Revista Română de Inginerie Civilă

Indexată în bazele de date internationale (BDI)

ProQuest, INSPEC, EBSCO

INDEX COPERNICUS, ULRICH'S şi JOURNALSEEK

Volumul 11 (2020), Numărul 3

MATRIX ROM
OP CHIAJNA CP 2
077040 – ILFOV
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www.matrixrom.ro

COLEGIUL EDITORIAL

Revista Română de Inginerie Civilă este fondată, publicată şi finanţată de editura MATRIX ROM
Director executiv: mat. Iancu ILIE

Online edition ISSN 2559-7485
Print edition ISSN 2068-3987; ISSN-L 2068-3987

Revista Română de Inginerie Civilă, Volumul 11 (2020), Numărul 3

Alimentarea centralizată cu energie termică de joasă temperatură. Justificare energetică şi economică

Low temperature district heating. Justification from an energy and economic standpoint

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DOI:10.37789/rjce.2020.11.3.1

Rezumat

Setul temperaturilor nominale ale agentului termic adoptat în dimensionarea instalaţiei de încălzire centrală are consecinţe directe atât asupra mărimii instalaţiei de încălzire, cât şi asupra pierderilor de energie în reţeaua termică de distribuţie. În cadrul lucrării se stabileşte corelaţia dintre cele două aspecte menţionate şi se încearcă identificarea unui set optim al temperaturilor nominale ale agentului termic care trebuie abordat la dimensionarea instalaţiilor de încălzire centrală pentru clădirile alimentate din sistemul centralizat de încălzire districtuală.

Cuvinte cheie: energie termică, consum, eficacitate

Abstract

The set of design temperatures adopted in the sizing of the district heating systems has direct consequences on both the heating system size and the energy losses in the distribution network. This paper establishes the correlation between the two issues mentioned and attempts to identify an optimal set of design temperatures of the heat carrier to be chosen in sizing the heating system for buildings connected to district heating systems.

Keywords: thermal energy, consumption, efficiency

1. Introducere

Alimentarea centralizată cu energie termică a ansamblurilor de cladiri din mediul urban reprezintă o preocupare continuă a specialiştilor din acest domeniu în ceea ce priveşte măsurile concrete de reabilitare şi modernizare menite să eficientizeze acest sector extrem de important din punct de vedere energetic.

Lucrarea de faţă se încadrează în acest domeniu, dat fiind că măsura reducerii nivelului temperaturilor agentului termic în reţelele de distributie are drept consecinţă directă scăderea pierderilor de energie termică aferente acestor reţele. Pe de altă parte, scăderea nivelului temperaturii agentului termic are şi o consecinţă negativă, şi anume creşterea suprafeţei de încălzire cu care sunt echipate clădirile deservite.

Având în vedere cele 2 aspecte, unul direct benefic din punct de vedere energetic, iar cel de al doilea implicând un cost de investiţie mai mare, în cadrul lucrării se încearcă punerea în balanţă a celor 2 aspecte, astfel încât, prin evaluarea duratei de recuperare a investiţiilor suplimentare pe baza beneficilor energetice, să se poată aprecia în ce măsură reducerea temperaturii agentului termic în sistemele de încălzire districtuală este rentabilă.

2. Descrierea metodei de evaluare şi rezultate energetice-economice

În prima etapă se va analiza corelaţia între nivelul temperaturii nominale a agentului termic şi suprafaţa de încălzire instalată. Din bilanţul termic al sistemului format din clădire şi instalaţia de încălzire avem:

$$k \cdot S \cdot \left(t_{m0} - t_{i0}\right) = H \cdot \left(t_{i0} - t_{e0}\right) \tag{1}$$

Dacă notăm :

$$R_t = \frac{t_{i0} - t_{e0}}{t_{m0} - t_{i0}} \tag{2}$$

Rezultă :

$$S = \frac{H}{k} \cdot R_t \tag{3}$$

Suprafaţa instalaţiei de încălzire centrală aferentă consumatorului este direct proporţională cu raportul R_t. În figura 1 se prezintă grafic dependenţa raportului R_t a diferenţelor de temperaturi nominale de temperatura nominală a agentului termic la intrarea in instalaţia de încălzire. Cu cât temperatura nominală medie a agentului termic scade, cu atât este necesar ca suprafaţa de încălzire să crească, pentru a se putea livra către spaţiul încălzit fluxul termic necesar aferent consumatorului, care va fi acelaşi indiferent de temperatura aleasă a agentului termic.

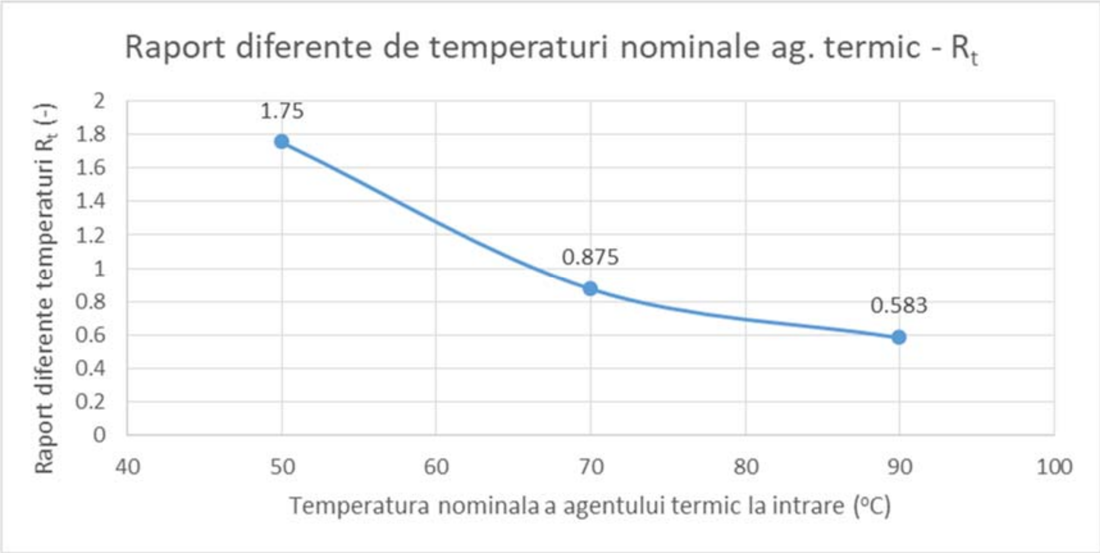

Figura 1 Dependenţa raportului R_t a diferenţelor de temperaturi nominale de temperatura nominală a agentului termic la intrarea in instalaţia de încălzire

Clădirea este caracterizată termic prin capacitatea de transfer termic H (constantă), şi se consideră că instalaţia de încălzire centrală are ca valoare constantă coeficientul global de transfer termic al corpurilor de încălzire k, pentru care se consideră o valoare medie de 7 W/m^2·K.

În cele 3 variante de dimensionare a suprafeţei de încălzire aferente consumatorului (90/70 – varianta 1; 70/50 – varianta 2; 50/30 – varianta 3), acestea se corelează astfel : S_2 = 1,5·S1 şi S_3 = 3,0·S1.

În ceea ce priveşte evaluarea fluxului de căldură pierdut de către reţeaua termică de distribuţie, se face apel la [1]. Aici, în cadrul lucrării „Randamentul unui sistem districtual de încălzire centrală” pag. 187-194, se defineşte şi se stabileşte expresia randamentului sistemului districtual de încălzire ca fiind:

$$\eta = \frac{\Phi_C}{\Phi_F} = \frac{\Phi_C}{\Phi_C + \Phi_P} = \frac{E_R \cdot (1 - E_C)}{1 - E_R^2 \cdot E_C} \tag{4}$$

Relaţia (4) reflectă faptul că randamentul sistemului de încălzire districtual depinde atât de modulul termic aferent consumatorului, cât şi de modulul termic aferent reţelei de distribuţie. Prelucrând relaţia (4) se pot stabili pierderile termice ale reţelei de distribuţie (Φ_P) ca o cotă parte din puterea termică utilă livrată consumatorului de către instalaţia de încălzire centrală (Φ_C) :

$$\xi = \frac{\Phi_P}{\Phi_C} = \left(\frac{1}{\eta} - 1\right) = \frac{(1 - E_R) \cdot (1 + E_R \cdot E_C)}{E_R \cdot (1 - E_C)} \tag{5}$$

După cum se observă, şi această cotă parte utilă în deteminarea pierderilor de energie termică aferentă reţelelor de distribuţie este dependentă tot de modulul termic aferent consumatorului şi de cel al reţelei termice de distribuţie. Se ţine seama de faptul că modulul termic aferent reţelei de distribuţie are în general valori între 0.98 şi 0.99, iar modulul termic aferent instalaţiei de încălzire a consumatorului se poate calcula cu :

$$E_C = \frac{t_{R0} - t_{i0}}{t_{T0} - t_{i0}} \tag{6}$$

În acest mod se obţin valorile prezentate in tabelul 1.

Tabelul 1

Valorile modulului termic aferent instalaţiei de încălzire a consumatorului

$t_{T0}/t_{R0}/t_{i0}$	E_C
90/70/20	0.714
70/50/20	0.6
50/30/20	0.333

În figurile 2 şi 3 se prezintă grafic dependenţa randamentului sistemului de încălzire districtuală (η) şi cota pierderilor reţelei de distributie (ξ) în funcţie de modulul termic aferent instalaţiei de încălzire centrală şi de cel aferent reţelei termice de distribuţie.

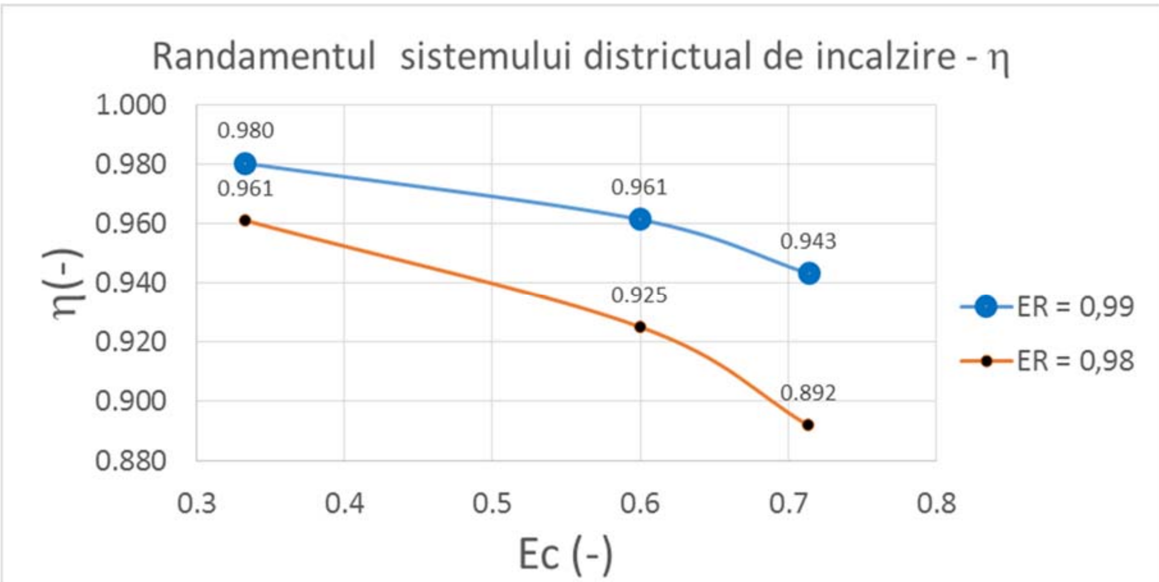

Figura 2 Randamentului sistemului de încălzire districtuală (η) în funcţie de modulul termic aferent instalaţiei de încălzire centrală (E_C) şi de cel aferent reţelei termice de distribuţie (E_R)

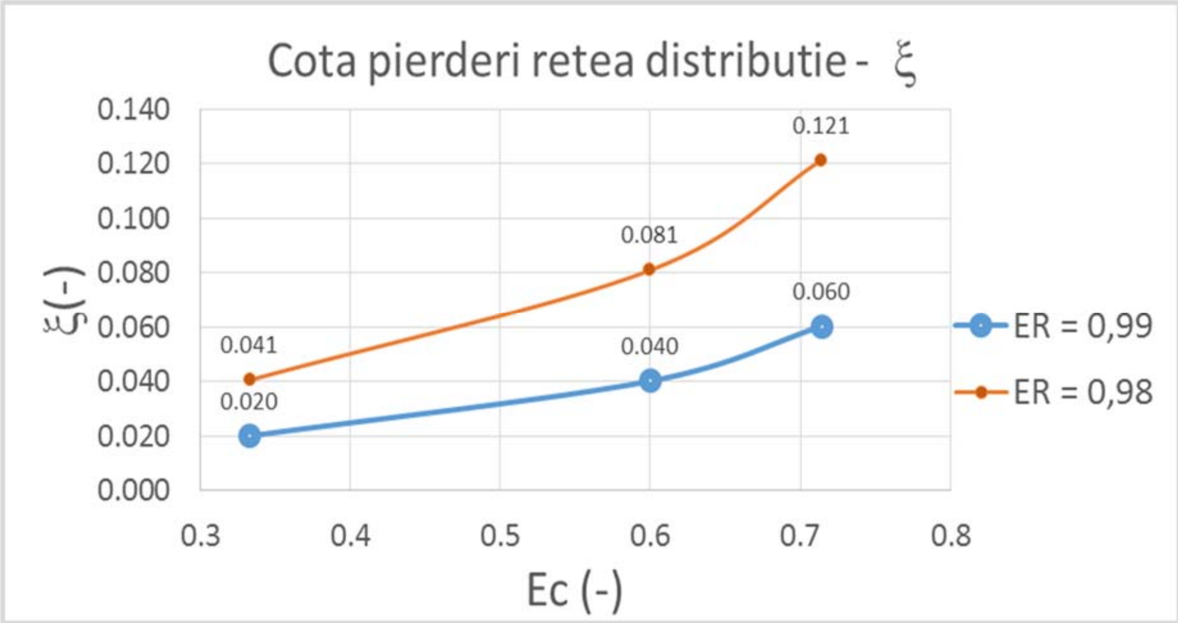

Figura 3 Cota pierderilor reţelei de distributie (ξ) în funcţie de modulul termic aferent instalaţiei de încălzire centrală (E_C) şi de cel aferent reţelei termice de distribuţie (E_R)

Astfel, dacă dimensionarea instalaţiei de încălzire centrală a consumatorului se face pentru setul de temperaturi nominale ale agentului termic 90/70 °C, atunci modului termic al instalaţiei de încălzire centrală este E_C = 0,714, suprafaţa instalaţiei de încălzire fiind mai redusă, iar dacă dimensionarea instalaţiei de încălzire centrală a consumatorului se face pentru setul de temperaturi nominale ale agentului termic 50/30 °C, atunci modului termic al instalaţiei de încălzire centrală este E_C = 0,333, suprafaţa instalaţiei de încălzire fiind sensibil mai mare.

Mai mult, dacă dimensionarea instalaţiei de încălzire centrală a consumatorului se face pentru setul de temperaturi nominale ale agentului termic 90/70 °C, randamentul sistemului de încălzire districtuală este de circa 89%, iar cota de pierderi termice aferente reţelei termice de distribuţie este de 12%, iar dacă dimensionarea instalaţiei de încălzire centrală a consumatorului se face pentru setul de temperaturi nominale ale agentului termic 50/30 °C, randamentul sistemului de încălzire districtuală este de circa 96%, iar cota de pierderi termice aferente reţelei termice de distribuţie este de 4%, acest lucru fiind valabil în cazul în care modulul termic al reţelei termice este E_R = 0,98.

Fluxul termic pierdut în reţeaua de distribuţie se poate scrie ca fiind:

$$\Phi_P = \xi \cdot \Phi_C \quad (7)$$

Deci în cele 3 variante de dimensionare a suprafeţei de încălzire aferente consumatorului (90/70 – varianta 1; 70/50 – varianta 2; 50/30 – varianta 3) vom avea:

$$\begin{aligned}\Phi_{P1} &= \xi_1 \cdot \Phi_C \\ \Phi_{P2} &= \xi_2 \cdot \Phi_C \\ \Phi_{P3} &= \xi_3 \cdot \Phi_C\end{aligned} \tag{8}$$

Reducerile de fluxuri termice pierdute în reţeaua de distribuţie aferente variantelor 2 şi 3 vor fi :

$$\begin{aligned}\Delta\Phi_{P12} &= (\xi_1 - \xi_2)\cdot\Phi_C = (\xi_1 - \xi_2)\cdot H\cdot(t_{i0} - t_e) \\ \Delta\Phi_{P13} &= (\xi_1 - \xi_3)\cdot\Phi_C = (\xi_1 - \xi_3)\cdot H\cdot(t_{i0} - t_e)\end{aligned} \tag{9}$$

Economiile energetice pe toată perioada sezonului rece se calculează ca fiind:

$$\begin{aligned}\Delta Q_{P12} &= \int \Delta\Phi_{P12}\cdot d\tau = (\xi_1 - \xi_2)\cdot H\cdot\int(t_{i0} - t_e)\cdot d\tau \\ \Delta Q_{P13} &= \int \Delta\Phi_{P13}\cdot d\tau = (\xi_1 - \xi_3)\cdot H\cdot\int(t_{i0} - t_e)\cdot d\tau\end{aligned} \tag{10}$$

Sau practic în kWh:

$$\begin{aligned}\Delta Q_{P12} &= 0.024\cdot(\xi_1 - \xi_2)\cdot H\cdot\sum_j (t_{i0} - t_{ej})\cdot Nz_j \\ \Delta Q_{P13} &= 0.024\cdot(\xi_1 - \xi_3)\cdot H\cdot\sum_j (t_{i0} - t_{ej})\cdot Nz_j\end{aligned} \tag{11}$$

Considerând un consumator caracterizat prin H = 1 W/K şi un sezon de încălzire caracterizat prin valorile din tabelul de mai jos, se obţin următoarele economii:

Tabelul 2

Economii obţinute prin reducerea temperaturii nominale a agentului termic

ti (oC)	te (oC)	Nz (zi)	Q (kWh)	Qp1	Qp2	Qp3	Qp1-Qp2	Econom	Qp1-Qp3	Econom
20	-15	2	1.68							
20	-10	11	7.92							
20	-5	32	19.20							
20	0	60	28.80							
20	5	53	19.08							
20	10	24	5.76							
			82.44	9.893	6.595	3.298	3.298	**0.330**	6.595	**0.660**
				kWh	kWh	kWh	kWh	**euro**	kWh	**euro**

Pe parte de pierderi de caldura in reteaua termica, pentru H = 1 W/K, s-a estimat un consum anual de 82,44 kWh/an. La acest consum anual de energie termica s-a evaluat o pierdere pe reteaua termica de 12% din acest consum, adica 9,893 kWh/an in varianta 1, 6,595 kWh/an in varianta 2 si 3,298 kWh/an in varianta 3, ceea ce conduce la o economie de 3,298 kWh/an si 0,33 euro/an intre variantele 2 si 1 si respectiv 6,595 kWh/an si 0,66 euro/an intre variantele 3 si 1.

Pe parte de costuri de investitie, pentru H = 1 W/K, s-a estimat o suprafata de incalzire de 0,083 m^2 in varianta 1, de 0,125 m^2 in varianta 2 si de 0,25 m^2 in varianta 3, adica surplusurile de suprafata de incalzire de 0,042 m^2 intre variantele 2 si 1 si de 0,167 m^2 intre variantele 3 si 1. Diferenta de 0,042 m^2 costa 0.042*30=1,25 euro, care se recupereaza in 1,25/0,33 =3,791 ani iar surplusul de 0,167 m2 costa 0,167*30=5 euro, care se recupereaza in 5/0,66=7,58 ani

Valoarea este rezultată în urma unui calcul static, însă dacă se apelează la un calcul dinamic prin intermediul valorii nete actualizate (VNA), vor rezulta durate de recuperare a investiţiei mai scăzute.

Tabelul 3

Durata de recuperare a investiţiei în cele trei variante

Varianta	Durata de recuperare (ani)
90/70	0.0
70/50	3.8
50/30	7.6

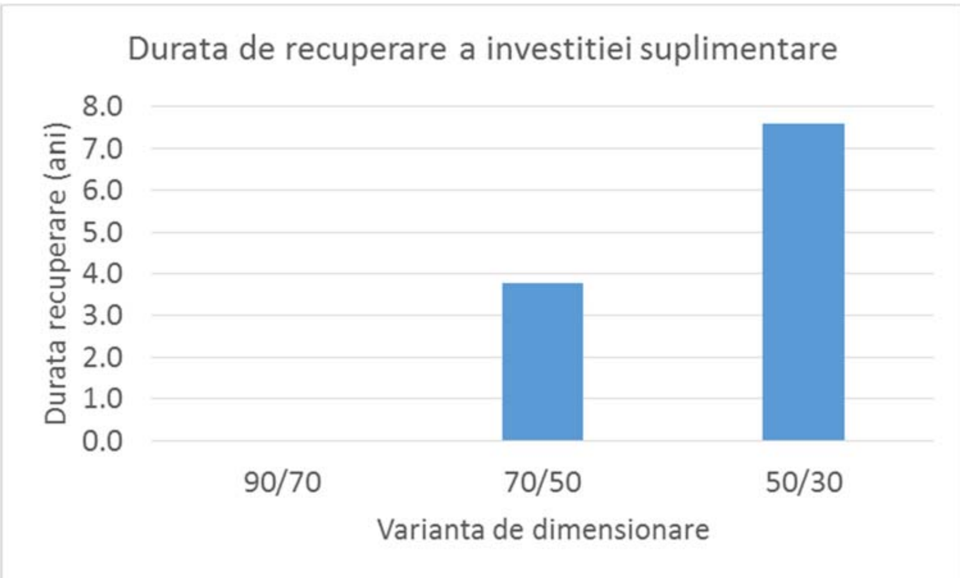

Figura 4 Durata de recuperare a investiţiei suplimentare

În tabelul 3 şi figura 4 se prezintă duratele de recuperare a investiţiilor suplimentare făcute în cazul variantelor 2 şi 3 faţă de varianta 1. Se observă că o varianta de dimensionare foarte bună este varianta 2 (70/50 ^oC), durata de recuperare a investiţiilor suplimentare faţă de varianta 1 fiind de circa 3,8 ani. Dacă se adoptă varianta 3 (50/30 ^oC), durata de recuperare a investiţiilor suplimentare faţă de varianta 1 este de cca. 7,6 ani.

3. Concluzii

Pierderile de cădură ale reţelelor termice de distribuţie reprezintă valori importante de care trebuie să se ţină seama in cadrul efortului de eficientizare a sistemelor de încălzire districtuală.

O variantă foarte bună din punct de vedere energetic, care poate fi abordată pentru dimensionarea instalaţiilor de încălzire centrală, este reprezentată de setul de temperaturi nominale t_{T0}/t_{R0} = 70/50 ^oC. Investiţia suplimentară în suprafaţa instalaţiei de încălzire se recuperează destul de repede, în circa 3,5-4,0 ani. Considerăm că reducerea şi mai accentuată a temperaturilor nominale ale agentului termic poate continua până la setul de temperaturi nominale t_{T0}/t_{R0} = 60/40 ^oC. Sub aceste valori de temperatură se intră in domeniul încălzirii de joasă temperatură de pardoseală sau de plafon.

Lista de notaţii

t_{i0} – temperatura interioară nominală, ^oC;
t_{e0} – temperatura exterioară nominală, ^oC;
t_{T0} – temperatura nominală a agentului termic pe conducta de tur, ^oC;
t_{R0} – temperatura nominală a agentului termic pe conducta de retur, ^oC;
t_{m0} – temperatura medie nominală a agentului termic, ^oC;
H – capacitatea de transfer termic a consumatorului, W/K;
k – coeficientul global de transfer termic al suprafeţei de încălzire, $W/m^2.K$;
S – suprafaţa instalaţiei de încălzire centrală a consumatorului, m^2;
Φ_C – fluxul termic livrat consumatorului, W;
Φ_F – fluxul termic furnizat de sursă sistemului districtual, W;
Φ_P – fluxul termic pierdut de reţeaua termică de distribuţie, W;
Φ_{P1}, Φ_{P2}, Φ_{P3} – fluxurile termice pierdute de reţeaua termică de distribuţie în cele 3 variante de dimensionare a suprafeţei instalaţiei de încălzire centrală, W;
$\Delta\Phi_{P12}$, $\Delta\Phi_{P13}$ – fluxurile termice pierdute de reţeaua termică de distribuţie suplimentar în varianta 1 de dimensionare faţă de varianta 2 şi respectiv faţă de varianta 3 de dimensionare, W;

ΔQ_{P12}, ΔQ_{P13} – energia termică pierdută anual de reţeaua termică de distribuţie suplimentar în varianta 1 de dimensionare faţă de varianta 2 şi respectiv faţă de varianta 3 de dimensionare, kWh;
τ - timpul, s;
N_z – numărul anual de zile de încălzire, zile;
E_C – modulul termic al suprafeţei instalaţiei de încălzire a consumatorului, -;
E_R – modulul termic al reţelei termice de distribuţie, -;
η - randamentul sistemului de încălzire districtuală, -;
ξ - cota pierderilor de energie termică ale reţelei de distribuţie, -;
ξ_1, ξ_2, ξ_3 - cotele pierderilor de energie termică ale reţelei de distribuţie în cele 3 variante de dimensionare a suprafeţei instalaţiei de încălzire a consumatorului, -;
j – indice aferent lunii de încălzire din cadrul sezonului rece al anului, -;

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Performance Evaluation of Plastic Modified Asphalt Enhanced with Recycled Glass Powder

Evaluarea performanței asfaltului plastic modificat îmbunătățit cu pulbere de sticlă reciclată

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Abstract. *This study investigates the use of non-biodegradable wastes namely plastic water bottles and recycled glass in the construction of flexible pavements which, conventionally, uses bitumen as the binder and cement or stone dust as the filler. Consequently, the binder and filler were modified using varying percentages of pulverized plastic and recycled glass powder respectively. The modified binder showed improvement in properties when compared to the unmodified bitumen. The asphalt produced thereafter using the modified materials indicated a stability of 3.33kg obtained at an optimum value of 6% plastic replacement which is higher than the 2.017kg obtained without modifying the bitumen.*

Key words: non-biodegradable, bitumen, pulverized, stability, asphalt

1. Introduction

The construction of highways involves a huge outlay of investment. A precise engineering design may save considerable investment but the selection of improved and better mixes will reliably improve the performance of the in-service highway. The quantum of non-biodegradable waste in municipal solid wastes is increasing due to population increase, industrialization and change of life style, which lead to widespread littering of the landscape [1]. Thus, the disposal of these wastes has become a serious problem globally due to their non-biodegradability and unaesthetic sight. Since these wastes can take several years to degrade, it is of urgent need to look for alternative ways to dispose of them. There are three major ways to deal with this kind of wastes namely burying, incineration and recycling [1].

In a bid to be actively involved in the waste to wealth policies through recycling and transformation of non-degradable waste, the re-introduction of these waste as raw materials can be effective in reducing the consumption of natural resources and in managing the environment [2]. Re-introducing these wastes into construction is an important step in reducing the cost of construction, creating stronger asphaltic concrete for road construction, creating other products like asphalt-based roofing tiles as well as managing the quantity of waste especially the non-biodegradable ones from the environment thus, making it multi-advantageous.

Plastics and polythene do not decompose naturally and they have been found to be environmentally unacceptable due to their negative impacts on the environment, thus, alternative methods have to be implemented to recycle these materials. There have been numerous modifiers that can be used to improve the properties of road surfaces, but most of these had been found to be uneconomical [3]. Use of Low Density Polyethene (LDPE) and waste plastic bottles as modifiers in road surfaces can potentially reduce material wastage and improve the performance of road surfaces. Recycling of waste materials serves important purpose of eliminating an expensive and environmentally unacceptable solid waste disposal problem [3]. At present, researchers have been finding ways of incorporating recycled materials into asphalt pavements instead of disposing off in landfill because of the risks associated with land filling using waste materials as well as disposal problem.

Waste glass is one of the least recycled materials globally as it requires relatively large amount of energy to melt the cullet. Over the last 10 years, the quantity of treated waste glass has risen to about 70% due to improved glass collection systems in developed countries [4]. Notwithstanding, the glass waste recycling infrastructure still suffers from unavailability in developing countries thus an alternative solution is required to solve the problems of glass waste. Being an amorphous material and having relatively high silicon and calcium contents, glass is pozzolanic or even cementitious especially when the finesse of the glass powder is much greater than that of the Portland cement [5].

Hence, this study aims at determining the effectiveness of using recycled glass powder as filler replacement in the production of plastic modified asphalt by comparing the properties of the unmodified asphalt with those of the asphalt modified with recycled glass and plastic. This study provides information about the optimum utilization of these wastes (plastic and recycled glass powder) in the production of enhanced bituminous mix, as well as highlights the potential use of these wastes as large scale modifiers and raw materials for the production of asphalt.

2. Background Literature

The poor performance of bituminous mixtures under increased traffic volume and heavier axle loads has led to increased use and development of modified bitumen especially the use of discarded vehicle tires in pavement construction. Modified binders generally exhibit decreased temperature susceptibility and potentially improved mix performance [6].

Relevant studies considered the improvement in physical and chemical alternative materials as they may enhance efficiency and lifetime of asphalt [1]. A great amount of money is spent on rehabilitation and reconstruction of roads and pavements in most countries every year. One of the major disadvantages of using bitumen in road construction is its phase change as a function of temperature. Bitumen is brittle at low temperatures and turns into liquid at high temperatures, which is called temperature susceptibility. Base bitumen should be modified to reduce its temperature susceptibility hence prompting various researches on ways to enhance the material economically.

Asphalt modification can be made at different stages of its usage from binder production to asphalt pavement production and can be made using different modifiers [7]. Glass is a potentially promising modifier to asphalt as it is a non –metallic and inorganic material made by sintering selected raw materials comprising silicate and other minor oxides. The ratio of its main oxides namely, SiO_2, Na_2O, CaO are: 77%, 9.4% and 6.7% respectively. Glass can be recycled without changing its composition and properties. Because of the availability and wide spread application and increased consumption in our daily lives, a large quantity of this waste is generated annually. The best way to deal with these wastes is to recycle and reuse them as raw material or modifiers,

There are two primary approaches of recycling waste glass, one is direct and the other is indirect. The first process is to manufacture tabulate glass products utilizing worked broken glass particles. This can save 1.1 tonnes of raw materials such as (quartzite gravel and limestone) and 140 liters of heavy oil. The second process is to manufacture products with some glass content, such as clay bricks, filling materials, building decorations, soundproof or adiabatic materials [8].

By crushing and sieving, waste glass can be used as fine aggregate in asphalt concrete. This is called glasphalt. Satisfactory performance of upper asphalt pavement layers can be obtained with a dosage of between 10 and 15% by weight of the asphalt. Larger amounts may induce stripping problems and make the pavement sensitive to water damage [8].

Investigation into the effects of the use of waste plastic as strength modifiers in the surface course of flexible and rigid pavements showed that despite the large number of polymeric products, only a few are compactable with asphalt cements and these compactable ones are thermoplastics, plastomers and reactive polymers [3]. The thermoplastics were able to embed good elastic properties on the modified binders while the plastomers and reactive polymers were added to improve the rigidity and reduce deformation under load. Their tests showed a substantial increase in Marshall

Stability values of the Bituminous Concrete (B.C) Mix in the order of 2 to 3 times higher than B.C with untreated/ modified Bitumen.

Recent research carried out on the performance of asphalt modified with used tires through the wet process deduced that the asphalt produced had improved Marshall stability values, higher resistance to deformation and increased resistance to temperature changes [6].

In the study conducted on utilization of waste plastic fibers as partial replacement of bitumen through the dry process, it was discovered that at 6% by weight of binder plastic fiber replacement, an optimum stability was achieved and an increase in Marshall Stability of the mix was obtained to a tune of 50-60% above that of the unmodified sample [2].

In the process of improving asphalt by modifying it with plastic, it was discovered that the bitumen modified with crumb rubber (CR) and recycled glass powder (RGP) was more flexible than the unmodified material and that the rutting parameters of the samples modified with CR and RGP were about 180% higher than the control sample and about 40% higher than samples modified with CR alone. It was also observed that the mixtures modified with RGP had higher stiffness than the control mixture and the pavement constructed showed less strain at lower temperatures [1].

Similar studies showed that some of the benefits associated with incorporating glass into asphalt include: reduction of cost through utilizing of waste as raw materials, improved asphalt characteristics, pavement surface appears to dry faster than conventional asphalt because glass does not absorb water. The surface showed reflective characteristics which improve night travels, the mix is highly workable when paving and compacting as it retains heat more than conventional asphalt and above all, it helps reduce the volume of waste glass littering the environment [4].

2.1 Asphalt Concrete

This is a composite material commonly used in construction projects such as road surfaces, airports and parking lots. It consists of bitumen (used as a binder) and mineral aggregates which are mixed together, laid down in layers and compacted. Mixing of asphalt and aggregate is accomplished in one of several ways namely hot mix asphalt concrete (considered in this study), warm mix asphalt concrete, cut-back asphalt concrete and cold mix asphalt concrete.

Hot mix asphalt as the name implies is mixed at high temperatures and possesses the following properties: resistance to permanent deformation, resistance to fatigue and reflective cracking, resistance to low temperature (thermal) cracking, durability, resistance to moisture damage (stripping), workability and skid resistance.

3. Methodology and Materials

The materials used for this study are coarse aggregates comprised of crushed rock that cannot pass through sieve No. 4 with an aperture of 4.76mm, fine aggregates comprised of crushed rock aggregates which pass through a 9.51mm (3/8-in.) sieve, pass almost entirely through a 4.76-mm (No. 4) sieve and is predominantly retained on a 74-µm (No. 200) sieve and filler (in this case, stone dust which was selected because of its high use as mineral filler in asphalt production plants in Nigeria) which fills the pore spaces and aids and comprise of any of Portland cement, charcoal, palm kernel ash, kieselguhr (the silicon remains of mollusk shells) and sieved fine crushed rock aggregates with particles passing through sieve No. 200.

Other materials used are:

Bitumen, which is a crude oil derivative having black to dark brown color. It is a semi-solid hydrocarbon product produced by removing the lighter fractions (such as liquid petroleum gas, petrol and diesel) from heavy crude oil during the refining process. As such, it is correctly known as refined bitumen. At ambient temperatures bitumen is a stable, semi-solid substance. By increasing the temperature of bitumen, it turns into plastic and liquid material. In North America, bitumen is commonly known as “asphalt cement” or “asphalt” while elsewhere, “asphalt” is the term used for a mixture of small stones, sand, filler and bitumen, which is used as road paving material.

Glass Powder which was obtained as a result of grinding waste glass bottles obtained from refuse dumps into smaller particles with size 0.075mm which pass through sieve No 200. Plate 1 shows a sample of the recycled glass powder used in this study.

Plate 1. Sample of the recycled glass powder used in the study

Plastic, which is typically a synthetic polymer, most commonly derived from petrochemicals. They can be molded into shape while soft, and then set into a rigid or slightly elastic form. Due to their adhesive properties, they can be utilized in the production of asphalt by shredding or blending them. In this study, pulverized Polyethylene Terephthalate (PET) plastic, as shown in plate 2, was used as plastic modifier.

Plate 2. Sample of the pulverized PET plastic

The selected aggregates were air dried to remove moisture from them, the air drying was preferred to the oven drying because loss of material quality was avoided. The mix design method used for producing the asphalt is the recipe method and it was found to be in compliance with standard requirements [9]. The plastic additive can be introduced into the mix using two methods namely the dry process and the wet process. The wet process was adopted in this study in which the plastic was first shredded and further ground into granular form and introduced directly into the binder at the temperature of 25°C. The pulverized plastic quantities used can be measured as a fraction of total weight of sample of asphalt or as a fraction of the measured weight of binder. The pulverized PET was added in proportions of 2%, 4%, 6%, 8%, 10% by weight of the binder used.

The temperature of the mixing tray was increased to 50°C in preparation for the asphalt production. The accurately weighed aggregates and filler types were poured into the tray and heated to a temperature of 130°C by the heat source. During the heating, the aggregates were mixed thoroughly using the stirrer for 20 minutes. After the mixing, the bitumen which had already been measured, pre-heated to 45°C and modified with the plastic was poured on the heated aggregate and filler. The mixture was stirred thoroughly for 7 minutes so as to get an even distribution of binder. During the mixing, care was taken not to exceed the 160°C temperature so that the binding characteristic of plastic as well as the bitumen did not evaporate.

In carrying out the asphalt compaction, the base plate, the Marshall molds, as well as the full assembly for the compaction were cleaned thoroughly and then all movable joints screwed in properly. The base plate and the asphalt mold were conditioned to 20^{o}C temperature in order to prepare it for the hot asphalt which was compacted. The hot mix asphalt was placed into the assembled mold using the spatula and care was taken not to spill any quantity during this operation. After the placing in the mold, a 7.5kg Marshall Hammer was used to compact the sample by applying 50 blows falling from a height of 45cm freely to each sides of the asphalt sample. At the end of the compaction, the samples were taken to the asphalt extruder so as to remove the samples from the Marshall molds. After the removal, the height and weight of each sample was recorded and the samples were left to cure in air for 24 hours as shown in plate 3.

Plate 3. Air curing of the asphalt samples

The water bath was heated to a constant temperature of 60^{o}C, then the air cured samples were placed into the water bath for 45 minutes thus raising the temperature of the already compacted and cured asphalt. During the heating up process, the Marshall stability testing machine was set up for the tests. It was ensured that the time of removal of samples from the water bath to the period of which the sample failed on the Marshall Stability testing machine did not exceed 30 seconds.

The Marshall stability of the asphalt concrete was determined next according to standard specifications [10]. Before testing of the asphalt samples, they were conditioned in the water bath having a temperature of 60^{o}C for half an hour. The specimen was brought to the desired temperature by immersing them in the water bath. The specimens were removed from the water bath, dried and carefully placed in the lower testing head. The complete assembly was placed in position on the testing machine. The dial micrometer was placed in position over one of the guide rods and the flow meter reading was adjusted to zero. The flow meter was firmly held against the upper segment of the breaking head. The load was applied on the specimen by means of constant rate of movement of the load jack or testing machine head at 50cm per minute until the maximum was reached and the load decreased as indicated by the dial. The indicated flow value was recorded in terms of 0.25mm (one hundredth of an inch) of the micrometer dial used. The elapsed time for the test from removal of the specimen from the water bath to the maximum load determination did not exceed 30 seconds. The average stability which is the resistance to flow was then determined using equation 1.

$$\text{Average Stability} = \frac{stability(a) + stability(b) + stability(c)}{3} \qquad (1)$$

4. Discussion of Results

The Marshall stability test was conducted to measure the resistance to plastic flow of cylindrical specimens of bituminous paving mixtures when tested in a Marshal loading frame. The specimens were tested at a speed of 50.8mm/min. The maximum load (stability) and deformation (flow) of the specimens were recorded. Table 1 shows the stability values for the unmodified asphalt and the stone dust asphalt containing varying percentages of plastic.

Table 1

Stability values for the unmodified asphalt and the stone dust-asphalt containing varying percentages of plastic

	Flow	Sample A (KN)	Sample B (KN)	Sample C (KN)	Average Stability
0% P+S. D	2.5	47	38	50	
	5.0	61	42	63	
	7.5	63	50	62	58.33
2% P+S. D	2.5	78	75	65	
	5.0	83	78	70	77.0
	7.5	73	70	68	
4%P+S D	2.5	79	81	71	
	5.0	89	90	74	84.3
	7.5	82	69	79	
6%P+S.D	2.5	89	86	84	
	5.0	110	96	99	101.6
	7.5	82	69	79	
8%P+S D	2.5	59	76	61	
	5.0	71	90	77	79.3
	7.5	62	80	69	
10%P+S. D	2.5				
	5.0	72	66	72	70
	7.5	68	53	64	

Table 2 shows the stability values for the unmodified asphalt and the recycled glass powder-asphalt containing varying percentages of plastic.

Table 2

Stability values for the unmodified asphalt and the recycled glass powder-asphalt containing varying percentages of plastic

	Flow	Sample A (KN)	Sample B (KN)	Sample C (KN)	Average Stability
0%P+RGP	2.5	63	68	60	
	5.0	71	74	70	71.667
	7.5	68	67	74	
2%P+RGP	2.5	79	81	83	
	5.0	87	89	89	88.33
	7.5	90	86	81	
	10	84			
4%P+RGP	2.5	86	80	86	
	5.0	92	94	90	92
	7.5	88	86	82	
6%P+RGP	2.5	94	90	89	
	5.0	100	102	100	100.67
	7.5	88	86	82	
8%P+RGP	2.5	90	94	88	
	5.0	96	100	96	
	7.5	104	107	101	104
	10	98	100	9 2	
10%P+RGP	2.5	96	99	100	
	5.0	100	104	108	
	7.5	107	110	114	110.3
	10	88	86	82	

The stability values of the asphalt were then multiplied with the proving ring factor of 0.03272 to give the final stability values as shown in tables 3 and 4.

Table 3

Stability values for stone dust-asphalt containing varying percentages of plastic (after being multiplied by the proving ring factor)

	FLOW	SAMPLE A	SAMPLE B	SAMPLE C	AVERAGE STABILITY
0% P +S.D	7.5	2.061	1.636	2.356	2.0176
2% P +S.D	5.0	2.7158	2.5522	2.2904	2.5196
4% P +S.D	5.0	2.9121	2.9448	2.4213	2.7594
6% P +S.D	5.0	3.5992	3.1411	3.2393	3.3265
8% P +S.D	5.0	2.3231	2.9448	2.8698	2.7126
10% P +S.D	5.0	2.3558	2.1595	2.3558	2.2904

Table 4

Stability values for recycled glass powder-asphalt containing varying percentages plastic (after being multiplied by the proving ring factor)

	FLOW	SAMPLE A	SAMPLE B	SAMPLE C	AVERAGE STABILITY
0% P +RGP	5.0	2.323	2.4213	2.2904	2.345
2% P +RGP	5.0	2.847	2.912	2.912	2.890
4% P +RGP	7.5	3.010	3.076	2.945	3.010
6% P +RGP	7.5	3.272	3.337	3.305	3.304
8% P +RGP	7.5	3.4028	3.501	3.305	3.403
10% P +RGP	7.5	3.501	3.599	3.730	3.610

Figure 1 shows the graph comparing the stability values of the unmodified asphalt with those of the stone dust-asphalt modified with varying percentages of plastic while figure 2 shows the graph comparing the stability values for the unmodified asphalt with those of the recycled glass powder-asphalt modified with varying percentages of plastic.

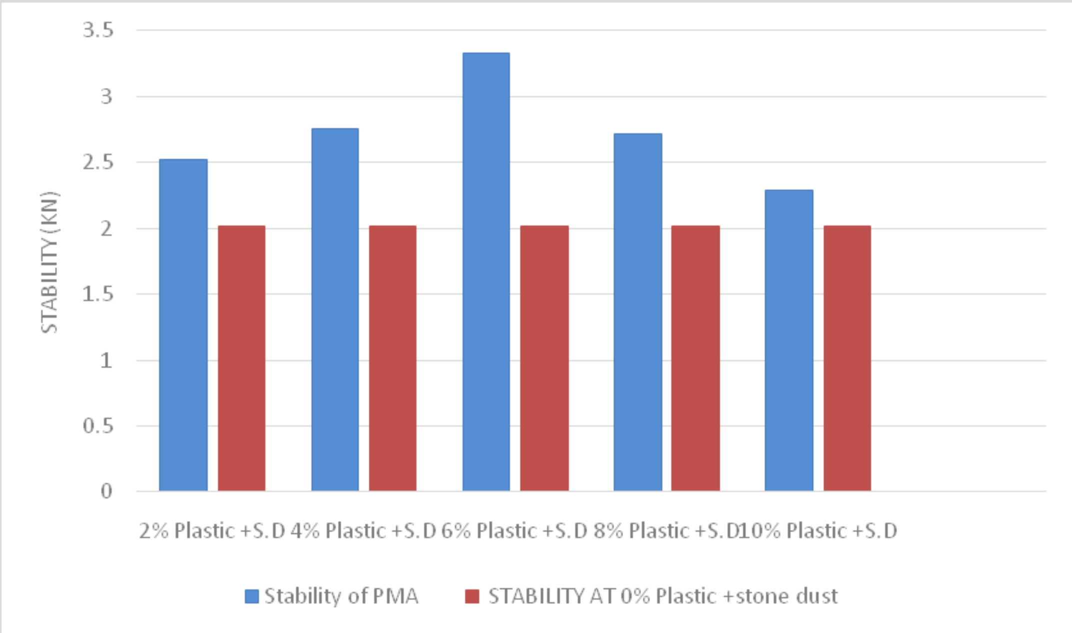

Fig. 1. Graph showing comparison between the stability values for the unmodified asphalt and stone dust-asphalt containing varying percentages of plastic.

Fig. 2. Graph showing comparison between the stability values for the unmodified asphalt and recycled glass powder-asphalt containing varying percentages of plastic.

Figure 3 shows the graph comparing the plastic modified stone dust-asphalt (PMSDA) and plastic modified recycled glass powder-asphalt (PMRGPA)

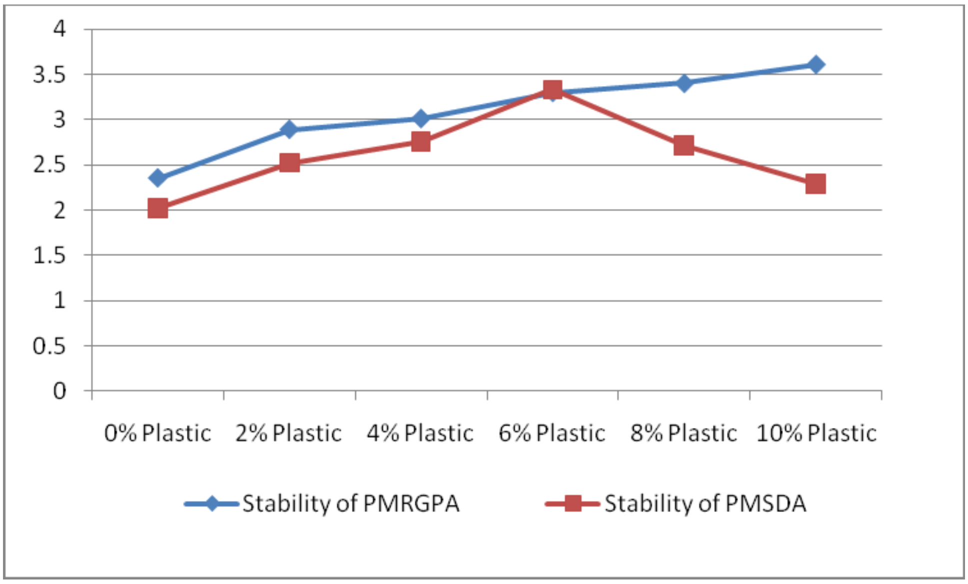

Fig.3. Graph showing comparison between the stone dust-asphalt and recycled glass powder-asphalt with varying percentages of plastic

Tables 1, 2, 3 and 4 show that the introduction of pulverized PET plastic into the stone dust-asphalt and recycled glass powder-asphalt mixes enhanced the adhesive characteristic of the mixes as well as their overall strength in comparison with the unmodified asphalt. The inclusion of recycled glass powder filler also produced an increase in the Marshall stability properties of the asphalt as shown in figure 2 thus, re-emphasizing the effect of the cementitious nature of glass powder when blended to ultra-fine sizes. The optimum strength for plastic modified stone dust-asphalt (PMSDA) was reached at the inclusion of 6% PET plastic whereas further addition of plastic i.e. 8% and 10% led to a decline in strength because the bituminous mix showed more plastic characteristics. On the other hand, the plastic modified recycled glass powdered asphalt continued to show increasing strength up to 10% plastic inclusion.

6. Conclusion and Recommendations

Based on the results of the study, it was concluded that modification process of asphalt using the wastes identified are very effective in controlling the menace of non-biodegradable wastes which pollute the environment. The stone dust-asphalt mix into which plastic is introduced in powder form at 2%, 4%, 6%, 8% and 10% by weight of bitumen showed improved stability compared to the unmodified asphalt. The optimum stability for the plastic modified stone dust-asphalt (PMSDA) was achieved at 6% plastic content and the addition of more plastic fibers thereafter led to a sharp decline in stability due to the asphalt being plasticized. Lastly, the optimum stability for the plastic modified recycled glass powder-asphalt (PMRGPA) was not reached even at 10% plastic content addition thus showing the wider possibilities of increase in the Marshall stability of the mix on the addition of higher plastic content into the mix. Hence the following are recommended:

- The use of pulverized PET plastic waste in asphalt concrete mixture is recommended to the general construction industry because it helps in improving the strength / stability of the asphaltic concrete as shown in this study.
- The use of pulverized waste plastics and recycled Glass Powder in asphaltic concrete should be encouraged to help to tackle the menace of improper disposal of these non-bio degradable municipal solid wastes in the environment.
- Proper sensitization on how to dispose waste and proper collection of non-biodegradable wastes should be set up by the government as well as individuals so that these wastes will be easily sorted out and made accessible for use by asphalt manufacturing companies and other companies which draw value from waste.

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Methane emissions and global methane budget

Emisiile de metan și bugetul global de metan

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DOI:10.37789/rjce.2020.11.3.3

Abstract: *The levels of greenhouse gases in the atmosphere are increasing since the industrial revolution. The main cause is associated to anthropogenic activities. Contrarily to what has been observed to atmospheric carbon dioxide levels, the evolution of the atmospheric methane concentration is still not fully understood. A relative stagnation of the methane concentration was observed from 2000 to 2006. After that, the levels of methane continue to increase. The global methane budget is assessed using two different approaches. It is verified the existence of inconsistencies between the results obtained from them. A better understanding of the methane cycle is needed to reduce the discrepancy and uncertainties associated to the methane sources and sinks and its quantification. This would allow a more reliable image of future scenarios.*

Keywords: *Methane emissions, Methane cycle, Methane budget*

Rezumat: *Nivelurile de gaze cu efect de seră din atmosferă sunt în creștere de la revoluția industrială. Cauza principală este asociată activităților antropice.*
Contrar celor observate la nivelurile de dioxid de carbon atmosferice, evoluția concentrației de metan atmosferic nu este încă înțeleasă pe deplin. S-a observat o stagnare relativă a concentrației de metan din 2000 până în 2006. După aceea, nivelurile de metan continuă să crească. Bugetul global al metanului este evaluat folosind două abordări diferite. Se verifică existența unor inconsistențe între rezultatele obținute din acestea. O mai bună înțelegere a ciclului metanului este necesară pentru a reduce discrepanța și incertitudinile asociate cu sursele și rezervele de metan și cuantificarea acestuia. Aceasta ar permite o imagine mai fiabilă a scenariilor viitoare

Cuvinte cheie: *emisiile de metan, ciclul metanului, bugetul metanului.*

1. Introduction

The majority of climate scientists (97%) agree that the primary cause of climate change, since the beginning of the industrial revolution, is due to human activities (anthropogenic activities) [1]. These activities are generally associated with the over-exploitation of ecosystem services and natural resources, for the sake of satisfying the excessive demand of goods and services. These actions lead to environmental degradation and the emission of greenhouse gases to the atmosphere. Today, we listen a lot about the increase in carbon dioxide (CO_2) levels in our atmosphere/ However, this is not the only greenhouse gas that is increasing.

More powerful greenhouse gases (i.e., with higher global warming potential) like methane (CH_4) and nitrousoxide (N_2O) are also increasing. The atmospheric methane concentration varied during the time, rising from an estimated of 375 ppb 21000 years ago [2], to 772 +- 25 ppb before the industrial revolution. At that time, the methane production by the wetlands contributed to 70% of its total atmospheric level. After the year 2000 is considered that 50 - 70% of the total atmospheric methane is produced by anthropogenic activities [3].

Anthropogenic methane, mainly resultant from the extraction and use of fossil fuels, entered in the methane cycle after that period. Between 2000 and 2006, the levels of methane in the atmosphere stayed relatively constant. Some authors suggest that this plateau in atmospheric methane levels may be related to an increase in hydroxyl radical (•OH) concentration, the main sink of methane, in the atmosphere. However, from 2006 up to now, measurements have shown the rise of the atmospheric methane levels. Studies suggest that the increase in methane levels may be related with an increase in fossil fuel emissions [4] and with the expansion of tropical wetlands as well as the intensification of agricultural activity after 2006 [5]. The increase in the atmospheric methane levels has also contributed around 17% of the radiative forcing from well-mixed greenhouse gases since 1750 [2]. However, contrarily to the carbon dioxide case, the exact drivers of the global methane concentration growth are still debated [6]. The carbon dioxide cycle is already well known. On the other hand, the full picture of the methane cycle is still not completely understood. A better comprehension of the sources and mechanisms which increase the concentrations of methane in the atmosphere translates in a better comprehension of the methane cycle, which in turn is fundamental to reduce the uncertainties in the global methane budget, allowing to trace more plausible scenarios of methane future emissions.

2. The greenhouse effect and radiative forcing

Since the last seventy decades, greenhouse gases (GHGs) start to become more famous due to the global warming discussion. The most well-known greenhouse gases are the carbon dioxide, methane, nitrous oxide, ozone, and water vapor. The molecular structure of these gases allows them to vibrate at different frequencies within the infrared (IR) spectrum. Therefore, these gases are allowed to interact with infrared radiation, i.e., they will absorb and emit this type of radiation. It is fundamental to have these gases in the atmosphere (troposphere and stratosphere).

Without them, the planet would be colder [7] (average surface temperature of 255 K) and would not have the ozone protective layer against ultra-violate radiation. The radiation emitted by the Sun is the main contributor to the warming of the planet. The presence of greenhouse gases in the atmosphere is another factor that contributes to warm the planet. These interact with the infrared radiation emitted by the Earth's surface. Part of that radiation goes to space, while another part is absorbed and re-emitted by the greenhouse gases back to the Earth. This fraction warms the planet.

This effect is called the greenhouse effect (GHE), which was firstly proposed in 1824 by Joseph Fourier. The presence of the greenhouse gases at the atmosphere, establishes an energetic imbalance since the energy flux entering the planet is higher than the energy flux leaving it. This difference is called radiative forcing and is, typically, given in units of Wm^{-2}. This quantity may be positive or negative depending if the energetic flux entering is higher or lower compared to the energetic flux leaving the planet, respectively. Greenhouse gases are considered a climate forcing factor (climate driver) since they influence this balance, and so Earth's climate. The climate forcing factors can have a natural or anthropogenic origin. Natural climate forcing factors are, for example, the variations in Sun's energy output, variations in the Earth's orbital parameters (Milankovitch cycles), emission of particles to the atmosphere resulting from volcanic eruptions. Anthropogenic ones are like the emissions of greenhouse gases to the atmosphere and land-use change [8].

Like the other greenhouse gases, methane is a colourless and odourless gas that is found in nature, as a product of nature or as a product of human activity. The methane is lighter than air, having a lower density than normal atmospheric gases. In the following points some facts about the methane are given:

- after the carbon dioxide (60%), methane is the second main responsible for global warming (17%) [9];
- it has a smaller lifetime (time it takes for a molecule of to be removed from the atmosphere) in the atmosphere (12 years) compared with carbon dioxide (>100 years);
- its concentration in the atmosphere is about 220 times smaller than the concentration of carbon dioxide;
- it has a global warming potential (GWP), i.e., effectiveness in absorbing infrared radiation, about 28 times higher than carbon dioxide an in an interval of time of 100 years [10].

3. Methane cycle

Knowing what are the sources and sinks of methane is fundamental to compute the methane budget, try to understand what was the leading cause of the increase of the methane levels in the atmosphere since 2005, as also as to make predictions about possible future scenarios.

3.1 Methane sources

As for the carbon dioxide greenhouse gas, methane production may result from natural or anthropogenic processes. Natural sources of methane are wetlands, or other inland water systems, offshore and onshore geological sources, biomass and biofuel burning, termites, wild animals, oceans, and permafrost. The methane is mainly produced through the decomposition of organic matter by bacteria when submitted to proper conditions like in anaerobic environment, specific temperature and pressure, and wet conditions. The quantity and efficiency in producing methane depend on these conditions as well as in the available amount of organic matter. However, recent studies have discovered that methane can also be produced in aerobic environment in a near- ambient condition [11]. Additionally, human activities like agriculture, extraction and use of fossil fuels, livestock, waste storage and incomplete combustion of biomass are some of the main anthropogenic sources of methane.

Contrarily to carbon dioxide production, the main process behind methane comes from biotic processes. These processes are still not yet fully understood. An example is the "ocean methane paradox" [12], that states that the surface of oceanic waters are supersaturated with the greenhouse gas, although most bacteria that can generate the gas can not survive in oxygen-rich surface waters. New evidences suggest the possibility of methane production at well-oxygenated zones, in the sea and lakes, typically close to the water-air interface.

3.2 Methane sinks

Methane can be removed from the atmosphere primarily in two ways. The first and main process to sink the methane from the atmosphere results from the interaction between methane and the hydroxyl radicals. These reactions occur mainly in the troposphere (88%) and much less frequently in the stratosphere (7%) [3]. Depending on the compounds presented in the atmosphere, ozone, water vapour and carbon dioxide may result from secondary reactions triggered by the initial reaction between methane and the hydroxyl radicals. Therefore, the remove of methane from the atmosphere is highly dependent on the hydroxyl radical concentration. If hydroxyl radical concentration is lower/higher the atmospheric methane concentrations will tend to be higher/lower. Some authors suggested that the stagnation observed in atmospheric methane levels were a result of an increase of the hydroxyl radicals levels at the atmosphere [3]. Given the role of the hydroxyl radical in the methane cycle, is fundamental to understand what are the factors which influence its concentration. Various studies affirm that hydroxyl radical concentrations are dependent on the flux of ultraviolet radiation, on the water vapour concentration, as well as nitrous oxide and carbon dioxide emissions. Given the highest ability of the troposphere to remove the methane, its importance as chemical composition, especially the hydroxyl concentration is understandable. The second main sink of methane (5%) are the soils. The methanotrophic bacteria living in the soils can remove methane from the atmosphere by oxidising it, in a process known as "high-affinity methane oxidation", to produce energy. However, the contributions of methane sources and sinks to the computation of the methane budge still have several uncertainties associated, since neither the biotic processes associated to methane production nor the sink in the atmosphere are still not fully understood, what makes the methane cycle assessment a real challenge.

4. Global methane budget

The measurement of the total methane emissions and the concentration in the atmosphere is essential for calculating the global methane budget. A global methane budget is an important component in understanding and quantifying the methane sources and sinks and assessing the concentrations of the gas in the atmosphere. A higher concentration of methane in the atmosphere results in a higher radiative forcing, which results in warming of the climate. A global methane budget is also a powerful tool for designing realistic pathways to mitigate climate change. Studies [3] have tried to quantify the total budget, using different approaches, but because of the uncertainties in the methane formation and emissions, the methods used to assess them had led to different results. The whole processes that influence the methane formation and the sinks are still under debate.

4.1 Measurement approaches

To calculate the global methane budget, the total methane emissions are measured. The measurements are also useful in assessing the reduction potential, by identifying the sources and the amount of greenhouse gases that can be avoided. Methane emissions are measured using two different approaches [13]: top-down and bottom-up and the most common techniques. Both top- down and bottom-up measurements are useful in calculating the total emissions and can be used in assessing from a small-scale individual source to large-scale global assessment, over short timescale or for a total annual. The large-scale global assessments involve the use of models and assumptions, and considers the emissions from all the sources, while small-scale local emissions are calculated from source-specific data and the measurements may not account for all the sources. Top-down techniques are mainly used for large-scale emissions assessment and bottom-up techniques are mainly used for specific local or facility area emissions assessment.

4.2. Methane budget

The global methane budget for year 2008 - 2017, was estimated at 572 Tg CH4/yr (a range between 538–593 taking into account uncertainties) with the top-down approach and at 737 Tg CH4/yr (a range between 538–880 taking into account uncertainties) with the bottom-up approach [3]. The difference in the global methane emissions between the top-down approach and the bottom-up approach is mainly because of the uncertainties in the bottom-up approach, with overestimating emissions from the natural sources. Based on the top-down approach, from the total budget, 60% are attributed to anthropogenic sources mainly from fossil fuels and 40% are attributed to natural sources. However, in the bottom-up approach, the ratio between anthropogenic and natural sources is balanced (50%-50%). The natural emissions are dominated by natural wetlands and other inland water systems. Uncertainties are smaller for anthropogenic sources than to natural sources. One of the largest uncertainties in the assessment of the methane budget is associated with the mechanisms of methane formation from the natural sources, mechanisms which are not yet fully understood. However, the anthropogenic sources have also a grade of uncertainty, for both unintentional and intentional emissions, like leaks from fossil fuel production or agriculture emissions.

Future trends are difficult to anticipate, not only because of the uncertainties in the natural processes of methane, but also because of uncertainties in future trends of human behaviour. The increase in population and the increase in energy and food demand, or the climate change impact like global temperature increase and rising ocean levels can make it much more difficult to predict the upcoming methane levels and concentration in the atmosphere and its future impact on the global methane budget.

5. Final remarks

According to the current assessment, it was noticed that the methane role in climate science is still under many uncertainties and still a lot of gaps are to be filled with future research. Many of the gaps are related to the knowledge of the methane cycle, mainly the methane emissions from different sources and the quantification, and also the methane removal from the atmosphere. This creates further uncertainties for the computation of the global methane budget. To assess the global methane budget, different approaches are used, which can result in different conclusions, dependent on the given situations. A top-down approach is favourable compared to a bottom-up approach when a regional area needs to be assessed. A top-down approach can give a broader view of the methane emissions in the atmosphere and it is based on inversion modelling. Inverse modelling is a reliable technique for temporal and spatial assessment of atmosphere methane emissions [13]. A bottom-up approach is preferable for local assessments, and it is based on estimations and representative samples, which can have a high level of uncertainty. Because of the existence of a knowledge gap in the methane cycle, the assessment of the specific sources or the global methane budget will have discrepancies between the two different approaches. An alternative strategy is the use of a mix approaches, in order to optimize the methane assessment process. Also, a proper assessment of the anthropogenic sources, using a suitable approach, it will be possible to have a better picture of the nature contribution to methane emission in the atmosphere. To have a more exact global methane budget, reducing the uncertainties is a priority. Having a clearer picture of the global budget will show the total methane emission level that cannot be exceeded, in order to keep a balance between the sources and the sinks. Uncertainties can be reduced for both anthropogenic and natural methane sources. Methane emissions from natural gas and oil are equal to 6% of the total greenhouse gas emissions in the energy sector, mainly caused by deliberated or accidentally leaks [14]. Taking into account that natural gas demand and oil demand increased and it is expected to increase further more [15], makes it important to develop a proper mechanism in order to detect and reduce the amount of leaks from the fossil fuel sector which will reduce the uncertainties in the methane emission assessment. The contribution associated to the natural methane sources is related to biotic processes. Uncertainties are high because of the lack of a complete understanding of the natural processes which lead to methane emissions. A better assessment of the aerobic and anaerobic processes in different environments is required.

Also, there are uncertainties in the atmospheric chemistry. The concentration of hydroxyl radicals influences the ability of the atmosphere to reduce the methane levels and the variation of hydroxyl in the lower levels of the atmosphere is not well known.

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Revista Română de Inginerie Civilă, Volumul 11 (2020), Numărul 3

Optimisation techniques of urban water distribution networks

Tehnici de optimizare a rețelelor urbane de distribuție a apei

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DOI:10.37789/rjce.2020.11.3.4

Abstract: *The distribution network is an essential part of all urban water supply systems that requires efficient design and operation, which may be achieved through effective application of optimisation methods. This paper provides a briefly overview of the most approached methods for optimisation of water distribution networks (WDNs) design and operation. The main deterministic and heuristic optimisation techniques are synthesised and described, and several optimisation models in literature, which used these methods for WDN design/rehabilitation and operation are indicated. Finally, the advantages and disadvantages of the optimisation techniques for urban WDNs are presented.*

Keywords: *water distribution, pipe network, optimal design, deterministic methods, heuristic techniques.*

Rezumat: *Rețeaua de distribuție este o parte esențială a tuturor sistemelor urbane de alimen-tare cu apă care necesită o proiectare și funcționare eficientă, se se poate realiza prin aplicarea eficace a metodelor de optimizare. Această lucrare oferă o scurtă prezentare a celor mai abordate metode pentru optimizarea proiectării și funcționării rețelelor de distribuție a apei (RDA). Principalele tehnici de optimizare deterministe și heuristice sunt sintetizate și descrise și sunt indicate mai multe modele de optimizare din literatura de specialitate, care au utilizat aceste metode pentru proiectarea/reabilitarea și funcționarea sistemelor urbane de distribuție a apei. În final, sunt prezentate avantajele și dezavan-tajele tehnicilor de optimizare a RDA urbane.*

Cuvinte cheie: *distribuția apei, rețea de conducte, dimensionare optimală, metode deterministe, tehnici heuristice.*

1. Introduction

Distribution system costs within any water supply scheme may be equal to or greater than 60% of the entire cost of the project [1,2]. These observations highlight the need for an efficient and safe water distribution network (WDN). The reduction of the cost and energy consumption of the WDN can be achieved through its design and operational optimisation. An important stage of network design is to find the optimum network layout which satisfies requirements such as pressure, power consumption and demands at different nodes and also to minimise cost while meeting a performance criterion. The development of WDNs without the use of optimisation provides non-optimal structures, based essentially on the immediate response to the growing water demand of population and industry [1]. These non-optimal structures are translated into non-efficient systems in terms of design and operation. The unpredictability of growing water demand also creates a challenge for optimisation techniques. For these reasons, recourse to the optimisation tools is crucial. For the optimal design of WDNs both steady and transient states must be taken into consideration.

Optimisation problems can be solved using conventional trial and error methods or more effective optimisation methods. However, in WDNs, the optimisation process by trial and error methods can present difficulties due to the complexity of these systems such as multiple pumps, valves and reservoirs, head losses, large variations in pressure values, several demand loads, etc. For this reason, innovative linear [3], non-linear [4, 5] and heuristic [6-11] optimisation algorithms are becoming more widely explored in optimisation processes of the WDNs. In the solution procedure, each algorithm is linked with a hydraulic analysis solver of WDNs to obtain the optimum solution. Consideration of reliability in WDNs also has been drawing increasing attention over the past few years [12, 13].

This paper provides a briefly overview of the most approached methods for optimisation of water distribution networks (WDNs) design and operation. The main deterministic and heuristic optimisation techniques are synthesised and described, and several optimisation models in literature, which used these methods for WDN design/rehabilitation and operation are indicated. Finally, the advantages and disadvantages of the optimisation techniques for urban WDNs are presented.

2. Methods and techniques of optimisation

Due to the complexities in the optimal design of WDNs, many researchers have applied diverse suitable calculation methods to solve the problem. The optimisation methods and techniques can be classified into two main categories: (1) *deterministic* methods, based essentially on the computation of the objective function gradient and/or function evaluations, and (2) *heuristic* techniques, based essentially on exploratory search and natural phenomena or even on artificial intelligence. Heuristic searches that use the heuristic function in a strategic way are referred to as *meta- heuristic* techniques.

2.1 Deterministic methods

The deterministic methods most applied in WDN optimisation comprise linear programming (LP), integer linear programming (ILP), non-linear programming (NLP), integer non-linear programming (INLP), and dynamic programming (DP). Optimisation problems that combine continuous and integer values are referred to as *mixed-integer* programming (MIP). These kinds of algorithms enable finding the exact position of an optimal solution. However, they usually converge to local optimal solutions which may not be the global optimum. In addition, the need of derivative evaluations can, in some cases, complicate the optimisation process.

• *Linear programming* (LP) consists of determining the minimum (ma-ximum) of the linear objective function F with several unknown *decision variables* x_i linked by a system with a number of linear equations and inequations which represent the constraints:

$$\text{subject to: } F = c_1 x_1 + c_2 x_2 + \ldots + c_n x_n \rightarrow \min(\max)$$

$$\begin{array}{l} a_{11} x_1 + a_{12} x_2 + \ldots a_{1n} x_n \leq b_1 \\ a_{21} x_1 + a_{22} x_2 + \ldots a_{2n} x_n \leq b_2 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ a_{m1} x_1 + a_{m2} x_2 + \ldots a_{mn} x_n \leq b_m \\ x_j \geq 0 \text{ ; } j=1,2,\ldots,n \end{array} \qquad (1)$$

where c_j (j = 1,…,n) are the constant coefficients of the objective function; a_{ij} (i = 1,…,m; j = 1,…,n) are the constant coefficients of the constraints; and b_i (i = 1,...,m) are the free terms in the system of constraints.

The most commonly used algorithm for solving the LP model is the *Simplex algorithm* [14], which has been developed in several variants. Mays and Tung [15] recommended strongly the use of the LP method in designing pipe networks. LP works well for pipe sizing problems involving branched networks with one-directional flow. However, Sarbu and Ostafe [3] developed a mathematical model and a numerical procedure based on LP for optimal design of a looped pipe network supplied from one or more sources, according to demand variation operating in a transitory turbulence flow, considering the pipe lengths as decision variables.

- *Non-linear programming* (NLP) is a method of optimising problems that can be described by a non-linear objective function or/and some non-linear constraints. The model of NLP with constraints is defined by equations:

$$\begin{array}{ll} \text{subject to} \qquad & F(X) \rightarrow \min(\max) \\ & \varphi_j(X) \{\geq; =; \leq\} 0;\ j=1,2,\ldots,m \end{array} \qquad (2)$$

Where, the objective function F and the constraints φ_j constitute continuous non-linear functions, and $\mathbf{X}=\{x_1, x_2, \ldots, x_n\}$ is the vector of decision variables with dimension n.

NLP can be classified into *convex programming* and *non-convex program-ming*. The *conditional gradients* method can be used to minimise a non-linear function in a domain in which the minimum of a linear function is obtained without any difficulty and the well-known *Newton-Raphson* method is quite good when the trial solution is close to the optimum but can be quite unreliable for solutions far from the optimum [16].

Different NLP methods, such as the *substitution* and *Lagrange multipliers* methods, or a specific case of NLP such as *quadratic programming* (QP), were detailed by Hillier and Lieberman [17]. The generalised *reduced gradient* (RG) has been used for WDN design [18] and WDN operation [19]. Sarbu and Kalmar [5] developed an improved non-linear optimisation model for looped networks supplied by direct pumping based on NLP. This problem of NLP with equality constraints finally turns into a system of non- linear equations to be solved by the „gradient method“.

- *Dynamic programming* (DP) is a method of optimising a multistage decision process in which a decision is required at each stage. This method is based on Bellman’s optimality principle [20], which, in short, is formulated as follows: “an optimal policy can only be made up of optimal sub-policies.” To solve a DP problem, it is necessary to evaluate both immediate and long-term consequence costs for each possible state at each stage. This evaluation is done through the development of the following recursive functional equation (for minimisation):

$$\min Z = f_{0,i}(X_0, X_i) = \min_{\{X_{i-1}\}}[V_i(X_{i-1}, X_i) + f_{0,i-1}(X_0, X_{i-1})] \tag{3}$$

Where, $V_i(X_{i-1}, X_i)$, (i = 1, 2... N) are the costs attached to each stage; Z is the cost function attached for the set of stages; N is the total number of stages; the terms X_i are vectors with n components $\{x_{1i}, x_{2i}, \ldots x_{ni}\}$; and the notation $\{X_{i-1}\}$ means that X_{i-1} belongs to a values set which depend only on X_0 and X_i.

Because DP works for a series of stages, the only types of design problems it is applicable to are single pipes with multiple withdrawals as described by Liang [21].

2.2 Heuristic techniques

The group of heuristic techniques mainly includes genetic algorithms (GAs), evolutionary algorithms (EAs), and other heuristic algorithms such as differential evolution (DE), cross- entropy (CE), shuffled frog leaping algorithm (SFLA), simulated annealing (SA), tabu search (TS) algorithm, particle swarm optimi- sation (PSO), ant-colony optimisation (ACO), harmony search (HS), etc. Heuristic searches that use the heuristic function in a strategic way are referred to as *meta-heuristic* techniques. These techniques provide the advantages of not requiring derivatives calculations and do not rely on the initial choice of values for the decision variables. Due to the exploratory nature of the heuristic algorithms, the probability of finding global optimal solutions using these advanced techniques is higher than in the case of deterministic methods. The main disadvantage of these techniques is related to the higher computational effort [22].

• *Genetic algorithm* (GA) is a powerful search technique based on the genetic process of biological organisms proposed by Holland [23]. The theory behind GAs was developed in the 1980s by Goldberg [24] and others. Murphy and Simpson [25] were the first to apply a GA on WDNs, followed by Simpson et al. [26].

The use of a GA involves the following five steps:

1. Randomly generate a set of individuals, which is called an *initial population*. Usually, a binary alphabet (characters may be 0 or 1) is used to form chromosomes represented as a binary string.

2. Compute the *fitness function* analogous to the *objective function,* which determines the ability of an individual to compete with other individuals in the initial population. A *penalty coefficient* incorporated in the objective function is activated for an infeasible solution (e.g., pressure violation).

3. Produce a new population using the *reproduction* (crossover) and *mutation* operators. The fittest individuals are selected for reproduction to produce offspring of the next generation.

4. Compute the fitness function of the new solutions.

5. Terminate the algorithm if the population has converged or repeat steps 3 through 5 to produce successive generations.

A GA based multi-objective optimisation tool called "GANetXL" for solving both single and multi-objective optimisation problems was initially developed by Savic et al. [27], and later used by many researchers in the field of water systems [28]. This optimisation tool is an add-on to Microsoft Excel, and it has the provision to link up with a hydraulic simulator such as EPANET [29] for constraint verification. From the family of multi- objective genetic algorithms, GANetXL incorporates the non- dominated sorting genetic algorithm II (NSGA-II) [30]. Creaco et al. [31] performed the optimal design of a new WDS considering two objectives, the construction costs and network reliability, using NSGA-II.

• *Differential evolution* (DE) algorithm was developed by Storn and Price [32] for optimisation problems over continuous domains. DE uses crossover and mutation operators to generate new solutions, but with two main differences compared to GA [8]. Accordingly, DE calculates the mutation size for a randomly selected solution *a*, from the population as described by Yazdi [33]: (1) Two members (say *b* and *c*) are selected randomly from the population;

(2) A multiplicative of "differential vector" is considered as mutation size: $\beta\times(b-c)$ where β is called scaling factor.

Then, a temporary solution is generated by the mutation as: $y=a+\beta\times(b-c)$. After doing mutation, crossover is carried out to generate a new solution $z=\{z_1, z_2,\ldots, z_n\}$ using the solution $x=\{x_1, x_2,\ldots, x_n\}$ of the population and temporary solution $y=\{y_1, y_2,\ldots, y_n\}$ obtained by mutation task.

Recently, Mansouri et al. [34] used DE to optimise the design of a branched WDN.

• *Cross-entropy* (CE) method is an adaptive algorithm based on variance minimisation [35]. CE method involves an iterative procedure in which iterations can be broken down into two phases: (1) generate a random data sample according to a specified mechanism; (2) update the parameters of the random mechanism based on the data to produce a "better" sample in the next iteration. Perelman and Ostfeld [36] applied this method to the optimisation of WDNs.

• *Shuffled frog leaping algorithm* (SFLA), introduced by Eusuff and Lansey [37], is a meta-heuristic technique whose operating principles are similar to other existing evolutionary techniques, which try to find an optimal solution to a problem from the evolution of an initial population. SFLA performs a heuristic search based on the evolution of particles called memes, carried by a number of interacting individuals (frogs) that perform a global exchange of information among the population. Mora-Melia et al. [38] presents a modified SFLA applied to the design of WDNs.

• *Simulated annealing* (SA) is a stochastic technique based on the physical annealing process in a solid material [39]. The SA method was adapted to be applied to the low cost design of WDNs [40]. Costa et al. [41] applied the SA technique for the optimal design of pipe networks including pumps.

• *Particle swarm optimisation* (PSO) is a concept developed by Kennedy and Eberhart [42], which has overcome the limitations of GA. Specifically, the PSO technique maintains a population of *particles*, each of which represents a potential solution to an optimisation problem. In this technique, the co-ordinates of each particle represent the possible solution and after each iteration, the particle moves towards optimal solution [43]. The convergence condition requires setting the move iteration number of the particle. Izquierdo et al. [44] have applied PSO in existing problems and concluded that PSO gives better results as compared to other classical methods like DP.

• *Ant-colony optimisation* (ACO) is a meta-heuristic algorithm based on the analogy of the foraging behaviour of a colony of ants, and their ability to determine the shortest route between their nest and an eating source by means of chemical pheromone (marker) trails [45]. In ACO algorithms, the optimisation search procedure is conducted by the number of artificial ants moving on a graph in the search space. Several special cases of the ACO meta-heuristic have been proposed in the literature such as the ant-system [46]. Ostfeld and Tubaltzev [47] linked an ant-colony scheme with EPANET for the minimisation of the system design and operation costs. Gil et al. [48] evaluated the performances of a new ACO implementation adapted to solve the single-objective constrained non-linear WDN for minimum investment. Much more interesting problem was approached by Abbasi et al. [49] like the design of a water adduction main under transient condition using ACO algorithm.

• *Harmony search* (HS) introduced by Geem and Kim [50] mimics the improvisation of music players. In its basic form, this technique starts by generating a set of random solutions called the harmony memory (HM), in which a predetermined number of harmonies have been stored, and then produces new solutions by sampling either from previously generated solutions in HM or from a random distribution. The best harmony stored in HM is returned as the found optimum solution. Geem and Cho [51] applied HS to the optimisation of WDNs. Baek et al. [52] employed HS to optimise the simulation of hydraulic under abnormal operating conditions in WDNs. The previously described existing meta- heuristic techniques can be divided into three classes [53]: (1) *local search meta-heuristics* (SA, TS) operate on a single complete solution and iteratively improve it by making small adjustments called moves; (2) *population-based meta-heuristics* (GA, DE, CE, SFLA) operate on a set of solutions and find better solutions by combining solutions from that set into new ones; and (3) *constructive meta-heuristics* (PSO, ACO, HS) build a solution by working with a single, unfinished, solution and adding one solution element at a time.

3. Conclusions

In this study, the general optimal WDN design problem was presented and various successful optimisation methods and techniques were reviewed.

The optimisation of pipe networks under steady-state conditions has been studied and different researchers proposed the use of mathematical programming techniques (LP, NLP, and DP) to identify the optimal solution for WDNs. However, these deterministic methods either use some gradient information or require restrictive assumptions such as linearity, convexity, and generally satisfied and they usually converge to local optimal solutions that may not be the global optimum.

Recently, the focus of the research in this area has shifted to the meta-heuristic based optimisation methods like GA, SA, ACO, PSO, SFLA, DE, HS, etc. As meta-heuristic optimisation methods use only the values of the objective function in the search for optimal solutions, a large number of numerical simu-lations are required to reach these solutions. This is time consuming for small problems, but for larger problems it may be the only feasible way, and in that sense the required computational effort is actually the benefit of this approach.

Further research in heuristic optimisation methods should focus on hybrid methods, which combine the specific advantages of different approaches. These studies should also contain the use of hyper-heuristic techniques for optimising WDNs, which are more general and can solve a wider series of problems compared to the current meta-heuristic methods specialised in a narrow class of problems.

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Theoretical analysis of water demand for apartment buildings in Romania, Ukraine and Slovakia

Analiza teoretică a cererii de apă pentru clădirile cu apartamente din România, Ucraina și Slovacia

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DOI:10.37789/rjce.2020.11.3.5

Abstract: *The design of new water supply networks as well as the reconstruction and modernization of the existing water supply networks is highly dependent on the calculated water demand for the urban population and its various needs. The aim of the paper is to make a comparison of urban water needs in Romania, Ukraine and Slovakia, considering different categories of consumption specific to apartment buildings. Using large diameters for the water supply network pipes will cause a decrease of the drinking water velocity, therefore the duration of stay in the water network will increase and chances for worsening the water quality will be higher. On the opposite, using small diameters for pipes will cause an increase of the water velocity, which will increase the head losses in the distribution network, causing significant energy demands for pumping. After presenting the technical legal framework concerning water demand calculation in Ukraine, Slovakia and Romania, a comparison was made for the selected apartment buildings and also for urban green areas watering. From the calculated results of total water demand it can be stated that the difference in water demand for the neighboring areas of Ukraine, Slovakia and Romania is significant.*

Keywords: *comparison; water demand; apartment building; urban green spaces watering.*

Rezumat: *Atât proiectarea noilor rețele de alimentare cu apă, precum și reabilitarea și modernizarea rețelelor existente depind în mare măsură de determinarea cantităților de apă potabilă pentru diversele nevoi ale populației urbane. Scopul lucrării este de a face o comparație între cerința de apă urbană din România, Ucraina și Slovacia, ținând cont de diferitele categorii de consum specifice clădirilor de apartamente. Utilizarea diametrelor mari pentru conductele rețelei de alimentare cu apă va determina scăderea vitezei apei, astfel că durata de stagnare în rețeaua de distribuție va crește și șansele de degradare a calității apei vor fi mai mari. Pe de altă parte, utilizarea unor diametre mai mici pentru conducte va determina o creștere a vitezei apei, ceea ce va duce la creșterea pierderilor de sarcină în rețeaua de distribuție și implicit la creșterea cosumurilor de energie pentru pomparea apei. După prezentarea cadrului legislativ tehnic privind calculul cerinței urbane de apă în Ucraina, Slovacia și România, s-a făcut o comparație pentru clădirile de apartamente selectate, precum și pentru necesarul de apă pentru udarea spațiilor verzi urbane. Analizând rezultatele calculate ale cerinței totale de apă pentru zonele învecinate din Ucraina, Slovacia și România, se poate afirma că diferențele între cantitățile de apă rezultate sunt semnificative.*

Cuvinte cheie: *comparaţie; cerere de apă; clădiri cu apartamente; stropirea spațiilor verzi urbane.*

1. Introduction

During the last decades, human activity has produced unfortunately not only a global climate change, but also a significant reduction of the quantity and quality of drinking water sources. In some areas of the planet there is a large shortage of drinking water supplies [1]. In many countries, water losses in the distribution networks show alarming figures.

According to Roy [2], the US Environmental Protection Agency has recently been asking water companies to provide annual water quality reports to their consumers. Powell & Yurchenko [3] are presenting a dynamic picture of the development of private provision in urban drinking water. Privatisation versus remunicipalisation depend on the power balance configuration of the state, capital and society and it is a political decision.

Both the design of new and the reconstruction of existing water supply networks are based on estimating the drinking water demand. In particular, the value of demand of drinking water by the inhabitants (daily water consumption of the residential sector) and by the workers in industrial enterprises will have a strong influence on the determination of optimal diameters for the water pipes. Recently, Ukrainians are consuming less water than before from water supply networks, due to the increased tariffs for centralized water supply and sewerage. So, the vast majority of the existing water supply networks in Ukraine are designed for higher values of water flow in the pipes, which causes a decrease of the velocity of water, an increase of the duration of stay for water in the network and a deterioration of water quality. The oversized diameters of the pipes in the distribution network are the reason for the deterioration of the hydraulic performance of its functioning [4, 5].

Reduction of water consumption and rational use of water is one of the priority tasks of humanity today. A comparison of the existing norms of drinking water consumption in Ukraine (100-285 l/day per one inhabitant) with the previous ones (125-350 l/day per one inhabitant) indicates a decrease by about 25% [6, 7, 8].

2. Aim

The aim of the paper is to make a comparison of urban water needs in Romania, Ukraine and Slovakia for different categories of consumption specific to apartment buildings.

3. Method

During this research we have compared the legislative requirements in Romania, Ukraine and Slovakia in terms of water needs. Accordingly, a calculation of the water demand for the selected apartment building was carried out. Finally, a comparison was made.

4. Results

4.1 Analysis of legislative requirements

The values of the estimated daily water demand (average per year) for different consumers of the three countries are given in Table 1.

Table 1

Average specific water demand for apartment buildings

Type	Apartment building description	Average specific water demand for apartment buildings per one person (litres/day)		
		Ukraine [6,7]	**Slovak Republic** [9]	**Romania** [10]
1	Apartments that are connected to the public water supply and are equipped with shower	100–110	100	100-120
	Apartments that are connected to the public water supply, are equipped with shower and have gas supply	120–135		
2	Apartments that have local hot water preparation and are equipped with bathtub	150–170	135	
	Apartments that have local hot water preparation and are equipped with bathtub and gas water heaters	210–235		
3	Apartments that have central heating and central hot water preparation and are equipped with bathtub	230–260	145	150-180
	Apartments that have central heating and central hot water preparation and are equipped with a bathtub longer than 1500 mm	250–285		

The daily drinking water demand indicated in Table 1 is in a certain range of values because the territory of Ukraine according to climatic conditions is divided into IV districts [11]. For this paper and further calculations (comparison of Romanian, Ukrainean and Slovak legislative framework), the north-western architectural and construction climatic region of Ukraine (district I) has been selected.

In Slovakia, following the [9], the water demand can be reduced by 25% if consumers live in a building that is not connected to the public sewerage network. For apartments in a building with over- standard sanitary equipment (for example a swimming pool), the water demand is increased by 15%.

The analysis of Table 1 shows that (taking into account the architectural, structural and climatic regionalization of the territory of Ukraine), the daily Ukrainean water demand (averaged per year) is exceeding the Slovakian demand by: up to 35% - for residential buildings with water supply and sewerage without bathtubs; from 11% to 74% - for buildings with local hot water heaters; from 59% to 96.5% - for buildings with central hot water supply.

The Romanian Standard 1343-1/2006 does not take into account the bathroom equipment (showers/bathtubs), therefore only two types of apartments will be considered, based on the hot water preparation mode (local or centralized). In the case of local hot water preparation, Romanian values of the daily water demand are close to Slovakian ones, but in the case of centralized hot water preparation, Romanian values are slightly higher (up to 24%).

Table 2

Estimated water daily demand

Type of consumption	**Water daily demand (liters/(m^2.day))**		
	Ukraine [6]	**Slovakia [9]**	**Romania** [10]
Urban green spaces watering	3 – 6	1	1.5 – 2.5

Table 2 shows that the water daily demand for urban green areas watering is 3 to 6 times bigger in Ukraine than in Slovakia. In Romania, the water daily demand for urban green areas watering (average value) is still 2 times bigger than in Slovakia.

4.2 Theoretical comparison of the selected apartment building

For the comparison it was selected an apartment building with 110 occupants, situated in a town with 95,000 inhabitants.

The average specific water demand was calculated for the three types of apartment buildings. Water consumption for firefighting was not considered in any of these examples.

The first type of apartment building is considering apartments that are connected to the public water supply including apartments with shower and with gas supply.

The second type of apartment building is considering apartments that have local hot water preparation, bathtub and gas water heaters.

The third type of apartment building is considering apartments that have central heating and central hot water preparation and bathtub longer than 1500 mm.

The results of calculating the daily consumption of drinking water for every type of apartment building are shown in Table 3.

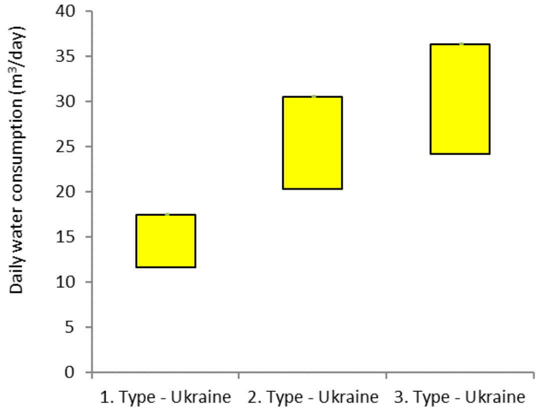
In Slovakia, the average daily water demand for the apartment building of the first type is about 22% lower than in Ukraine, for the second type is about 40% lower than in Ukraine and for the third type is about 46% lower than in Ukraine.

Romania’s values are higher than in Slovakia (for type 2 about 23% higher and for type 3 about 63% higher), but lower than in Ukraine (for type 2 about 26% lower and for type 3 about 12% lower).

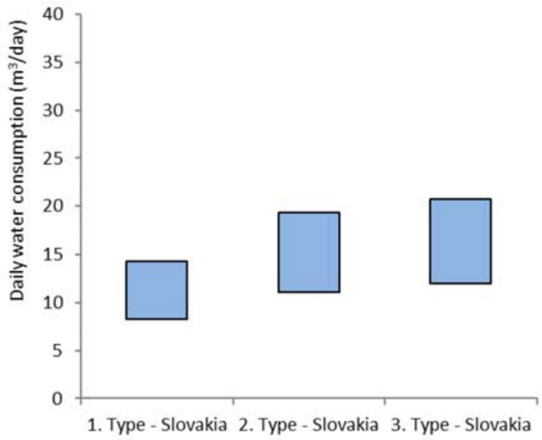
Table 3.

Daily water demand in apartment buildings

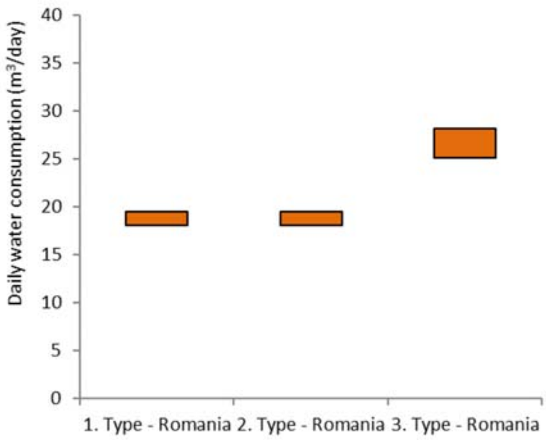
Type of apartment building	**Number of occupants in house**	**Daily water consumption for one occupant (l/(day.pers.)**	**Unaccounted consumption**		**Coefficient of daily non-uniformly consumption**		**Daily water consumption (m^3/day)**		
			%	**γi**	**K_{max}**	**K_{min}**	**Minimum**	**Average**	**Maximum**
Ukraine									
1	110	120	10	1.1	1.2	0.8	11.62	14.52	17.42
2	110	210	10	1.1	1.2	0.8	20.33	25.41	30.49
3	110	250	10	1.1	1.2	0.8	24.20	30.25	36.30
Slovakia									
1	110	100	-	-	1.3	0.75	8.25	11.28	14.30
2	110	135	-	-	1.3	0.75	11.14	15.22	19.31
3	110	145	-	-	1.3	0.75	11.96	16.35	20.74
Romania									
1	110	110	15	1.15	1.4	1.3	18.09	18.79	19.48
2	110	110	15	1.15	1.4	1.3	18.09	18.79	19.48
3	110	165	15	1.15	1.35	1.20	25.05	26.61	28.18



Ukraine



Slovakia



Romania

Figure 1. Comparison of the daily water demand in Ukraine, Slovakia and Romania

Similarly, it was calculated the daily demand for watering the urban green spaces in Ukraine, Slovakia and Romania according to the legislative framework. The green area considered was 5000 m^2. The results are presented in Table 4.

Table 4.

Daily water demand for watering the urban green spaces

Type of consumption	**Watering area (ha)**	**Water demand (l/m^2)**	**Number of watering during the day (-)**	**Daily water demand for watering (m^3/day)**		
				Minimum	**Average**	**Maximum**
Ukraine						
Urban green spaces watering	0.5	3	1	0	15	15
Slovakia						
Urban green spaces watering	0.5	1	1	0	5	5
Romania						
Urban green spaces watering	0.5	1.5 - 2.5	1	7.5	10	12.5

In Slovakia, the average daily water demand for watering of urban green areas is about 67% lower than in Ukraine. In Romania, the average daily water demand for watering of urban green areas is about 33% lower than in Ukraine.

The total daily water demand from water supply networks for apartment buildings of third type (including watering of 5000 m^2 green area around this building) is shown in Table 5.

Table 5.

Total daily water demand for the third type of apartment building

Type of consumption	**Total daily water demand (m^3/day)**		
	Minimum	**Average**	**Maximum**
Ukraine			
Type 3 apartment building	24.20	30.25	36.30
Watering of urban green areas	0.00	15.00	15.00
Total:	24.20	45.25	51.30
Slovakia			
Type 3 apartment building	11.96	16.35	20.74
Watering of urban green areas	0.00	5.00	5.00
Total:	11.96	21.35	25.74
Romania			
Type 3 apartment building	25.05	26.61	28.18
Watering of urban green areas	7.50	10.00	12.50
Total:	32.55	36.61	40.68

In our case, the average water demand for watering of green areas is about 1/3 of the average total water requirement in Ukraine, 23.4% in Slovakia, respectively 27.3% in Romania. For a better representation of water needs for all three countries, data are presented in Figure 2, where we can see that for this selected apartment building, the maximum water demand in Slovakia is about the same as the minimum water demand in Ukraine. Romania's average total water demand is about the same as in Ukraine, but the amplitude between minimum and maximum values is much smaller than in Ukraine.

From the calculated results of total water demand shown in Figure 2 and map in Figure 3, it can be stated that the difference in water demand for neighboring areas of Ukraine, Slovakia and Romania is significant and perhaps unjustified.

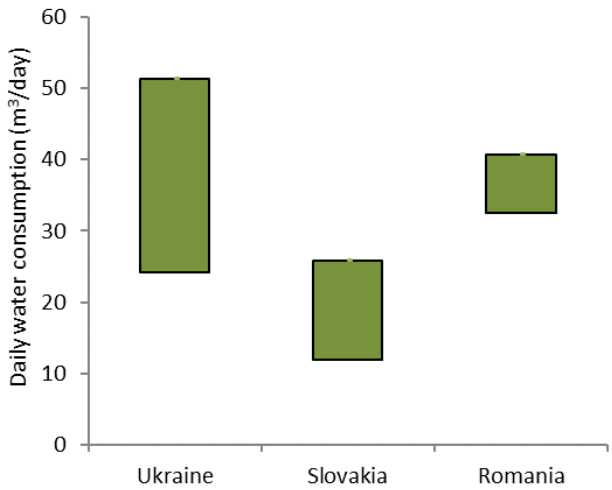


Figure 2. Comparison of the total average daily water demand in Ukraine, Slovakia and Romania

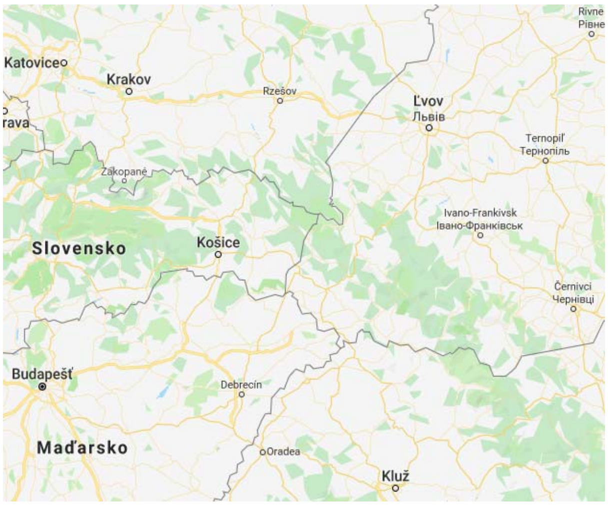


Figure 3. Neighboring countries Ukraine, Slovakia and Romania on the map
(Source: www.google.com/maps)

5. Conclusions

From the analysis of drinking water demand in Ukraine, Slovakia and Romania we noticed important differences between Ukraine and Slovakia. For the selected apartment building with 110 occupants, situated in a town with 95,000 inhabitants, in the case of Type 3 apartments (central heating and central hot water preparation and bathtub longer than 1500 mm), the average daily water demand in Slovakia was about 46% lower than in Ukraine. The average water demand for watering of green areas is about 1/3 of the average total water requirement in Ukraine, 23.4% in Slovakia, respectively 27.3% in Romania. The maximum water demand in Slovakia is about the same as the minimum water demand in Ukraine. Romania's average total water demand is about the same as in Ukraine, but the amplitude between minimum and maximum values is much smaller than in Ukraine.

From the calculated results of water demand it can be stated that the difference in water demand for neighboring areas of Ukraine, Slovakia and Romania is significant. From a practical point of view, the reduction of water consumption standards in Ukraine will reduce the diameters of water supply networks and, consequently, substantially reduce the amount of pipe materials necessary for water supply systems and save raw materials and energy resources.

Acknowledgements *This article was elaborated in the framework of the project VEGA 1/0697/17.*

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Revista Română de Inginerie Civilă, Volumul 11 (2020), Numărul 3

Performance Assessment of Selected Intersections in Akure, Nigeria

Evaluarea performanței intersecțiilor selectate în Akure, Nigeria

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DOI:10.37789/rjce.2020.11.3.6

Abstract. *This study assesses the performance of selected intersections in Akure, Nigeria. The identified intersections were Road block, Bye-pass and Cathedral intersections. Data for this study which included traffic volumes was collected through semi-automatic method, personal observations and questioning of individuals. The results of the data analysis revealed that the Level of Service (LOS) for Road block intersection was critically low (LOS = F) due to on-street parking and the absence of traffic signals to aid drivers. Likewise, the LOS for Cathedral intersection is low (LOS = E) while that of Bye-pass (LOS = C) appears to be adequate.*

Key words: Intersections, traffic volumes, semi-automatic, level of service

1. Introduction

Transportation can be defined as a process that involves the movement of commuters, goods and services from a given point of origin to a specific destination. However, transportation plays a major role in urban development and on city growth [1]. Transportation route is part of distinct development pattern or road network and mostly described by regular street patterns as an indispensable factor of human existence, development and civilization [2].

The major challenge of traffic on a roadway is traffic congestion; virtually every state capital city in Nigeria today faces the problem of traffic congestion [3]. In Akure city that was not previously associated with traffic congestion is now facing considerable traffic congestion on many of its urban roads, particularly when schools are in session. Although, a lot of research has been conducted on traffic congestion and delays in Nigeria, most of these studies concentrate on specific cities such as Lagos [4],[5] and Ilorin [6]; traffic problems surface when cities expand without control due to increase in population from rural to urban centres.

Traffic congestion occurs when a city's road network is unable to accommodate the volume of traffic that uses it. This situation is caused by rapid growth in motorization and with less than corresponding improvement in the road network, traffic management techniques and related transport facilities. Thus, traffic congestion is a phenomenon that is associated with urban environment all over the world. This is because we need transport to move from one place to another, especially when trekking becomes inefficient. While traffic congestion has been managed very well in some developed countries, it has continued to defy solutions in the developing world.

In this study, the selected intersections are assessed to determine their levels of performance by carrying out the following: traffic count at the intersections to determine the traffic volumes on each leg, determining the levels of service of the intersections as well as each leg that meets at the intersection and determine appropriate measures to improve on the performance of the intersections.

2. Background Literature

Traffic congestion occurs when a volume of traffic or modal split generates demand for space greater than the available road capacity; this point is commonly termed saturation. There are a number of specific circumstances which cause or aggravate congestion; most of them reduce the capacity of a road at a given point or over a certain length, or increase the number of vehicles required for a given volume of people or goods. About half of U.S. traffic congestion is recurring, and is attributed to sheer weight of traffic; most of the rest is attributed to traffic incidents, road work and weather events [7]. Traffic research still cannot fully predict under which conditions a "traffic jam" (as opposed to heavy, but smoothly flowing traffic) may suddenly occur. It has been found that individual incidents (such as accidents or even a single car braking heavily in a previously smooth flow) may cause ripple effects (a cascading failure) which then spread out and create a sustained traffic jam when, otherwise, normal flow might have continued for some time longer.

Congestion can be reduced by either increasing road capacity (supply), or by reducing traffic (demand). Capacity can be increased in a number of ways, but needs to take account of latent demand otherwise it may be used more strongly than anticipated. Critics of the approach of adding capacity have compared it to "fighting obesity by letting out your belt" (inducing demand that did not exist before). For example, when new lanes are created, households with a second car that used to be parked most of the time may begin to use this second car for commuting. Reducing road capacity has in turn been attacked as removing free choice as well as increasing travel costs and times, placing an especially high burden on the low income residents who must commute to work.

Incidentally, many urban centers in Nigeria suffer from inadequate facilities that could ensure smooth urban movement. This is because the rapid growth of cities anywhere in the world has impact not only for the land use but also for the spatial expansion. For example, the commuting distance of Lagos increased from 20km in 1970 to 35km in 1995 while that of Kaduna increased from 6km to 10km during the same period [8]. In Akure, the commuting distance increased from 5.2km in 1966 to 6.4km in 1976, 10.5km in 1986, 13km in 1996 and 19km in 2006 [9]. The increase in commuting distance has impact on trip attraction, fares paid by commuters and traffic build-up in some land use areas. It also shows the need for different modes of transportation. Thus, a number of factors have been found to influence trip generation, attraction and distribution in any urban environment.

The level of urbanization in the developing world indicates that more people now live in cities than before. Cities with one million people and above, according to the United Nations forecasts increased to over 300 by the year 2000 in the developing world [10]. This trend will continue because of the rapid growth in population, resulting from improvement in health services and the multifarious functions performed by cities, which have been another major attractive force. The situation as described above has its impact on traffic congestion in the cities of developing world. Thus, the activities, which take place in them, make them generators and attractors of traffic, which, of course, has implications on mobility. The automobiles have an inevitable appetite for space. It uses space at home, at work, shopping places, religious centers and recreational centers. Ironically, when some of these spaces are empty, they are still reserved for the automobiles. Thus, a large chunk of the urban land, which could have been used up for productive activities, is consumed by the transport sector.

The roadway carrying capacity, also, determines the maximum number of vehicles that would pass through a given section of a lane or road way in one direction or both for a two lane roadway, during a given time period. Thus, as traffic volume increases, the speed of each vehicle is influenced, to a large measure, by the speed of the slower vehicles. Thus, as traffic density increases, a point is reached where all vehicles would travel at the speed of the slower vehicle. This condition, when attained, indicates that the ultimate capacity has been reached and that would result in congestion on the road.

Most major Nigerian cities, which include Akure Township, have been developing without the conventional land use approach [11]. This has generated different urban problems in the form pollution of the environment, transportation problems, insanitary condition and epidemics. This is because the physical growth and development of cities have not been properly managed. It allows conversion of residential uses and other types of buildings to 3 commercial use, street trading, parking and infrastructural facilities, which increases the volume of traffic in such neighbourhood.

Illegal parking is also a major problem in urban environment. This is because parking on roadside, which is a common phenomenon, reduces the traffic corridors meant for the efficient movement of automobiles. Thus, it becomes a major problem in cities and especially in the Central Business District (CBD), where multi-storey buildings are common and the land use is devoted mostly to commercial purposes. The resultant effect of such illegal parking, therefore, is traffic congestion. This illegal parking leads to delay in traveling time and increases the cost of traveling because more fuel is used up in the process of accomplishing a delayed journey (go-slow / traffic jam). Most of these identified traffic congestion related problems still persist in our cities in the less developed countries due to lack of adequate geospatial information in usable format to tackle these spatially related problems.

Over the years, the transportation route of Oba Adesida road, Akure along the Oja-Oba (king's market) axis has allowed the commercial activities along that route to be very efficient serving larger percentage of the Akure populace. However, it is important to note that when the commercial activities of any area rises, the transportation route and facilities are likely to be neglected, which later deteriorate due to over use and lack of maintenance. Most often, coincidence arises from individual commuter's journey during peak hour periods. This type of coincidence, if not well managed, may lead to traffic crisis that makes traveling burdensome in addition to wasting person-hour productive time.

3. Methodology

In this study, the primary source of data collection involved direct collection of information on the field using traffic counts and observations. Such data included pictures of traffic-congested zones, information on traffic-congested junctions (points), the roads (lines) and the land use (areas). In the course of the study, traffic volume data was collected semi automatically through the use of a video camera and analyzed using a software known as SIDRA [12]. Three intersections within Akure were identified for the study namely Road block, Bye-pass and Cathedral intersections.

3.1 Description of the Study Area

Akure city is located within Ondo State in the South Western part of Nigeria. Ondo state is one of the 36 states of Nigeria which lies approximately on latitude 7° 15' North of the Equator and longitude 5° 12' East of the Greenwich Meridian. Akure is a medium- sized urban centre which became the capital city of Ondo State and a Local Government Headquarters in 1976. Figure 1 shows the map of Nigeria showing Ondo state and Akure.

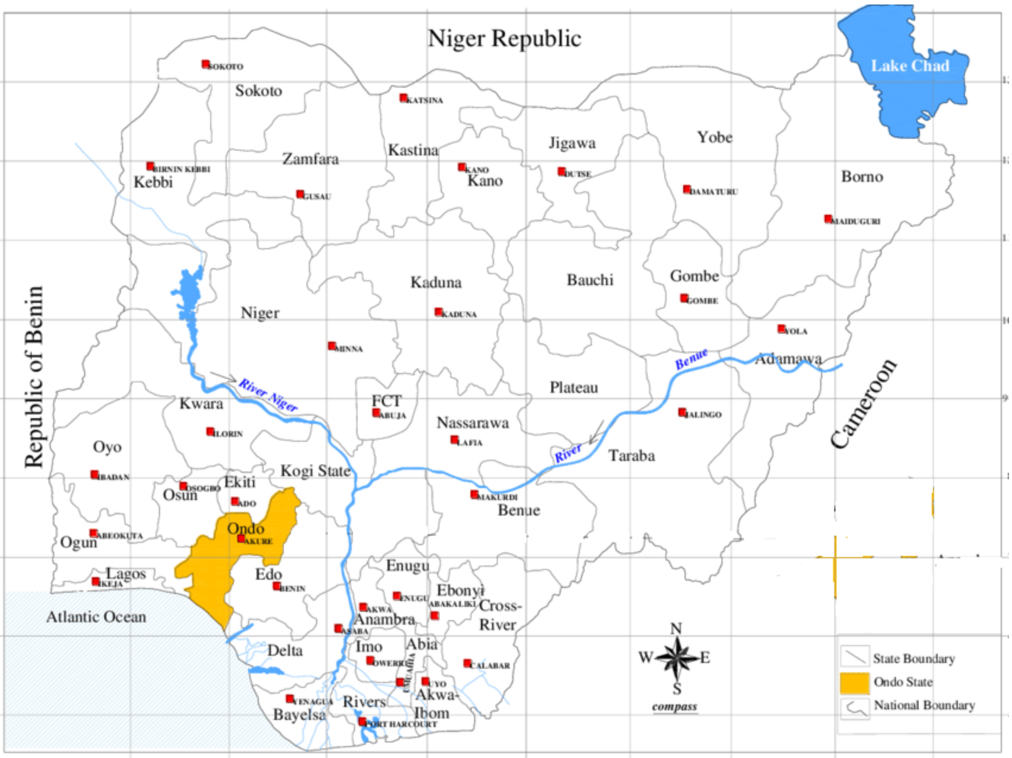

Fig. 1. Map of Nigeria showing Ondo State and Akure Source: Ministry of Works and Housing, Akure (2012)

In 1991, the provisional population for Akure was put at 316,925 (1991 census). The increased relative political influence of Akure as a State capital since 1976, when Ondo State was created has been partly responsible for its rapid development. This is because, the decentralization exercise, which accompanied the policy that led to the creation of the State led to the creation of jobs, which attracted many people. Improvements in transport facilities were given prominence in Akure shortly after 1976 when the city became the seat of Government. Figure shows the base map of the study intersections within Akure city. The intersections considered for this study and their locations are as shown in Figure 3.

3.2 Level of Service, Delay and Degree of saturation

Level of Service (LOS) is a qualitative measure that describes traffic conditions in terms of speed, travel time, freedom to maneuver, comfort, convenience, traffic interruptions, and safety. Six classifications are used to define LOS, designated by letters A through F [13]. Level A represents the best quality of traffic where the driver has the freedom to drive with free flow speed and level F represents the worst quality of traffic.

Delay to a vehicle is the difference between interrupted and uninterrupted travel times through the intersection while the degree of saturation is a ratio of demand to capacity on each approach to the intersection, with a value of 100% indicating that demand and capacity are equal and no further traffic is able to travel through the junction. The degree of saturation is usually expressed as the ratio of the volume to capacity (v/c) of traffic at any point in the highway segment.

The LOS can then be expressed in terms of the delay and degree of saturation as follows:

- Level of Service “A”: Free flow, with low volume and high speed. Traffic density is low, with speed controlled by drivers’ desired speed limits and physical roadway conditions. Individual users are virtually unaffected by others in the traffic stream; v/c = 0.00 to 0.60.
- Level of Service “B”: represents the range of stable flow but the presence of other users in the traffic stream begins to be noticeable. Freedom to select desired speeds is relatively unaffected but there is a slight decline in the freedom to maneuver within the traffic stream from LOS A; v/c = 0.61 to 0.70.
- Level of Service “C”: represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user, v/c =0.71 to 0.80. This is the target LOS for some urban and most rural highways.
- Level of Service “D”: Approaches unstable flow, with tolerable operation speed being maintained through considerably affected changes in operating conditions. Fluctuations in volume and temporary restrictions to flow may cause substantial drops in operation speeds. Drivers have little freedom to maneuver; comfort and convenience are low, but conditions can be tolerated for short periods of time. Minor incidents are expected to create delays, v/c=0.81 to 0.90.
- Level of Service “E”: unstable flow, operating at capacity, Cannot be describe by speed alone but represent operations at even lower operating speeds than in level D with volumes are or near the capacity of highway. At capacity speed are typical but not always in the neighborhood of 50 km/h. Flow is unstable, and there may be stoppage of momentary duration. Drivers' level of comfort becomes poor. Freedom to maneuver within the traffic stream is extremely difficult, v/c=0.91 to 1.00.
- Level of Service “F”: Forced flow operations at low speeds, where volumes are below capacity. Conditions result from queues of vehicles backing up from a restriction downstream. Speeds are reduced substantially and stoppage may occur for long or short period of time, because of downstream congestion. Travel time cannot be predicted, with generally more demand than capacity. A road in a constant traffic jam is at this LOS. In extreme, both speed and volume can drop to zero, v/c greater than 1.00.

3.3 SIDRA intersection software

This is the software that was used for analyzing the traffic volume data obtained in this study. It is capable of:

- analyzing a large number of intersection types including signalized intersections (fixed-time / pre-timed and actuated), signalized pedestrian crossings, single point interchanges (signalized), roundabouts, roundabout metering, two-way stop sign control, all-way stop sign control, and give-way / yield sign-control;
- obtaining estimates of capacity and performance characteristics such as delay, queue length, stop rate as well as operating cost, fuel consumption and pollutant emissions for all intersection types; analyzing many design alternatives to optimize the intersection geometry, signal phasing and timings specifying different strategies for optimization;
- handling intersections with up to 8 legs, each with one-way or two-way traffic, one-lane or multi- lane approaches, and short lanes, slip lanes, continuous lanes and turn bans as relevant;
- determining signal timings (fixed-time / pretimed and actuated) for any intersection geometry allowing for simple as well as complex phasing arrangements and carrying out a design life analysis to assess impact of traffic growth;
- carrying out a parameter sensitivity analysis for calibration, optimisation, evaluation and geometric design purposes;
- designing intersection geometry including lane use arrangements taking advantage of the unique lane-by-lane analysis method of Sidra intersection;
- designing short lane lengths (turn bays, lanes with parking upstream, and loss of a lane at the exit side);

4. Discussion of Results

The three intersections considered are hereby analyzed and discussed.

4.1 Road Block Intersection

Road Block intersection is a T- junction in which the major road links Akure-Ilesha road to Benin road and the minor road links the intersection to Oba Adesida road. It experiences slightly heavy traffic as it leads to one of the major commercial centers in Akure. Figure 2 shows a pictorial representation of Road Block intersection.

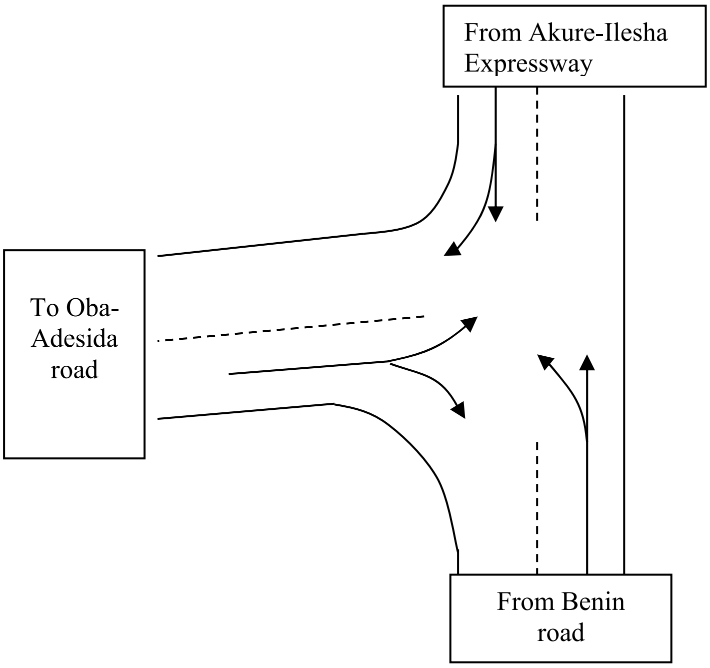

Fig. 2. Pictorial representation of Road Block intersection

Tables 1 and 2 show the number of vehicles going in (from Akure-Ilesha road and Benin road) and out (from Oba Adesida road) of the intersection between the hours of 7am and 5pm for 14 days. It also indicates the peak period observed from 7am to 9am due to the early morning rush caused by civil servants rushing to work, traders hawking and students heading to school, and 1pm to 3pm for Fridays due to Muslims going to mosque which incidentally is also the closing hours for secondary school students thereby contributing to the traffic on the road and 3pm to 5pm on Mondays to Thursdays. Traffic volumes on weekends (Saturdays and Sundays) were generally low and had their peak periods between 9am to 11am and 3pm to 5pm.

Table 1

Traffic volume data for Road Block Intersection - week 1

DAY		TIME									
		7AM-8AM	8AM-9AM	9AM-10AM	10AM-11PM	11AM-12PM	12PM-1PM	1PM-2PM	2PM-3PM	3PM-4PM	4PM-5PM
MONDAY	IN	1890	1801	1500	1299	1086	1103	1335	1510	1466	1310
	OUT	1520	1733	1503	1190	1114	1202	1280	1420	1317	1390
TUESDAY	IN	1662	1700	1517	1320	1434	1100	1390	1500	1680	1435
	OUT	1234	1341	1418	1100	1200	1231	1345	1535	1695	1515
WEDNESDAY	IN	1901	1712	1320	1010	1210	1222	1507	1509	1615	1616
	OUT	1727	1434	1111	931	1009	1176	1531	1707	1803	1605
THURSDAY	IN	1776	1780	1894	1200	1320	1210	1401	1568	1600	1531
	OUT	1530	1483	1322	1016	1200	1294	1134	1443	1514	1532
FRIDAY	IN	1300	1451	1500	1105	1288	1498	1300	1392	1000	1031
	OUT	1392	1399	1380	1008	1192	1302	1451	1400	1214	1215
SATURDAY	IN	1171	1210	1298	1015	994	952	1140	1271	1031	900
	OUT	1098	1082	1115	1129	1009	1100	1093	1051	993	1071
SUNDAY	IN	900	1310	1294	1300	1101	1074	1228	1400	1204	1396
	OUT	891	1398	1211	1109	984	950	1189	1399	1306	1400

Table 2

Traffic volume data for Road Block Intersection - week 2

DAY		TIME									
		7AM-8AM	8AM-9AM	9AM-10AM	10AM-11PM	11AM-12PM	12PM-1PM	1PM-2PM	2PM-3PM	3PM-4PM	4PM-5PM
MONDAY	IN	1795	1800	1740	1430	1261	1202	1438	1677	1630	1641
	OUT	1610	1552	1538	1214	1272	1281	1357	1600	1727	1681
TUESDAY	IN	1588	1570	1589	1320	1118	1078	1300	1570	1599	1600
	OUT	1268	1489	1590	1210	1203	1009	1219	1495	1584	1620
WEDNESDAY	IN	1601	1555	1521	1077	1009	1205	1302	1534	1591	1502
	OUT	1539	1571	1560	1210	1178	1220	1300	1560	1570	1555
THURSDAY	IN	1498	1504	1410	1011	1190	1200	1491	1600	1504	1510
	OUT	1561	1491	1333	1121	1191	1240	1481	1542	1561	1557
FRIDAY	IN	1391	1400	1351	1201	1200	1224	1408	1431	1110	1002
	OUT	1302	1430	1390	1006	1100	1231	1393	1450	1228	1131
SATURDAY	IN	1008	1109	1189	1001	956	993	1215	1300	1107	1103
	OUT	923	980	1009	1138	991	1115	1091	1003	986	1180
SUNDAY	IN	827	1238	1299	1376	901	932	1157	1399	1332	1222
	OUT	794	1193	1238	1006	810	823	1173	1340	1392	1345

Figure 3 shows the LOS for each leg at the intersection.

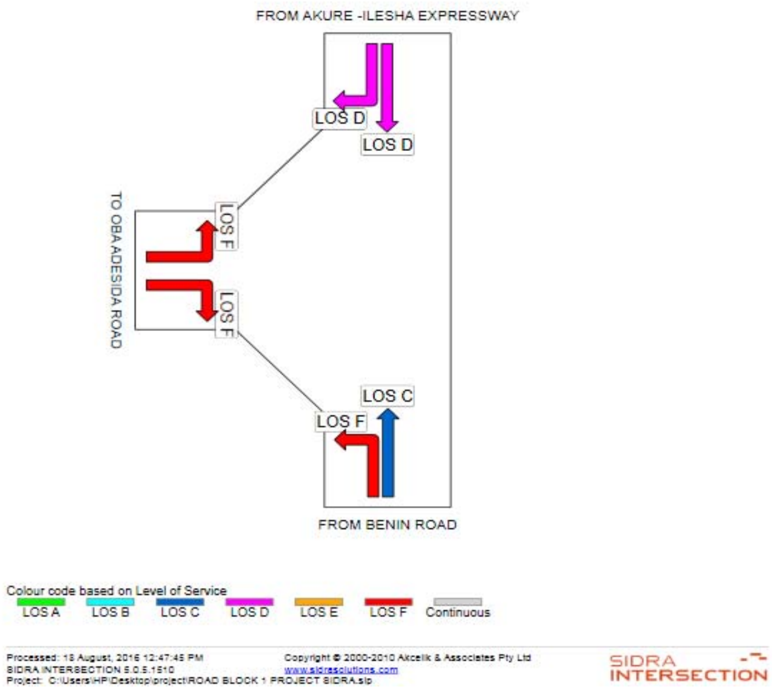

Fig. 3. LOS on each leg at Road block intersection

Table 3 shows the inferences drawn from the values of the LOS obtained for each leg of road meeting at the intersection.

Table 3

Levels of Service for the legs meeting at Road Block intersection

LEGS OF THE INTERSECTION	LEVEL OF SERVICE (LOS)	Implications of the Level of Service (HCM)	CAUSES
From Akure-Ibadan expressway to Benin road	D	Approaches unstable flow, high density, reduced speed, significant operational difficulties on the highway, delay. There are severe restrictions on a driver's ability to manoeuvre, with poor levels of comfort and convenience.	Poor parking system, abandon vehicles on road, increased volume of traffic which is predominated by passenger car/taxi.
From Akure-Ibadan expressway to Oja road	D	Approaches unstable flow, high density, reduced speed, significant operational difficulties on the highway, delay. There are severe restrictions on a driver's ability to manoeuvre, with poor levels of comfort and convenience.	Poor parking system, abandon vehicles on road, increased volume of traffic which is predominated by passenger car/taxi.
From Benin road to Akure-Ibadan express	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user	Increase volume of traffic which is predominated by passenger car/taxi, increased socio-economic activities poor parking system, ribbon development, width of intersection legs is small.
From Benin road to Oba Adesida road	F	Travel time cannot be predicted, with generally more demand than capacity. A road in a constant traffic jam is at this LOS. In extreme, both speed and volume can drop to zero, v/c greater than 1.00	Geometric and/or operational constraints external to the intersection i.e illegal parking system, increased economic activities.
From Oba Adesida road to Benin road	F	Travel time cannot be predicted, with generally more demand than capacity. A road in a constant traffic jam is at this LOS. In extreme, both speed and volume can drop to zero, v/c greater than 1.00	Geometric and/or operational constraints external to the intersection i.e illegal parking system, increased economic activities.
From Oba Adesida road to Akure- Ilesha road	F	Travel time cannot be predicted, with generally more demand than capacity. A road in a constant traffic jam is at this LOS. In extreme, both speed and volume can drop to zero, v/c greater than 1.00	Absence of traffic personnel i.e. traffic warden or traffic signals to control traffic

The overall LOS for the intersection was obtained as F based on the fact that the degree of saturation is greater than 1.

4.2 Bye-pass intersection

Bye-pass intersection is also a T-junction whose major road links road block intersection to Cathedral junction and the minor road links the intersection to Bishops court road. Figure 4 shows a pictorial representation of Bye-pass intersection.

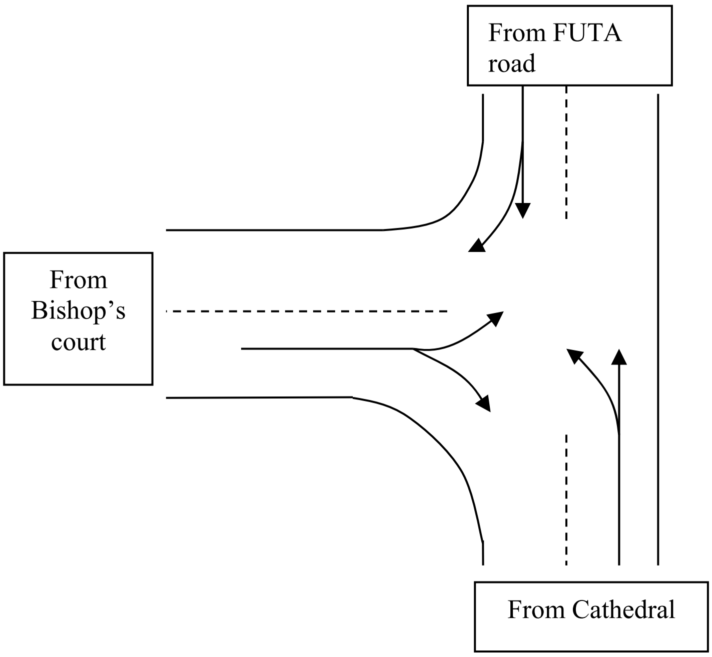

Fig. 4. Pictorial representation of Bye-pass intersection

Traffic volume data was also obtained for this intersection and inputed into SIDRA to get the LOS for each leg meeting at the junction as well as the overall LOS at the intersection. Figure 5 shows the LOS for each leg at the intersection.

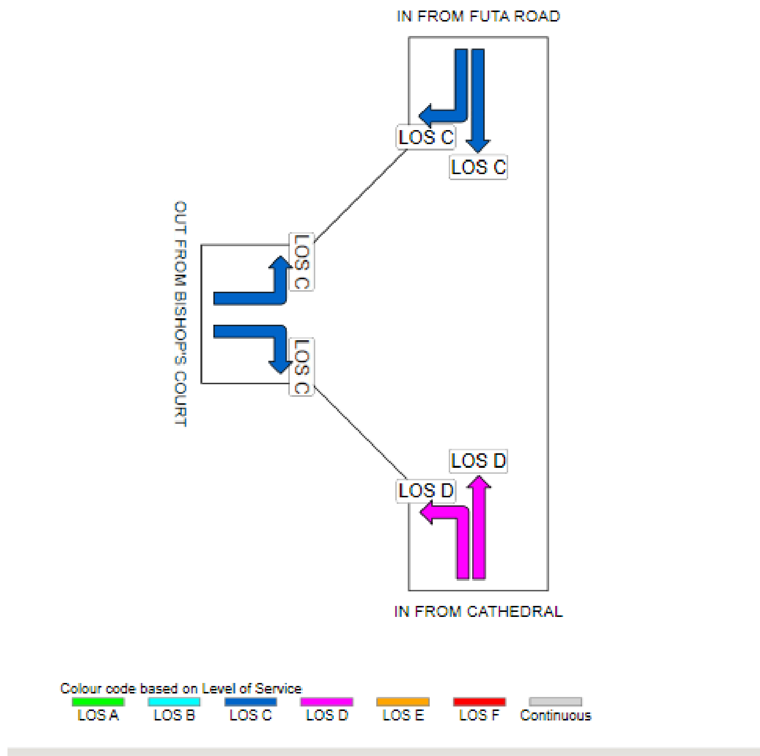

Fig. 5. LOS on each leg at Bye-pass intersection

Table 4 shows the inferences drawn from the values of the LOS obtained for each leg of road meeting at Bye-pass intersection.

Table 4

Levels of Service for the legs meeting at Bye-pass intersection

LEGS OF THE INTERSECTION	LEVEL OF SERVICE (LOS)	Implications of the Level of Service (HCM)	CAUSES
In from FUTA road to Cathedral	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user.	Poor parking system, abandon vehicles on road, increased volume of traffic which is predominated by passenger car/taxi.
In Cathedral road to FUTA road	D	Approaches unstable flow, high density, reduced speed, significant operational difficulties on the highway, delay. There are severe restrictions on a driver's ability to manoeuvre, with poor levels of comfort and convenience.	Poor parking system, abandon vehicles on road, increased volume of traffic which is predominated by passenger car/taxi.

LEGS OF THE INTERSECTION	LEVEL OF SERVICE (LOS)	Implications of the Level of Service (HCM)	CAUSES
From FUTA road to Bishop’s court	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user	Increase volume of traffic which is predominated by passenger car/taxi, increased socio-economic activities poor parking system, ribbon development, width of intersection legs is small.
From Cathedral to Bishop’s court	D	Approaches unstable flow, high density, reduced speed, significant operational difficulties on the highway, delay. There are severe restrictions on a driver’s ability to manoeuvre, with poor levels of comfort and convenience.	Geometric and/or operational constraints external to the intersection i.e faulty fixed time signal, illegal parking system, increased economic activities.
From Bishop’s court to Cathedral	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user	Geometric and/or operational constraints external to the intersection i.e faulty fixed time signal, illegal parking system, increased economic activities.
From Bishop’s court to FUTA road	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user	Narrow width of circulating carriageway width of the roundabout, street trading/ribbon development.

The overall LOS for Bye-pass intersection was obtained as C which indicates stable flow of traffic and easy maneuvering by drivers is possible, also it signifies stable operating conditions with average traffic delays at the intersection.

4.3 Cathedral Intersection

Cathedral intersection is a T-junction whose major road links Oyemekun road to Oja Oba road and the minor road links the intersection to Ondo road. Figure 6 shows a pictorial representation of Cathedral Intersection.

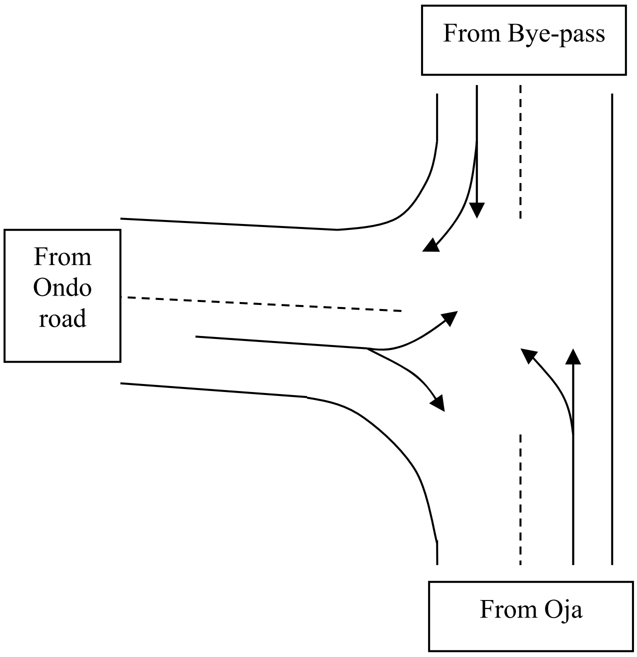

Fig. 6. Pictorial representation of Cathedral Intersection

Analyses of the traffic volume data collected for 14 days at this intersection in SIDRA gave the LOS for each leg of road meeting at the junction as well as the average LOS for the entire intersection. Figure 7 shows the LOS for each leg at the intersection.

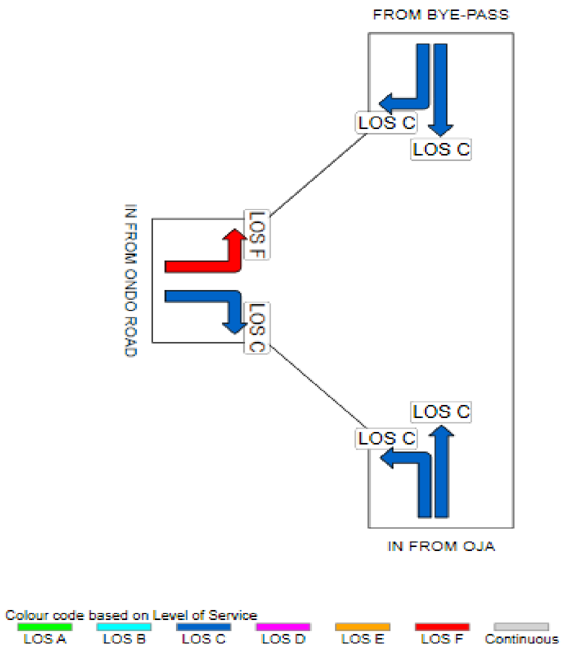

Fig. 7. LOS on each leg at Bye-pass intersection

Table 5 shows the inferences drawn from the values of the LOS obtained for each leg of road meeting at Cathedral intersection.

Table 5

Levels of Service for the legs meeting at Cathedral intersection

LEGS OF THE INTERSECTION	LEVEL OF SERVICE (LOS)	Implications of the Level of Service (HCM)	CAUSES
From bye-pass to Oja	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user.	Poor parking system, abandon vehicles on road, increased volume of traffic which is predominated by passenger car/taxi.
From Ondo Road to Bye-pass junction	F	Travel time cannot be predicted, with generally more demand than capacity. A road in a constant traffic jam is at this LOS. In extreme, both speed and volume can drop to zero, v/c greater than 1.00	Poor parking system, abandon vehicles on road, increased volume of traffic which is predominated by passenger car/taxi.
From Oja to bye-pass junction	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user	Increase volume of traffic which is predominated by passenger car/taxi, increased socio-economic activities poor parking system, ribbon development, width of intersection legs is small.
From Oja To Ondo road	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user	Geometric and/or operational constraints external to the intersection i.e faulty fixed time signal, illegal parking system, increased economic activities.
From Ondo road to Bye-pass junction	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user	Geometric and/or operational constraints external to the intersection i.e faulty fixed time signal, illegal parking system, increased economic activities.
From bye pass to Ondo road	C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user	Narrow width of circulating carriageway width of the roundabout, street trading/ribbon development.

The overall LOS for Cathedral intersection was obtained as E which indicates that there is delay at the intersection and also flow of traffic is greatly impeded.

5. Conclusion and recommendations

An appraisal of the three intersections studied indicated road block intersection is not efficient enough for the volume of traffic plying the roadway and in the same vein Cathedral intersection also is not effective enough for the volume of traffic traversing the roadway but By-pass intersection proved efficient. The maximum volume of veh/hr was an average of over 1700vehicles per hour for all intersection.

An appraisal of Road block intersection reveals that the presence of two close intersections at that junction is sometimes abused as some drivers take the wrong intersection turn to maneuver their way around traffic, this is more possible since there is absence of any traffic personnel to put them in order. Also from the west approach i.e. approach from the minor road, there is high level of delay indicating a Level of Service of F on that leg and signifying poor operating conditions resulting in lower travel speeds. However, at the Northern and Southern approaches (Akure - Ibadan Expressway) and (Benin expressway) the average delays are quite minimal but still not efficient enough as it indicated a Level of Service D and C respectively which translates to impeded traffic flow.

Bye-Pass intersection has been adjudged to be efficient and it has a delay of 24.5s indication an average Level of Service C i.e. reasonably unimpeded traffic operations with only short traffic delays at intersections. Cathedral intersection’s challenges can also be attributed to be similar with that of Road blocks’ as it also has a low efficiency rate.

Based on the results obtained in this study, the following should be carried out:

- Widening of Road block to Oba Adesida road as well as the road joining Ondo Road to Bye Pass in order to allow the road meet up with future traffic demands
- Maintenance and repair of the traffic signal system at Cathedral intersection.
- Provision of traffic personnel or traffic signals at road block intersection so as to put drivers in order.
- Provision of proper off -street parking facilities at Road block intersection

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Revista Română de Inginerie Civilă, Volumul 11 (2020), Numărul 3

Experimental stand for the study of energy conversion and storage

Stand experimental pentru studiul conversiei și stocării energiei

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DOI:10.37789/rjce.2020.11.3.7

Abstract: *This paper presents an experimental stand for the study of energy conversion and storage. The hybrid system has as component elements: water- water heat pump, the supply system of the heat pump with flow control, storage tank of the waste water discharged from a water-water heat pump, compressed air storage tank, compressor, Pelton turbine, photovoltaic system for electricity supply of the system, automation system, load resistance, wattmeter. With the help of the experimental stand were determined: the running idling characteristic of the electric generator at different simulated turbine drop and the operating characteristic under load. Thus, the efficiency of the system has been demonstrated by increasing the Coefficient of Performance (COP) of the heat pump.*

Keywords: *conversion, storage energy, hybrid system, electricity, COP.*

Rezumat: *Această lucrare prezintă un stand experimental pentru studiul conversiei și stocării energiei. Sistemul hibrid are ca și elemente componente: pompă de căldură apă-apă, sistem de alimentare pompă de căldură cu reglajul debitului, rezervor de stocare a apei reziduale evacuate de la o pompă de căldură apă-apă, rezervor de stocare aer comprimat, compresor, turbină Pelton, sistem fotovoltaic pentru alimentarea cu energie electrică a sistemului, sistem de automatizare, rezistență de sarcină, wattmetru. Cu ajutorul standului experimental au fost determinate: caracteristica de mers în gol a generatorului electric la diferite căderi simulate, ale turbinei și caracteristica de funcționare în sarcină. Astfel, s-a demonstrat eficența sistemului prin creșterea COP al pompei de căldură.*

Cuvinte cheie: *conversie, stocarea energiei, sistem hibrid, electricitate, COP.*

1. Introduction

The effects of climate change have gradually caused human societies to use renewable energy sources to reduce greenhouse gas emissions.

As a result of establishing maximum permitted values for greenhouse gas emissions released into the atmosphere, for the period 2020-2029, for energy security - as a basic condition of sustainable development, it is necessary to efficiently integrate the renewable energy sources, which to gradually replace conventional resources [1], [2].

The model of the three pillars, Economy - Ecology - Society, is the key to sustainable development [3], [4].

Even though, the renewable energy sources could satisfy most of the total energy demand, their intermittent nature brings an instability between the production and the demand for energy for a day or even an hour. Figure 1.

Schematically illustrates the difference between energy production and consumption within 24 hours [5].

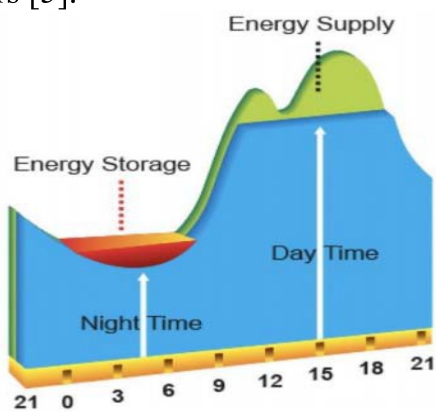

Figure 1. Variation of the load curve during a day

It can be observed that in the 9-18 hour interval, the basic production can be largely ensured by the photovoltaic systems, being necessary to provide a fast reaction energy source capable of providing the peaks of load. These sources are represented by storage systems that can accumulate energy during the night (from wind, tidal) when consumption is low, or during the day (on days with maximum sun from photovoltaic systems and/or other systems). The interest of the researchers, motivated by the energy policies regarding the promotion of microturbines, which, unlike the turbines of medium and large power, have a reduced effect on the environment [1, 2, 6, 7, 8]

So, the solution of the problems raised by the use of renewable sources is the storage of energy. In this way, energy availability can be ensured when needed.

2. Storage systems

If the use of distributed generation represents more than twelve percent of the energy production, then the problem of energy compensation will arise in the local network or in the whole system that can be solved by storing energy. In fact, it is not possible to achieve the direct storage of electricity, since it is necessary to convert it into other forms of energy.

Energy storage systems must be able to store the energy produced under favorable climatic conditions and return it to cover peak loads during the daytime or when production of renewable systems is not possible.

Possible solutions for storage systems include:

➤ ***Mechanical storage***:

- *the storage based on Pomped Hydro* - is a technology confirmed with long storage period, high efficiency and relatively low cost per unit of energy [6]

- *the storage with Compressed Air* - it is largely similar to the operation of pumped hydroelectric plants, but during periods of surplus power, this technology produces compressed air that it injects into underground caverns. To return the stored energy, the pressurized air is heated and expanded into an expansion turbine unit and generator that converts rotational kinetic energy into electricity [6].

- *storage with flywheel*- The technology uses electric motors to engages a flywheel to spin at high speed, so that the electrical power is transformed into mechanical power and stored, and when necessary, the flywheel command an electric generator [9].

➢ ***Electrochemical storage:***
- batteries with internal storage (eg Pb, NiCd, Li-ion)
- batteries with external storage:
- primary batteries with external regeneration (eg Zn- air)
- gas storage (electrolyser, combustion cells)
- torage with liquid electrodes (eg redox with vanadium)

➢ ***Electrical Storage***:
- superconducting coils
- capacitors (different technologies)

Storage should not only be seen at the level of the national energy systems (SEN), but also at the level of the distribution operators for supplying in remote areas and prosumers . At the prosumers level, the surplus of energy can also be stored in the form of thermal energy for heating/cooling in order to increase the degree of thermal comfort.

3. Description of the experimental stand

Starting from the fact that any technical system evacuates in the external environment a certain fraction of the useful energy, as lost energy, the experimental installation (Figure 2) highlights ways of converting and storing energy. The experimental stand was created in the "Energy Conversion" Laboratory of the Polytechnic University of Timisoara. Water discharged from the primary circuit of a water-to-water heat pump is fed into the R1 storage tank to be distributed to a small Pelton turbine (Figure 3) on which a DC generator is mounted. Thus, the potential energy of the waste water will be converted into kinetic energy of rotation and then into electrical energy.

Figure 2. Experimental installation Figure 3. Pelton turbine

The inlet of the water in the turbine is done by means of the solenoid valve mounted at the exit of the storage tank R_1. For adjusting the flow rates and pressure on the nozzles, two adjusting valves have been mounted. In order the establish operating regimes that ensure the coverage of the load peaks, the turbine drop is simulated by increasing the pressure in the water storage tank using the compressed air stored in the R_2 tank. The air pressure introduced into the water storage tank is regulated by means of a compressed air pressure regulator. The stored compressed air is produced using a compressor. A photovoltaic system with two panels, was designed to supply the compressor with electricity.

3. Results and discussions

The potential energy of the waste water, stored in the R1 storage tank, is transferred to the Pelton microturbine at a pressure of 1.5bar, equivalent to a fall 15mWC level.

In order to highlight the efficiency of the system, we recorded the operating parameters of the heat pump and determined its COP. The amount of heat supplied by the heat pump was measured with a Multical 402 thermal energy meter, and for the electricity consumed by the heat pump and the feedwater pump an electronic wattmeter was used. Thus, a COP of 3.49 was obtained. The proposed hybrid system produces electricity throughout the operation of the heat pump which results in a COP exceeding 3.49. The generator idle operation is illustrated in Figure 4.

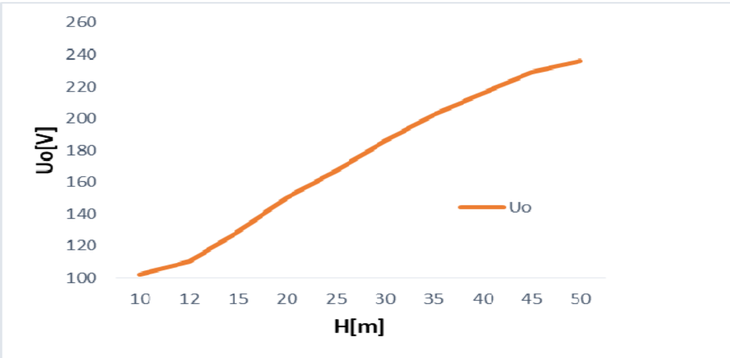

Figure 4. The running idling characteristic of the electric generator

To determine the maximum power output of the electric generator (Figure 5.), tests were performed on different turbine drops. For the considered turbine drops, in Table 1 is presented the flow rate and electrical generator efficiency.

Table 1.

The electrical generator efficiency

H [m]	**Q [l/h]**	**η [%]**
15	2556	31
20	3204	31
25	3348	32
30	3412	36
35	3528	38
40	3924	40
45	4212	43

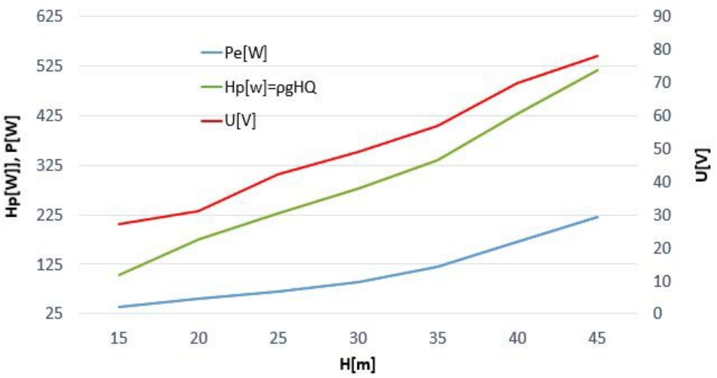

Figure 5. The maximum power output of the electric generator

4. Concluzii

Hydraulic energy conversion systems are robust systems, have very low inertia, require relatively low maintenance and have service life of over 50 years. Microturbines integrated in recovery systems are sometimes the only solution for the electricity supply to small consumers, but especially a solution for covering peak loads.

It has been experimentally determined that the yield of the Pelton microturbine used is between 30-50%

By integrating the microturbine into the outlet circuit of the water-water heat pump, at the available pressure of the 1.5bar supply pump, the equivalent of a 15 mWC drop, 40W can be recovered, resulting in a COP increase to 3.57. If a 45m drop is assured, the COP of the heat pump can reach 3.99.

Proposing a hybrid system, the experimental installation is a necessary tool for the study of energy conversion and storage and is an open topic for further research.

Acknowledgment: *This work was financial supported by the study program Ph.D. at the Polytechnic University of Timisoara - IOSUD-UPT for the doctoral thesis entitled "Contributions concerning the functional- energy optimization of renewable energy conversion systems".*

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Revista Română de Inginerie Civilă, Volumul 11 (2020), Numărul 3

HVAC system influence during refurbishment on reaching nearly zero energy residential building in Serbia

Influența sistemelor HVAC asupra renovarării cu privire la atingerea nivelului aproape zero energie a clădirilor rezidențiale în Serbia

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DOI:10.37789/rjce.2020.11.3.8

Abstract: *Building sector in Serbia is the most energy intensive of all economic sectors with some data showing the buildings are accounted for nearly 50% of final energy consumption of country, large portion of consumption related to covering building heating and cooling needs. New EU Directives covering energy efficiency and energy use target refurbishment of existing buildings, as well as the construction of new ones in a direction to represent nearly zero energy buildings (nZEB). Although the building stock turnover rate is very low, even in the most developed countries, and the energy retrofits of existing building stock towards nearly Zero Energy Buildings are becoming more important compared to new buildings, the HVAC system selection while designing new buildings could be the corner-stone for achieving nZEB goals. In this paper, energy performance of one residential building type in Serbia was analyzed with different combinations of HVAC secondary and primary systems, with several levels of building envelope thermal properties, as well as for several locations spreading north-south across Serbia. The heating and cooling energy consumption in all cases was contrasted with electricity produced from roof-mounted PV central, and it is found that electricity produced from roof area is more than enough to balance the energy consumption of the legislative-required refurbished building, from the primary energy perspective.*

Keywords: *nZEB, refurbishment, residential buildings, EnergyPlus, Serbia*

Rezumat: *Sectorul construcțiilor din Serbia este cel mai mare consumator de energie din toate sectoarele economice, cu date care arată că aproximativ 50% din consumul final de energie al țării este reprezentat de clădiri , o mare parte a acestui consum este legată de acoperirea nevoilor de încălzire și răcire a clădirilor. Noile directive UE care acoperă eficiența energetică și utilizarea energiei vizează renovarea clădirilor existente, precum și construcția de noi clădiri într-o direcție care să reprezinteclădiri cu aproape zero energie (nZEB). Deși rata cifrei de afaceri a fondului de clădiri este foarte scăzută, chiar și în țările cele mai dezvoltate, iar reabilitarea energetică a stocurilor de clădiri existente către aproape Zero Energy Buildings devine din ce în ce mai importantă în comparație cu clădirile noi, selecția sistemului HVAC la proiectarea clădirilo noi ar putea fi piatră de temelie pentru atingerea obiectivelor nZEB. În această lucrare, a fost analizată* *performanța energetică a unui tip de clădire rezidențială din Serbia cu diferite combinații de sisteme secundare și primare HVAC, cu mai multe niveluri ale proprietăților termice ale anvelopelor clădirii, precum și pentru mai multe locații răspândite de la nord la sud, în toată Serbia. În toate cazurile, consumul de energie de încălzire și de răcire a fost în contrastcu energia electrică produsă de sistemul fotovoltaic montat pe acoperiș și se constată că energia electrică produsă de sistemul fotovoltaiv este mai mult decât suficientă-conform cerințelor legislative, pentru a echilibra consumul de energie al clădirii renovate din perspectiva energiei primare.*

Cuvinte cheie: *nZEB, renovare, clădiri rezidențiale, Energy Plus, Serbia*

1. Introduction

Continuous improvement of building energy performance represents one of the key (if not the key) challenges of the 21st century (at least in the energy sector), since buildings account for up to 40% of the final energy consumption in European Union [1], and more than 40% of primary energy consumption in USA [2], while residential buildings in USA accounted for 21% of the total building energy consumption and 20% of the total carbon dioxide emissions in 2016 [3]. The situation in Serbia is similar, where building sector participates with more than 50% of consumed energy [4]. Dominant energy source in Serbia are fossil fuels for both electricity production (needed for space cooling) and for space heating in both residential and non-residential buildings (natural gas or other fossil fuels are mainly used) thus making buildings one of the main emitters of greenhouse gases (GHG). Throughout the World, the situation is similar, labeling building sector as the most energy intensive, and consequently focusing more attention from both researchers and policy makers to this sector. For example, European Union [5] imposes that the share of renewables in the total gross of member states energy consumption should be 20%, the emissions of carbon dioxide, GHG and the final energy consumption must decrease by 20% and that all new buildings must be nearly Zero Energy Buildings (nZEB), starting from 2020. This Directive represented the turning point in the design and construction of new buildings. Considering existing buildings, all EU member states are dealing with minimum energy performances during refurbishment of these buildings, but one must have in mind that existing buildings are far more numerous than the new ones, and that many years will pass when the building fund is fully refurbished.

In Serbia, residential buildings represent the most numerous types of buildings (both in number and in building area) and make an excellent starting point for the analysis of improving their energy performance toward nZEB. Assuming all new buildings will be nZEB, it is very interesting to analyze what are the potentials for refurbishing existing residential buildings in such a manner to make them nZEB. There are numerous definitions for nZEB [6], numerous metrics [7] and tools [8-10] to obtain and represent results, cost-optimal and life-cycle approaches to create nZEB and all have in common that building should produce energy on-site in quantity that is approximately equal to building energy consumption.

Since there are numerous types of residential buildings (single- family, multi-family, high-rise, apartment etc.), constructed in various decades, this paper will deal with only one type of building (single/multi-family). The building is constructed during 1980's, and the possibilities to make this type of building nZEB depending on the type of HVAC systems used will be presented. In the analysis, the primary energy consumption only for providing space heating and space cooling will be used, thus neglecting modeling assumptions influencing other energy end-uses in the building (lighting, appliances, domestic hot water, HVAC auxiliaries etc.). The nZEB refurbishment possibilities were quantified by applying building energy performance simulation software EnergyPlus [11], which is a well-known in research and engineering circles and is readily used in all phases of building life cycle.

2. Building and systems description

The building is shown in figure 1. It is a three-story residential multi-family building, with main façade exposed to the South, with total floor area of roughly 350m^2. It was built in the early 1980's. It is not surrounded by other buildings. Each building story represents an apartment with living room, dining room, two bedrooms, bathroom, corridor which is conditioned and two additional unheated rooms. All the apartments have joint unconditioned staircase. Basement and roof are unconditioned as well. For the energy simulation purposes, all the rooms are modelled as separate thermal zones, which enables defining occupancy, lighting, equipment usage, and heating and cooling setpoint schedules individually for each zone of the building.

In order to simplify the model, heating and cooling setpoints were set at 22^{o} C and 26^{o} C, considering that heating season starts on October 15th and ends on April 15th. During heating period, no cooling is provided in the building and vice-versa. The roof of the building is free for generating electricity from PV panels, and it is assumed that PV panels will have small-to-none effect on the overall building energy balance, since there is unconditioned area under the roof. For this research whole roof (app. 140m^2; roof is tilted 15^o and 25^o toward W and E respectively) is assumed to be covered with PV panels.

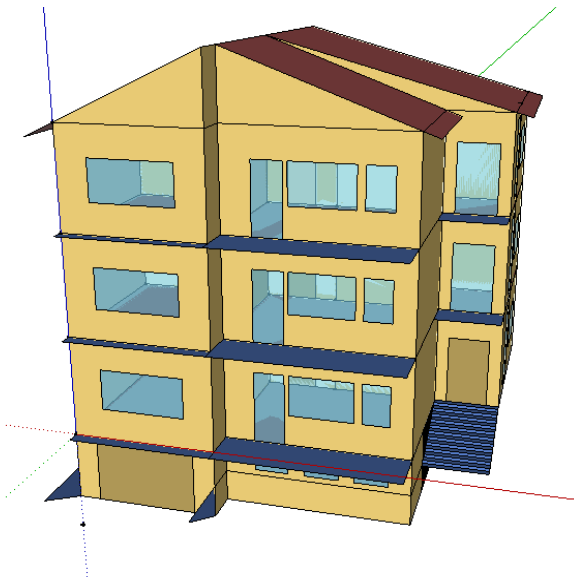

Figure 1. Model of the building in GoogleSketchUp (South-East view)

2.1 Building thermal properties and improvements:

Since the period during which building was constructed, thermal properties of the building do not satisfy the propositions of Ordinance on Energy Efficiency in Buildings [12]. For better overview, all the, maim, envelope constructions with corresponding U-values are shown in table 1. Building airtightness which influences infiltration loads is selected for façades in medium condition and for exposed position of the building and is set to 0.8 ACH (air changes per hour) in all cases.

Table 1.

Composition and U-value of the main building envelope elements

Construction	Material	Thickness [m]	U-value [W/m2K]
External wall	Mortar	0.015	0.76
	Polystyrene	0.03	
	Brick	0.25	
	Mortar	0.015	
Floor toward unconditioned basement/floor on ground	Ceramic floor tiles	0.015	0.74
	Insulation	0.02	
	Concrete	0.1	
	Concrete	0.25	
	Mortar	0.015	
Ceiling towards unconditioned roof area	Stone wool	0.05	0.77
	Concrete plate	0.25	
	Mortar	0.015	
Windows	Double glazed, air filled	4-12-4mm	3.0, SHGC=0.71

Since, building envelope components do not satisfy minimum energy performance requirements, for the purpose of this research, two refurbishment options have been analyzed:

- Refurbishment for minimum energy performance according to [12], named "Legislative", by adding 7cm insulation on outside walls, 3cm insulation in floor toward unheated basement and 5cm insulation toward unheated roof and replacing windows with new ones (U-value of 1.5W/m^{2}K, SHGC=0.61);
- Refurbishment for high energy performance, named "Passive", by adding 17cm insulation on outside walls, 6cm insulation in floor toward unconditioned basement and 5cm insulation toward unconditioned roof and replacing windows with new ones (U-value of 0.7W/m^{2}K, SHGC=0.48).

2.2. Building HVAC systems

For the analysis, the following ideally sized and controlled HVAC systems (or combinations) have been modelled for thermal zones (with the exception that in bathroom no cooling is possible):

- Radiator heating system for space heating in combination with split-type DX air-conditioners,

- Fan-coil system for both space heating and space cooling,

As the primary energy source, the following energy supply combinations have been modelled:

- For providing energy for space heating either gas condensing boiler (CGB) or district heating (DH) for locations where DH exists,
- For providing energy for space cooling air-cooled water chiller has been modeled.

All HVAC components, with their characteristics were taken from EnergyPlus libraries, and represent generic components, without any manufacturer data preference. Depending on the types of energy supply systems and space heating/cooling system, outputs from simulations have been tailored in order to quantify energy (per carrier: natural gas, district heating and electricity) consumption only for space heating and space cooling, thus neglecting energy consumption for auxiliaries in each system and energy consumption for other end-uses (preparing domestic hot water, electricity for lighting, electricity for appliances etc.). In addition, these outputs have been combined in order to quantify primary energy consumption for space heating and space cooling, by multiplying relevant results with primary energy conversion factors [12] which are: 1.1 for natural gas, 1.8 for district heating systems based on fossil fuels, 2.5 for electricity. The same coefficients (electricity) are used for converting produced electricity from PV central mounted on roof.

2.3. Locations

In order to obtain more general conclusions, all combinations of different envelope properties ("No refurbishment", "Legislative" and "Passive") and different HVAC and supply systems described above, have been simulated for different locations in Serbia. For this purpose, typical meteorological years [13] have been obtained for: locations in Serbia specified in table 2. In addition, table 2 contains data on annually produced electricity from roof mounted PVs.

Table 2.

Electricity generated from PV central

Location	PV produced	Location	PV produced
Subotica	15520.	Negotin	16577
Kikinda	15879	Valjevo	16381
Sombor	15874	Kragujevac	16672
Zrenjanin	16238	Užice	13846
Novi Sad	14963	Ćuprija	16629
Vršac	15680	Kraljevo	16146
Sremska Mitrovica	15908	Kruševac	16420
Banatski Karlovac	16074	Niš	16119
Beograd	16226	Kuršumlija	15933
Veliko Gradište	16280	Leskovac	17012
Smederevo	16132	Dimitrovgrad	16908
Loznica	15376	Vranje	17564

3. Results and discussion

Based on the described approach, total of 288 combinations of various levels of building refurbishment, HVAC secondary systems, HVAC supply systems and 24 different locations have been created and simulated. Simulation outputs, for several locations are given in tables 3 and 4, and figures 2-5.

Table 3.

Heating and cooling energy consumption in [kWh], different energy carriers

Location	Refurbishment Level	Fan Coil Boiler&Chiller Heating Energy consumption [kWh]	Fan Coil Boiler&Chiller Electricity consumption for cooling [kWh]	Fan Coil District Heating&Chiller Heating Energy consumption	Fan Coil District Heating& Chiller, Electricity consumption for cooling [kWh]
01-Subotica	0- NoRef	26816	3612	23335	3611
	1-Leg.	14711	3750	13293	3746
	2-Pass.	9398	3430	8630	3424
04-Zrenjanin	0-NoRef	24482	4310	21641	4303
	1-Leg.	13152	4308	11994	4298
	2- Pass.	8204	3866	7590	3856
05-Novi Sad	0-NoRef	26527	3017	23553	3016
	1- Leg.	14458	3423	13131	3416
	2- Pass.	9026	3198	8274	3189

Location	Refurbishment Level	Fan Coil Boiler&Chiller Heating Energy consumption [kWh]	Fan Coil Boiler&Chiller Electricity consumption for cooling [kWh]	Fan Coil District Heating&Chiller Heating Energy consumption	Fan Coil District Heating& Chiller, Electricity consumption for cooling [kWh]
07- Sremska Mikrovica	0-NoRef	25565	3801	22367	3798
	1-Leg	13793	3957	12456	3950
	2- Pass.	8605	3549	7898	3542
09-Beograd	0-NoRef	21577	4288	19070	4281
	1-Leg	11099	4352	10183	4342
	2- Pass.	6642	3933	6184	3925
12-Loznica	0-NoRef	23107	3919	20224	3914
	1-Leg	12660	4036	11409	4028
	2- Pass.	7959	3681	7244	3673
15-Kragujevac	0-NoRef	20441	4553	18070	4548
	1-Leg	10591	4547	9597	4539
	2- Pass.	6421	4108	5867	4099
16-Užice	0-NoRef	29655	1629	26333	1628
	1-Leg	15799	2183	14487	2181

Location	**Refurbishment Level**	**Fan Coil Boiler&Chiller Heating Energy consumption [kWh]**	**Fan Coil Boiler&Chiller Electricity consumption for cooling [kWh]**	**Fan Coil District Heating&Chiller Heating Energy consumption**	**Fan Coil District Heating& Chiller, Electricity consumption for cooling [kWh]**
	2- Pass.	9564	2180	8891	2177
19-Kruševac	0-NoRef	23933	3848	21028	3845
	1-Leg	12990	3890	11736	3883
	2- Pass.	8175	3479	7468	3473
20-Niš	0-NoRef	23743	3248	20900	3245
	1-Leg	12418	3601	11298	3595
	2- Pass.	7560	3319	6974	3313
24-Vranje	0-NoRef	23998	3166	21252	3165
	1-Leg	12996	3255	11865	3249
	2- Pass.	8073	2886	7477	2880

Table 4.

Heating and cooling energy consumption in [kWh], different energy carriers

Location	**Refurbishment Level**	**Radiators&Split, Boiler Heating Energy Consumption [kWh]**	**Radiators&Split, Boiler Electricity consumption for cooling [kWh]**	**Radiators&Split, District Heating, Heating Energy Consumption [kWh]**	**Radiators&Split, District Heating, Electricity consumption for cooling [kWh]**
01-Subotica	0-NoRef	27168	2928	21594	2928
	1-Leg.	15046	3367	12785	3366
	2-Pass.	9622	3304	8488	3302
04-Zrenjanin	0-NoRef	24979	3403	20468	3402
	1-Leg.	13473	3774	11773	3773
	2-Pass	8421	3632	7569	3631
05-Novi Sad	0-NoRef	27145	1816	22799	1816
	1-Leg.	14813	2434	13079	2428
	2-Pass	9267	2530	8318	2528
07-Sremska Mitrovica	0-NoRef	26006	2971	21133	2973
	1-Leg.	14131	3426	12151	3423
	2-Pass	8859	3357	7838	3354

Location	Refurbishment Level	Radiators&Split, Boiler Heating Energy Consumption [kWh]	Radiators&Split, Boiler Electricity consumption for cooling [kWh]	Radiators&Split, District Heating, Heating Energy Consumption [kWh]	Radiators&Split, District Heating, Electricity consumption for cooling [kWh]
09-Beograd	0-NoRef	21890	3628	17971	3629
	1-Leg.	11365	3974	9966	3971
	2-Pass	6807	3811	6169	3808
12-Loznica	0-NoRef	23519	3084	19163	3084
	1-Leg.	12967	3418	11120	3414
	2-Pass	8177	3328	7171	3327
15-Kragujevac	0-NoRef	20866	3753	17416	3755
	1-Leg.	10855	4019	9538	4018
	2-Pass	6597	3825	5899	3823
16-Užice	0-NoRef	30389	1026	25247	1026
	1-Leg.	16231	1649	14315	1651
	2-Pass	9853	1895	8928	1895
19-Kruševac	0-NoRef	24372	3135	19996	3129

Location	Refurbishment Level	Radiators&Split, Boiler Heating Energy Consumption [kWh]	Radiators&Split, Boiler Electricity consumption for cooling [kWh]	Radiators&Split, District Heating, Heating Energy Consumption [kWh]	Radiators&Split, District Heating, Electricity consumption for cooling [kWh]
	1-Leg.	13297	3472	11536	3469
	2-Pass	8390	3347	7447	3345
20-Niš	0-NoRef	24211	2626	19762	2627
	1-Leg.	12715	3218	11062	3212
	2-Pass	7764	3234.99	6934	3237
24-Vranje	0-NoRef	24499	2879.29	20168	2875
	1-Leg.	13308	3224.70	11652	3222
	2-Pass	8292	3097.43	7428	3098

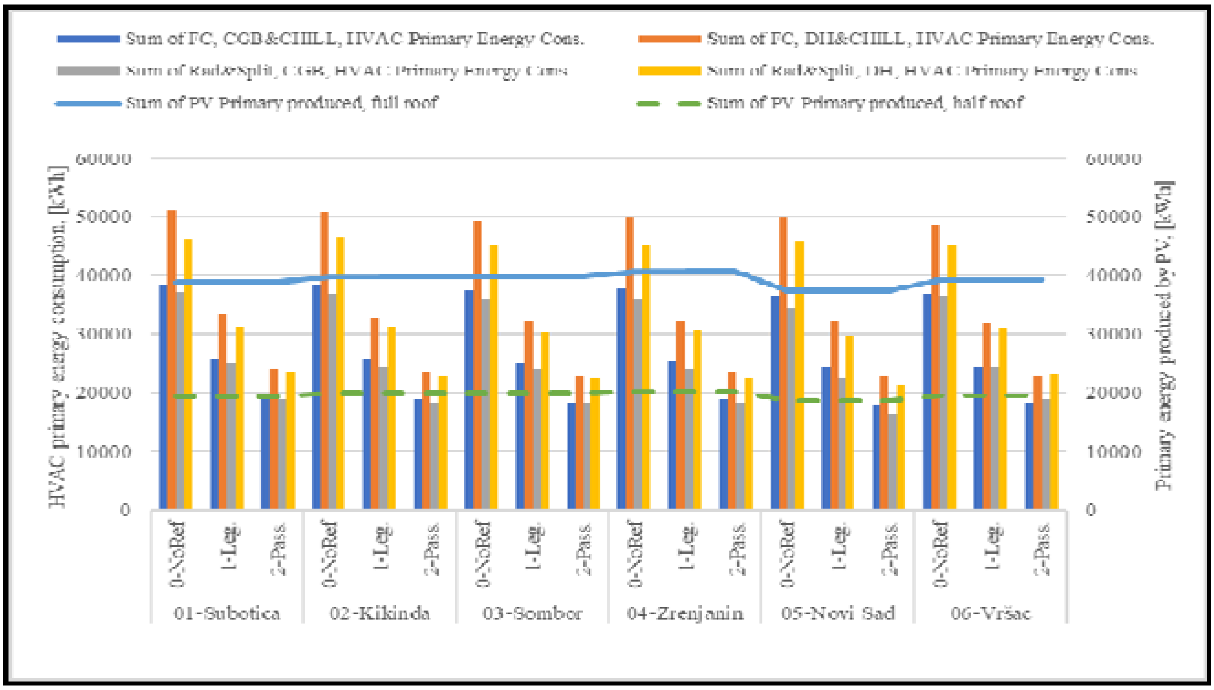

Figure 2. Comparison of primary energy consumption for space heating and cooling for various combinations and on-site produced electricity

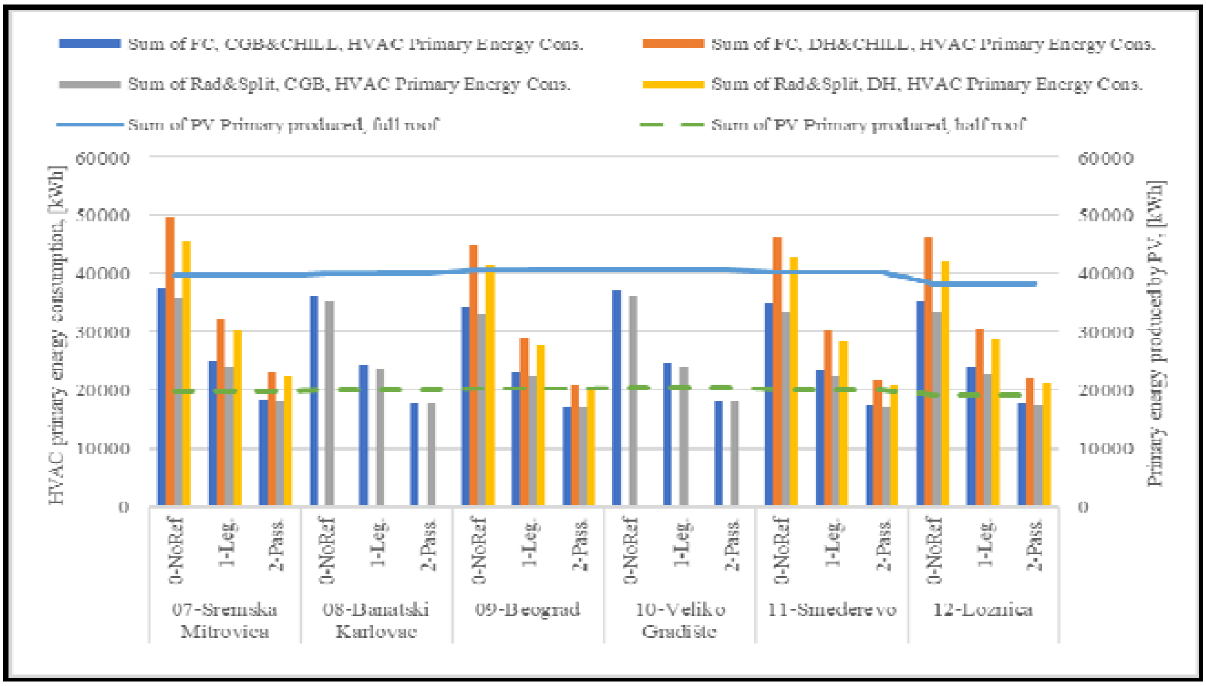

Figure 3. Comparison of primary energy consumption for space heating and cooling for various combinations and on-site produced electricity

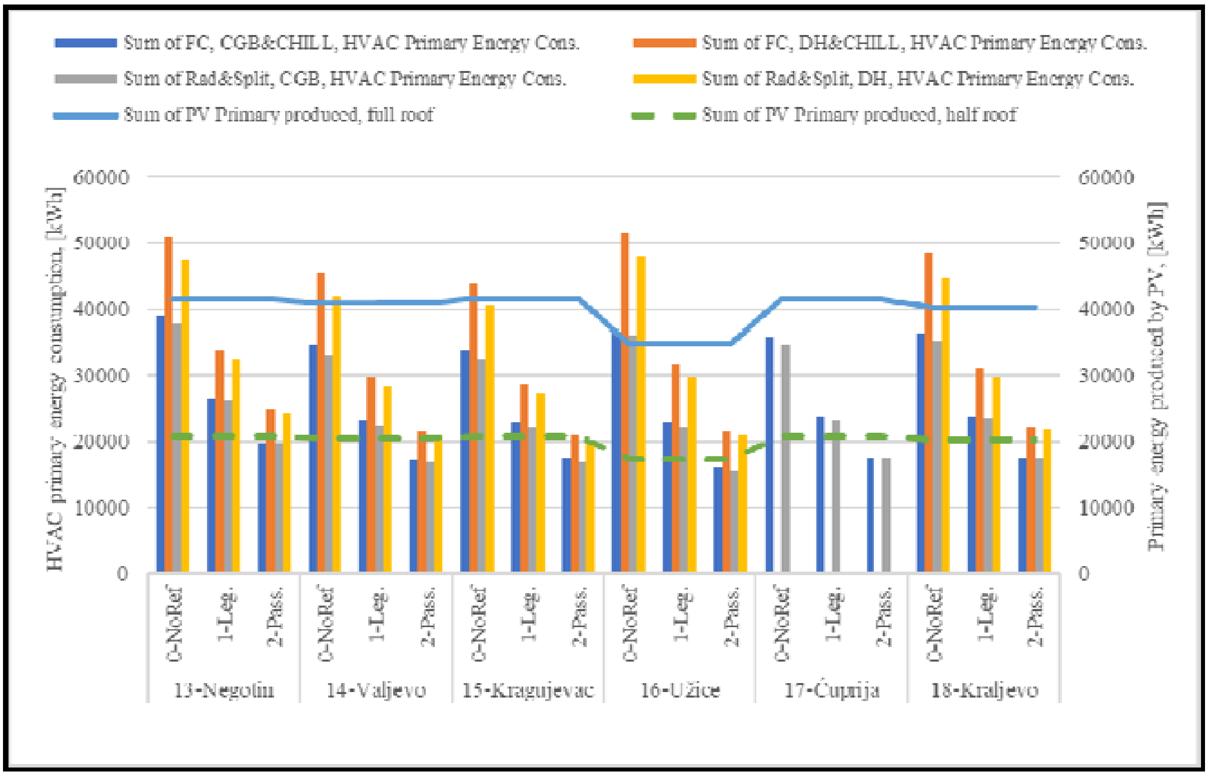

Figure 4. Comparison of primary energy consumption for space heating and cooling for various combinations and on-site produced electricity

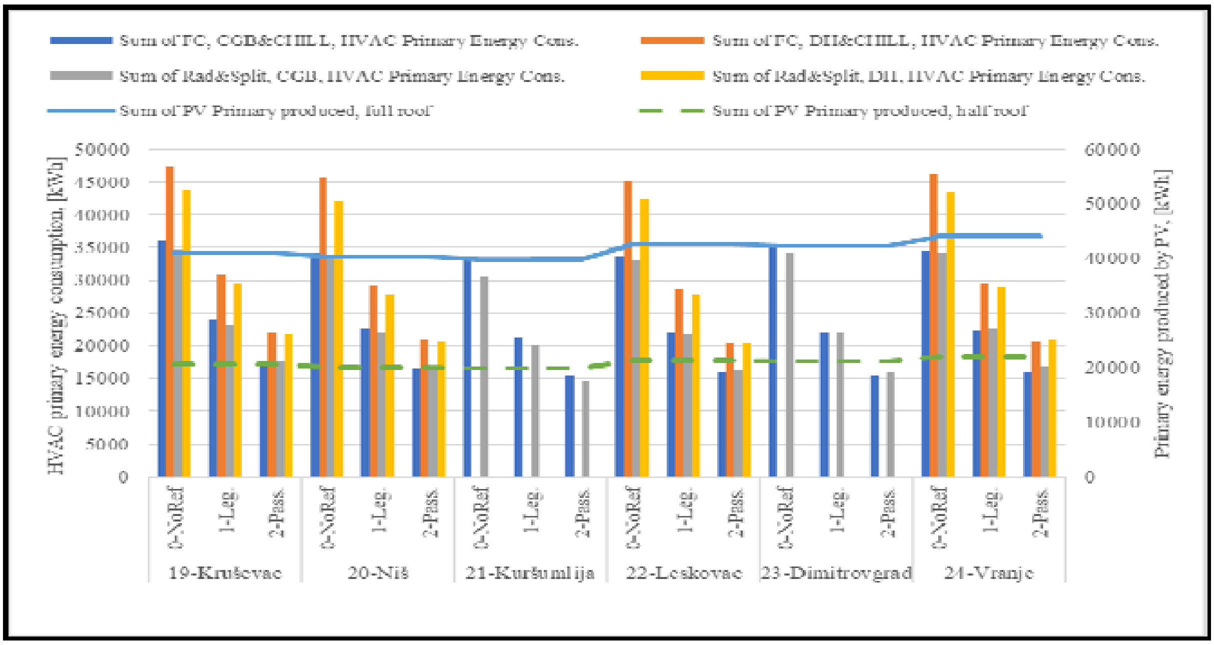

Figure 5. Comparison of primary energy consumption for space heating and cooling for various combinations and on-site produced electricity

The above presented results show that envelope improvement leads to significant reduction in heating energy consumption, while cooling energy consumption (expressed as electricity consumption for cooling) in some cases is higher, and in some lower than in case without envelope improvements. In cases when heating energy is provided by district heating, there is a slight reduction compared to cases when heating is provided by condensing gas boiler. The difference is in the modelled system availability: when district heating is used, heat emitters are available only in part of the day (from 6AM until 10PM), compared to cases with condensing boiler when heat emitters are always available during the heating season. This increased energy consumption would certainly lead to better occupant thermal comfort and satisfaction, which is not analyzed in this paper.

From the primary energy consumption standpoint, from figures 2-5 it is obvious that in Serbia, produced electricity (converted to primary energy) from roof-mounted PV central can balance the primary energy needs for heating and cooling even with minimum envelope refurbishment (referred as “legislative”) for every analyzed HVAC system combination. If the refurbishment goes beyond minimum requirements (referred as “passive”), there is a significant surplus of primary energy produced onsite from PV central, which would probably balance other energy end-uses in analyzed type of building, but most certainly would balance HVAC auxiliary energy consumption, thus enabling HVAC systems to be zero, and the whole building nearly zero.

4. Concluzii

From the presented results it can be concluded that in Serbia, there is an energy potential (especially in Solar energy) to refurbish residential buildings of analyzed type towards nZEB, by implementing PV panels on the roof to balance the energy consumption for space heating and cooling. It this paper, only several combinations of HVAC secondary and primary systems have been analyzed, and in all cases, it is found that for all locations only small envelope improvements can give the wanted results. Further research should be widened to include: other types of residential buildings with different levels of envelope thermal properties, more secondary and primary HVAC systems and their combinations, other energy uses in residential buildings (to make building really nZEB), renewables better suited locally for every location, occupant thermal comfort and more importantly to apply cost-optimal approach in order to find optimal levels and scenarios for every combination of parameters stated above. Conclusions from this type of research would help policy and decision makers to create financially attractive incentives for residents and finally it can help Serbia go “green” in building energy sector.

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Heat from grey wastewater – a sustainable heat pump energy source

Căldura apelor gri de canalizare - o sursă durabilă de energie a pompei de căldură

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DOI:10.37789/rjce.2020.11.3.9

Abstract: *Systems for Domestic Hot Water (DHW) preparation generally represents a considerable part (up to 35%) of energy and water consumption in hotels worldwide. As a consequence of that, a vast amount of heat is wasted through the drainage system from rooms and kitchens. Also, in hotel type of buildings, according to their occupancy, demand for DHW can vary. Researchers and practitioners have a very challenging task to select optimal and sustainable solution. This paper describes a DHW heating system operation with a heat pump system which use Grey Waste Water (GWW) and rainwater energy source. The application is developed in combination with experimental site measurements (real system operation) and required standards. The proposed system consists of three energy source parts: the main heat pump system, heat accumulation tanks, and gas boiler as a reserve. In order to evaluate application of the selected heat pump DHW heating system, a comprehensive assessment was carried out with the conventional gas boiler (base case) and solar collectors system. Assessment results for optimized heat pump system operation showed a very good economic indicators (PBP=4.5%, POP=5.1%, IRR=16% and MIRR 13%). The analysis confirmed the main advantages of this heat pump system which are (consists of) lowered energy consumption and reduced total operating costs. Also, this study results can be used for the planning of hotel DHW systems as an example of the best available system selection. In the end, the research presented encouraging practical application as a cost-effective hotel DHW heating system.*

Keywords: *domestic hot water-DHW, grey waste water-GWW, heat pump, rainwater, economic assessment.*

Rezumat: *Sistemele pentru prepararea apei calde menajere reprezintă, în general, o parte considerabilă (până la 35%) din consumul de energie și apă, din hotelurile din întreaga lume. În consecință, o cantitate mare de căldură este irosită prin sistemul de canalizare din camere și bucătării. De asemenea, în clădirile hoteliere, în funcție de ocupația acestora, cererea de apă caldă poate varia. Cercetătorii și practicienii au o sarcină foarte dificilă la selectarea soluției optime și durabile. Acest articol descrie funcționarea sistemului de încălzire a apei cu un sistem de pompe de căldură care utilizează apă uzată gri (GWW) și apa de ploaie ca sursă de energie. Aplicația este* *dezvoltată în combinație cu măsurători experimentale în șantier (funcționare reală a sistemului) și standarde necesare. Sistemul propus constă din trei părți sursă de energie: sistemul principal de pompe de căldură, rezervoarele de acumulare de căldură și cazanul de gaz ca rezervă. Pentru a evalua aplicarea sistemului de încălzire a apei calde menajere selectate, a fost efectuată o evaluare completă cu centrală convențională de gaz (elementul de bază) și sistem de colectoare solare. Rezultatele evaluării pentru funcționarea optimizată a sistemului de pompe de căldură au arătat indicatori economici foarte buni (PBP = 4,5%, POP = 5,1%, IRR = 16% și MIRR 13%). Analiza a confirmat principalele avantaje ale acestui sistem de pompe de căldură, care sunt (constă în) consum redus de energie și costuri totale de funcționare reduse. De asemenea, rezultatele acestui studiu pot fi utilizate pentru planificarea sistemelor de canalizare hotelieră ca exemplu prin alegerea celui mai bun sistem disponibil. În cele din urmă, cercetarea a prezentat o încurajare a aplicării practice ca sistem de încălzire a apei calde menajere în hoteluri.*

Cuvinte cheie: *apă caldă menajeră - DHW, apă uzată gri-GWW, pompă de căldură, apă de ploaie, evaluare economică.*

1. Introduction

If we treat tourism as the biggest single economy branch worldwide, we have to state that more than 210 million employees [1] and thousands of accommodation facilities are an essential part of this still-growing branch. In basics, hotels are actually real estates and which can potentially obtain profit growth by higher investments to make immense capacities and entertainment facilities and by reducing operational costs. If we observe the structure of total operational costs, energy costs will appear as the highest ones with up to 50%. Since those costs have the potential for an increase in price, energy costs come as an obvious first choice in cutting off in order to increase the share of profit. It's estimated that in 2018 hotel revenue worldwide went up to 141,600 mil USD and the economic forecast for 2022 is even higher – up to 187.000 mil USD [2], so it's clear that there is vast possibility for somewhat small measures that can cut costs and increase benefit. Nowadays, the majority of EU countries are searching and applying various technical solutions that grant part restoration of the lost heat and maintain the saved energy as an alternative source for other building needs. This recovered energy can be further used in water preheating, building heating or as a source for air conditioning during summer [3]. The survey presented in [4] shows that DHW represents a substantial part of the energy balance in Norway's hotel sector. According to [5, 6], indicated the share of energy consumption can be in the range of 20-35% of the total energy bill. The maximum energy usage can be up to 50%. Overall, the DWH systems in hotels represent the second-largest consumer after HVAC systems [7]. The study [8], related to the environmental impact of DHW systems in hotels estimates very high, in the range of 2.87–3.2 kg-CO_2/ (person · night), specific CO_2 emissions.

Some estimations are that it is possible to recover up to 90% of the thermal energy from the GWW [9]. Wastewater contains heat energy mainly from bathing, laundry services, cooking process [9-11]. Flow of GWW is accessible during whole year with its temperature approximately around 30°C. This makes the energy utilization of this low-enthalpy source a suitable option (e.g. a heat pump application) [3]. A GWW can be more applicable as recovered energy because it represents a relatively clean source one [9].

One of the main issues when it comes to the hotel DHW heating system design (or other accommodation facilities), is to foresee the number of occupants because the tourism industry is highly dependent on the season and the occupancy rate may drastically vary on that and many other factors.

Statistical office of the EU, known as Eurostat gives us data that shows the mean occupancy rate of hotels in South part of Europe is around 69%. In Eastern part of Europe this rate has a little bit lower value, around 64% [12]. Regained energy from GWW in the tourism industry can be used for heating and cooling systems in accommodation facilities, agricultural greenhouses and draining dewatered sediment. In scientific circles, studies that are focused on raw GWW energy recovery stated some functional problems such as system corrosion, clog, or bio filth [13, 14].

In order to achieve a highly efficient DHW system, the main task is to select the appropriate renewable or heat recovery source. In the studies [15-17], the authors presented the implementation of a heat pump system with wastewater and solar energy source for a hotel type of building. Those studies mainly analyse the system's efficiency of the system without a techno-economical assessment. In [15], the authors provided data for the economic and environmental impact of integrated solar and wastewater source system. On the other side in this research, the real operated case study with a heat pump system with GWW plus rainwater collection system source associated with a gas boiler is comprehensively analysed (technologically and economically). Optimized system design and operation is proposed. An extensive assessment is carried out in comparison with the solar collectors system and with the conventional gas boiler system as the base case.

2. DHW system selection and description

In general, there are two ways of providing DHW - locally (decentralized) or by centralized systems. Decentralized DHW heating is used for individual consumers, due to their lower water consumption and consequently heat demand, while for a group of consumers, flow-through water heaters may be used. Accumulation heating is used for central systems when consumption is higher with a highly variable number of consumers. Fig. 1 is presented a detailed classification of systems for DHW preparation.

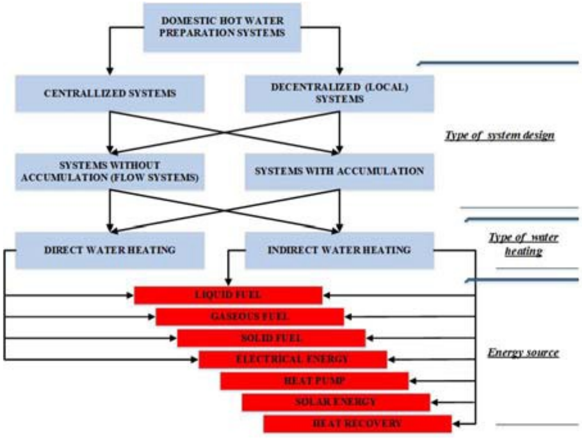

Figure 1: Classification of DHW systems

Depending on the category and year of construction of the hotel, various types of DHW heating systems can be found. In older hotels, the most commonly used systems are electric, oil or gas boilers, which can be implemented as a central or single design. Additionally, where conditions exist, a district heating system can be applied with central design (with accumulation or flow systems).

For the novel or refurbished hotels, DHW production in most cases is obtained by unconventional heating systems usually supported with one conventional source. The most used unconventional system in countries with good solar radiation is the solar collector system with accumulation. In Middle East countries this heat source can be used for the water desalination process, cooling absorption and also for the DHW production. In Europe in countries with similar climatic conditions like Serbia (moderate- continental), this system is mostly used supported with a conventional heat source for building heating or DHW production. For the DHW production in the middle and big size of hotels in Serbian climatic condition, rational techno-economic analysis suggests that solar fraction should be up to 40% of total energy demand.

The second commonly used unconventional system is a heat pump system. In the design process of the DHW system where the main source is the heat pump, one should pay attention to the device limits (maximum water temperature inlet and outlet, changes in capacity under variable operating conditions), compressor and refrigerant type, etc. For each system, the design of the device is considered separately, depending on the price and method of use.

For DHW systems in which the heat pump is the main source of heat, the design practice is most common in terms of capacity sizing. Namely, for the system where the gas boiler is the main and only source, the system is dimensioned for about 2-3 hours of heating. This is a short period for the heat pump system, as a result of the big investment rate of high heat pump capacity. According to that, these pumps are dimensioned to daily operate between 10-12h. With concerning this period it is necessary to provide more significant accumulation buffer volume. The total amount of DHW is usually dimensioned in three tanks, two with 30% and one of with 40% total volume, where operated water temperature in the buffers is achieved one by one. For these systems, one conventional boiler should be added, to ensure that water can heat up to 60°C, since most heat pumps can heat water up to 45-50°C. The boiler is dimensioned for a standard operating time, resulting in a small capacity reserve.

Heat pumps for the energy source usually use air, well water or ground heat. In this case, the system is modified to use waste heat from the sanitary and rainwater collectors. Using wastewater as a heat source for heat pumps requires a separation of grey and black wastewater as well as the filtration of GWW. GWW includes water from showers, washbasins, bars, or water that does not have solids, while black water includes wastewater from toilets and kitchens. Due to complicated purification, black water is not suitable for use in such systems. For this case study, rainwater (depending on the temperature level) is added as an additional heat source.

Coalescent filters are most commonly used for filtration of the GWW reused as an energy source. In addition to coalescent filters, Bernoulli filters, sand filters can be used, although sand filters are more complex to clean and rarely used in such systems. In order to understand which filters are suitable for water purification, it is mandatory to recognize the content of impurities in the wastewater and of course what is actually required for the operation of the system. For this case study, the purpose of wastewater treatment is to protect the plate heat exchanger from soiling, so in this case, mechanical water purification is required (removing elements in water that are not dissolved). Those that are dissolved, like oil, do not pose a problem in this case. A schematic of a coalescent filter is shown in Fig. 2.

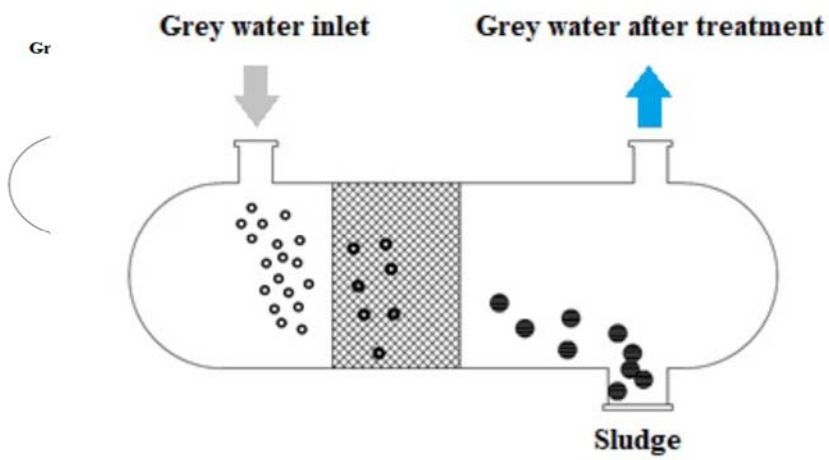

Figure 2: Schematic illustration of a horizontal coalescence filter

Coalescence filters are process vessels filed with the large surface area on which the particles are grouped, which causes them to be separated from the liquid phase by gravity or filtration. The main element of the filter is cartridge, which for water filters are usually made from PVC, in different dimensions of the openings. Filter sizing is based on water characteristics and flow parameters.

3. Selected hotel case study

For this research, a four-star hotel in climatic conditions of Novi Sad is selected and analysed. The building was opened in 2017. The hotel consists of two underground levels which provide space for a garage and technical rooms, and the ground floor has an entrance hall, reception, restaurant with a convenient kitchen for food, area for offices, as well as sanitary blocks. The gallery has a congress hall, a café-restaurant with kitchen, management offices and two sanitary blocks. From the first to the ninth floor are rooms and suites. Totally, the hotel has 144 rooms, 9 apartments, and a restaurant with a café for 136 people. Space for HVAC installations is on the roof. This research investigated totally 167 shower nozzles and bathroom faucet. The DHW is used for guest's personal hygiene and for facility cleaning.

3.1 Description of initial hotel design DHW system

The current hotel system for DHW heating consists of heat pump, gas boiler and other equipment necessary for operation (buffers for GWW collection, DHW accumulation tanks, heat exchangers, pumps, etc.). The problem with this system is the lack of a GWW source to ensure enough energy for heat pump operation. In case when there is a shortage of GWW flow, heat pump system stops and DHW heating is obtained by a gas boiler. In the last 2 years, according to the hotel management, the DHW system had a lot of operational problems where the gas boiler was the dominant energy source. Also, there is a lack of information related to energy data, consumption profiles, GWW capacity, etc.

3.2 System sizing and simulation of DHW energy needs

To ensure adequate DHW system design, this paragraph will provide necessary information related to system sizing and simulation of energy needs. System elements sizing and calculation of DHW requirements are carried out according to ISO 18523-1:2016 [18]. The ASHRAE Standard 90.1-2016 (section for hotel facilities) [19], is used to determine required daily DHW need. These standards showed similar numbers for DHW requirements. Calculated daily hotel demand for DHW is presented in Table 1.

Table 1:

Required daily hotel demand for DHW

Space type	Number of rooms (apartments)/ number of persons	The required daily need for DHW at 50°C [l/individual]	Total daily demand [l/day]
Double-bed room	144	100	14,400
Apartments	9	130	1,170
Café + Restaurant	136	28	2,120
TOTAL			17,690

For the selected hotel, dynamic energy simulation of DHW needs is done by T*SOL software [20]. Software calculation is based on the balance of energy flows and set up for a hotel building type with the usual operation schedule. The results are obtained by a mathematical model calculation with variable time steps from 1 to 6 minutes. In this case, the results of annual energy simulation showed the DHW heating energy supply of 178,824 kWh. Fig. 3 presents the average monthly results collected from dynamic energy simulation.

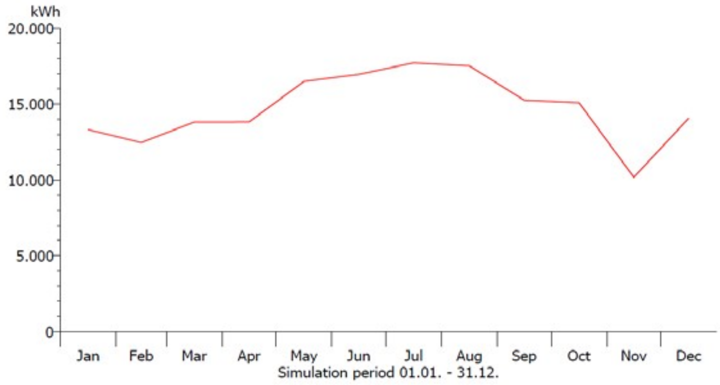

Figure 3: Average monthly values of DHW heating energy requirement

3.3 Onsite measurements

The building has a smart building management system which controls and operates the HVAC system, indoor temperature, and occupancy. Currently, there isn't a separate energy meter for the DHW system, and it's not possible to measure energy consumption. To optimise current design data and equipment capacities, onsite measurements were carried out from 1st May until 1st of October 2017.

During this period, hotel occupancy, GWW temperatures, and quantity of collected rainwater were monitored. On Fig. 4 minimal (33%) and maximal (88%) hotel occupancy can be observed. These values are corresponding to the measured minimal (10.8°C) and maximal (29.4°C) temperatures of GWW. The calculated average values of hotel occupancy are 68% (in agreement with [21]) and corresponded GWW temperature of 25.1°C. The temperature value dependence on occupancy is presented in Fig. 4.

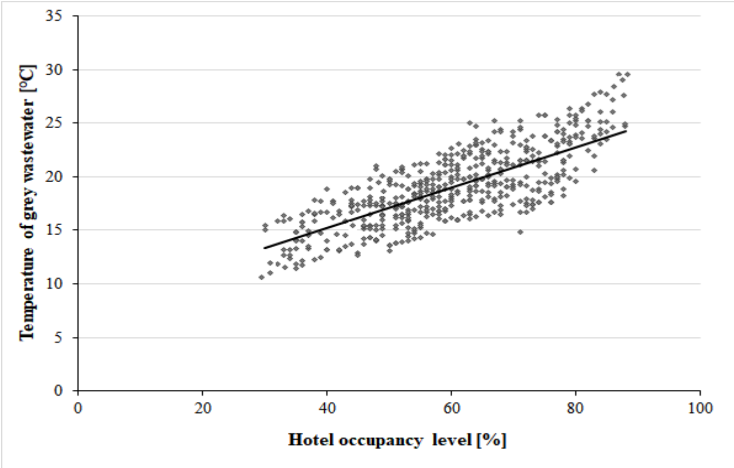

Figure 4: Temperature of GWW vs occupancy level in a hotel in Novi Sad

Additionally, in the same period from nearby meteorological station [22], data of rainwater perspiration were collected (Fig. 5). For the other remaining period of the year, the quantity of rainwater has 20-30% lower values. Average daily volume of collected rainwater from hotel roof area (700 m2) is 1,240 l/day.

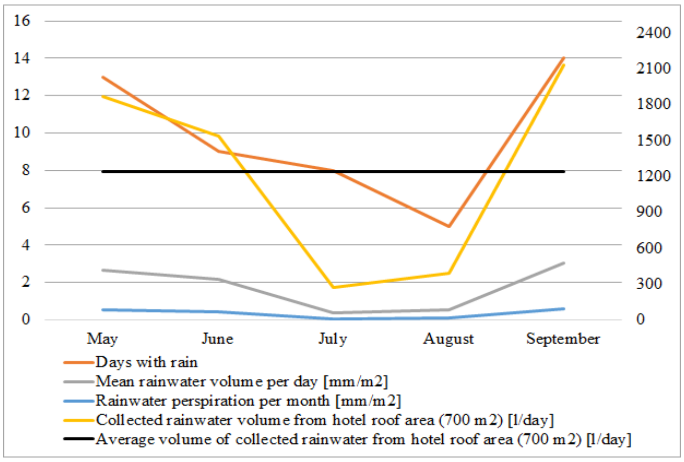

Figure 5: Novi Sad rainwater perspiration data collection [22]

In order to detect the design capacity of DHW system components, summarised initial conditions are provided in Table 2. Information is provided according to measurements and standards requirements. Period for measurement (May to September) is selected based on practice when the DHW is used for the longest time.

Table 2:

Initial hotel design conditions based on measurements and standards requirement

Component	Initial condition/measurement	Remarks
DHW heating temperature	50°C	The gas boiler operates to preheat the water (65°C) to eliminate Legionella
Required daily hotel demand for DHW	17,690 l	Standard requirement (100% hotel occupancy), for 68% hotel occupancy daily demand is 11,968 l
Annual energy for DHW heating	176.6 MWh	Result of dynamic simulation Daily value is 483.8 kWh
Average hotel occupancy	68%	Monitoring result
Average GWW temperature	25.1°C	Measurement result
Mass of GWW	26,693 kg	Calculated on 100% occupancy
GWW tank	15 m^3	Five tanks times 2.5m^3, calculated based on two daily peak consumption.
Mass flow of wastewater		
Minimum temperature of wastewater for heat pump operation	9°C	Control prerequisite
The daily working period for heat pump	16h	Design consideration
The daily working period for gas boiler	2h	Design consideration
The daily average quantity of collected rainwater (rainy day)	1,240 l	Monitoring result
Average rainwater temperature	12°C	Monitoring result, rainwater is used for (as) energy source only in case when the temperature is higher than 9°C. Otherwise, all water will be (is) diverted to the sewer drains.
DHW tank	13 m^3	Design condition for 68% occupancy (5+5+3m^3)
Technical water tank	0.8 m^3	Design consideration

The formula for a mass balance of GWW can be interpreted as:

$$m_{GWW}= m_{DHW}+ m_{RW} \quad (1)$$

where are:
m_{GWW} – GWW mass;
m_{DHW}– At 100% hotel occupancy DHW mass of restaurant and room sinks;
m_{RW} – Rainwater mass with Novi Sad mean annual temperature of (average of 12°C).

Accordingly, the GWW system energy balance is equal to:

$$m_{GWW} \cdot c_{wGWW} \cdot t_{wGWW} = m_{DHW} \cdot c_{wDHW} \cdot t_{wDHW}+ m_{RW}\cdot c_{wRW}\cdot t_{wRW} \quad (2)$$

c_{wGWW} – GWW specific heat [kJ/kgK];
t_{wGWW} – GWW temperature [°C];
c_{wDHW} - DHW specific heat [kJ/kg];
t_{wDHW} - DHW temperature [°C];
c_{wRW} - Rainwater specific heat [kJ/kg]
t_{wRW} - Rain temperature [°C].

The calculated total mass of GWW for hotel 100% is 26,693kg. For this kind of hotel facility a peak consumption can occur twice per day (first part of the day in the period of 7-9 AM, and a late one in the period of 9 - 11 PM). According to that an entire GWW tanks capacity of 15m^3 is adopted. The GWW accumulation consists of 6 tanks, where each has a capacity of 2.5m^3.

Besides GWW, the system allows the collection of rainwater which can be used also as a source of heat. Minimum temperate of the rainwater is set to 9°C. During the monitoring period [22], a 1,240 l is proved as the daily potential of rainwater accumulation.

Required daily need at 100% hotel occupancy for DWH is 17,690 l. Thus for the occupancy level of 68%, the daily demand is 11,968 l. Therefore, the three water reservoirs with cell configuration are selected for DHW system accumulation (two reservoirs with 0.5m^3 and one with 0.3m^3). The total annual energy consumption obtained from dynamic simulation is 178.8 MWh.

Adopted DHW heating system utilize a GWW collected from rooms and cafe restaurant. Additionally, in system can be added rainwater collection. A system operation precondition is a separation of GWW (hot water from showers and sinks) from black one (toilets). GWW collection varies from hotel occupancy and rainwater perspiration potential. Table 2 shows the calculated quantity of GWW, according to mass and energy balance, and measured data.

4. DHW system selection

4.1 Gas boiler system only

According to design considerations in section 3, the selection of a gas boiler is made. Considering that the gas boiler is the only energy source, the system will be dimensioned to 130% of the required capacity (DHW must be heated for 2 hours). Selection is made for two boilers (261 kW each), which is 65% of the total required capacity, as protection against possible damage to one of the boilers.

4.2 Solar collectors system assisted with gas boiler

For the second case, a solar collector system assisted with a gas boiler is selected. Dynamic simulation is done by T*SOL software [20]. Table 3 and Fig. 6 represent simulation results. This result allows to select an optimal number of solar collectors and the absorber area. The total solar absorber area is 77.7 m^2 (37 plate solar collectors), with inclination and azimuth angle of 30° and 40°, respectively. According to the climatic zone and hotel position with south-west solar collector orientation, this is an optimal system selection. This kind of systems in Serbia requires additional conventional energy source in order to substitute and to help water fast heating. For this purpose is a selected boiler with a nominal capacity of 350 kW.

Table 3:
T*SOL simulation results

Description	Value
Installed solar collector power	65.01 kW
Active irradiation on to collector surface	129,452 kWh
The energy delivered by collectors	57,598 kWh
Solar energy contribution to DHW	54,642 kWh
Energy from auxiliary heating – gas boiler	124,182 kWh
DHW solar fraction	31.2%
System efficiency	40%

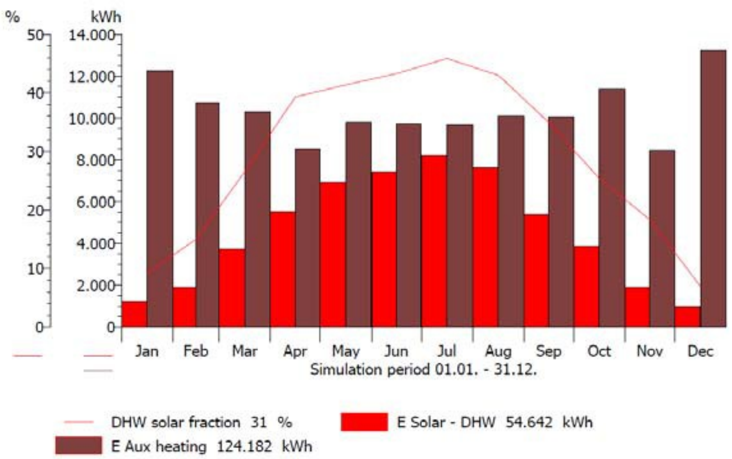

Figure 6: Participation of solar energy in the total DHW heating energy

4.3 Heat pump system with GWW source assisted with gas boiler

The basic requirement for DHW heat pump system design with GWW source is the separation of so-called black water and other GWW from showers, bathtubs, sinks, and bars. Of course, the pipes that conduct the water to the technical room should be preinsulated to preserve energy potential.

In order to choose an appropriate heat pump first step is to calculate available daily water flow. The technical recommendation is that, on the user heat pump side, water temperature change should be in the range from 3 to 5°C. For this case elements of the system at GWW side are selected with a temperature difference of 5°C (Evaporating temperature: te = tGWW - 5 [°C], Condensing temperature: tc = tDHW + 5[°C]). Water diverts to the sewer system by the three way-valve, if the GWW temperature doesn't meet the specification stated before.

In order to have more operating heat pump hours, a three-way regulation valve shall be set up on the return water pipe of the GWW side system. In that case, GWW can be re-used again by returning to the GWW reservoirs (a selected minimum return temperature is 9°C). For safe and stable DHW heating system operation (back up, filter maintenance, accident situation and water fast heating) an additional conventional energy source is necessary. For this purpose, a commercial gas boiler is picked (same as for solar collector system) with the capacity of 345 kW. Daily GWW flow can be calculated as:

$$\dot{V}_{\max}=n\cdot\dot{V}_{mo} \tag{3}$$

where are:

$\dot{V}_{\max}$ – The maximum water flow [l/day];

n – Re-circulations of GWW flow [-];

$\dot{V}_{mo}$ – GWW flow at maximal hotel occupancy [l/day];

$$n=\frac{t_{max}-t_{min}}{\Delta t_{mean}} \tag{4}$$

t_{max}– GWW temperature for selected hotel occupancy 29.4°C;

t_{min}– GWW minimum temperature of 9°C;

Δt_{mean}– Mean temperature difference of 5°C.

Depending on the occupancy level, the maximum possible recirculation for the maximal registered occupancy is n=3.22, while the average and minimal occupancy are 2.2 and 1 respectively. For further analysis re-circulations of GWW flow, n = 3 is adopted. The maximum daily GWW flow average of 64,400 l/day is calculated regarding starting and minimal required GWW temperature and adopted re-circulations rate. Also, the calculated heat pumps regime on the use side of 17/12°C is adopted.

Since the inflow of GWW is highly variable throughout the year, a heat pump with a power section of 0-50-100% with an operation time of 16 hours per day is adopted. According to that calculated mass flow is 1.12 kg/s. According to flow from the source side, two commercially available heat pumps were selected. Each flow rate from the side of the brine circuit is 0.55 kg/s, the heat capacity of 17.8 kW, with an adopted temperature difference of 55/50°C on the user side. Heat pump performance simulation is done with ProChill SWEGON software [23]. Simulation results, with a variation of GWW temperature at the evaporator side, are presented on Fig. 7. The figure presents values of the heat pump heat load capacity, electrical power, and expected COP. According to that, the calculated average COP of the heat pump is 3.7.

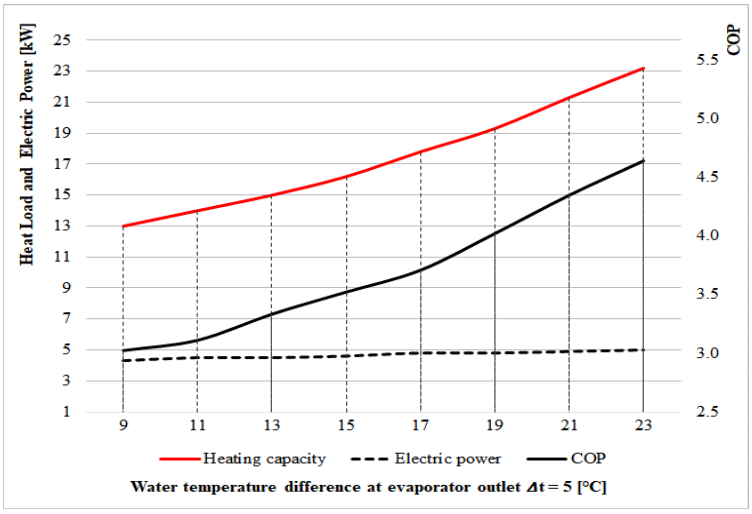

Figure 7: Simulation results of the heat pump performance

4.3.1 DHW heating system control modification and optimization

Fig. 8 presents the new hydraulic scheme of the DHW system with GWW as a source of heat. The new regulation system has two levels of control, which is connected to the hotel reservation system. The first signal comes from a sensor of GWW capacity, while the second signal is obtained by the temperature sensor of the DHW tank. If there is a minimum of $0.3m^3$ of GWW in the tank (capacity for one heat pump), heat pump/s will be on depending on the available GWW. The heat pumps heat the technical water tank in the limits from 40°C to 55°C, regarding the GWW capacity and required system response rate (quicker response - lower temperature). After the technical water has been heated according to the mentioned range, a circulating pump of the technical water and DHW tanks will be on. DHW tanks filling priority are determined on the basis of the anticipated hotel occupancy for the next day.

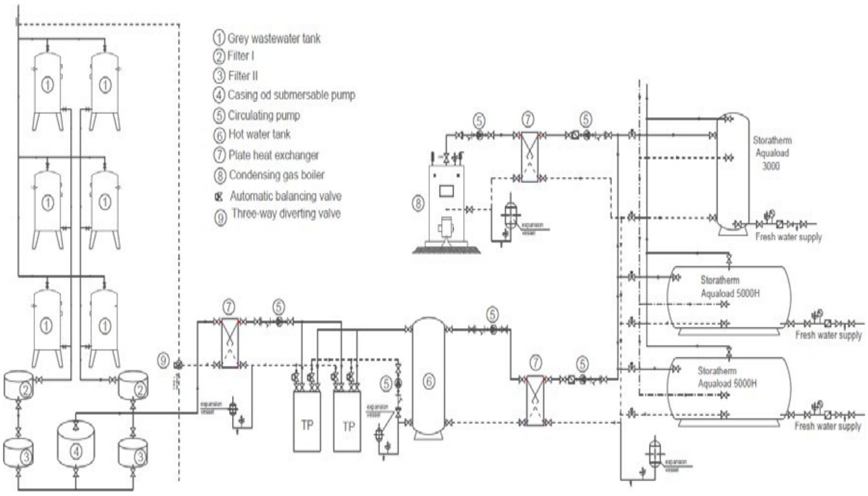

Figure 8: Proposed hydraulic scheme of DHW system with a GWW as a source of heat

The DHW system control is prioritized to operate with the heat pumps part. If there is not enough capacity due to insufficient GWW or slow response, a timed programmed gas boiler for the quick reaction will be on (the time range is from 6h to 23h). An additional exception is when the system is operating in anti- legionella mode (every weeknight between Sunday and Monday, from 1 AM to 3 AM, the total amount of DHW in the tanks is warmed to temperature 65-68°C, minimum for 2h). If the temperature in the DHW tanks falls below 40°C in the day period from 6 to 23h, the gas boilers will be on due to faster water heating. When the DHW temperature reaches 45°C, the gas boiler will switch off to turn off the heat pumps. Regarding interruptions due to coalescence filters cleaning (predicted once in 60 days) or because of potential demands for faster DHW heating, a gas boiler will be more in operation. If collected rainwater is with the temperature above 9°C, the additional water flow will be diverted to the GWW tanks. This can provide a greater potential for DHW system operation due to higher flow. If the temperature of rainwater is below 9°C, water is diverted into the sewage system. According to this optimized DHW system, the calculated percentage of gas consumption from the gas boiler is 6.8%.

Depending on the temperature after the heat exchanger, with a three-way switch valve, the GWW is returned to the tanks (a process of water recirculation). Idea is to reuse the water as long as it has a required temperature potential. If the return flow temperature of the GWW on the heat exchanger is lower than 9°C, the water is diverted to the sewer (controlled by three-way valve T1), which interrupts its further use in the system and disconnect the heat pumps. (Fig. 6).

5. Comparative techno-economic analysis

In today's practise, the final decision of DHW system selection usually comes from an investor or a company owner. Criteria such as system functionality and reliability are the most common, but in the end, the „decision-maker", usually become economical assessment. Also, an environmental impact and $CO2$ footprint are very respectable, but often (in developing countries such as Serbia) they become an added system value or promotional information.

In order to benchmark performed optimization of the heat pump DHW system with GWW source, a comparative techno-economic assessment is done. The analysis includes investment, operation and maintenance costs for three proposed DHW system solutions. For the base case, a gas boiler, as the most usual conventional system for DHW heating, was selected. A comparative analysis is done for the solar collectors' system and optimized heat pump system with the GWW source. Both of analysed systems are assisted with gas boiler. The Payback Period (PBP), discounted payback period (POP), Modified Internal Rate of Rate (MIRR) and Internal Rate of Return (IRR) and are used as economic indicators.

A payback period is a time (in years) it takes to receive cash flows sufficient to cover initial costs of investment with a 0% interest rate. If there is a real interest rate payback period is marked down.

IRR is only on cash flows on the specific project and this is the interest rate that generates the Present Worth PW = 0. The IRR measures the attractiveness of a single project. The main disadvantages of the IRR are:

- in case of two or more jointly privileged investment options IRR can’t be compared;
- in case of multiple sign changes of cash flows-e.g. a challenge with 3 negative cash flows, after which come 4 positive cash flows, and then again two negative cash flows-there are 2 sign changes and it may not have an exclusive solution in ***i*** for PW = 0.

Investments that show a negative IRR are very unappealing, and there is a range of negative and positive outcomes that can happen. Sometimes, governments and their agencies also award loans where part of the principal doesn’t need to be reimbursed, and those kind of loans are very appealing economically, but they have negative IRR [24].

Changed MIRR that entrust on external rates for investing and financing in order to handle several sign shifts in the series of the cash flow. The Modified Internal Rate of Rate can be calculated by either a single external rate or an external financing rate and an external investment rate. The extraneous qualifier highlights that these rates are extraneous to the project being judged. They come directly from the rates that investor regularly raises its investments [24].

Investment estimation, annual operation costs and results of comparative financial analysis are presented in table 4 and table 5. The result of the first IRR (-13%) iterations of the solar collectors' system revealed at least 26 years of lifespan, which is more than the optimal lifetime of equipment (20 years).

For the optimized heat pump system with GWW source, financial analysis proved very good indicators (PBP=4.5 years, POP=5.1 years, IRR=16%, MIRR=13%). The adopted discount rate for Serbia in 2018 was 4.39 % [24].

Table 4:
Investment estimation and annual operation costs

Selected DHW heating system	Estimation of investment cost [EUR]	Annual operation costs [EUR]	The difference investment costs [EUR]	Difference in annual operation costs [EUR]
Gas boiler system	55,230	7,060	-	-
Solar collectors system assisted with gas boiler	78,500	5,442	23,270	1,618
Optimized heat pump system with GWW source assisted with gas	65,090	4,854	9,860	2,206

Table 5:
Results of comparative financial analysis

System	PBP [years]	POP [years]	IRR [%]	MIRR [%]
Solar collectors system assisted with gas boiler	14.4	26	-13	-100
Optimized heat pump system with GWW source assisted with gas boiler	4.5	5.1	16	13

The previous cost analysis has not included the cost of technical maintenance. For the purpose of the analysis, these costs are projected at 0.5% of the annual investment cost for gas boilers, 1% for the solar system and 2% for heat pumps. The difference between investment, operation costs, and included maintenance costs are shown in Table 6.

Table 6:
Difference between investment and annual operation with maintenance costs

Selected DHW heating system	Estimation of investment cost [EUR]	Annual operation costs [EUR]	Annual operation with maintenance costs [EUR]	The difference in investment costs [EUR]	Difference in annual operation costs [EUR]
Gas boiler system	55,230	7,060	7,336.9		
Solar collectors system assisted with gas boiler	78,500	5,442	6,227.2	23,270	1109.8
Optimized heat pump system with GWW source assisted with gas boiler	65,090	4,854	6,094.5	9,860	1242.5

For the solar plate collectors system, analysis of the PBP has indicated that cumulative cash flows will be equal to investment costs after 21.3 years that is longer than 20 years of projected exploitation period (Table 7). According to PBP investment should not be realized. Calculating period of dynamic payback period would result in even more years and this method of investment's justification could not be applied.

Table 7:

Results of comparative financial analysis (added maintenance costs)

System	PBP [years]	POP [years]	IRR [%]	MIRR [%]
Solar collectors system assisted with gas boiler	21.3	-	-	-
Optimized heat pump system with GWW source assisted with gas boiler	7.9	9.3	5	10

Having in mind that the hotel's occupancy rate depends on the season, the next analysis shows the annual operation costs, including maintenance costs when the occupancy rate is above or below average 60-70%.

For the base scenario of the optimized heat pump system with GWW source, with average hotel occupancy of 68%, simulation results showed total gas participation of 5.1.

The decreasing number of guests results in a reduction of the GWW flow used for DHW heating with heat pumps system.

This will increase the participation of gas heating.

According to that, Table 8 and Fig. 7 show a sensitivity analysis in the case of an increase in gas participation in total consumption.

Table 8:

Adopted trend of an increasing percentage of gas consumption and operation costs

The trend of an increasing percentage of gas consumption [%]	Annual operation with maintenance costs [EUR]
10%	6496.4
15%	6909.1
20%	7321.6
25%	7734.2

Also, in Fig. 9 is presented link with total annual operation cost of gas boiler system only (dotted line).

Analysis of the hotel occupancy data and the gas consumption percentage in the heat pump system with GWW source, regarding only the total operating costs, with the increase of the gas participation from 6.8% to 20%, the heat pump cost-effectiveness will be equal as gas boiler system.

In case when the total costs (investment and total operation costs) are calculated, the cost-effectiveness of investment in heat pumps equals the gas boiler with an increase of the gas participation from 6.8% to 11% (Fig. 10).

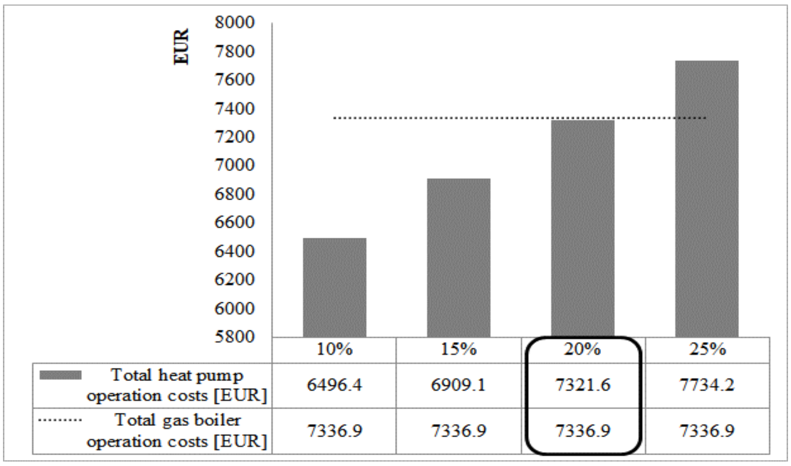

Figure 9: The link of total operating costs and the trend of gas consumption participation

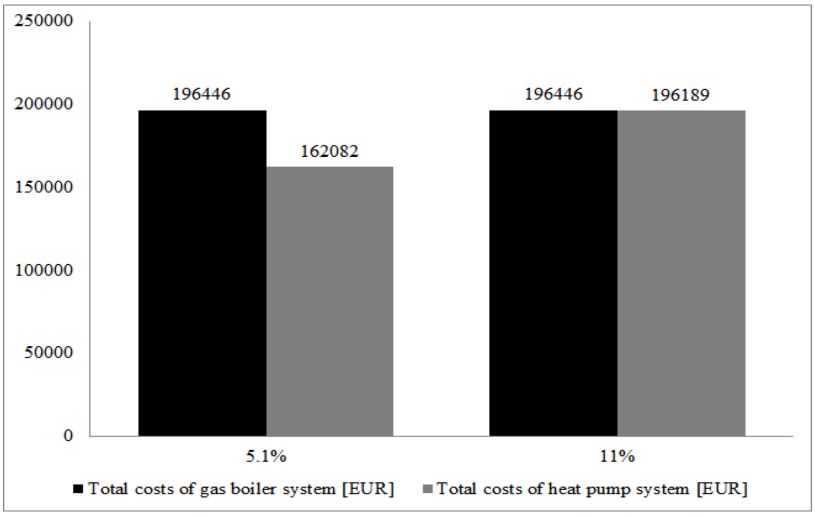

Figure 10: The link of total systems cost and gas consumption participation

6. Conclusions

DHW heating systems are one of the major technical elements of a hotel facility that must be operational all 365 days a year. In addition to the economic side of the system, equally important is the efficiency of the system and the reduction of environmental pollution, which directly affects the health and quality of life of each individual, and as such are very often the subject of analysis and refinement in many branches of engineering.

The conceptual designs for three different DHW heating systems, one system with gas boilers (conventional energy source) and two systems with renewable energy sources in bivalent connection with gas boiler, are presented in the paper. As shown through the calculation, a system that uses a gas boiler (only energy source) has the most expensive energy cost and the least expensive in terms of investment, while a system that uses waste heat from GWW is by far the cheapest operationally, while the investment is slightly higher than the gas boiler system.

Although Serbia is located in a part of Europe with high solar irradiation, solar collectors systems have proven to be an unprofitable choice. The reason for that is because electricity and gas prices are quite low, which is not the case in countries (e.g. Germany and Austria) with significantly higher electricity and gas prices and much lower solar potential. This shows that the profitability of the system depends on the energy market and country energy policy to which the target building belongs.

The system that uses waste heat from the GWW, as a heat pumps energy source, is the most cost-effective since the operation costs are much more favourable than the other two selected systems. The GWW system has great potential as an energy source, but it is very dependable on hotel occupancy and system maintaining. Also, the advantage of this system is that the heat from the GWW is not thrown away, but it is also a disadvantage because the system is quite complex and requires filter maintenance. If the system is not properly maintained, then it does not work properly and efficiently.

Financial analysis proved that the system with heat recovery from GWW is cost-effective and presents an excellent investment, in terms of all economic parameters. Results are very good, even if the worst scenario for the discount rate and maintaining cost is selected. Also, this creates a distinguished image for the hotel and company that operates a technical facility. In the end, the research presented encouraging practical application as a cost-effective hotel DHW heating system.

From the above, in order to have a cost-effective DHW system that functions 365 days a year, it is necessary to consider the real needs of the building for which the system is being dimensioned, the way the facility is used and to project peak consumption. In addition to the design of the system itself, it is necessary to anticipate the control system by which the system operates in the most efficient mode. Unless the system is properly designed and operated, in addition to being expensive, it will not meet customer needs, which is a far greater problem than high costs.

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Revista Română de Inginerie Civilă, Volumul 11 (2020), Numărul 3

Elemente privind certificarea si auditarea sistemelor districtuale de incalzire

Elements regarding the certification and audit district heating systems

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DOI:10.37789/rjce.2020.11.3.10

Rezumat

In lucrare se prezinta schema de baza a procedurilor de certificare si auditare energetica pentru doua componente termice de baza ale sistemului districtual de incalzire centrala : schimbatoarele de caldura si reteua termica de distributie. Dupa etapa de identificare constructiv-functionala a componentelor se evalueaza eficientele energetice ale acestora pe baza efectuarii de experimentari si se compara eficienta energetica obtinuta cu eficientele teoretice stabilite in doua variante functionale de referinta. Se face descrierea procedurii de certificare energetica pe baza notelor energetice si se evalueaza energiile disipate suplimentar, nejustificat, in vederea auditarii energetice, tinand seama de costurile de investitie a solutiilor de reabilitare propuse.

Cuvinte cheie: sisteme districtuale, incalzire

Abstract

The paper presents the basic schema of energy certification and auditing procedures for the two basic thermal components of district district heating: heat exchangers and thermal distribution network. After the constructive-functional identification of the components, their energy efficiency is evaluated based on experimentation and the energy efficiency obtained with the theoretical efficiency established in two functional reference variants. Describing the energy certification procedure on the basis of energy notes and assessing the additional unjustified energy dissipated for energy auditing, taking into account the investment costs of the proposed rehabilitation solutions

Keywords: district systems, heating

1. Introducere

Prin sistem districtual de incalzire se intelege un sistem de alimentare centralizata cu caldura a consumatorilor urbani. Acestia pot fi cladiri rezidentiale sau nerezidentiale, care utilizeaza energia termica pentru incalzirea spatiilor si/sau pentru prepararea apei calde. Componentele termice de baza ale unui sistem districtual de incalzire sunt schimbatoarele de caldura din punctele termice si reteaua de distributie de tip arborescent prin care se alimenteaza fiecare dintre consumatorii racordati la acest sistem centralizat.

Fiecare dintre cele doua componente mentionate lucreaza la parametrii energetici optimi in situatia in care starea constructiv-functionala a acestora este cea proiectata. Functionarea continua in regim curent de exploatare a acestor sisteme conduce inerent la deprecierea starii constructiv-functionale a acestor componente, cu consecinte energetice negative.

Reabilitarea constructiv-functionala a celor doua componente presupune in primul rand aplicarea unei proceduri coerente de identificare a starii acestor componente procedura care se finalizeaza cu certificarea energetica a fiecareia dintre componente. In continuare se propun solutiile de reabilitare pe fiecare componenta si se estimeaza costurile de investitie aferente si totodata beneficiile energetice rezultate astfel incat sa se poata estima rentabilitatea fiecarea dintre solutiile propuse. Procedurile care vor fi prezentate pe scurt se bazeaza pe o serie de cercetari teoretice si experimentale efectuate anterior, dintre care mentionam in principal o teza de doctorat [1].

2. Proceduri de identificare a starii constructiv-functionale a componentelor termice ale unui sistem districtual de incalzire.

Prin analiza starii constructiv-functionale cautam sa identificam masura in care starea constructiva a componentei este comparabila cu starea constructiva de proiectare a componentei respective, iar starea functionala a componentei este comparabila cu starea functionala de proiectare a respectivei componente. Mai concret, in cazul unui schimbator de caldura, afectarea starii constructive poate aparea prin depunerile de saruri de calciu pe peretii suprafetei de schimb de caldura sau prin blocarea / intreruperea circulatiei agentilor termici prin anumite circuite, iar afectarea starii functionale prin modificarea debitelor de agent termic fata de valorile de proiect. In cazul retelei termice afectarea starii constructive presupune degradarea gradului de izolare termica a tronsoanelor de conducta prin deteriorarea izolatiei termice atat in ceea ce priveste grosimea ei cat si a conductivitatii termice a acesteia. Starea functionala a retei termice este afectata prin modificarea debitelor de agent termic prin tronsoanele retelei fata de situatia de proiect. De regula, modificarea starii constructive are consecinte negative importante atat pentru schimbatoarele de caldura cat si pentru retelele termice in timp ce modificarea starii functionale are consecinte negative mai putin importante din punct de vedere energetic decat cele care apar in cazul deprecierii starii constructive si mai usor remediabile.

Pentru a descrie coerent procedurile de identificare se va face referire in mod separat la schimbatorul de caldura si separat la reteaua termica de distributie.

a. Cazul schimbatorului de caldura

In primul rand trebuie identificat tipul schimbatorului de caldura, suprafata acestuia si valorile nominale ale debitelor de agent termic : S, G_{10}, G_{20}.

Se efectueaza o prelevare a parametrilor termo-hidraulici pe schimbatorul de caldura in conditii curente de functionare, adica a parametrilor : G_1, G_2, t_{11}, t_{12}, t_{21}, t_{22}. Este de presupus ca aceste valori vor fi diferite de valorile omoloage nominale : G_{10}, G_{20}, t_{110}, t_{120}, t_{210}, t_{220}. Se va evalua eficienta schimpatorului de caldura in 3 ipoteze de functionare dintre care a treia este cea efectiva, identificata in cadrul experimentului.

a1. Prima ipoteza de functionare - se considera ca schimbatorul de caldura este curat, suprafata de schimb de caldura fiind neafectata iar debitele de agent termic sunt cele de proiectare. Se evalueaza prin calcul eficienta schimbatorului de caldura in conditiile in care setul parametrilor termo-hidraulici este : G_{10}, G_{20}, t_{11}, t_{12r}, t_{21}, t_{22r}. Debitele agentilor termici sunt considerate pe valorile nominale iar temperaturile agentilor termici la intrarea in schimbator au valorile prelevate in cadrul experimentului. Temperaturile agentilor termici la iesirea din schimbator se determina teoretic pe valorile t_{12r}, t_{22r} utilizand setul de relatii, [3], [4] :

$$\begin{aligned} t_{12r} &= \frac{(1-y)E}{1-yE}\cdot t_{11} + \frac{1-E}{1-yE}\cdot t_{21} \\ t_{22r} &= \frac{y(1-E)}{1-yE}\cdot t_{11} + \frac{1-y}{1-yE}\cdot t_{21} \end{aligned} \tag{1}$$

$$\begin{aligned} y_0 &= \frac{G_{10}}{G_{20}}; \\ NTU &= \frac{k\cdot S}{G_{10}\cdot(\rho\cdot c)} \\ E &= \exp[-NTU\cdot(1-y_0)] \end{aligned} \tag{2}$$

Determinarea coeficientului global de transfer termic al schimbatorului de caldura, k, se face urmand un calcul iterativ pe baza relatiilor, [5] :

$$\frac{1}{k} = \frac{1}{\alpha_1} + \frac{\delta_p}{\lambda_p} + \frac{1}{\alpha_2} \tag{3}$$

$$\alpha = \frac{\lambda}{\delta}\cdot Nu \tag{4}$$

$$\begin{aligned} Nu &= 0{,}0209\cdot \mathrm{Re}^{0,8}\cdot \mathrm{Pr}^{0,45} \quad \text{Timofeev - incalzire} \\ Nu &= 0{,}0263\cdot \mathrm{Re}^{0,8}\cdot \mathrm{Pr}^{0,35} \quad \text{Timofeev - racire} \end{aligned} \tag{5}$$

Procedura efectiva de lucru urmeaza o dezvoltare suplimentara privind criteriile Re si Pr, si expresiile specializate aferente constantelor de baza ale agentilor termici in ceea ce priveste proprietatile fizice ale acestora. S-a considerat ca in cadrul acestei lucrari nu este necesara intrarea in toate detaliile, cele prezentate fiind suficiente pentru intelegerea modului in care a fost pusa problema. Procedura mai amanuntita in acest sens este prezentata in unul din capitolele din lucrarea [5].

In continuare se calculeaza eficienta schimbatorului de caldura utilizand relatia :

$$\varepsilon_r = \frac{1-E}{1-y_0 \cdot E} \tag{6}$$

Se calculeaza si fluxul termic transferat in aceasta ipoteza de functionare cu :

$$\Phi_{SCH\_r} = G_{20} \cdot \rho \cdot c \cdot \left(t_{22r} - t_{21}\right) \tag{7}$$

a2. A doua ipoteza de functionare in care se considera ca schimbatorul de caldura este curat, suprafata de schimb de caldura fiind neafectata, iar debitele de agent termic sunt cele reale prelevate in cadrul experimentului. Se evalueaza prin calcul eficienta schimbatorului de caldura in conditiile in care setul parametrilor termo-hidraulici este : G_1, G_2, t_{11}, t_{12e}, t_{21}, t_{22e}. Temperaturile agentilor termici la iesirea din schimbator se determina teoretic pe valorile t_{12e}, t_{22e} utilizand acelasi set de relatii ca si in cazul a1, descris sintetic prin grupul de relatii (1)…(5). In final, dupa parcurgerea procesului iterativ de identificare a valorii coeficientului global de transfer de caldura, k, se calculeaza eficienta schimbatorului de caldura utilizand relatia :

$$\varepsilon_e = \frac{1-E}{1-y \cdot E} \tag{8}$$

Se determina si fluxul termic transferat in aceasta ipoteza de functionare cu :

$$\Phi_{SCH\_e} = G_2 \cdot \rho \cdot c \cdot \left(t_{22e} - t_{21}\right) \tag{9}$$

a3. A treia ipoteza de functionare este reprezentata chiar de situatia reala, cand parametrii termo-hidraulici au fost efectiv prelevati in cadrul experimentului. In aceasta situatie suprafata de schimb de caldura este afectata intr-o anumita masura, pe care tocmai suntem interesati sa o stabilim. Valoarea reala a eficientei schimbatorului de caldura, in aceasta situatie se stabileste direct pe baza parametrilor termici prelevati conform relatiei :

$$\varepsilon = \frac{t_{11} - t_{12}}{t_{11} - t_{21}} \tag{10}$$

La fel se determina fluxul termic transferat in aceasta ipoteza de functionare cu :

$$\Phi_{SCH} = G_2 \cdot \rho \cdot c \cdot (t_{22} - t_{21}) \tag{11}$$

In final se poate acorda schimbatorului de caldura un set de 3 note energetice, nota functionala (N_F), nota constructiva (N_C) si nota totala (N_T):

- Nota functionala : $N_F = \frac{\varepsilon_e}{\varepsilon_r} \cdot 100$ (12)
- Nota constructiva : $N_C = \frac{\varepsilon}{\varepsilon_e} \cdot 100$ (13)
- Nota totala : $N_T = \frac{\varepsilon}{\varepsilon_r} \cdot 100 = \frac{N_F \cdot N_C}{100}$ (14)

In vederea stabilirii pierderilor termice determinate de scaderea performantelor energetice ale schimbatorului de caldura prin depunerile de saruri de calciu pe placile schimbatorului, se va compara puterea termica transferata in situatia reala (ipoteza de functionare 3) cu puterea termica transferata in ipoteza de functionare 2, in care schimbatorul de caldura a fost considerat curat. Astfel :

$$\Delta\Phi_{SCH} = \Phi_{SCH\_e} - \Phi_{SCH} \tag{15}$$

Se poate defini un factor de depreciere energetica datorita depunerilor in timp pe placile schimbatorului de caldura ca raportul dintre caderea fluxului termic transferat conform relatiei (15) raportata la fluxul termic transferat in ipoteza 2 de functionare :

$$\gamma = \frac{\Delta\Phi_{SCH}}{\Phi_{SCH\_e}} = 1 - \frac{\Phi_{SCH}}{\Phi_{SCH\_e}} \tag{16}$$

b. Cazul retelei termice de distributie

Reteaua termica de distributie este o retea bifilara cu structura de regula arborescenta avand doua zone distincte : zona de ducere (tur) – care face legatura intre punctul termic si consumatori si zona de intoarcere (retur) – care face legatura intre consumatori si punctul termic. Din punct de vedere formal, matematic, relatiile sunt similare pe cele doua trasee astfel incat se va face referire numai la zona de tur.

Prima investigatie facuta consta in identificarea retelei expertizate, ceea ce presupune stabilirea geometriei retelei (traseele conductelor, lungimile si diametrele tronsoanelor), a starii functionale (debitele proiectate de agent termic si grosimea si tipul izolatiei termice a tronsoanelor retelei).

In continuare se trece la expertizarea termo-hidraulica efectiva prin prelevarea experimentala a parametrilor termo-hidraulici la capetele amonte si aval ale zonei de tur: debitul de agent termic la intrarea in reteaua termica si debitele de agent termic la fiecare din capetele aval (consumatori) si de asemenea temperaturile agentului termic la capul amonte si capetele aval ale retelei. La fel ca in cazul schimbatorului de caldura, se va evalua eficienta retelei termice in 3 ipoteze de functionare dintre care a treia este cea efectiva din cadrul experimentului.

b1. Prima ipoteza de functionare este, ca si in cazul schimbatorului de caldura, caracterizata prin :

- Tipul si grosimea izolatiei termice a tronsoanelor de conducta conform cu valorile de proiect;
- Debitul de agent termic la capul amonte a retelei si la toate capetele aval au valorile de proiect;
- Temperatura agentului termic la intrarea in retea are valoarea din cadrul experimentului efectuat;

Se calculeaza temperatura medie a agentului termic la capetele aval ale retelei termice utilizand setul de relatii :

$$t_m = \frac{G_1 \cdot t_1 + \ldots + G_k \cdot t_k + \ldots G_n \cdot t_n}{G_1 + \ldots + G_k + \ldots G_n} \tag{17}$$

Unde :

$$t_k = \left(E_1 \cdot \ldots \cdot E_k \cdot \ldots \cdot E_p\right) \cdot t_{PT} + \left[1 - \left(E_1 \cdot \ldots \cdot E_k \cdot \ldots \cdot E_p\right)\right] \cdot t_c \tag{18}$$

In relatia (17), k este indicele consumatorului iar in relatia (18), k este indicele de tronson de pe traseul care porneste din punctul termic si ajunge la consumator.

Modulii termici aferenti tronsoanelor de conducta se calculeaza conform relatiilor cunoscute (19):

$$E_k = \exp\left(-\frac{1}{\rho \cdot c} \cdot \frac{L_k}{R_k \cdot G_k}\right) \tag{19}$$

Cu valoarea temperaturii medii stabilite se calculeaza modulul termic echivalent al intregii retele care este ca valoare si eficienta retelei termice :

$$\varepsilon_r = E_{ech\_r} = \frac{t_{mr} - t_c}{t_{PT} - t_c} \tag{20}$$

b2. A doua ipoteza de functionare este caracterizata prin :

- Tipul si grosimea izolatiei termice a tronsoanelor de conducta conform cu valorile de proiect;
- Debitul de agent termic la capul amonte a retelei si la toate capetele aval au valorile prelevate in cadrul experimentului efectuat;
- Temperatura agentului termic la intrarea in retea are valoarea din cadrul experimentului efectuat;

Ca rezolvare, in aceasta a doua ipoteza de lucru, situatia este similara cu prima ipoteza, numai ca setul de debite prin tronsoanele de conducta ale retelei este de aceasta data cel efectiv identificat in cadrul experimentului. Se intelege ca daca sunt cunoscute valorile debitelor de agent termic la capetele aval ale retelei si cunoscand geometria arborelui retelei se pot cu usurinta determina valorile debitelor de agent termic pe fiecare tronson de retea. Urmand aceeasi procedura de lucru ca in cazul b1, rezulta in final modulul termic echivalent al intregii retele care este ca valoare si eficienta retelei termice:

$$\varepsilon_e = E_{ech\_e} = \frac{t_{me} - t_c}{t_{PT} - t_c} \tag{21}$$

b3. A treia ipoteza de functionare este reprezentata chiar de situatia reala, cand atat parametrii hidraulici cat si cei termici au fost efectiv prelevati in cadrul experimentului. In aceasta situatie avem de face cu starea reala a gradului de izolare termica a tronsoanelor de conducata din cadrul retelei ceea ce conduce la valorile efectiv prelevate ale temperaturilor agentului termic la capetele aval ale retelei. In aceasta situatie trebuie doar sa determinam media ponderata a temperaturilor agentului termic la capetele aval ale retelei cu debitele de agent termic corespunzatoare, conform relatiei (17) .

Rezulta in consecinta modulul termic echivalent real al intregii retele care este ca valoare si eficienta reala a retelei termice :

$$\varepsilon = E_{ech} = \frac{t_m - t_c}{t_{PT} - t_c} \tag{22}$$

3. Certificarea si auditarea energetica a componentelor sistemului districtual

Referitor la schimbatorul de caldura, prin cele 3 note se certifica starea constructiv-functionala a schimbatorului de caldura. Cu cat valorile acestor note sunt mai scazute decat 100 cu atat starea constructiv-functionala a schimbatorului de caldura este mai afectata.

De regula nota functinala este mare chiar daca debitele de agenti termici sunt alterate, insa de asemenea de regula, nota constructiva este sensibil mai scazuta, atestand o depreciere a suprafetei de schimb de caldura. Nota totala a schimbatorului de caldura trebuie asociata cu o crestere de putere termica furnizata de sursa, astfel incat prin schimbatorul de caldura afectat de deprecierile constructiv-functionale identificate, sa poata fi transferata puterea termica necesara la consumator. Astfel pentru ca prin schimbatorul de caldura avand in situatia existenta o capacitate de transfer termic mai redusa sa poata fi transferta puterea termica necesara la consumator este necesara ridicarea potentialului termic pe agentul primar, ceea ce insemna o scadere a randamentului la cazan si o crestere a pierderilor termice pe reteaua termica primara.

Evaluarea puterii termice suplimentare furnizate de sursa pentru ca prin schimbatorul de caldura existent, afectat functional si constructiv, sa poata fi transmisa puterea termica necesara consumatorului se va face cu relatia :

$$\Delta\Phi_{SCH} = \gamma \cdot \Phi_{SCH\_e} \tag{23}$$

Stabilirea unor domenii de valori ale notei energetice totale astfel incat sa se poata face o grupare pe clase energetice, va fi realizata in viitor, astfel incat sa se poata avea o imagine mai clara asupra starii schimbatorului de caldura investigat.

Evaluarea puterii termice suplimentar furnizata de sursa datorita deprecierii starii constructiv-functionale a schimbatorului de caldura este direct corelata cu puterea termica necesara consumatorului care la randul ei depinde direct de temperatura exterioara. In acest fel rezulta o corelatie directa intre puterea termica suplimentar furnizata de sursa datorita deprecierii starii constructiv-functionale a schimbatorului de caldura cu temperatura exterioara. Tinand in continuare seama de duratele de aparitie pe parcursul sezonului rece a diferitelor valori de temperatura exterioara se pot evalua consumurile termice suplimentare corespunzatoare puterilor termice suplimentar furnizate de sursa si in final consumul energetic nejustificat la nivelul intregului an. Acestui consum energetic nejustificat la nivelul intregului an ii corespunde o valoare in euro care este cheltuita nejustificata si care poata fi anulata prin masuri de reabilitare termo-hidraulice la nivelul schimbatorului de caldura. O analiza mai amanuntita conduce la identificarea solutiei de reabilitare celei mai rentabile pentru a fi implementata. In acest fel se realizeaza auditul energetic al schimbatorului de caldura din punctul termic.

In ceea ce priveste reteaua termica de distributie, la fel, se poate acorda un set de 3 note energetice, nota functionala, nota constructiva si nota totala :

- Nota functionala : $N_F = \dfrac{\varepsilon_e}{\varepsilon_r} \cdot 100$ (24)

- Nota constructiva : $N_C = \frac{\varepsilon}{\varepsilon_e} \cdot 100$ (25)

- Nota totala : $N_T = \frac{\varepsilon}{\varepsilon_r} \cdot 100 = \frac{N_F \cdot N_C}{100}$ (26)

Prin cele 3 note se certifica starea constructiv-functionala a retelei termice. Cu cat valorile acestor note sunt mai scazute decat 100 cu atat starea constructiv-functionala a retelei termice este mai afectata.

De regula nota functionala este mare chiar daca debitele de agent termic sunt alterate, insa de asemenea de regula, nota constructiva este sensibil mai scazuta, atestand o depreciere a gradului de izolare termica a retelei pe ansamblul ei. Nota totala a retelei termice trebuie asociata cu o pierdere nejustificata de putere termica pe traseul retelei catre canalul termic datorata in special deprecierii gradului de izolare termica a tronsoanelor acesteia.

In cazul in care se considera oportuna identificarea in detaliu a starii gradului de izolare termica pe fiecare tronson al retelei termice se poate face apel la lucrarea [5] unde intr-unul din capitole este descrisa procedura experimentala mentionata.

Evaluarea puterii termice pierdute suplimentar, nejustificat, in canalul termic, se va face evaluand pe rand pierderile termice ale retelei in ipoteza functionala 3 si in ipoteza functionala 1 (in ultimul capitol din [2] se gaseste prezentarea in detaliu) :

$$\Delta\Phi_{RT} = \Phi_{RT} - \Phi_{RTr} = (\xi - \xi_r) \cdot \Phi_r \qquad (27)$$

Unde :

$$\xi = \frac{(1-\varepsilon)\cdot(1+\varepsilon \cdot E_C)}{\varepsilon \cdot (1-E_C)}$$
$$\xi_r = \frac{(1-\varepsilon_r)\cdot(1+\varepsilon_r \cdot E_C)}{\varepsilon_r \cdot (1-E_C)} \qquad (28)$$

Iar :

$$E_C = \frac{t_{R0} - t_{i0}}{t_{T0} - t_{i0}} \qquad (29)$$

Stabilirea unor domenii de valori ale notei energetice totale astfel incat sa se poata face o grupare pe clase energetice, va fi realizata in viitor, astfel incat sa se poata avea o imagine mai clara asupra starii retelei termice investigate.

Evaluarea puterii termice pierdute nejustificat datorita deprecierii starii constructiv-functionale a retelei termice este direct corelata cu puterea termica necesara consumatorului care la randul ei depinde direct de temperatura exterioara. In acest fel rezulta o corelatie directa intre puterea termica pierduta nejustificat datorita deprecierii starii constructiv-functionale a retelei termice, de temperatura exterioara. Tinand in continuare seama de duratele de aparitie pe parcursul sezonului rece a diferitelor valori de temperatura exteriora se pot evalua consumurile termice suplimentare corespunzatoare puterilor termice pierdute nejustificat si in final consumul energetic nejustificat la nivelul intregului an. Acestui consum energetic nejustificat la nivelul intregului an ii corespunde o valoare in euro care este cheltuita nejustificat si care sa poata fi anulata prin masuri de reabilitare termo-hidraulica la nivelul retelei de distributie. O analiza mai amanuntita conduce la identificarea solutiei de reabilitare celei mai rentabile pentru a fi implementata. In acest fel se realizeaza auditul energetic al retelei termice de distributie.

4. Concluzii

Identificarea starii constructiv-functionale a componentelor unui sistem districtual de incalzire este posila prin evaluarea eficientei termice a celor doua componente in situatia de exploatare curenta si compararea cu valorile omoloage de eficiente in varianta de proiectare.

In lucrare se disting 3 variante functionale care permit aprecierea efectului dereglarilor functionale si a deprecierilor constructive. Se remarca faptul ca dereglarile functionale nu au consecinte energetice negative semnificative in raport cu deprecierile constructive care afecteaza eficienta energetica in mod semnificativ. Si din punct de vedere al reabilitarii starii componentelor sistemului districtual de incalzire se poate spune ca este mult mai usor si mai ieftin de a corecta dereglarile hidraulice fata de corectiile constructive necesare (depunerile de piatra in cazul schimbatoarelor de caldura si deterioararea izolatiei termice in cazul retelelor de distributie).

Procedura de certificare si auditare energetica a componenetelor termice din cadrul sistemului districtual de incalzire are la baza conventia ca eficienta energetica a acestor componente este maxima in varianta functionala 1 (de proiectare).

Certificarea energetica se face pe baza notelor totale acordate celor doua componente si poate fi dezvoltata, daca se face apel la clase energetice. Auditarea energetica a celor doua componente face apel la evaluarea energiilor termice disipate suplimentar nejustificat si la evaluarea costurilor de investitie necesare pentru reabilitarea respectivelor componente. Pe baza acestora se poate trece la evaluarea rentabilitatii solutiilor de reabilitare propuse si a stabilirii solutiei cele mai oportune.

Lista de Notatii

SCH – schimbator de caldura;
RT – retea termica;
t_{11} – temperatura de intrare a agentului termic primar in schimbatorul de caldura, ^oC;
t_{12} – temperatura de iesire a agentului termic primar din schimbatorul de caldura, ^oC;
t_{21} – temperatura de intrare a agentului termic secundar in schimbatorul de caldura, ^oC;
t_{12} – temperatura de iesire a agentului termic secundar din schimbatorul de caldura, ^oC;
t_{PT} – temperatura agentului termic la intrarea in reteaua termica, ^oC;
t_1, t_2, …, t_n – temperaturile agentului termic la capetele aval ale retelei termice, ^oC;
t_c – temperatura mediului din canalul termic, ^oC;
$t_{m,}$ t_{mr}, t_{me}– temperaturea medie a agentului termic la capetele aval ale retelei termice, ^oC;
t_{T0}/t_{R0} – temperaturile nominale ale agentului termic la dimensionarea instalatiilor de incalzire a consumatorilor deserviti, ^oC;
t_{i0} – temperatura interioara normata din spatiile incalzite, ^oC;
G – debitul de agent termic printr-un tronson de conducta, m^3/s;
G_1 – debitul de agent termic primar prin schimbatorul de caldura, m^3/s;
G_2 – debitul de agent termic secundar prin schimbatorul de caldura, m^3/s;
G_{10} – debitul nominal de agent termic primar prin schimbatorul de caldura, m^3/s;
G_{20} – debitul nominal de agent termic secundar prin schimbatorul de caldura, m^3/s;
G_1, G_2, …, G_n – debitele de agent termic la capetele aval ale retelei termice, m^3/s;
S – suprafata schimbatorului de caldura, m^2;
k – coeficientul global de transfer termic aferent schimbatorului de caldura, $W/m^2.K$;
α_1 – coeficientul de transfer termic convectiv pe circuitul primar al schimbatorului de caldura, $W/m^2.K$;
α_2 - coeficientul de transfer termic convectiv pe circuitul secundar al schimbatorului de caldura, $W/m^2.K$;
ρ - densitatea agentului termic, kg/m^3;
c – caldura specifica masica la presiune constanta a agentului termic, J/kg.K;
δ - dimensiunea caracteristica in cazul convectiei, m;
λ - conductivitatea termica a agentului termic, W/m.K;
δ_p – grosimea placii schimbatorului de caldura, m;
λ_p - conductivitatea termica a placii schimbatorului de caldura, W/m.K;
Φr – necesarul termic al consumatorului intr-o situatie curenta, W;
$\Delta\Phi_{SCH}$ – pierderi termice suplimentare nejustificate aferente SCH, W;
$\Delta\Phi_{RT}$ – pierderi termice suplimentare nejustificate aferente RT, W;
L – lungimea tronsonului de conducta, m;
R – rezistenta termica liniara a tronsonului de conducta, m.K/W;
Nu – criteriul Nusselt , -;

Re – criteriul Reynolds, -;
Pr – criteriul Prandtl, -;
y – raportul subunitar al debitelor G_1/G_2, -;
y_0 – raportul subunitar al debitelor nominale G_{10}/G_{20}, -;
NTU – numarul de unitati de transfer termic aferent schimbatorului de caldura, -;
E – modulul termic aferent schimbatorului de caldura / tronsonului de conducta, -;
E_1, E_2, …,E_p – moduli termici aferenti tronsoanelor de pe un traseu al retelei, -;
E_{ech_r} – modulul termic echivalent al retelei termice in ipoteza functionala 1, -;
E_{ech_e} – modulul termic echivalent al retelei termice in ipoteza functionala 2, -;
E_{ech} – modulul termic echivalent al retelei termice in ipoteza functionala 3, -;
E_C – modulul termic aferent instalatiilor de incalzire ale consumatorilor, -;
ε_r – eficienta energetica a SCH sau RT in ipoteza functionala 1, -;
ε_e – eficienta energetica a SCH sau RT in ipoteza functionala 2, -;
ε – eficienta energetica a SCH sau RT in ipoteza functionala 3, -;
ξ_r, ξ - cotele pierderilor termice in reteua termica de distributie din puterea termica livrata la consumatori, in ipoteza functionala 1 si respectiv 3;
Φ_{SCH} – fluxul termic transferat prin schimbatorul de caldura, W;
N_F – nota functionala a SCH sau RT, -;
N_C – nota constructiva a SCH sau RT, -;
N_T – nota totala a SCH sau RT, -;

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