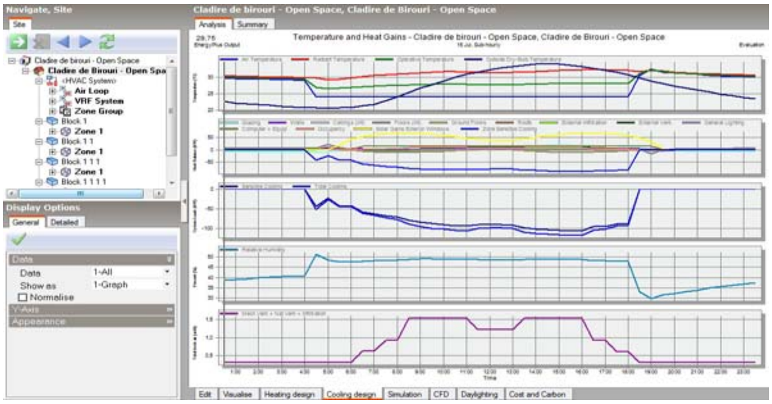


b)

Fig.2. Generating the energy requirement for heating – Solution 1

a) Entry data, b) Generation of the heat requirement



a)

b)

Fig.3. Generating the energy requirement for cooling – Solution 1
a) Temperature and Heat Gains, b) The cold requirement for cooling

Following the simulation, a heat demand for heating of 153.78 kW and a cold demand for heating of 134.13 kW respectively resulted for the air conditioning system with VRF.

- *Solution 2 - Water-based air-conditioning installation, with an air-cooled chiller for the production of chilled water, a thermal power plant (TPP) for the production of hot water and a non-cased indoor unit of the fan coil type*

The creation of the model is shown in Fig.4 [9], the heat demand for heating in Fig.5 and the cold demand for cooling in Fig.6 [9].

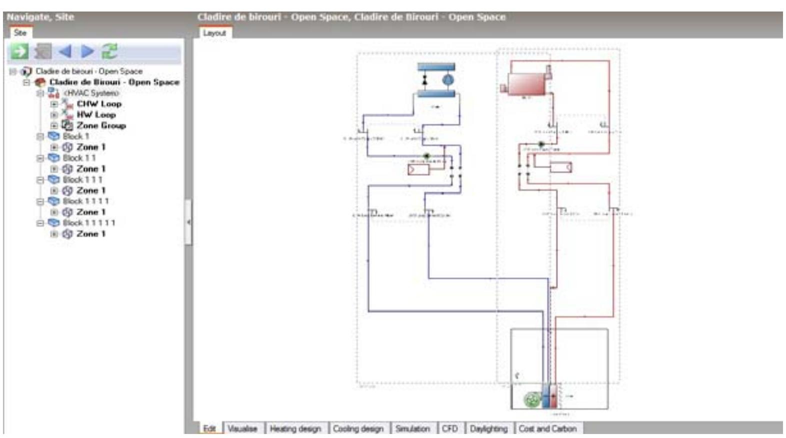
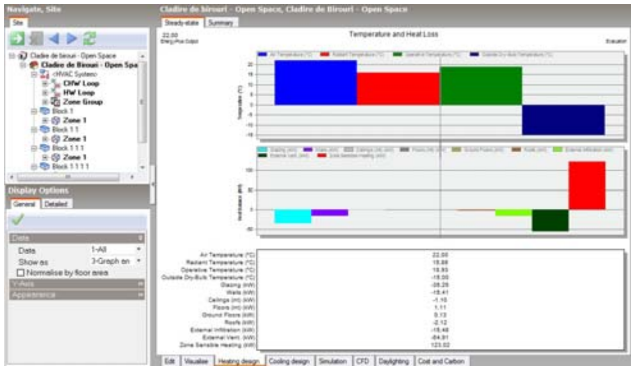


Fig.4. The creation of the model – Solution 2



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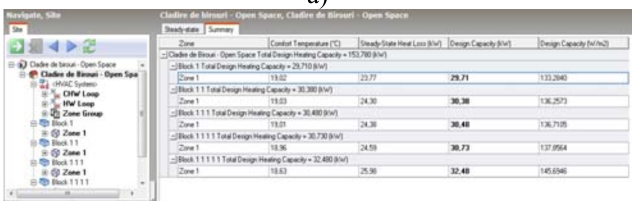
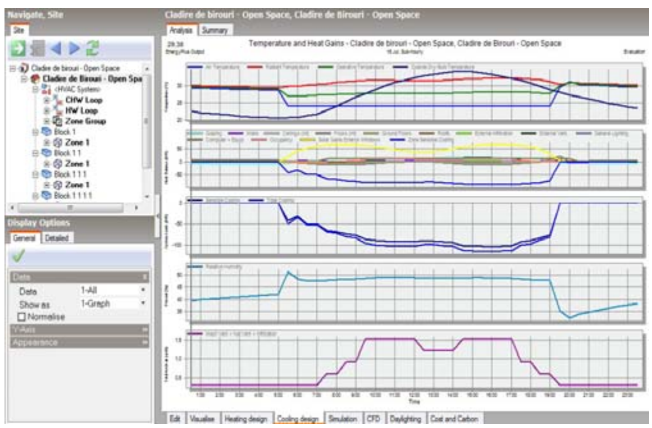


b)

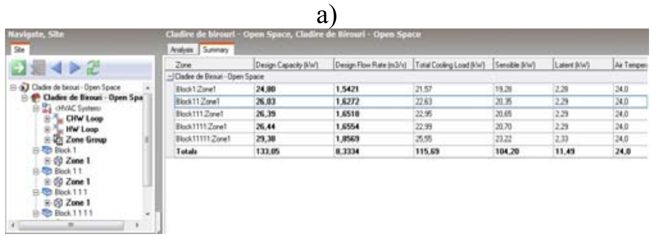
Fig.5.

Generating the energy requirement for heating – Solution 2

b) Entry data, b) Generation of the heat requirement



a)



b)

Fig.6. Generating the energy requirement for cooling – Solution 2

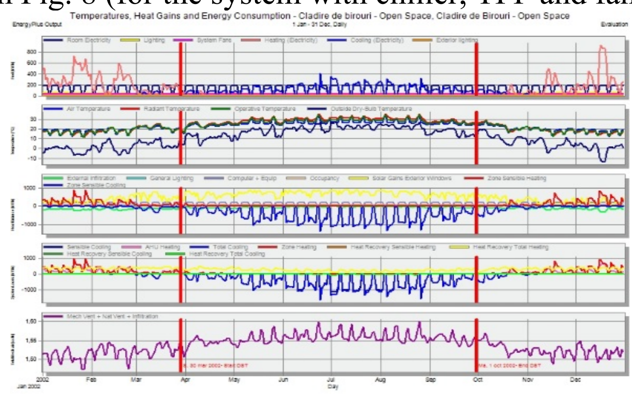
a) Temperature and Heat Gains, b) The cold requirement for cooling

Following the simulation for the air conditioning system with chiller, heating plant and fan coils, a heat requirement for heating of 153.78 kW and a cold requirement for heating of 133.05 kW respectively resulted.

4. Results and discussions

After entering the selection parameters and choosing the air conditioning system, the Design Builder program generates a data analysis over a determined period of time, staged where we find the cooling and heating periods.

The obtained data are present for the two types of systems in Fig. 7 (for the VRF system) and in Fig. 8 (for the system with chiller, TPP and fan coils).



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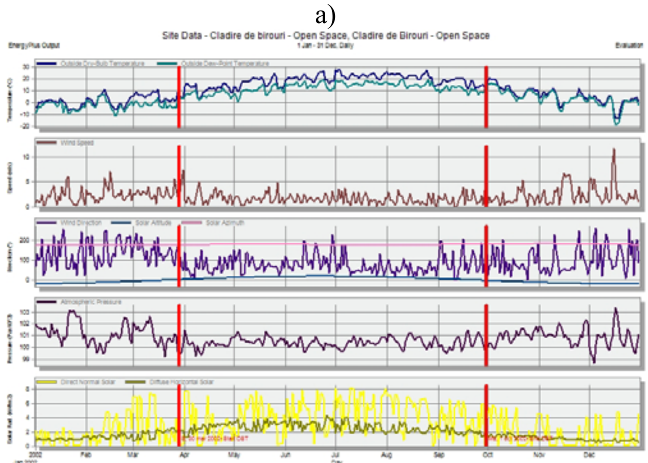

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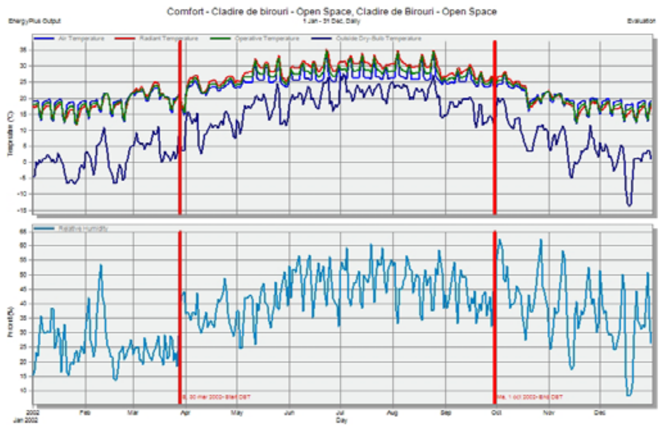

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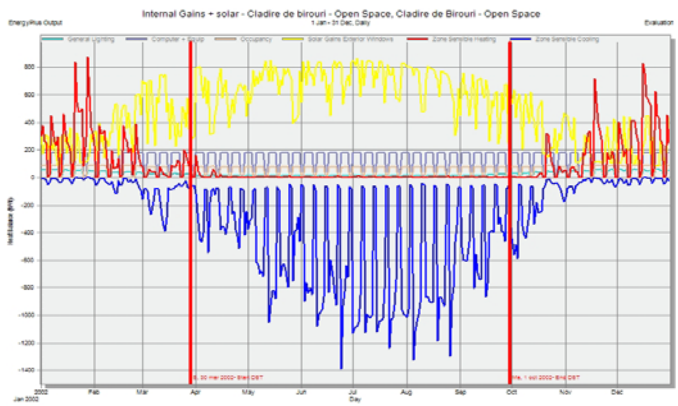

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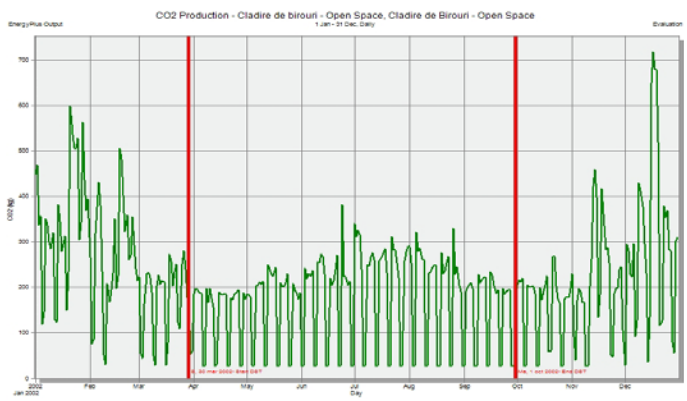
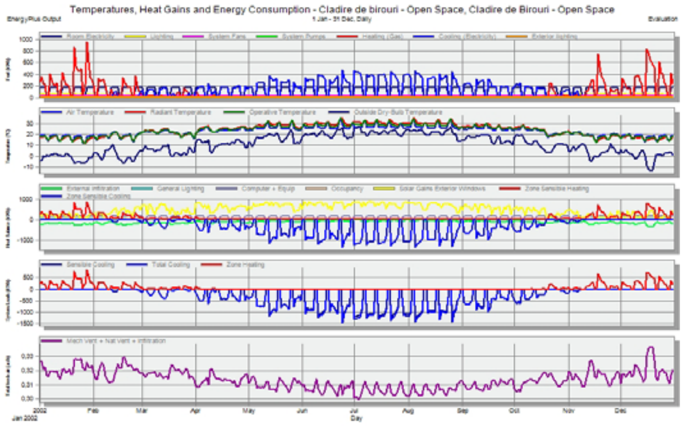


e)

Fig. 7. Simulation results for Solution 1 [9]
a) Temperature, heat gains and energy consumption, b) Site data, c) Comfort parameters, d) internal gains+solar, e) CO2 production

As in the case of Solution 1, the second variant was also simulated for the air conditioning system with chiller, TPP and fan coils for which the data is shown in Fig. 8 [9].



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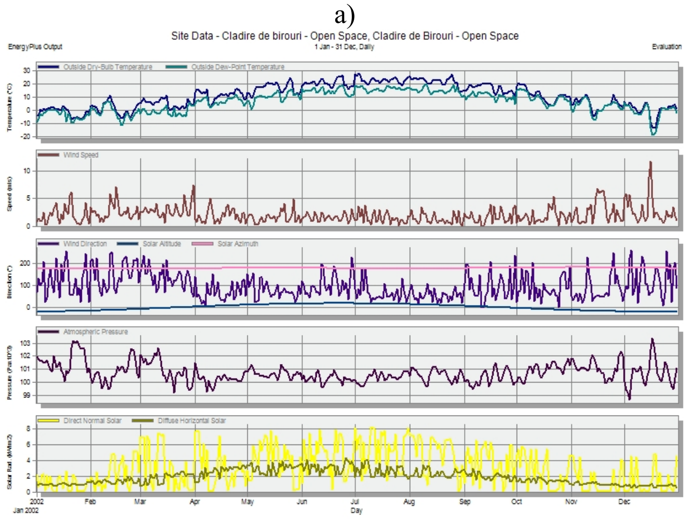

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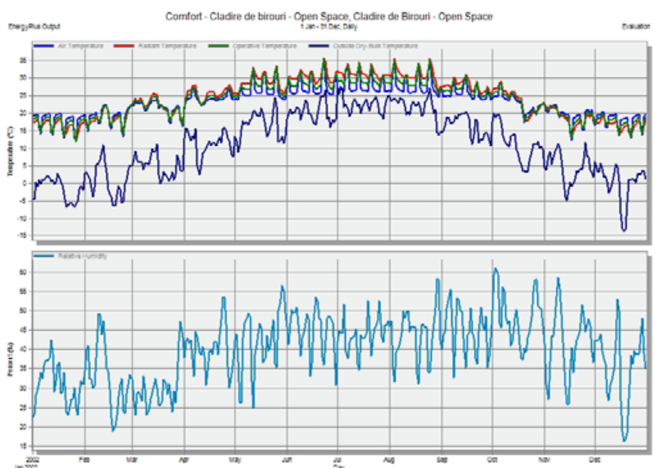

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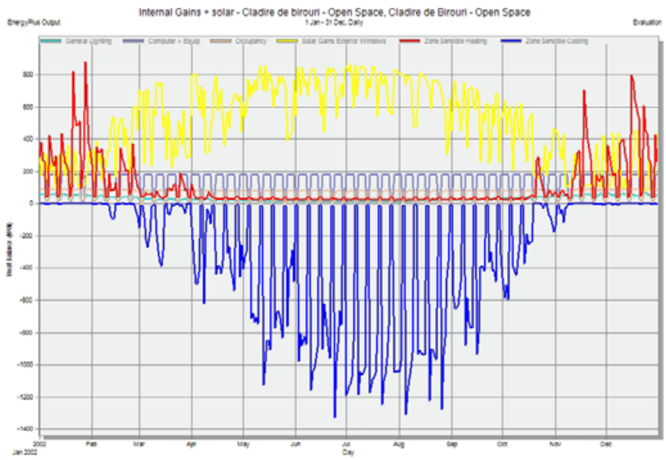

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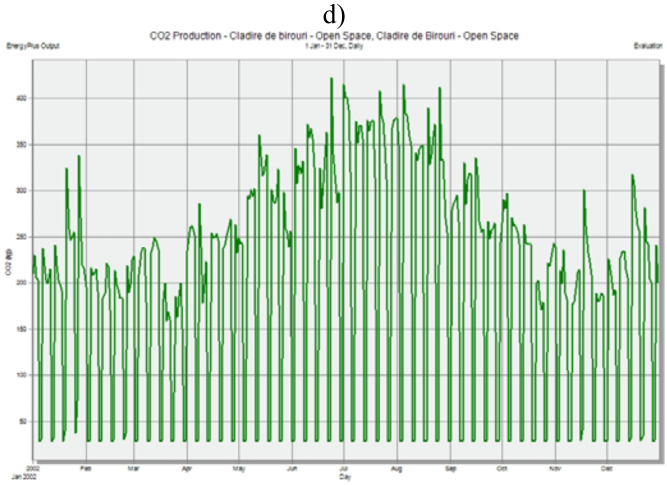

e)

Fig. 8. Simulation results for Solution 2 [9]
a) Temperature, heat gains and energy consumption, b) Site data, c) Comfort parameters, d) internal gains+solar, e) CO2 production

Analysis of energy consumption for the two analyzed system solutions

With the help of the report generated by the Design Builder program, the electricity consumption was compared in the case of the two variants.

A comparative analysis between the two analyzed systems, in terms of energy consumption for heating and cooling, is presented in Fig. 9 and respectively Fig. 10 [9].

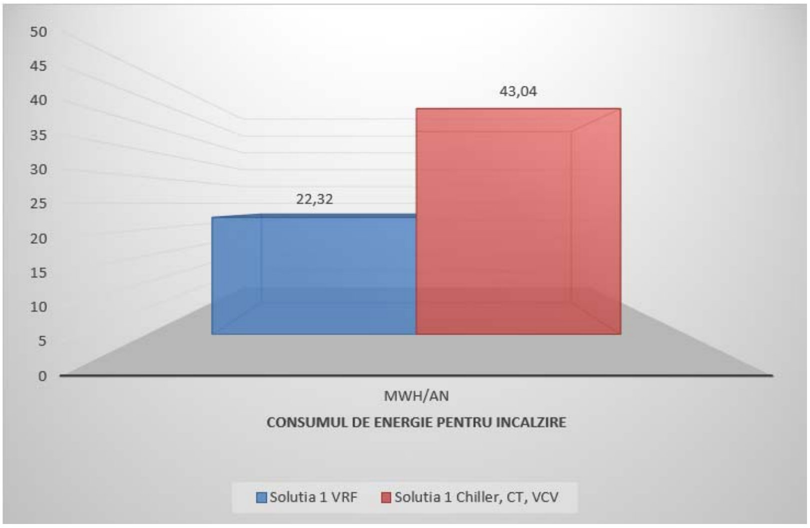

Fig. 9. Comparative analysis of energy consumption for office building heating. Solution 1 vs. Solution 2 [9]

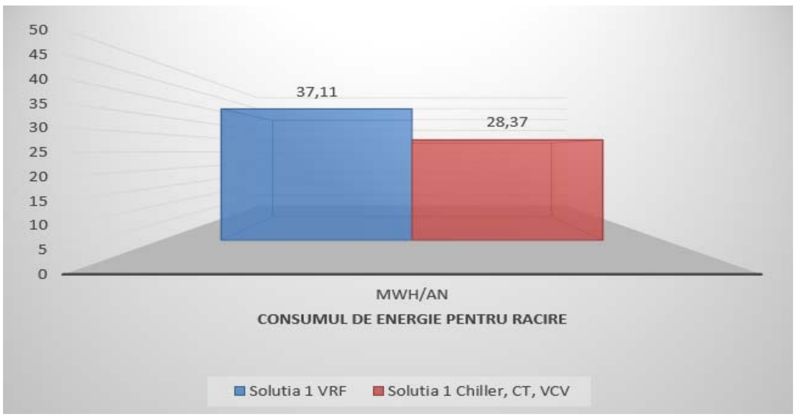

Fig. 10. Comparative analysis of energy consumption for office building cooling. Solution 1 vs. Solution 2 [9]

Also, the energy consumption for the preparation of domestic hot water was determined (Fig. 11) and the electricity consumption for lighting, which does not undergo changes depending on the chosen solution, recording a consume of 8.28 MWh/year. For domestic hot water, a consumption of 2.52 MWh/year was determined in the case of installing the system proposed in Solution 1 and 1.56 MWh/year for the system proposed in Solution 2, consumptions that do not differ between the two variants.

At the same time, the global energy consumption for the two systems, obtained after the simulation, is presented comparatively in Fig. 12.

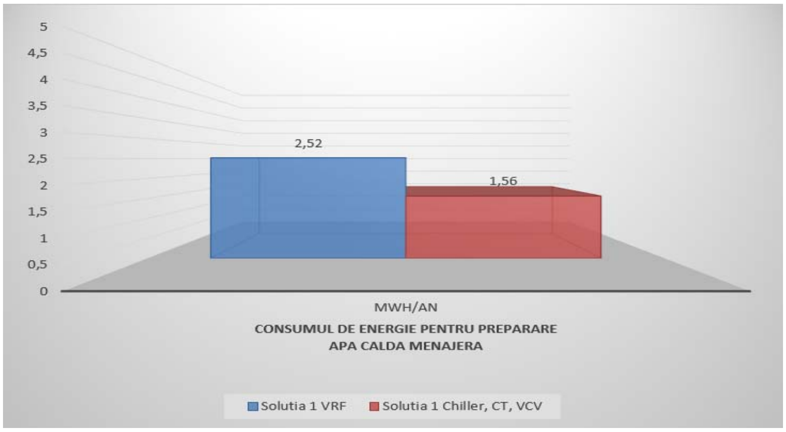

Fig. 11. Comparative analysis between the energy consumption for the preparation of domestic hot water related to the office building.
Solution 1 vs. Solution 2 [9]

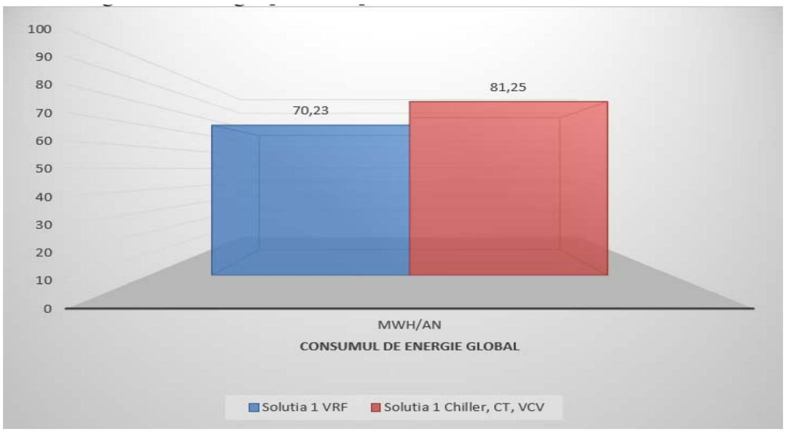

Fig. 12. Comparative analysis of global office building energy consumption.
Solution 1 vs. Solution 2 [9]

5. Conclusions

For the comparative analysis of the consumptions generated by the two types of analyzed systems (Solution 1 and respectively Solution 2) taking into account the same input data, different global consumptions were obtained. As the energy consumption for lighting is not influenced by the type of system, and the consumption for the preparation of domestic hot water shows small differences between the two systems (0.96MWh/year), it is obvious that the difference in consumption is determined by the heating/cooling of the building offices. Thus, it was found that there is a difference of 11.02MWh/year, a difference which in the current climatic conditions can be considered problematic. On the other hand, it is found that for cooling the most advantageous system is Solution 2, and for heating the advantageous system is Solution 1, but from the point of view of global consumption it is found that Solution 1 is the most advantageous system for the considered building and under the conditions imposed by the input data.

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Radiator heat transfer enhancement using nanofluid

Îmbunătăţirea transferului de căldură la radiatore folosind nanofluide

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Abstract. *This research article presents a computational fluid dynamics (CFD) analysis of the heat transfer enhancement in a radiator using nanofluid. The study investigates the effect of varying the concentration of nanoparticles and the inlet velocity of the fluid on the heat transfer rate and pressure drop. The simulation results show that the use of nanofluids in radiators leads to a significant increase in heat transfer rate compared to traditional fluids. However, the pressure drop also increases with the concentration of nanoparticles, which can affect the overall efficiency of the radiator. The study provides valuable insights into the design and optimization of nanofluid-based radiators using CFD simulations.*

Keywords: Nanofluids, Heat transfer enhancement, Thermal conductivity, Radiators, Nanoparticle concentration

1. Introduction

Research on radiator heat transfer enhancement using nanofluids has demonstrated promising results. Nanofluids are engineered colloidal suspensions of nanoparticles in a base fluid, which can improve the thermal conductivity of the fluid, leading to better heat transfer performance in radiators. [1, 2]

Some key findings and state-of-the-art developments in this area include:

- Enhanced thermal conductivity: Nanofluids exhibit improved thermal conductivity compared to their base fluids due to the high thermal conductivity of nanoparticles. Common nanoparticles used include metal and metal oxide nanoparticles, such as aluminum oxide (Al2O3), copper oxide (CuO), and titanium dioxide (TiO2).[3]
- Improved heat transfer coefficient: The presence of nanoparticles in the base fluid can result in higher heat transfer coefficients due to the altered thermal boundary layer and enhanced convective heat transfer. Studies have shown that using nanofluids can lead to an increase in the heat transfer coefficient by up to 20-30%.[4, 5]
- Optimal nanoparticle concentration: Researchers have found that there is an optimal concentration of nanoparticles in the base fluid that yields the maximum

enhancement in heat transfer performance. This concentration varies depending on the specific nanoparticles and base fluid used, and it is typically in the range of 0.5-5% by volume. [6, 7]

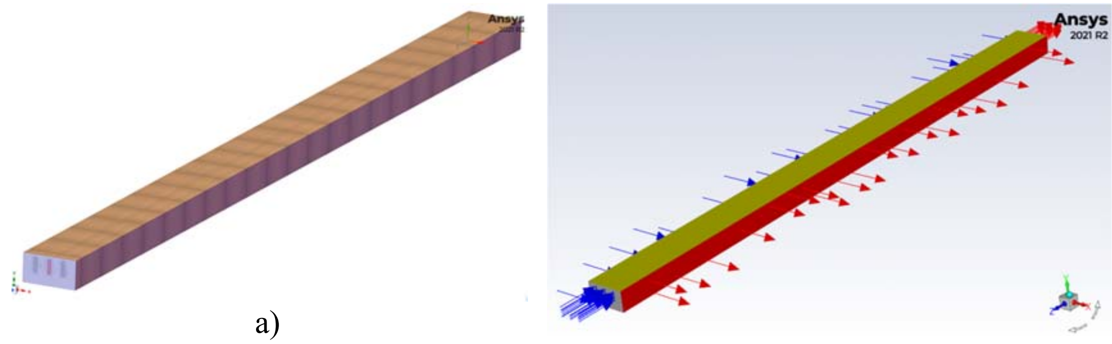
- Particle shape and size: The shape and size of nanoparticles can also influence the heat transfer performance of nanofluids. Smaller nanoparticles with a high surface area-to-volume ratio and irregular shapes have been found to provide better heat transfer enhancement.[8, 9]
- Stability of nanofluids: The stability of nanofluids is crucial for their long-term use in radiators. Researchers have focused on methods to enhance the stability of nanofluids, such as using surfactants or functionalizing the nanoparticles with specific surface coatings.

While the use of nanofluids for radiator heat transfer enhancement shows promising potential, further research is needed to address the challenges associated with their stability, long-term performance, and cost-effectiveness. Additionally, it is essential to investigate the environmental impact and safety aspects of using nanofluids in large-scale applications. [10-12]

2. Material and method

The current issue (Figure 1) uses ANSYS Fluent software to model heat transfer within a radiator using nanofluid flow. The way that these radiators function is such that both the air flow and the flow of hot fluid both travel through the radiator's internal pipes. In this technique, the hot air flow is transported to the outside environment when the air flow passes through the pipes carrying the hot flow and absorbs its heat. In this simulation, hot nanofluid moves through three pipes within the radiator at a speed of 0.1 ms-1 and a temperature of 343.15 K, while cold air moves over this pipe at a speed of 3 ms-1 and a temperature of 293.15 K.

A specific kind of nanofluid has been employed to specify the hot fluid within the radiator's pipes. Al2_O3-Water is the nanofluid employed in this model, and it has the following properties: density of 1086.287 kg/m3, specific heat capacity of 3804.691 j.kg-1.K-1, thermal conductivity of 0.6672643 Wm-1.K-1, and viscosity of 0.00108236 kg.m-1.s-1. This research aims to examine the effectiveness of heat transmission inside the radiator in the presence of hot nanofluid.



a) b)

Fig. 1. a) Storage geometry, geometry meshing; b) boundary conditions

Utilising the programme Design Modeller, the current model was created in three dimensions. The radiator in the model has a symmetrical geometric structure and is semi-drawn in order to avoid complex computations. The air input and outflow parts of this radiator are on each side. Three pipes have been created within this radiator to allow the flow of nanofluid.

Several presumptions are taken into account while simulating the current model:

- A pressure-based solver is used.
- Simulation is constant.
- The impact of gravity on the fluid is disregarded.

3. Results

At the end of the solving process, two-dimensional and three-dimensional contours related to pressure, velocity, and temperature are obtained. (Figure 2)

Radiator heat transfer enhancement using nanofluids has become a topic of significant interest in recent years, as researchers explore ways to improve the efficiency of heat transfer systems. Nanofluids are a mixture of nanoparticles and a base fluid, such as water, ethylene glycol, or oil. These nanoparticles, typically made from materials like copper, aluminum, or carbon nanotubes, enhance the thermal conductivity of the base fluid and thus improve heat transfer.

Several studies have been conducted to analyze the effects of using nanofluids in radiators, and results show promising potential for heat transfer enhancement. Some key findings include:

- Improved thermal conductivity: Nanofluids demonstrate enhanced thermal conductivity compared to traditional fluids, which can result in better heat transfer. The degree of improvement depends on factors like nanoparticle material, size, shape, and concentration.
- Increased heat transfer coefficient: Studies have shown that using nanofluids in radiators can lead to an increased heat transfer coefficient, which is a measure of how

efficiently heat is transferred between the fluid and the radiator surface. This could potentially lead to more efficient cooling systems.

● Optimal nanoparticle concentration: There is an optimal concentration of nanoparticles in a nanofluid that provides the best heat transfer enhancement. This concentration can vary depending on the specific application and the properties of the nanoparticles.

● Reduced pumping power: In some cases, nanofluids have demonstrated reduced pumping power requirements, which could contribute to energy savings.

● Stability of nanofluids: Ensuring the stability of nanofluids is crucial for maintaining their performance over time. Researchers are working on methods to prevent sedimentation, agglomeration, and oxidation of the nanoparticles.

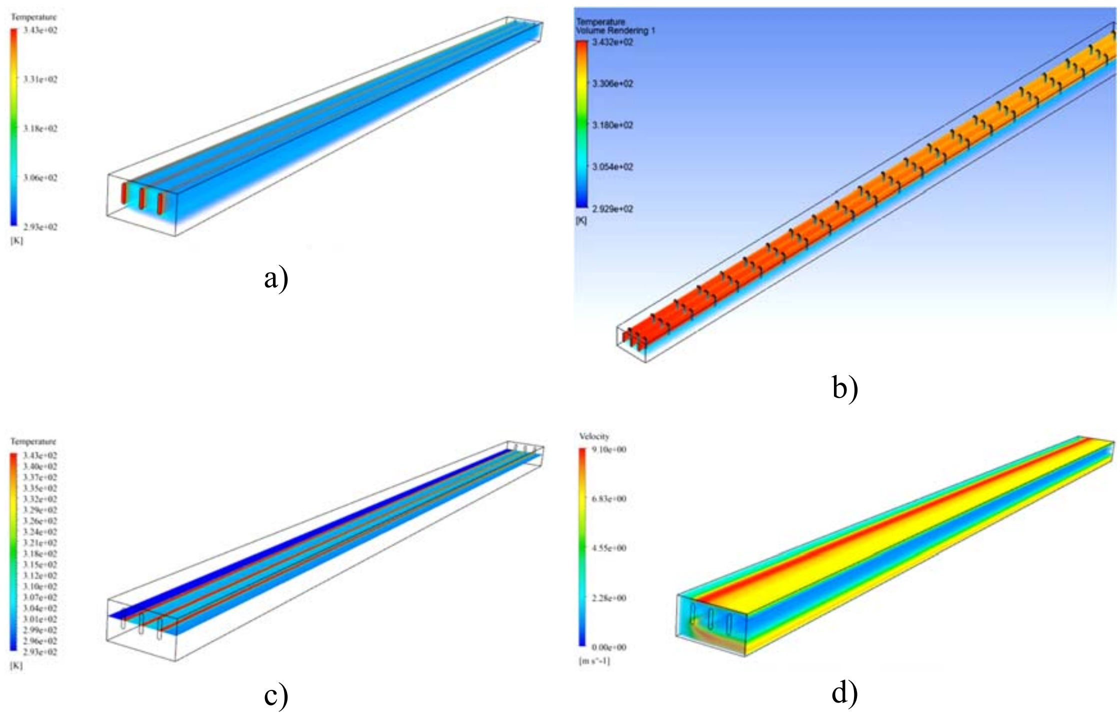


Fig. 2. a), b), c) Contours of temperature; d) Contours of Velocity

4. Discussion

Overall, the use of nanofluids in radiators has shown promising results for enhancing heat transfer. However, more research is needed to optimize their properties and understand their long-term performance in real-world applications. Future developments in this area could lead to more efficient cooling systems and energy savings in various industries.

The use of nanofluids for enhancing heat transfer performance in radiators has gained significant attention in recent years. The research on this topic shows that the addition of nanoparticles to the base fluid can improve the thermal conductivity of the fluid, leading to higher heat transfer rates.

Several studies have been conducted to investigate the effectiveness of different types of nanoparticles, including copper oxide, alumina, and titanium dioxide, in enhancing the heat transfer performance of radiators. The results of these studies indicate that the type and concentration of nanoparticles used, as well as the properties of the base fluid, play a crucial role in determining the effectiveness of nanofluids in heat transfer enhancement.

The research shows that the addition of nanoparticles to the base fluid can increase the heat transfer rate of a radiator by up to 38%. However, the effectiveness of nanofluids can be affected by several factors, including the size and shape of the nanoparticles, the stability of the suspension, and the flow rate of the fluid. Therefore, more research is needed to determine the optimal conditions for using nanofluids in radiators.

Overall, the research on "Radiator heat transfer enhancement using nanofluid" is promising and suggests that nanofluids could be a potential solution for improving the heat transfer performance of radiators in various applications, including automotive, aerospace, and industrial processes. However, further research is necessary to fully understand the effects of nanofluids on heat transfer performance and their long-term reliability and durability.

5. Conclusion

The research study found that using nanofluids, which are suspensions of nanoparticles in a base fluid, can significantly improve the thermal performance of heat transfer rate, total heat transfer coefficient, and Nusselt number in radiators. For instance, utilizing nanofluid with a volumetric concentration of 0.2% of nanoparticles can lead to maximum improvements in heat transfer rate of up to 41%, total heat transfer coefficient and Nusselt number of up to 50% and 31%, respectively. The study also found that Al2_O3-Water nanofluids exhibit impressive improvements in pressure drop and friction factor, along with excellent thermal performance. However, using nanofluids with large volumetric concentrations of nanoparticles may require additional pumping power. The study used ANSYS Fluent software to model heat transfer within a radiator using nanofluid flow and obtained two and three-dimensional contours related to velocity, pressure, and temperature. The temperature contour showed that the airflow passing over the tubes where hot water flows absorbs heat and leaves the domain with a higher temperature. The findings of this study have significant implications for enhancing the efficiency of heat transfer in various industrial thermal applications.

Research on radiator heat transfer enhancement using nanofluids has shown that the use of nanofluids can enhance the heat transfer performance in radiators. Nanofluids are suspensions of nanoparticles in a base fluid, which can improve the thermal conductivity of the fluid. Key findings include enhanced thermal conductivity, increased heat transfer coefficient, optimal nanoparticle concentration, reduced pumping power, and stability of nanofluids. However, more research is needed to optimize the properties of nanofluids and understand their long-term performance in real-world applications. The stability, long-term performance, cost-effectiveness, and environmental impact of nanofluids also need to be addressed. Despite these challenges, the use of nanofluids in radiators has the potential to improve the efficiency of cooling systems and contribute to energy savings in various industries. The research indicates that continued research and development in this area could lead to significant advancements in heat transfer technology.

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