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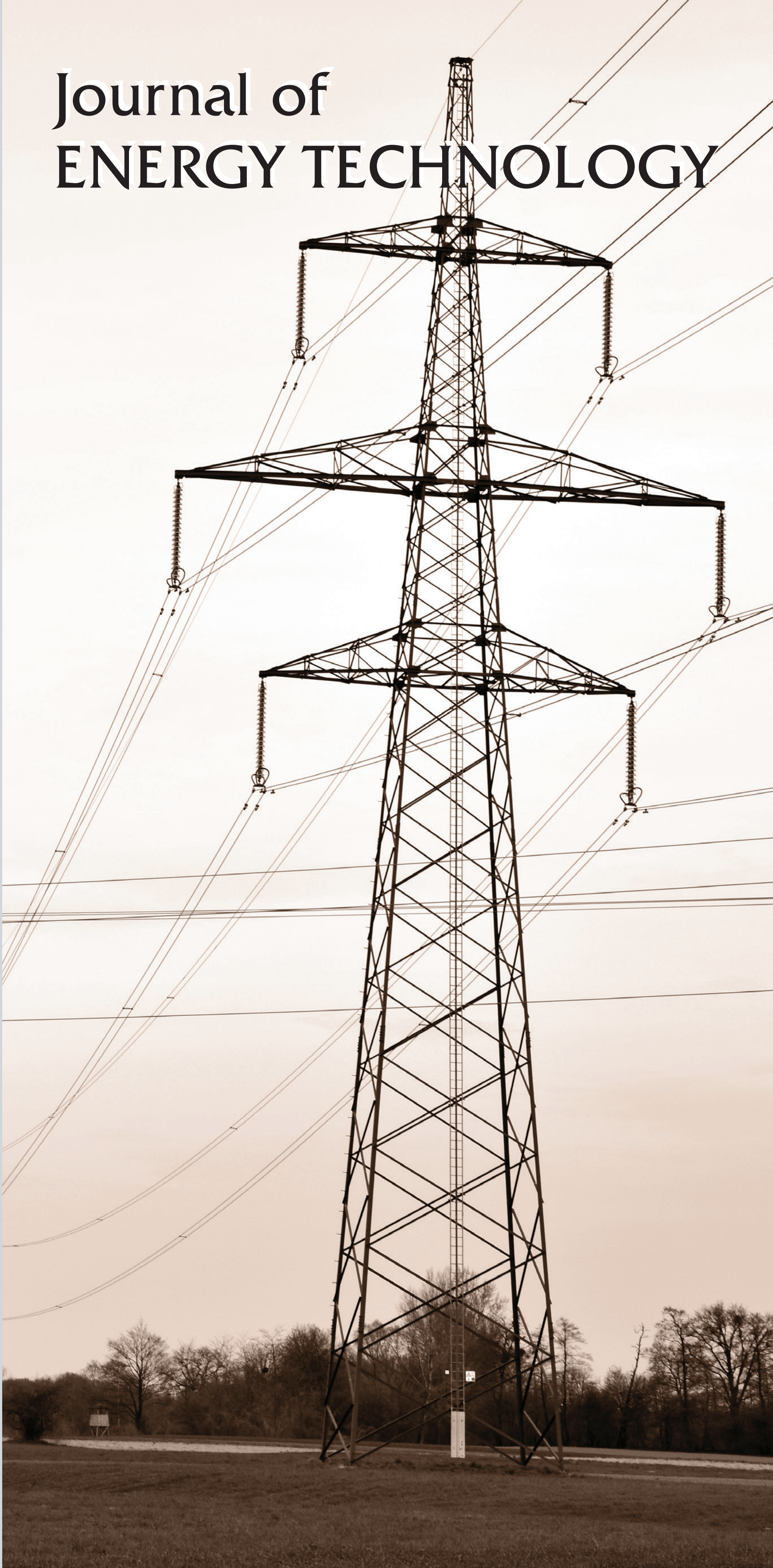

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Spoštovani bralci revije Journal of energy technology (JET)

Pridobivanje električne energije iz potencialne energije vode je izjemnega pomena. Največja hidroelektrarna na svetu je Three Georges Dam na reki Jangce na Kitajskem in v literaturi navajajo, da je inštalirana moč elektrarne preko 22500 MW. Zgrajena je bila leta 2007. Pred njo je imela sloves največje elektrarne na svetu hidroelektrarna Itaipu, na meji med Brazilijo in Paragvajem na reki Parana z močjo približno 14000 MW. Največja elektrarna v Evropi je ukrajinska jedrska elektrarna Zaporizhia z inštalirano električno močjo 5700 MW. Največja evropska vodna elektrarna je Đerdap 1 (na meji med Srbijo in Romunijo) z inštalirano močjo 2252 MW (56. največja hidroelektrarna na svetu). Zanimiv je podatek, da je med prvimi desetimi največjimi elektrarnami na svetu kar devet hidroelektrarn.

Tudi v Sloveniji predstavlja električna energija, ki jo pridobimo iz hidroelektrarn, pomemben delež, saj le ta znaša tretjino vse pridobljene električne energije. Seveda so vodne elektrarne v Sloveniji neprimerno manjših dimenzij; največja je HE Zlatoličje na reki Dravi z inštalirano močjo 130 MW. Kljub temu, da uvrščamo hidroelektrarne k obnovljivim virom energije, zaznavamo ekološke probleme, ki jih bo v prihodnje potrebno rešiti. Eden takšnih je zagotovo prehajanje vodnega življa; jezovi hidroelektrarn v mnogih primerih prekinejo ustaljeno gibanje živali, t. i. ribje steze oz. tuneli. Prav zato bo potrebno v bodoče pri gradnji upoštevati še bolj vse ekološke dejavnike, da se bodo zagotovili dobri pogoji za življenje ljudem ter celotnemu ekosistemu.

Veliko upanja se polaga v alternativne izvedbe hidroelektrarn in nadaljnji razvoj hidromehanike. Pri gradnji hidroelektrarn je v preteklih desetletjih sodelovalo več slovenskih podjetij. Prav zato je znanje, ki smo ga usvojili, še kako pomembno in dragoceno. V pričujoči številki revije JET si lahko preberete članek na tematiko s področja hidroenergetike.

Jurij AVSEC
odgovorni urednik revije JET

Dear Readers of the Journal of Energy Technology (JET)

Obtaining electricity from the potential energy of water is of utmost importance; energy from rivers and lakes is classified as a renewable source of energy. the largest hydroelectric power plant in the world is the Three Georges Dam, on the Yangtze River in China, with power exceeding 22500 MW. The dam was built in 2007, prior to which the largest hydroelectric power plant was Itaipu, built on the border between Brazil and Paraguay on the Parana River producing 14,000 MW. The largest power plant in Europe is the Ukrainian nuclear power plant Zaporizhia with installed power of 5700 MW, the largest European water power plant is Djerdap 1 (on the border between Serbia and Romania) with installed electric power of 2252 MW; it is the 56th largest hydroelectric power plant in the world.

It is interesting to note that there are nine hydroelectric plants among the top ten largest power plants in the world. In Slovenia, too, the exploitation of hydro energy is essential, as the nation acquires as much as a third of its electricity through hydroelectric power plants. Naturally, water power plants in Slovenia are of lesser size: the largest, HPP Zlatoličje is on the Drava River with a capacity of 130 MW. Despite the fact that such power plants are classified as renewable energy sources, there are quite a number of ecological problems that will need to be solved in the future. One of these is certainly the movement of aquatic life, for which the dam of hydroelectric power plants is in many cases an insurmountable obstacle. Therefore, it will be necessary to foresee all ecological factors in the future constructions of dams even more, so that we will provide favourable living conditions for both people and all ecosystem.

There is also much hope in alternative versions of hydroelectric power plants and in the development of hydrotechnics and hydromechanics. In the construction of hydroelectric power plants, many Slovenian companies have been involved in the past decades, which is why the knowledge we have and which we still have is valuable and should not be lost. In the present issue of JET magazine, we review an article on the topic of hydro-energy.

Jurij AVSEC
Editor-in-chief of JET

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Journal of Energy Technology

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EXPERIMENTAL INVESTIGATIONS OF PIPELINE FILLING AND EMPTYING IN A SMALL-SCALE APPARATUS

EKSPERIMENTALNE RAZISKAVE POLNJENJA IN PRAZNJENJA CEVOVODA MALIH IZMER

Uroš Karadžić[ℜ], Anton Bergant[1]

Keywords: pipeline, filling, emptying, instrumentation, results of measurements

Abstract

This paper serves as a reference for further investigations of pipeline filling and emptying in a relatively small-scale pipeline apparatus. The apparatus consists of an upstream end high-pressurized tank, horizontal steel pipeline, four valve units positioned along the pipeline including the end-points, and a downstream end tank. The filling of an initially empty pipeline is performed by a sudden opening of the valve positioned at the high-pressurized tank filled with water. The pipeline-emptying process is accomplished by high-pressurized air supplied from the air reservoir installed at the high-pressurized tank. The high-pressurized tank is closed, and the downstream end valve is opened. Experimental results indicate that pressure fluctuations are larger for pipeline filling in comparison to pipeline emptying. It is shown that a piezoelectric transducer with a fixed relatively low discharge time constant is not entirely appropriate for accurate low-frequency pressure measurements.

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Povzetek

Prispevek daje osnove za nadaljne raziskave polnjenja in praznjenja cevovoda relativno malih izmer. Preizkusno postajo sestavljajo gorvodna visokotlačna posoda, horizontalni jekleni cevovod, štirje bloki z ventili vgrajeni vzdolž cevovoda in robovih ter dolvodna posoda. Polnjenje praznega cevovoda izvedemo s hitrim odpiranjem ventila, ki je vgrajen pri gorvodni visokotlačni posodi napolnjeni z vodo. Praznjenje cevovoda napolnjenega z vodo dosežemo z vpihovanjem komprimiranega zraka na gorvodnem koncu. Visokotlačna posoda je pri tem zaprta, dolvodni ventil pa odprt. Rezultati meritev kažejo, da so tlačne obremenitve večje pri polnjenju cevovoda. Izkazalo se je, da piezometrično tlačno zaznavalo z relativno nizko tokovno konstantno ni najbolj primerno za merjenje nizkofrekvenčnih tlakov.

1 INTRODUCTION

The filling with liquid of an initially empty pipeline and the emptying of an initially liquid-filled pipeline are of great interest due to the many practical applications. Rapid pipe filling and emptying occur in various hydraulic applications, such as water-distribution networks, storm-water and sewage systems, fire-fighting systems, oil transport pipelines, and pipeline cleaning. During the rapid filling of an empty pipeline, while the water column is driven by a high head, air is expelled by the advancing water column. For emptying of a pipeline initially filled with water, water is expelled out of the system while the air is blown into the pipeline, *[1].* Rapid filling and emptying of the pipeline may be considered as a specific case of water hammer with column separation in which both vaporous and gaseous cavities may be present, *[2].* The filling and the emptying of the large-scale pipelines has been experimentally studied, *[1]*, *[3]*, *[4]*, *[5].*

Developers and users of computational codes (in-house, commercial) need measurement data with which to compare their theoretical models. Unfortunately, such data are limited and fragmented. There is a strong need for enhanced well-controlled measurements of the water hammer, column separation, fluid-structure interaction, and pipeline filling and emptying. To address these needs, a flexible experimental apparatus has been developed and installed at the University of Montenegro, *[6].* The small-scale apparatus consists of an upstream end high-pressurized tank, horizontal steel pipeline (length 55.37 m, inner diameter 18 mm), four valve units positioned along the pipeline including the endpoints, and a downstream end tank (outflow tank). The first tests of filling and emptying have been performed recently, and the initial results of the measurements are presented and discussed in this paper, an extended and updated version of a conference paper, *[7].*

2 EXPERIMENTAL APPARATUS

A small-scale unsteady friction-dominated pipeline apparatus has been designed and constructed at the Faculty of Mechanical Engineering, University of Montenegro, *[6]*, for investigating rapid water hammer events including column separation and fluid-structure interaction (pressure changes last for few seconds only), *[6].* Recently the apparatus has been modified for performing pipeline filling and emptying events that are characterized both by rapid and gradual pressure changes, *[4]*, *[5].* The apparatus is comprised of a horizontal pipeline that connects the upstream end high-pressurized tank to the outflow tank (steel pipe of total length L = 55.37 m (U_x = ±0.01 m); internal diameter D = 18 mm (U_x = ±0.1 mm); pipe wall thickness e = 2 mm (U_x = ±0.05 mm); maximum allowable pressure in the pipeline $p_{max,all}$ = 25 MPa); see Fig. 1. The uncertainty in a measurement U_x is expressed as the root-sum-square combination of bias and precision error, *[8].*

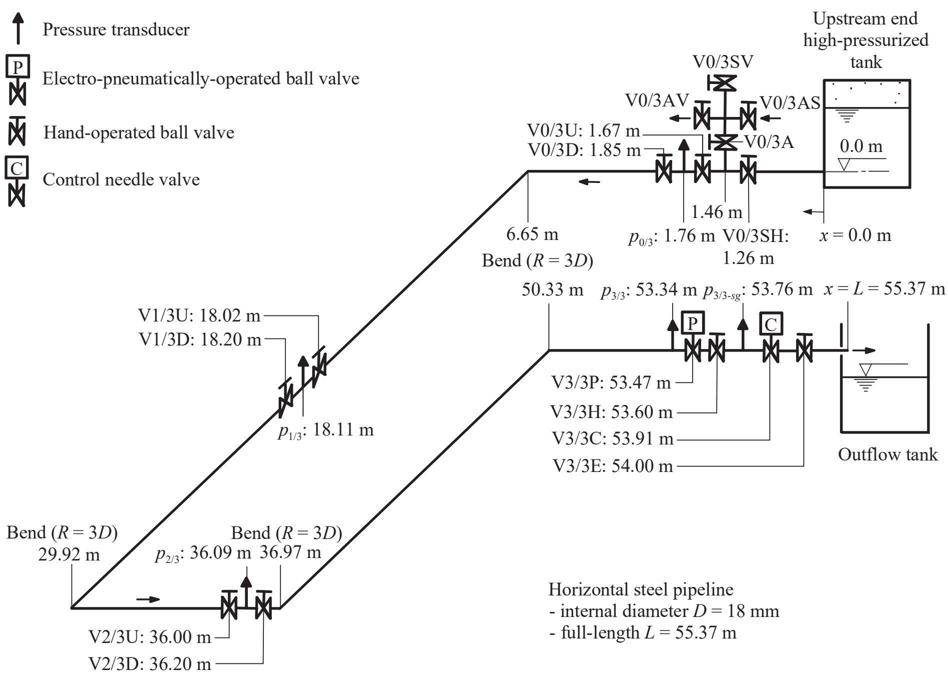

Figure 1: *Layout of small-scale pipeline apparatus*

Four valve units are positioned along the pipeline, including the endpoints. Valve units at the upstream end tank (position 0/3) and at the two equidistant positions along the pipeline (positions 1/3 and 2/3) are comprised of two hand-operated ball valves (valves Vi/3U and Vi/3D; i = 0, 1, 2) that are connected to the intermediate pressure transducer block. A T-section with an on/off air inlet valve (V0/3A) and a compressed-air supply valve (V0/3AS) is installed between the upstream end valve unit (position 0/3) and the high-pressurized tank to facilitate pipeline emptying tests. At the T-section, there is also an air vent valve (V0/3AV) and a vertical pipe upstream end service valve (V0/3SV). A horizontal pipe upstream end service valve (V0/3SH) is installed between the T-section and the high-pressurized tank in order to isolate the upstream end tank during emptying tests. There are four 90° bends along the pipeline with a radius of curvature R = 3D. The pipeline is anchored against the axial movement at 37 points (as close as possible to the valve units and bends). The anchors are loosened for fluid-structure interaction tests. The air pressure in the upstream end tank (total volume $\forall_{HPT}$ = 2 m^3;

maximum allowable pressure in the tank $p_{HPTmax,all}$ = 2.2 MPa) can be adjusted up to 800 kPa. The pressure in the tank is kept constant during each experimental run by using a high precision air pressure regulator (precision class: 0.2%) in the compressed air supply line, *[6].* The upstream end tank is used for the pipeline filling experiment where the valve V0/3A is closed, thus enabling isolation of the compressed air supply into the horizontal steel pipeline.

2.1 Instrumentation

Four dynamic high-frequency pressure transducers are positioned within the valve units along the pipeline including the endpoints (see Fig. 1). Pressures $p_{0/3}$, $p_{1/3}$, $p_{2/3}$, and $p_{3/3}$ are measured by Dytran 2300V4 high frequency piezoelectric absolute pressure transducers (pressure range: from 0 to 6.9 MPa; resonant frequency: 500 kHz; acceleration compensated; discharge time constant: 10 seconds (fixed); U_x = ±0.1 %). All four piezoelectric transducers were flush mounted to the inner pipe wall. These transducers perform accurately for rapid water hammer events including column separation and fluid-structure interaction, *[6].* In these events, the water hammer pressure pulse in the apparatus (Fig. 1) lasts about or less than the wave reflection time $2L/a$ = 0.08 seconds, which is an event lasting less than 10/100 of a second, during which the sensor will discharge 1% of the voltage. Because of the relatively short discharge time constant of these transducers which cannot be adjusted, a question is posed regarding their applicability for measurements of “rapid” filling and emptying events. Therefore, an Endress+Hauser PMP131 strain-gauge pressure transducer has been installed at the control valve V3/3C (pressure $p_{3/3\text{-}sg}$; pressure range: from 0 to 1 MPa; U_x = ±0.5 %). This transducer does not discharge the voltage (analogue output); consequently, it can be used for the measurement of “slow” events (low frequency). Figure 2 shows the layout of the downstream end valve unit with instruments including two pressure transducers (Dytran 2300V4 and Endress+Hauser PMP131).

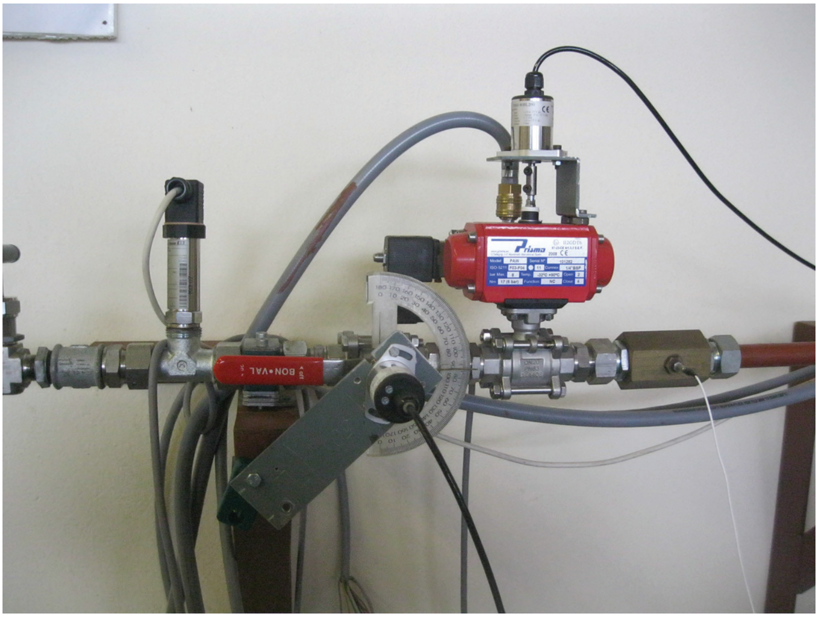

Figure 2: *Layout of downstream end valve unit with instruments*

The datum level for all pressures measured in the pipeline and at the tank is at the top of the horizontal steel pipe (elevation 0.0 m in Fig. 1). For initial flow velocities larger than 0.3 m/s, an electromagnetic flow meter is used (U_x = ±0.2%). The water temperature is continuously monitored by the thermometer installed in the outflow tank. The water hammer wave speed was determined as a = 1340 m/s (U_x = ±0.1%).

2.2 Test procedure for pipeline filling

The test procedure for the pipeline filling is as follows. The pressure in the upstream end high-pressurized tank is adjusted to a desired value using a high precision air pressure regulator. The control needle valve (V3/3C) is opened to the appropriate position. The upstream end valve (V0/3U) at the pressurized tank (position 0/3 in Fig. 1) is closed. All other valves of the four valve units are fully opened. The air inlet valve (V0/3A) is closed (isolation of the compressed air supply into the pipeline), and the horizontal pipe upstream end service valve (V0/3SH) and the downstream end emptying valve (V3/3E) are opened. The filling of the initially empty pipeline is initiated by quickly opening valve V0/3U. When a steady state is achieved, the final flow velocity (V_f) is measured using an electromagnetic flowmeter.

2.3 Test procedure for pipeline emptying

The pipeline is emptied using compressed air supplied from the air reservoir connected to a high precision air pressure regulator. The air pressure for the pipeline emptying is first adjusted to a desired value as well as the opening of the control needle valve. All valves of the four valve units and the horizontal pipe upstream end service valve (V0/3SH) are fully opened. The air inlet valve (V0/3A) (isolation of T-section) and the downstream end emptying valve (V3/3E) are closed. Next, the high-pressurized tank is isolated from the system by shutting the horizontal pipe upstream end service valve (V0/3SH); after that, the compressed-air supply valve (V0/3AS) and the air inlet valve (V0/3A) are opened. The process of emptying is started by quickly opening the downstream end emptying valve (V3/3E).

3 RESULTS OF MEASUREMENTS

This section presents measurement results from pipeline filling and emptying runs in a small-scale experimental apparatus (see Fig. 1). All experimental runs have been carried out for the “same” initial conditions at least three times to achieve repeatability of experiments. The measurements include pipeline filling and the emptying runs with different initial values of the pressure (p_{HPT} = 300 and 400 kPa) in the high-pressurized upstream tank (filling procedure) and air supply line (emptying procedure).

3.1 Pipeline filling

Figure 3 shows a comparison of heads at the two end valve sections and along the pipeline for the case of pipeline filling with the “same” initial conditions (repeatability study). The pressure in the upstream end tank is p_{HPT} = 400 kPa (head H_{HPT} = 39.2 m), the control needle valve is fully open, and the final flow velocity in the pipe after the filling process is completed is V_f = 2.21 m/s. From Fig. 3, it can be seen that bulk patterns of the pressure history during filling events are similar for both tests. As explained in Section 2.1, Dytran 2300V4 dynamic pressure transducers accurately measure high-frequency pressure changes. Therefore, when a new steady state is attained after some time, these transducers do not show the final value of the pressure because the signal discharges to its initial state (63% discharge drop in 10 seconds). Figure 4 shows a comparison of heads at the downstream end of the pipeline (position 3/3 in Fig. 1) measured both by the Dytran 2300V4 piezoelectric pressure transducer and by the E+H PMP131 strain-gauge pressure transducer for Test 1. It can be seen that the E+H transducer, after the filling process is completed, shows the steady state (actual) value of the pressure, which is not the case with the Dytran transducer (step-like pressure pulse).

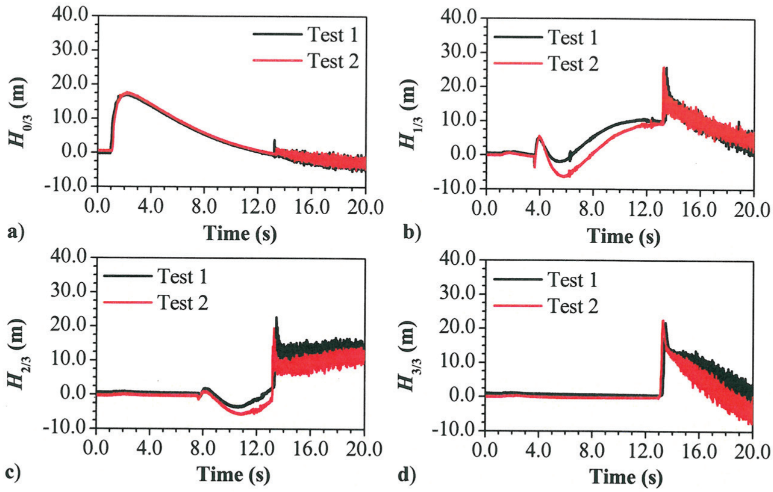

Figure 3: *Comparison of heads at the end valves ($H_{3/3}$ and $H_{0/3}$) and along the pipeline ($H_{2/3}$ and $H_{1/3}$) for the same initial conditions: pipeline filling*

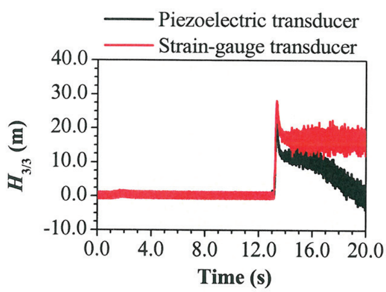

Figure 4: *Comparison of heads at the position 3/3 measured by Dytran piezoelectric and E+H strain-gauge pressure transducers: pipeline filling*

Figure 5 shows a comparison of heads at the two end valve sections and along the pipeline for the case of pipeline filling with the two different values of pressure in the upstream end high-pressurized tank: p_{HPT} = 300 and 400 kPa (head H_{HPT} = 29.4 and 39.2 m). The control needle valve is fully open and the final water flow velocity in the pipe is V_f = {1.93; 2.21} m/s for p_{HPT} = {300; 400} kPa, respectively. As expected, the head rise at the position 0/3 is higher for the tank head H_{HPT} = 39.2 m; it is ΔH = 17.1 m. The corresponding value of the head rise for H_{HPT} = 29.4 m is ΔH = 12.6 m. The head rise at the end of the system at position 3/3 is ΔH = {12.5; 21.8} m for p_{HPT} = {300; 400} kPa, respectively. During the pipeline filling the head rise along the pipeline is practically of the same order. The measured maximum heads along the pipeline are to be considered with caution because of the Dytran transducer behaviour. Our objective is to add miniature strain-gauge pressure transducers at all four transducer blocks fitted with existing piezoelectric transducers. However, the timing of the propagation of pressure wavefronts and the values of first sharp pressure shocks are correct. The timing of pressure pulses in later times is also correct but not the magnitude of the instantaneous pressure (head) due to the discharge leakage.

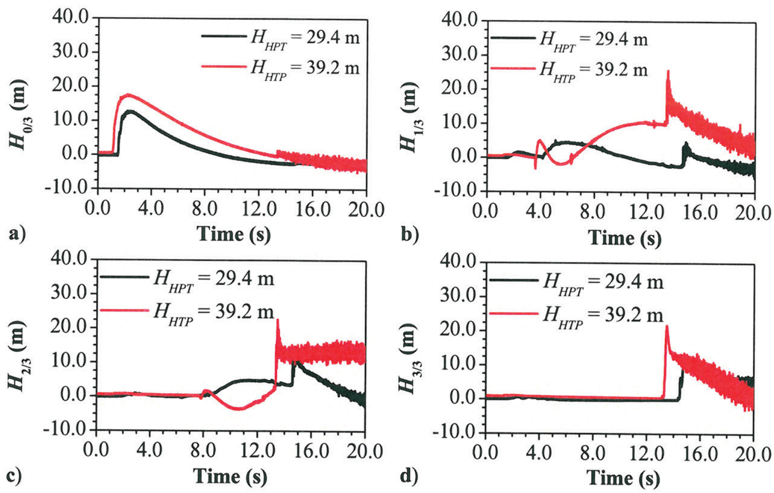

Figure 5: *Comparison of heads at the end valves ($H_{3/3}$ and $H_{0/3}$) and along the pipeline ($H_{2/3}$ and $H_{1/3}$) for the different pressure values: pipeline filling*

3.2 Pipeline emptying

Figure 6 shows a comparison of heads at the end valve sections and along the pipeline for the case of pipeline emptying using the "same" initial conditions (repeatability study). The pressure in the air supply line is p_{HPT} = 400 kPa (head H_{HPT} = 39.2 m), and the control needle valve is fully open. The process of emptying is started by quickly opening the downstream end emptying valve (V3/3E in Fig. 1). From Fig. 6, it may be concluded that the head change for the same initial conditions during pipeline emptying is similar. The time for the complete emptying of the pipeline is about 18 s. The initial head drop along the pipeline is about 40 metres.

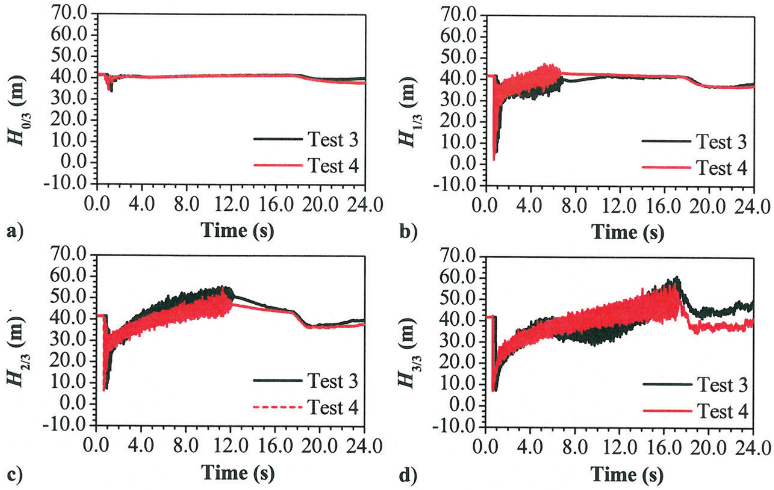

Figure 6: *Comparison of heads at the end valves ($H_{3/3}$ and $H_{0/3}$) and along the pipeline ($H_{2/3}$ and $H_{1/3}$) for the same initial conditions: pipeline emptying*

Figure 7 shows a comparison of heads at the position 3/3 measured by the Dytran 2300V4 piezoelectric pressure transducer and the E+H PMP131 strain-gauge pressure transducer for Test 3 (Fig. 6). Due to the nature of pressure pulses, the Dytran transducers exhibit better behaviour in the case of the pipeline emptying in contrast to the case of pipeline filling (Fig. 4). However, the conclusions regarding the transducers are the same as those in Section 3.1. In future experiments, the authors are planning to develop a numerical code for simulation of filling and emptying of pipelines, which will be validated against measured data using appropriate pressure transducers that cover low and high-frequency pressure pulses accurately.

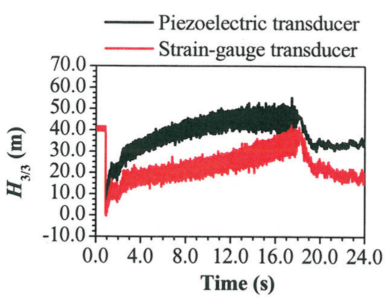

Figure 7: *Comparison of heads at the position 3/3 measured by Dytran piezoelectric and E+H strain-gauge pressure transducers: pipeline emptying*

Figure 8 depicts comparison of heads at the end valve sections and along the pipeline for the case of pipeline emptying with two different values of pressure in the air supply line: p_{HPT} = 300 and 400 kPa (head H_{HPT} = 29.4 and 39.2 m). Again, the control needle valve is fully open. The compressed air/water interface (front) at p_{HPT} = {300; 400} kPa needs $t_{0/3}$ = {0.9; 1.4} s to pass position 0/3, $t_{1/3}$ = {6.9; 6.2} s, to pass position 1/3, $t_{2/3}$ = {13.1; 11.7} s to pass position 2/3 and finally, it needs $t_{3/3}$ = {19.0; 17.4} s to expel water out of the pipeline.

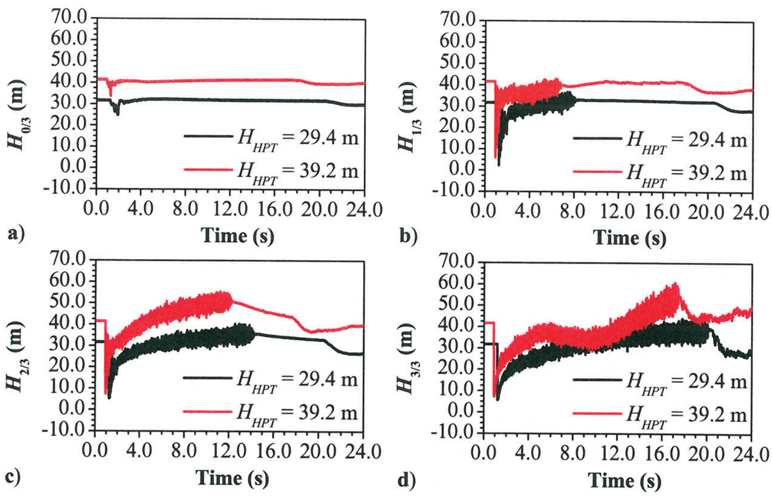

Figure 8: *Comparison of heads at the end valves ($H_{3/3}$ and $H_{0/3}$) and along the pipeline ($H_{2/3}$ and $H_{1/3}$) for the different pressure values: pipeline emptying*

4 CONCLUSIONS

A small-scale experimental apparatus for investigating rapid water hammer events, including column separation and fluid-structure interaction, has been designed and constructed at the University of Montenegro. The apparatus has been recently modified for performing pipeline filling and emptying runs that are characterized both by rapid and gradual pressure changes in the pipeline. The primary objective of the paper was to investigate effects of pipeline filling and emptying on head changes along the pipeline for different initial values of the pressure in high-pressurized upstream end tank (filling) and air supply line (emptying). The higher initial pressure in the upstream end tank produces higher head rise during the filling process. The minimum head along the pipeline is practically the same regardless of the magnitude of the initial pressure in the air supply line during the emptying process. From comparisons of measured data obtained by a piezoelectric transducer and by a strain-gauge transducer, it follows that the piezoelectric transducer with a fixed relatively low discharge time constant is not fully suitable for low-frequency pressure measurements. New miniature strain-gauge pressure transducers will be employed for the next set of the pipeline filling and emptying tests in order to obtain more accurate data that are needed as a reference for validation of numerical models.

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Nomenclature

(Symbols)	(Symbol meaning)
a	water hammer wave speed
D	pipe diameter, diameter
e	pipe wall thickness
H	head
L	length
p	pressure
R	pipe radius
t	time
U_x	uncertainty in a measured quantity
V	flow velocity
x	distance along the pipe
ΔH	head rise
$\forall$	volume
(Subscripts)	(Subscripts meaning)
f	final
HPT	high-pressurized tank
max	maximum

Acknowledgments

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HISTORY OF CLASSIC THERMODYNAMICS AND THE FUTURE OF THERMODYNAMICS

ZGODOVINA KLASIČNE TERMODINAMIKE IN PRIHODNOST TERMODINAMIKE

Jurij Avsec^ℜ, Urška Novosel [1]

Keywords: thermodynamics, classic thermomechanics, viscosity, statistical mechanics

Abstract

Whenever they hear the word "thermodynamics", many students of energy engineering, mechanical engineering, chemistry, physics and other natural sciences are filled with apprehension. This science has a reputation because of its abstract nature and the laws of thermodynamics. This review paper deals with the history of thermodynamics and shows how it is likely to evolve in the future.

Povzetek

Mnogim študentom energetike, strojništva, kemije, fizike in drugih naravoslovnih znanosti gredo lasje pokonci in jim obraz potemni, ko slišijo za besedo termodinamika. Tak sloves si je ta veda pridobila zaradi svoje abstraktne narave in zloglasnih termodinamičnih zakonov. Predstavljen pregledni članek obravnava zgodovino nastanka termodinamike in prikazuje, kako bi se naj termodinamika razvijala tudi v prihodnosti.

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1 INTRODUCTION

In a book on thermodynamics, I read the following sentence written by Professor M. L. McGlashan 1965: "I can't recall whom I lent specific books, but I remember well when I burnt one: it was a textbook on laws of thermodynamics". In contrast, Albert Einstein, the greatest physicist of all time, had a very respectful attitude to classical thermodynamics. In 1951, he said at a convention: "A theory is more impressive the greater the simplicity of its premises, the more different are the kinds of things it relates, and the more extended its range of applicability. Therefore, the deep impression which classical thermodynamics made on me. It is the only physical theory of universal content, which I am convinced, that within the framework of applicability of its basic concepts will never be overthrown", *[1-8]*

2 HISTORY OF CLASSIC THERMODYNAMICS

As its name suggests, thermodynamics is the study of heat dynamics and their dynamics and energy transformation. It is one of the newest classical scientific disciplines, which began to develop only at the end of the 19th century. However, the beginnings of thermodynamics go back over two thousand years. Democritus and his mentor Leucippus may be regarded as the first serious researchers in the field of thermodynamics, in the 4th century B.C. They argued that all matter is composed of small indivisible, unchangeable, and indestructible particles – atoms. Only empty space is supposed to exist in addition to them. Even the human mind and gods should be made of such particles. Any changes that take place in the universe were attributed to the motion of atoms rather than to the capriciousness of the gods. Other philosophers at that time did not like the idea of the atomic structure of the universe and followed Socrates and his disciples instead. Therefore, Democritus is considered to be the founder of atomic theory, which is, in fact, the basis of statistical thermodynamics – a revolutionary theory describing nature through the understanding of the motion and interactions between molecules and atoms, *[2-6].*

In addition to the beginnings of the atomistic view of the universe, the first researchers who studied the behaviour of matter appeared in that period. One of them was Philo, who was born around three hundred years B.C. in Byzantium. He discovered that air expands in response to a temperature increase and that a burning candle in a vessel consumes oxygen from the surrounding air, *[1-11].*

The Greek inventor Heron (born in 20 AD), known for numerous ingenious solutions, continued Philo's work. His most important invention is that of a hollow sphere fitted with two bent tubes. When the water in the sphere was brought to a boil, the steam escaped through the tubes. As a result of the action-reaction principle, the sphere started to rotate rapidly, which is known as the first method of the transformation of steam energy into motion (steam engine). This invention began to be used for moving doors and statues, *[2-7].*

Moreover, Heron wrote books on mechanics, air, and mirrors that were far ahead of their times. His book on air, in which he proved that air is matter, is particularly significant. Based on the fact that air is compressible, he also argued that it is composed of individual particles separated by void spaces.

Heron did not have a worthy successor for more than 1600 years. Only Daniel Bernoulli (1700-1782), a member of the renowned Swiss school of mathematicians and physicists, continued his work. Today, he is famous primarily for his innovations in fluid mechanics. In 1738, he wrote a book entitled "Hydromechanics", in which he derived what became known as Bernoulli's equation. His contribution in the field of thermodynamics is perhaps even more critical. He was the first to attempt to explain the behaviour of gases when pressure and temperature vary. He used the assumption from the times of Heron, namely that gases consist of a large number of tiny particles. As part of further mathematical treatment, he used probability approaches developed by Pascal (1623-1662) and Fermat (1601-1665). Therefore, Bernoulli is considered to be the founder of the kinetic theory of gases.

The true discovery of the laws of thermodynamics began only in the 19th century in the most developed countries in that period: France, England, and Germany. The work of James Prescott Joule (1818-1889), the father of the law on conservation of energy or the first law of thermodynamics, is of immense value for the field of thermodynamics. Today, the first law of thermodynamics is attributed to Joule, Julius Robert Mayer (1814-1878) and Ferdinand Helmholtz (1821-1894), who discovered the law entirely independently of one another. Mayer was the first to publish the law on conservation of energy in 1842, which was as many as five years ahead of Joule, and in his very systematic paper, he also published in the law on conservation of energy, the impact of the tide, heating by meteorites and vital processes. Nevertheless, his paper aroused no interest within the scientific community at that time, *[1,5,8,11-15].*

Today, the definition of the first law of thermodynamics is twofold: the first part defines that heat is energy, whereas the second part is the law on conservation of energy. The types of energy can be divided into two groups: stored energies and transitional energies. As regards the stored energies, they can be preserved in the given form to the extent desirable. They include potential energy (E_{pot}), kinetic energy (E_{kin}), and internal energy (U). Transitional energies, on the other hand, pass through the borders of the systems in processes and are characterised by their short duration. It is impossible to store them in the given form, and they appear when the stored energy passes from one system to another. They include mechanical work, heat (Q), and the energy of electric current. Heat is energy, whereby a specific name is used to define how energy passes from one body to another. As far as the second energy exchange method is concerned, a body passes mechanical work to another body or receives it from the other body. The first law states that the change in overall energy (kinetic ΔE_{kin}, potential ΔE_{pot} and internal ΔU) of a system is equal to the difference between the heat Q added to the system and the work W done by the system. The mathematical expression of the first law is the following:

$$Q - W = \Delta U + \Delta E_{kin} + \Delta E_{pot} + \sum \Delta W_i \tag{2.1}$$

The last term covers the changes in other forms of energies of the entire system, e.g. potential energy in an electric or magnetic field, elastic energy, etc. Of course, a number of enthusiasts wanted to challenge the correctness of the first law. The machines they used in order to demonstrate the incorrectness of the first law are called perpetual motion machines of the first kind. Some scientists made much money through fraud based on such machines. J. W. Kelly from Philadelphia [8], for example, tried to prove between 1874 and 1894 that his "hydro-pneumatic-pulsating-vacuum engine" could supposedly push a railroad train 3000 miles on 1 litre of water. Only after his death, the investors who paid 2.5 million dollars discovered that it was a case of fraud because an additional engine was hidden inside the locomotive. The above-mentioned amount of money is a huge sum even today, but at the time it was truly astronomical, *[2,5,8,12].*

Rudolf Julius Clausius (1822-1888) was the founder of the second law of thermodynamics. He continued his research on the basis of the works by the French inventor Sadi Carnot, while at the same time he monitored the development of the work of William Thomson, the most acknowledged expert on thermodynamics at that time in England. In 1850, when he was a professor in Berlin, he sent to the Berlin Academy of Sciences a report in which he proved that the ratio between heat in a closed system and its absolute temperature only increases and can never decrease. He also introduced the notion of entropy, in connection with which he proved that the entropy of the universe always increases until its final thermal death. Then, all the planets will be in a state of thermal equilibrium; there will not be any changes and consequently no time which is actually measured by the course of such changes. Thanks only to the German mathematician, Constantin Carathéodory (1873-1950), the second law and entropy were explicitly derived by means of Pfaffian differential equations. Using entropy, the second law of thermodynamics can be expressed in a simple mathematical form:

$$dS \geq \frac{dU + dW + \sum y_i dX_i}{T} \tag{2.2}$$

The record with the equal sign applies to reversible processes, and the record with the not equal sign stands for inequality, determining the direction of natural processes. The last term in equation (2) is essential whenever thermoelectric and chemical processes, processes associated with magnetism, etc., are to be documented. The machines that would violate the second law are called perpetual motion machines of the second kind. Due to its abstract concept, the second law, in particular, makes students apprehensive. Thanks to statistical thermodynamics, we now know that entropy is a measure of the level of disorder of a system.

The third law of thermodynamics was developed in 1906 by Walther Hermann Nernst (1864-1941). The entropy change approaches zero at absolute zero temperature. Hence, it is possible to prove by means of mathematical procedures that absolute zero cannot be reached. The third law has also not been overthrown so far. In 1960, 10^{-6} K was attained using very expensive procedures, such as isentropic nuclear demagnetisation; however, nobody has achieved absolute zero as yet.

Sometime later, the so-called zero-th or empirical law of thermodynamics was developed randomly, also known as the fundamental law of thermodynamics: "If two systems are in thermal equilibrium with a third system, then they are in thermal equilibrium with each other. If the notion of temperature is introduced, we can also say that two systems are in thermal equilibrium when having the same temperature", *[2-8]*. This law was first formulated in 1931 by the American scientist R. H. Fowler.

Thermodynamics was also developed more recently with Ilya Prigogine (1917-2003), called the father of nonequilibrium thermodynamics, *[22, 23].* Thermodynamics is under development of Constructal Theory much more comprehensive. Prof. Adrian Bejan developed this modern theory to explain many natural, economic and social processes, *[24].* On the basis of the molecular motion of atoms and molecules in solids, liquids, gases and plasmas, as well as statistical thermodynamics theory, the work of Austrian physicist Ludwig Boltzmann (1844-1906) was published in 1870. In 1896, he also published a book of lectures on gas theory. After this period, many enormous important contributions were made both on theoretical, experimental and numerical parts, from many researchers, including Albert Einstein, Enrico Fermi, Paul Dirac, Stajedra Nath Bose, Keith Gubbins and many others.

On the basis of knowledge from statistical thermodynamics, researchers now are able to calculate thermodynamic functions of state for pure components, mixtures, for single-phase and multi-phase systems. Austrian Physicist Ludwig Boltzmann was also one of the founders of nonequilibrium statistical thermodynamics, this theory was developed from kinetic gas theory. On the basis of the Maxwell-Boltzmann transport equation, it is possible to calculate transport properties like thermal conductivity and viscosity for pure components and mixture. For the calculation of transport properties for polyatomic molecules in principle, a quantum mechanical treatment of processes is necessary to account for the changes of internal state. The quantum mechanical kinetic theory of polyatomic gases is based on the Waldman-Snider equation and summarized by McCourt and co-workers. Wang-Chang and Uhlenbeck (1951), de Boer (WCUB), and Taxman (1958) formulated a semiclassical kinetic theory.

2 APPLICATIONS OF THERMODYNAMICS

Thermodynamics explains that energy is indestructible and how energy can be converted from one form to another. With its help, we can now explain the operation of all power machines. The table below shows when they start using thermodynamics in practice.

Table 1: *Some critical moments in history regarding thermodynamics applications*

1698, *[25]*	T. Savery	First steam water pump
1712, *[25]*	T. Newcomen	First steam piston engine
1791, *[27]*	J. Barber	First working gas turbine
1801, *[18]*	H. Davy	Development of principle of the fuel cell
1852	W.T. Kelvin	Theory of heat pump
1853, *[9]*	E. Brisanti and F. Matteucci	First patent of internal combustion engine
1855	P.v. Rittinger	First working heat pump
1864, *[9]*	N. Otto	Patent of Laval nozzle
1873	Johannes Diderik van der Waals	VDW equation of state
1882, *[26]*	Edison	First cogeneration system and first coal power plant
1887, *[9]*	G.d. Laval	Invention of Laval nozzle
1893, *[9]*	R. Diesel	First patent of diesel engine
1939, [28]	H. von Oheim	First turbojet engine
1969, *[19]*		Apollo 11 First successful flight to the moon
1995, *[21]*	Adrian Bejan	Constructal theory

3 FUTURE DEVELOPMENT OF THERMODYNAMICS

Thermodynamics is developing today in many areas, as shown in Figure 1. One vital part is the calculation of thermodynamic properties. The calculation of thermodynamic properties of a state is possible using classical or statistical thermodynamics. Classic thermodynamics has no insight into the microstructure, but it allows the calculation of thermodynamic function of state with the assistance of the macroscopic observation of phenomena. Unlike classic thermodynamics, however, the statistical thermodynamics (ST) does enable the computation of the thermodynamic functions of the state by studying the molecular structure of the matter, *[11-15].*

The basis for molecular motion is the motion of atoms in molecules and performance of diverse, attractive and repulsion forces are intramolecular and intermolecular interactions between electrons and nuclei in a molecular system. The energy inherent in such a molecule system consists of *[11-17]*:

- kinetic energy of molecules and atoms (translation (trans), rotation (rot), internal rotation (ir), vibration (vib)).
- potential intermolecular energy (pot). Utilized as an intermolecular potential was the Lennard - Jones potential, *[5].*
- energy of electrons as to the energy level they belong to (el).
- energy of nuclei as to the energy level they belong to (nuc).

$$E = E_0 + E_{trans} + E_{rot} + E_{vib} + E_{el} + E_{nuc} + E_{ir} + E_{konf} \tag{3.1}$$

To calculate the thermodynamic functions of state, the canonical partition function [12-14] is applied:

$$Z = \sum_i \exp\left(-\frac{E_i}{kT}\right) \tag{3.2}$$

In equation (3.2), the sum runs over all feasible quantum states, EI is the energy of the I- quantum states.

Utilizing the semi-classical formulation for the canonical ensemble for the N indistinguishable molecules can be expressed as follows)[12-14]

$$Z = \frac{1}{h^{3N}} \int \ldots \int \exp\left(-\frac{E_{trans} + E_{rot} + E_{ir} + E_{vib} + E_{el} + E_{nuc}}{kT}\right) d\vec{p}_1 \cdot d\vec{p}_2 \ldots . d\vec{p}_N \cdot$$
$$\cdot \int \ldots \int \exp\left(-\frac{E_{pot}}{kT}\right) d\vec{r}_1 \cdot d\vec{r}_2 \ldots d\vec{r}_N \tag{3.3}$$

The second part of equation (3.3) on the right side we call the configurational integral. Using the canonical ensemble for the system of N, molecules can be like this:

$$Z = Z_0 Z_{trans} Z_{vib} Z_{rot} Z_{ir} Z_{el} Z_{nuc} Z_{conf} . \tag{3.4}$$

Thus, the partition function Z is a product of terms of the ground state (0), the translation (trans), the vibration (vib), the rotation (rot), the internal rotation (ir),the influence of electrons excitation (el), the influence of nuclei excitation (nuc) and the influence of the potential intermolecular energy (conf).

Utilizing the canonical theory for computing the thermodynamic functions of the state can be put as follows:

$$p = kT\left(\frac{\partial \ln Z}{\partial V}\right)_T, \quad U = kT^2\left(\frac{\partial \ln Z}{\partial T}\right)_V, \quad H = kT\left[T\left(\frac{\partial \ln Z}{\partial T}\right)_V + V\left(\frac{\partial \ln Z}{\partial V}\right)_T\right]. \tag{3.5}$$

Equilibrium statistical thermodynamics could be further divided to classic, Fermi-Dirac, and Bose-Einstein. For the calculation of the thermodynamic functions of state with the help of classical thermodynamics, we used the following equations of state:

Van der Waals TES (VDW) equation of state (EOS)

$$p = \frac{RT}{v-b} - \frac{a}{v^2} \tag{3.6}$$

Peng- Robinson TES (PR) EOS

$$p = \frac{RT}{v-b} - \frac{a(T)}{v^2 + 2bv - b^2} \tag{3.7}$$

3) Bennedict-Webb-Rubin (BWR) EOS

$$p = \frac{RT}{v} + \frac{B_0RT - A_0 - C_0/T^2}{v^2} + \frac{bRT - a}{v^3} + \frac{a\alpha}{v^6} + \frac{c}{v^3T^2}\left(1 + \frac{\gamma}{v^2}\right)\cdot \exp\left(-\frac{\gamma}{v^2}\right) \tag{3.8}$$

Figure 2 shows the deviation of the speed of sound for carbon dioxide between the analytical computation with the help of statistical thermodynamics (ST), classical thermodynamics (VDW-Ven der Waals equation of state, RK- Reedlich Kwong equation of state, PR- Peng-Robinson equation of state) and experimental data (exp.).

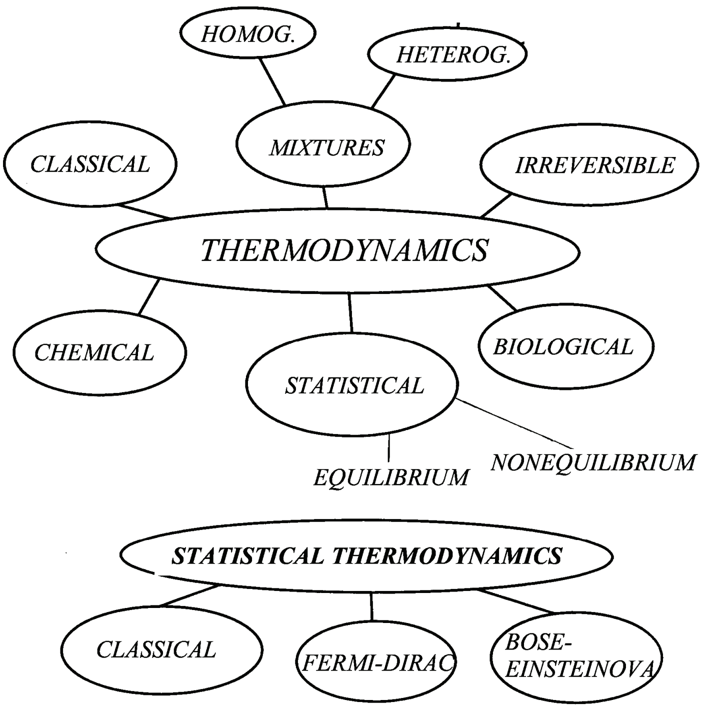
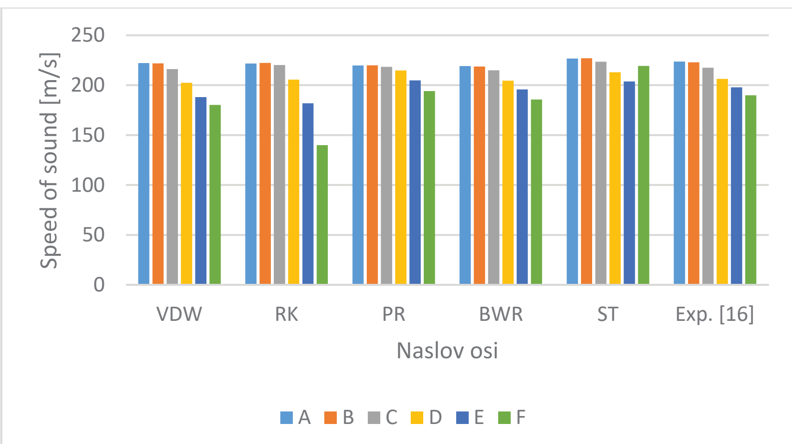


***Figure 1**: Scientific disciplines in thermodynamics*



A (T=223 K) , B (T=243 K), C (T=263 K), D(T=283 K), E (T=293 K), F (T=301 K)

Figure 2: The speed of sound c_0 for CO_2 (R-744) (saturated vapour) with various thermodynamic models

In all scientific areas of thermodynamics, the development in the coming years will be extremely exciting. Some of the most interesting topics for the future include:

- further development of the constructal thermodynamics theory (classical thermodynamics)
- calculation and measurement of thermodynamic properties for unknown substances (classical thermodynamics, statistical thermodynamics, experimental thermodynamics and thermal calorimetry)
- development of thermodynamic models for ionic liquids
- the application of new materials in fuel cells, nuclear engines, and similar technologies.
- the development of new thermal devices with better energy and exergy efficiency

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ENERGY ASPECTS OF URBAN LAST MILE DELIVERY

ENERGETSKI VIDIKI DOSTAV V MESTIH

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Keywords: transport, last mile delivery, loading bays, energy efficiency, optimization.

Abstract

Cities are growing and, consequently, so is the need for a more efficient supply system to customers located in urban areas. Increasing traffic congestion is hindering the efficiency of deliveries in city centres, which also negatively influences the energy aspects of transport processes. This paper considers an efficient solution for optimizing urban freight deliveries and presents the results of a case study for a small historical city centre. A tool is based on optimal vehicle routing and the assignment of the most optimal loading bay. It results in considerable savings in travel time, travel distance, and energy.

Povzetek

Mesta se povečujejo in posledično tudi potrebe po učinkovitejši oskrbi kupcev v urbanih območjih. Povečanje prometnih zastojev ovira učinkovitost dostav v mestnih središčih, kar negativno vpliva tudi na energetske vidike transportnih procesov. V članku je predstavljena učinkovita rešitev za optimizacijo dostav v mestih. Predstavljeni so tudi rezultati optimizacije dostav v mestno središče na primeru majhnega zgodovinskega mesta. Optimizacija temelji na učinkovitem vodenju dostavnih vozil in dodeljevanju najprimernejšega dostavnega mesta. Prikazan je precejšen prihranek pri času vožnje, prevoženi razdalji in porabljeni energiji.

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1 URBAN FREIGHT TRANSPORT AND ENERGY CONSUMPTION

High energy consumption and the negative effects of its use are currently one of the main concerns of the European Union (EU), *[1]*. Several policies, regulations, and initiatives have been launched to reduce energy demand, increase the share of renewable energy sources and improve energy efficiency, *[2]*, *[3]*. All these measures have helped to reduce total energy consumption in most sectors, except in transport, which remains the fastest growing consumer of energy and producer of greenhouse gases in the world, *[4].*

The share of final transport-related energy consumption in comparison to other sectors in the EU is presented in Figure 1.

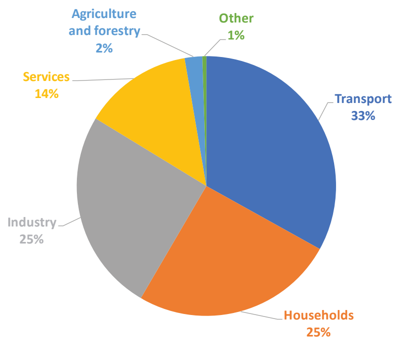

Figure 1: *Share of total final energy consumption, EU-28 (2015),* [5]

In Europe, the transport sector consumes 33% of final energy and produces 24% of total CO_2 emissions, *[5]*. Road transport holds the biggest share of the modes of transport and consequently consumes 83% of transport energy and produces 93% of the CO_2 emissions, *[6]*. With the aim of achieving a 60% CO_2 reduction by 2050 (compared with 1990), Europe will need to reduce its oil consumption by around 70%, *[7]*, *[8]*. The transport sector is currently 96% oil dependent, which is unsustainable, *[9].*

The majority of transport-related activities occur in cities, where passenger cars contribute more than 60% to the total transport energy consumption and emissions, *[10]*. Commercial vehicles contribute to about 19% of energy use and 21% of CO_2 emissions, *[11]*. In the field of urban passenger mobility, many policies and measures have been proposed and implemented (public transport, electric vehicles, car sharing and carpooling, cycling and walking, etc.), but urban freight has been neglected for decades. Consequently, this has resulted in an increasing share of energy consumption and emissions of freight vehicles in cities.

Urban freight deliveries are nowadays also confronted with requests for just-in-time deliveries and e-commerce, which results in high fragmentation of urban freight demand and supply, *[12]*–*[14]*. Many cities are consequently facing an increasing number of poorly utilized urban freight transport trips, which decreases energy efficiency and increases pollution, *[15]*, *[16]*. Empirical studies of urban freight deliveries show that the average load factor of urban freight vehicles is only at 30-40% *[1]*, *[17]* and more than 20% of vehicles drive empty, *[18]*.

The problem of the "last mile" is perceived as the most inefficient part of the supply chain. The final part of shipment typically involves multiple stops with small numbers and sizes of parcels, *[19]*. Last mile delivery is considered to be the most expensive (it represents from up to 53% of delivery costs, as seen in Figure 2) and the most time-consuming part of the shipping process (limited access to customers and congestion in cities), *[20]*.

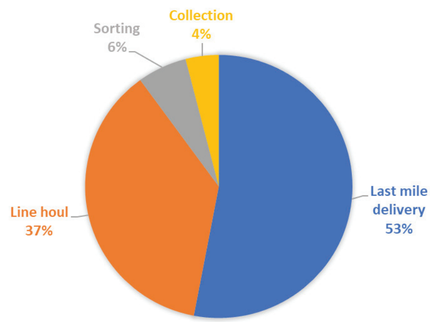

Figure 2: *Share of delivery costs by part of the journey,* [19]

With increasing urban population and economic activities in cities, the efficiency of last mile delivery needs to be appropriately addressed to influence improvement in energy savings and a decrease in pollution, *[21]*. Solutions for efficient urban freight movements are sought from both the practical and the theoretical points of view.

2 SOLUTIONS FOR ENERGY EFFICIENT URBAN DELIVERIES

Cities are most often addressing the urban freight delivery problems by implementing different kinds of restrictive policy measures, with the main aim of mitigating the negative effects of deliveries (e.g., ban for heavy-duty vehicles, low emission zones, implementing access time windows, congestion charging, etc.), *[22]–[27]*. These kinds of measures are indeed contributing to decreasing the number of delivery vehicles and their negative effects in city centres, but at the same time negatively influencing the efficiency of last mile delivery (costs and time). The solution that is most convenient for the city authorities is in many cases hindering the efficiency of city logistics services.

When customers cannot be reached directly by regular delivery vehicles, the usage of Urban Consolidation Centres (UCC), where transhipment of parcels from large trucks to smaller and environmentally friendly vehicles, is suggested. Experiences from different cities revealed that only a small part of users decide to opt for UCC, because it results in additional costs and time spent for last mile delivery, *[28].*

The other solution for the last mile delivery is the usage of (un)loading bays, which are dedicated to transhipment of parcels and parking of delivery vehicles near customers during last mile delivery operations. Loading bays are most often located on the border of restricted areas within the cities. The last part of the delivery, from the loading bay to the customer, is predominantly done on foot or by trolley, *[29]*.

Loading bays can be used as a stand-alone solution or can be integrated with Urban Consolidation Centres, as presented in Figure 3.

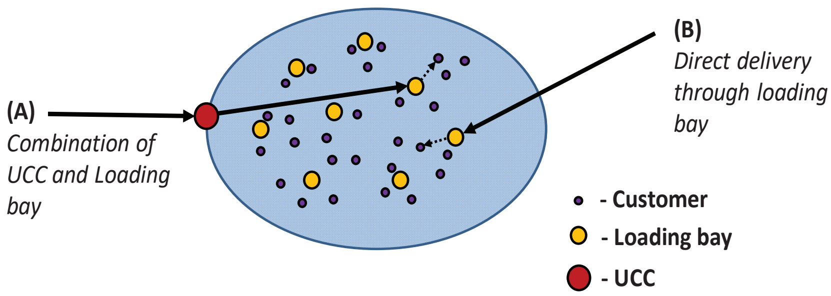

Figure 3: *Schematic presentation of direct delivery through loading bay and delivery in combination with UCC*

Urban areas are very often confronted with scattered loading bays. Cities are, therefore, attempting to identify the optimal number and position of loading bays to fulfil the requirements of the customers. Loading bays are also often occupied, sometimes by other delivery vehicles, but in most cases illegally from individual users, *[30]*, *[31]*. Delivery vehicles that are not able to find an available loading bay are forced to double park or cruise for parking (as seen in Figure 4), which is time-consuming and contributes significantly to the reduction of available road capacity and urban traffic congestion, *[32]*, *[33]*.

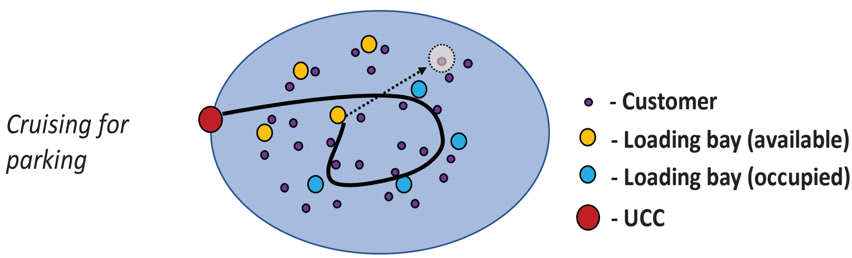

Figure 4: *Cruising for parking in the case of occupied loading bays*

To cope with the mentioned problems, cities are attempting to find delivery area management solutions. Different loading bay management solutions have been recently tested in several European cities. Lyon provided options to reserve a loading bay 24 hours in advance, which led to more efficient trips and routes in the city and resulted in a 40% reduction in double parking, as well as reduced congestion and pollution in the city centre, *[30]*. Vienna experimented with different management methods and technological solutions for the efficient and effective monitoring of the occupancy of loading bays with the aim of keeping loading bays at maximum availability and reducing impacts on traffic caused by the loading activities, *[34].* Lisbon adopted parking meters for loading/unloading operations and vehicle detection sensors installed on the ground of loading bays. This resulted with a reduced number of parking infractions, the reduced average duration of freight operations, and increased transport operators' and shopkeepers' satisfaction, *[35]*.

Possible approaches have been studied by Patier et al., *[36]*, highlighting the importance of the information system (or device) to inform all users of the occupancy of relevant loading bays. McLeod and Cherrett, *[37]*, investigated the impact of advanced booking of loading bays and observed the high level of sensitivity to early or late arrivals. In that case, the capacity of the system drops considerably. Based on that, they suggest opting for more dynamic loading bay reservation systems.

3 OPTIMIZATION OF LOADING BAYS FOR EFFICIENT DELIVERY

3.1 The algorithm and the model

An algorithm and model for the dynamic management of loading bays for efficient urban freight deliveries was developed recently by Letnik et al., *[26]*. The algorithm is briefly presented next (see Figure 5).

Generally, the last mile delivery problem can be divided into two sub-problems: the delivery of goods from outside the city to the loading bay; and the delivery of goods from the loading bay to the customer. The latter aims to select the most appropriate loading bay and the vehicle path, considering a predefined set of loading bays and dynamically changing traffic conditions. The most appropriate loading bay is in the model determined via fuzzy clustering algorithm (FCM). In reality, the loading bay is chosen according to two different approximation methods.

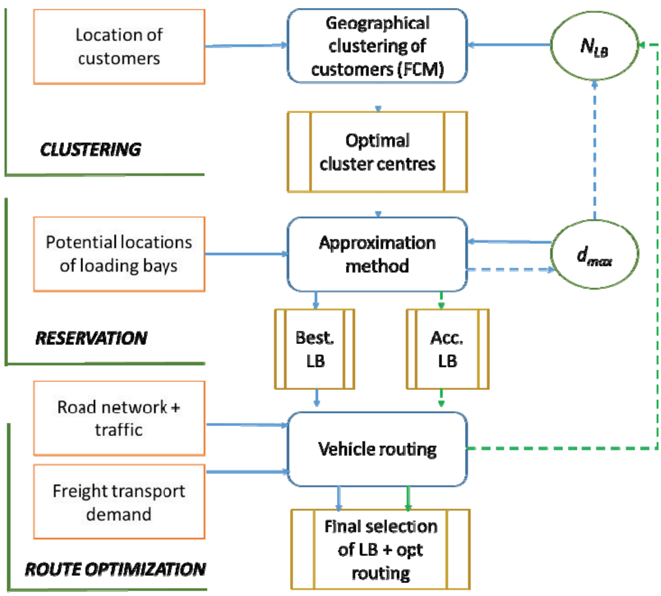

Figure 5: *The architecture of the proposed algorithm*

In the first approximation method, only the best potential loading bay (LB) (the closest to the cluster centre) is taken as an option. In the second approximation method, a set of acceptable LBs are considered. In both cases, čoading bays are considered only if the constraint of (predefined) maximal allowed walking distance from the LB to the customer is fulfilled.

The FCM procedure was used in the model because it permits the overlapping of clusters of customers and offers a more flexible selection of LBs. The clustering procedure searches for a maximum acceptable (walking) distance from the LB to the customer.

The routing is performed based on the Dijkstra algorithm, comparing travel distances among origins (entrance points to the urban area) and destinations (acceptable LBs). The most optimal (shortest/fastest) route is finally selected in combination with best or acceptable LBs. The routing algorithm also has the function of keeping vehicles outside the city in the case and until all acceptable LBs are occupied.

As seen from Figure 5, the location of customers (geographical coordinates) and a predefined number of LBs (N_{LB}) are two main elements needed for the clustering procedure and defining the optimal location of LBs (cluster centres). In the model, N_{LB} is determined based on the maximum allowed distance from the LBs to the assigned customers (d_{max}).

The best and acceptable LBs produced by approximation methods are determined according to the potential location of LBs and the value of d_{max}. If approximation methods do not result in finding an LB for all customers, then the d_{max} is increased, and clustering the algorithm runs again.

Vehicle routing aims to find the shortest possible path from outside the city to the LB, which is acceptable for a particular customer. The routing algorithm considers road network and traffic conditions relevant for a particular period of the day. At the end of the procedure, the routing algorithm determines which of the acceptable LBs results in the shortest and fastest path and selects this LB as optimal.

The environmental performance of the system is measured in travel times, travel distances, CO_2 emissions, and fuel consumption. Our calculation considers deliveries performed with an average light commercial vehicle (category N1 - up to 3.5 tons) with a diesel engine. In urban areas, this kind of vehicle consumes on average 11.4 l of diesel per 100 km, which results approximately with 300 g/km CO_2 (taking into consideration conversion factor of 1 l/100km = 26.5 g/km CO_2), *[38]*.

3.2 Case study and results

The model has been applied to a real case study of the historical city centre of Lucca in Italy. The city of Lucca is one of the most advanced historical cities with regard to the application of city logistics policies and measures. Consequently, many data have been available, which presents a good basis for modelling purposes and testing of the proposed model. A more detailed elaboration of the model and the case study can be found in Letnik et al., *[29]*.

Access to the city centre is restricted with a Limited Traffic Zone (LTZ), and the level of restriction differs with different periods of the day. The number of customers located in the city centre is 1,161, the average number of daily deliveries is 1,272, and the number of commercial vehicles entering the city centre is 1,058, *[39]*. These numbers result in around 1.2 deliveries performed by each vehicle. In the model, we, therefore, assume that each freight vehicle performs only one stop in the city centre.

Most of the deliveries are performed in the following three periods of the day: early morning (from 8 to 10 a.m.) 26.9%, late morning (from 10 to 12 a.m.) 29.1% and afternoon (from 4 to 6 p.m.) 15.7%, *[39]*. We have decided to simulate only these three periods because in these periods different access restrictions apply, which also results in the availability of a different number of LBs (some locations are not accessible during particular periods of the day). These characteristics have been used to simulate dynamically changing conditions for urban freight deliveries.

The modelling and optimization process results in optimal LB assignment and routing. It is presented with the following schematic (Figure 6).

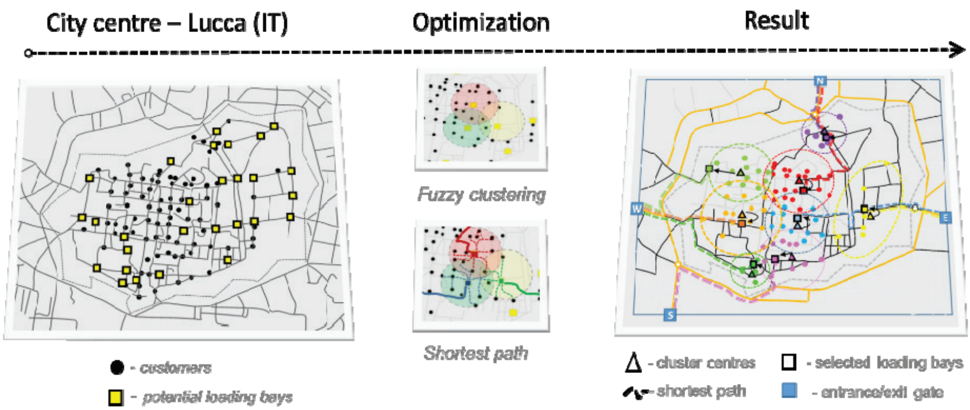

Figure 6: *Schematic presentation of the model application*

As seen from the Figure 6, we first identified the location of customers and potential location of loading bays (physical places in the city where loading bays can be placed and reached with delivery vehicles). The FCM algorithm was used to create clusters of customers with cluster centres, which represent the most optimal positions of loading bays. With an approximation approach, considering maximal allowed walking distance, each cluster of customers has been assigned with a potential set of loading bays. In the final step, a routing algorithm was used to calculate all the possible options of entering the city centre and reaching potential loading bays and, finally, to select the best possible loading bay and define the best possible vehicle path.

Several simulations of the algorithm result in significant savings in comparison to the existing scenario (direct delivery to each customer, without using LBs and without using the routing algorithm). In Table 1, total savings in terms of total travel time, driven distances, emissions of CO_2 and consumed fuel are reported, in terms of percentages, daily and yearly values. Total daily values are calculated according to the number of daily trips performed in each scenario (A=291, B=315, C=170). Total yearly values are calculated for 250 working days per year.

As seen from Table 1, daily savings altogether are: 147 hours of travel time, 3,021 km of distance travelled by freight vehicles, 906.2 kg of CO_2 emissions and 344 litres of diesel fuel, when the first approximation method is applied; and 170 hours of travel time, 3,489 km, 1,046.7 kg of CO_2 emissions and 398 l of diesel fuel in the case of the second approximation method. This account, on a yearly basis, for: 36,739 hours of travel time, 755,145 km, 227 tons of CO_2 emissions and 86,087 litres of diesel fuel, when the first approximation method is applied; and 42,559 hours of travel time, 872,273 km, 262 tons of CO_2 emissions and 99,439 litres of diesel fuel, in the case of the second approximation method.

Table 1: *Total daily and yearly savings in case of using the first and the second approximation method (for all three periods of the day)*

TOTAL SAVINGS		1st approximation method	2nd approximation method
Total travel time	*h/day*	147.0	170.2
	h/year	36,739	42,559
Total distance	*km/day*	3,021	3,489
	km/year	755,145	872,273
Total Co2	*kg/day*	906.2	1,046.7
	tons/year	227	262
Total fuel consumption	*litre/day*	344	398
	litre/year	86,087	99,439

Additionally, the two compared approximation methods result in different performance in walking distances of the deliverer (from loading bays to customers) and the waiting time of the delivery vehicle before entering the city centre. In the case of the first approximation method (only the best possible loading bay - the closest to the cluster centre is selected), the average walking distances are only at about 70 metres, but vehicles must wait outside the city centre for approximately 30 minutes on average. If the second approximation method is used (the algorithm chooses from among all the acceptable options of feasible loading bays, not only the closest one), the average walking distance is around 300 metres, but vehicles almost never wait outside the city before performing the deliveries.

The results clearly indicate the need to consider the dynamic management of loading bays for urban freight deliveries as one of the most promising measures for achieving more sustainable and energy efficient cities.

4 CONCLUSIONS

The optimization of urban freight deliveries, based on the optimal assignment of loading bays and optimal vehicle routing, can result in considerable savings of travel time, travel distance, fuel consumption, and CO_2 emissions. Energy savings are mainly related to the decrease of driven distances, mostly caused by increasing the walking part of the delivery. However, more critical energy savings are gained by optimal routing and selection of the most optimal entrance/exit gate for serving a particular customer located in the city centre.

The results considered in this paper are based on the assumption of a single delivery for each instance (i.e., the delivery vehicle serves only one customer at the time). For the future work, multiple deliveries should be considered (i.e., serving several customers during one delivery operation). In this case, the vehicle routing will not be limited to the shortest path but will search for the optimal combination of loading bays and entrance/exit gate for serving several customers during one vehicle trip.

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IMPROVING ENERGY MODELING AND RENOVATION THROUGH THE MONITORING OF MICROCLIMATE AND INDOOR AIR QUALITY

IZBOLJŠANJE ENERGETSKEGA MODELIRANJA IN PRENOVE Z MONITORINGOM MIKROKLIME IN KVALITETE NOTRANJEGA ZRAKA

Niko Natek[ℜ], Boštjan Krajnc[1]

Keywords: Energy efficiency, microclimate, building renovation, indoor air quality, radon, formaldehyde, Arduino, Raspberry Pi, wider benefits, HVAC

Abstract

This article examines the possibilities of supporting high-quality energy renovation projects that secure the optimal impact on the buildings' users, through the use of low-cost monitoring equipment. The demonstration pilot established a monitoring system in educational buildings and attempted to engage building users (primarily students) in several ways, from gathering information about their habits, level of understanding, willingness to be involved, co-creation workshops, information campaigns and application/testing of the developed tools.

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Povzetek

Članek obravnava možnosti za podporo visokokakovostnih projektov energetske prenove stavb, ki zagotavljajo optimalen vpliv na uporabnike, z uporabo nizko-cenovnih rešitev za izvajanje ciljnega spremljanja rabe energije in drugih parametrov. V sklopu demonstracijskega pilota je bil vzpostavljen sistem monitoringa v izobraževalnih stavbah s poudarkom na vključenosti uporabnikov (predvsem študentov) na več nivojih, od zbiranja informacij o njihovih navadah, ravni razumevanja, pripravljenosti na sodelovanje, aktivne udeležbe na delavnicah za soustvarjanje, izvedbe informativnih kampanj in uporaba/testiranje razvitih orodij.

1 INTRODUCTION

According to the three main targets defined within the 2020 Climate and Energy package of the European Union, Member States will achieve a 20% improvement in energy efficiency, a 20% share of renewables in the overall energy consumption and a 20% reduction of greenhouse gas (GHG) emissions (CO_2 equivalent) by the year 2020, *[7].* The total GHG emissions of the EU in 2016 (including emissions from international aviation and indirect CO_2 emission) were already down by 22.4 % in 2016 (relative to 1990), *[7]*; the EU is thus on its way to significantly surpass this target. However, in the same year, the EU had a dependency rate equal to 54%, meaning that more than half of the area's energy needs were met by net imports, mainly petroleum products (66%), natural gas (24%), and a smaller share of solid fuels, *[7].*

Gross inland consumption of energy (total energy demand of the region) within the EU-28 in 2015 was 1627 million tonnes of oil equivalent (Mtoe) of which it was estimated that buildings represented almost 40 % of this amount. Naturally, reducing energy consumption in buildings, whether in households, industry or otherwise, has been seen as a clear priority by transnational decision-making bodies in the context of achieving the goals defined in the climate and energy package. In the past, the main focus in the area of facilitating energy renovation was on economic feasibility and alternative financing models, that would foster increased investment into the sector. However, energy renovation measures that often make the most sense from the technical and environmental perspectives (reducing energy consumption and GHG emissions) can be dismissed solely due to their lack of securing good investment value, which is especially true in countries and regions where energy, in general, remains cheap. Frequently, the return of investment for energy renovation is too low (or negative) even within a long-term horizon of 15 years or more, also if aid through co-funding sources is provided.

Nevertheless, buildings have their own purposes and should not be viewed as financial derivatives or other such products; rather renovation strategies should focus on the individual user, how they will be affected and what the relevance to the broader community is. While it is understood that a building's indoor environment is a critical factor contributing to the well-being of its users, data about specific parameters that can lead to optimized conditions for health and productivity are seldom available.

Furthermore, the investment perspective does not currently, on any meaningful level, consider the wider benefits of energy renovation, and what the value of the energy renovation to the building users is and not exclusively to the investor. According to a study published by Environmental Health Perspectives in 2016, *[6]*, the cognitive performances of workers in an improved (renovated) building environment were found to be 101% higher than in conventional buildings. Crisis response scores were 131% better, strategy scores 288% greater, and information usage scores a staggering 299% higher for employees not exposed to the sort of elevated levels of CO_2 and volatile organic compounds (VOCs) typically found in urban building environments. Moreover, the main issue of including these types of monitoring capability within existing or planned to be established Energy Management Information Systems is the cost associated with additional equipment. However, low-cost and open source platforms exist, through which the facility/energy manager can be provided with this information; these platforms can be designed in a portable and compact form, so that they are easily distributed over a larger number of building quarters compared to expensive data loggers, and can easily be designed or repurposed for specific, individual situations.

These platforms include microcontrollers from Arduino and Raspberry Pi. This article will present the establishment of a low-cost monitoring system for indoor air quality and microclimate parameters within an existing EMIS of a school centre in Velenje, carried out within the THE4BEES project (Transnational Holistic Ecosystem 4 Better Energy Efficiency through Social innovation) funded by the Interreg Alpine Space transnational programme.

2 OVERVIEW OF THE MONITORING SYSTEM

The monitoring system for acquiring data on indoor air quality and microclimate parameters was established as a part of the demonstration pilot activities implemented within six individual buildings of the School Centre Velenje (ŠCV). The key parameters measured by the established sensor network are air temperature, relative humidity, levels of CO_2, radon and formaldehyde found in the indoor air. The core sensing network, in which the trial phase is carried out, is placed within a pre-existing energy management system with which buildings of the ŠCV (buildings A, B, C, D, E) are equipped. The main tasks of the existing system are the acquisition, processing and analysis of the energy used and its costs at the real current level (for e.g. minute, hourly and daily consumption with built-in measuring devices on the counters) and the monthly level, which is realized with the help of received invoices from suppliers of energy products. Thus, they form the basis of real and invoiced data of consumed energy, which can be compared with each other, and, in particular, on the basis of energy analytics, plan daily or, monthly spending. Databases are formed on the school centres internal server.

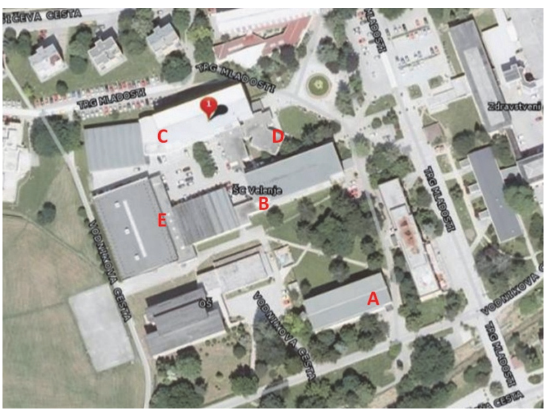

Figure 1: *Buildings of the School Centre Velenje (Source: Google)*

This existing capacity allowed for the introduction of additional measurements, focused on indoor air quality and microclimate parameters (thermal comfort), to be installed within THE4BEES project. The figure below represents an overview of the key components of the sensing network installed within one of the buildings (Building C) in the school centre.

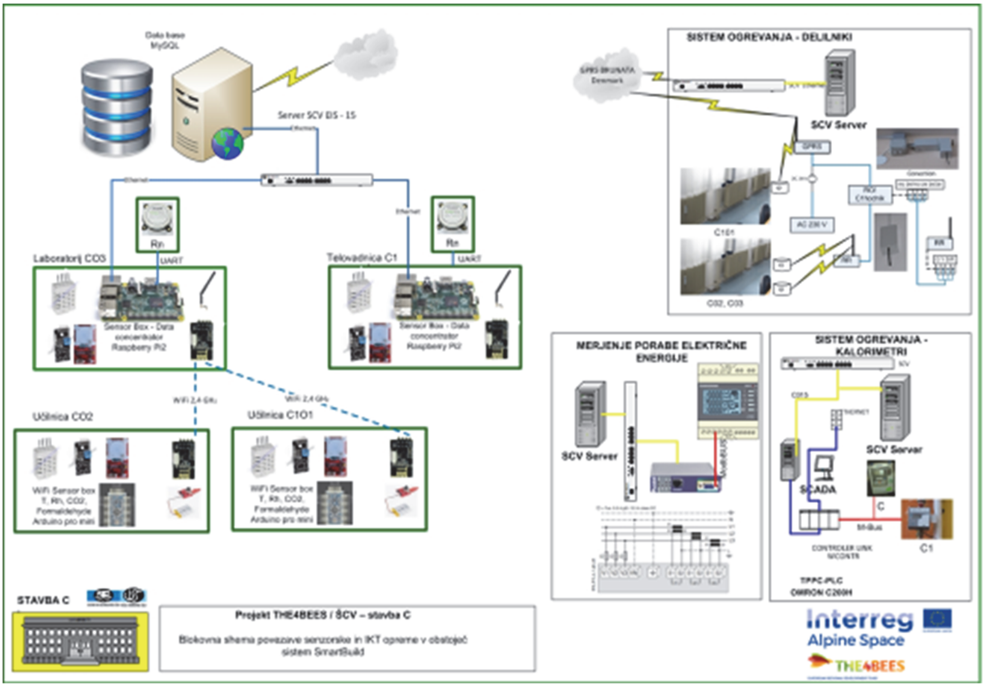

Figure 2: *Schematic presentation of the sensing network used in ŠCV (Source: School Centre Velenje)*

The figure portrays a schematic of some of the key parts of the monitoring system, which includes the measurements of electrical energy consumption (DIRIS A10 multi-function meter for measuring electrical values in low voltage networks in modular format), heat (heat dividers and/or calorimeters paired with smart thermostatic valves type Micropelt MVA-B00X and Thermokon SAB05) and microclimate data (E+E Elektronik wireless integrated temperature, humidity and CO_2 sensor). In addition, the classrooms are equipped with motion sensors, smart window handles (measuring of the open/closed state of the window) and smart handles on doors, all connected via periphery units, such as programmable industrial routers, remote ethernet modules and similar. Thus, a wide array of monitoring equipment has been installed within several projects and initiatives, from which THE4BEES demonstration pilot benefited. The monitoring equipment installed within THE4BEES, which contributes to the further development of the EMIS system of ŠCV, especially in terms of user-focused measurements, is visible on the left of Figure 2. There were two key components developed for the purpose of monitoring various variables of the indoor climate, a standard sensor box based on Arduino™ and a sensor box in the role of a data concentrator based on Raspberry Pi™. In addition to standard microclimate measurements, due to the local specifics (new construction and refurbishment of school buildings, the location of buildings in the vicinity of an abandoned lignite shaft), the systems include the capability to measure formaldehyde and radon gases.

Figure 3: ENIoTOR sensor box-Arduino (left) and data concentrator-Raspberry Pi (right)

3 COMPONENTS OF THE MONITORING SYSTEM

3.1. Standard sensor box - Arduino

The sensor box is based on the Arduino microprocessor on which sensors are wired. The focus of the design of the sensor box was to develop a compact system that can be easily installed on inner walls of indoor spaces or to function as a portable monitoring unit (LiPo battery with 150-200 mAh capacity), connecting to the server and sending data via the integrated WiFi module. The sensor box is used to measure temperature, humidity, CO_2, and formaldehyde levels.

Figure 4: *ENIoTOR sensor box (Source: THE4BEES project)*

The sensor box was designed as a standalone system with its own power supply that can be charged by maintenance if and when required. The sensor box unit is composed of off-the-shelf components described in the following sections.

3.1.1 Microcontroller Arduino pro mini

The Arduino Pro Mini is a microcontroller board based on the ATmega168 high-performance Microchip (newer versions are equipped with ATmega328). It features 14 digital input/output pins (of which six can be used as analogue, PWM-Pulse Width Modulation outputs), six analogue inputs, an on-board resonator, a reset button, and holes for mounting pin headers. A six-pin header can be connected to an FTDI cable or a breakout board to provide USB power and communication to the board. The Arduino Pro Mini is intended for semi-permanent installation in buildings or exhibitions. The board comes without pre-mounted headers, allowing the use of various types of connectors or direct soldering of wires. The pin layout is compatible with the Arduino Mini. There are two available versions of the microcontroller, of which the one with a lower voltage of 3.3.V and 8 MHz was used.

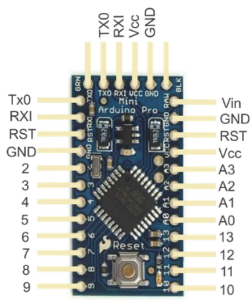

Figure 5: *Arduino Pro Mini microcontroller pins8*

3.1.2 Digital Temperature and Humidity Sensor DHT22/AM2302

The sensor box features the standard version of the DHT22 digital temperature and humidity sensor. The sensor was chosen for the application because of its relevant features, including a very compact design, low power consumption in normal operation as well as a long transmission distance (up to 100 m). The connection of the sensor is straightforward because of its four pins located in a single row.

3.1.3 Wi-Fi module NRF24L01P

To create a connection between two microcontrollers, the sensor box utilizes the nRF24L01P transceiver Wi-Fi module based on the nRF24L01 semiconductor by Nordic. The module uses a 2.4 GHz band and can operate with baud rates from 250 kbps up to 2 Mbps. The connection can reach up to 100 metres in open spaces at the lower baud rate. It can use 125 different channels, which enables it to connect a network of 125 independently working modems. Moreover, each channel can have up to six addresses, or each unit is capable of communicating with up to six other units at any given time.

Figure 7: *Wi-Fi module NRF24L01P (Source: How to mechatronics)*

3.1.4 Carbon dioxide sensor mh-z19

The MH-Z19 is a compact non-dispersive infrared (NDIR) sensor for monitoring the presence of carbon dioxide in the air. Its main features include excellent selectivity (monitoring not disrupted due to varying concentrations of other gases), a built-in temperature sensor for compensation, and long-life span.

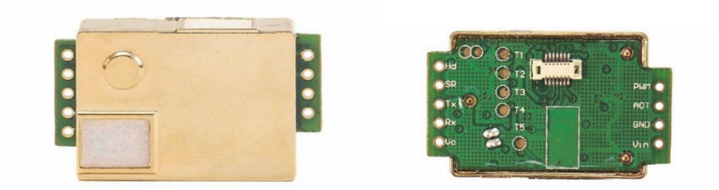

Figure 8: *Carbon dioxide sensor mh-z19*

3.1.5 Formaldehyde sensor ze08-ch20

The sensor box is equipped with a general-purpose, portable, miniature electrochemical detection model, which monitors the presence of formaldehyde (CH_2O). Its main features are high selectivity and stability, built-in temperature sensor as well as digital output and analogue voltage output at the same time.

Table 1: *Ze08-ch20 technical specifications*

Model No.	ZE08-CH2O
Target Gas	CH2O
Interference Gas	Alcohol, CO, etc.
Output Data	DAC(0.4~2V standard voltage output)
	UART output(3V Electrical Level)
Working Voltage	3.7V~9V (with voltage reverse connect protection)
Warm up time	≤3 minutes
Response time	≤60s
Resume time	≤60s
Detection Range	0～5ppm
Resolution	≤0.01ppm
Operating Temp.	0～50℃
Operating Hum.	15%RH-90％RH(No condensation)
Storage temp.	0～50℃
Working life	2 years（in air）

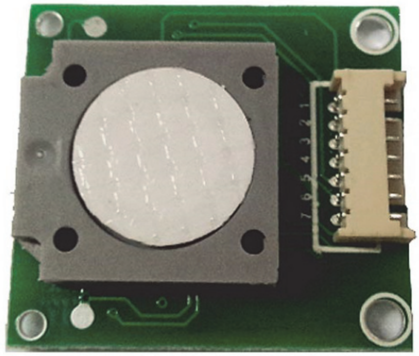

Figure 9: *Formaldehyde sensor ze08-ch20*

3.1.6 Power supply

The sensor box is charged via a standard micro USB connector/charger, with an output of 5.0V/0.7A (input ≈ 240V/50Hz). The unit is also able to function independently from a power source for up to six hours due to an integrated lithium polymer (LiPo) cell rechargeable battery with a capacity of either 150mAh or 200mAh and a voltage rating at 3,7V. The battery is charged through a constant voltage/current linear charger type TP4056.

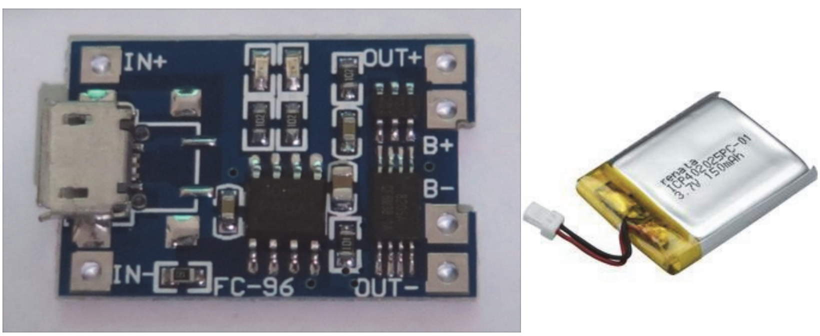

Figure 10: *Linear charger type TP4056 (left) and Renata Lithium Polymer rechargeable battery (right)*

3.2 Sensor box/Data concentrator – Raspberry Pi

The data concentrator is based on the Raspberry Pi (Raspberry Pi 3 model B) microprocessor platform that is used to gather data from sensor boxes and connect to the school's server. It allows for the independent measurement of temperature, humidity, CO_2 and radon concentrations.

The data concentrator has two main functions:

- Independent measurements of microclimate parameters and air quality
- Data concentrator (receiving and sending data from other sensor boxes in the network)

The data concentrator mostly utilizes the same sensors and equipment on the periphery (*Digital Temperature and Humidity Sensor DHT22/AM2302, Carbon dioxide sensor mh-z19, Wi-Fi module NRF24L01P*) as the sensor box built on the Arduino platform, with the exception of the radon eye external sensor with Bluetooth connectivity, described in this section. In addition, the temperature and humidity sensor is placed within a cylindrical extrusion on the ENIoTOR data concentrator in order to mitigate the measurement error due to excessive waste heat from the Raspberry Pi. In addition, the Wi-Fi module used in this configuration is connected to a standard antenna (original for the module) to improve connection signal and range.

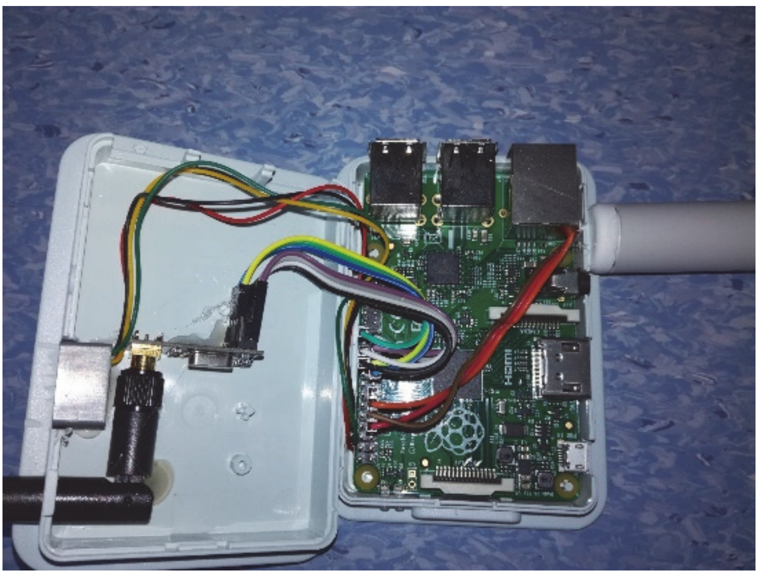

Figure 11: *ENIoTOR Sensor box/Data concentrator – Raspberry Pi (Source: THE4BEES)*

3.2.1 Raspberry Pi 3

The Raspberry Pi 3 Model B is the earliest model of the third-generation Raspberry Pi. It replaced the Raspberry Pi 2 Model B in February 2016 (see also the Raspberry Pi 3 Model B+, the latest product in the Raspberry Pi 3 range).

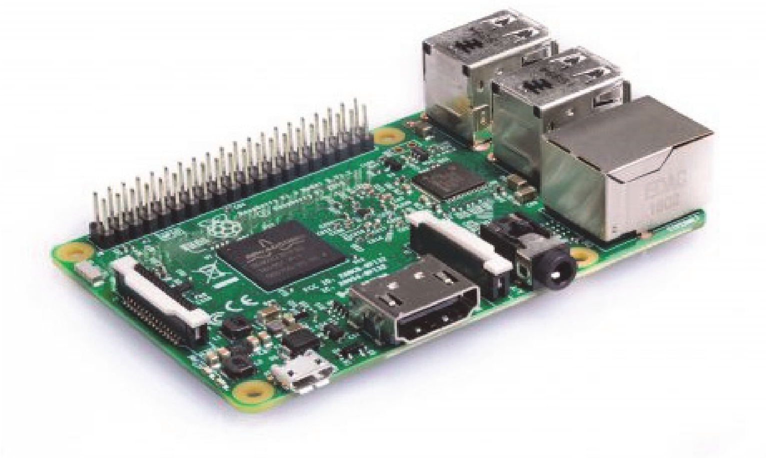

Figure 12: *Raspberry Pi 3 Model B (Source: Raspberry Pi portal)*

3.3 External sensors

3.3.1 Radon Eye

Radon Eye RD 200 is a smart radon detector with high sensitivity that can provide reliable data (in real time) less than one hour after the start of the measurements. Its measurements are based on detecting the radioactive decay of α-particles using a 0,2l pulsed ionization chamber and an individual amplifier circuit.

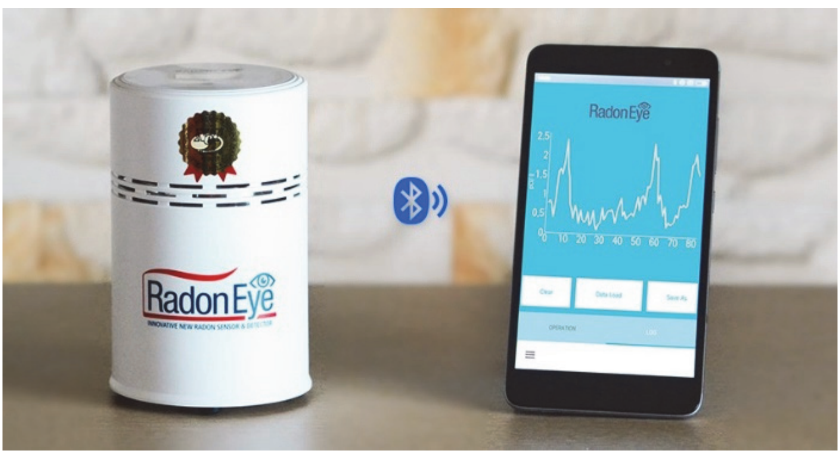

Figure 13: *Radon Eye RD 200 radon detector*

The sensor network was calibrated with professional (semi-professional) data loggers and compared to measurements carried out by existing monitoring systems in place at the location of the national pilot. Amongst the key equipment used to secure reliable measurements of the monitoring system were the Metrel POLY MI6401 and the Correntium plus/Canary pro II. The MI 6401 Poly is a multipurpose handheld instrument for measuring microclimate and lighting parameters inclusive of relative humidity, air temperature, air velocity and luminosity. The Canary pro II is a data logger for accurate and reliable measurement of the concentration of radon gas. It also offers additional functionality in terms of integrated sensors for temperature and humidity and air pressure as well as a comprehensive analytical capability (Correntium Report and Analysis software).

4 DATA MONITORING INTERFACES

Altogether, 73 additional data streams are collected with the monitoring system, primarily on a dedicated portal (http://www.energija-rr.si/admin/the4bees.php) from which they are transferred to the Yucca Smart Data Platform, operated by one of the Italian partners participating on THE4BEES project, CSI Piemonte. The data streams relevant to the pilot project of THE4BEES are gathered in a dedicated subsection within the portal.

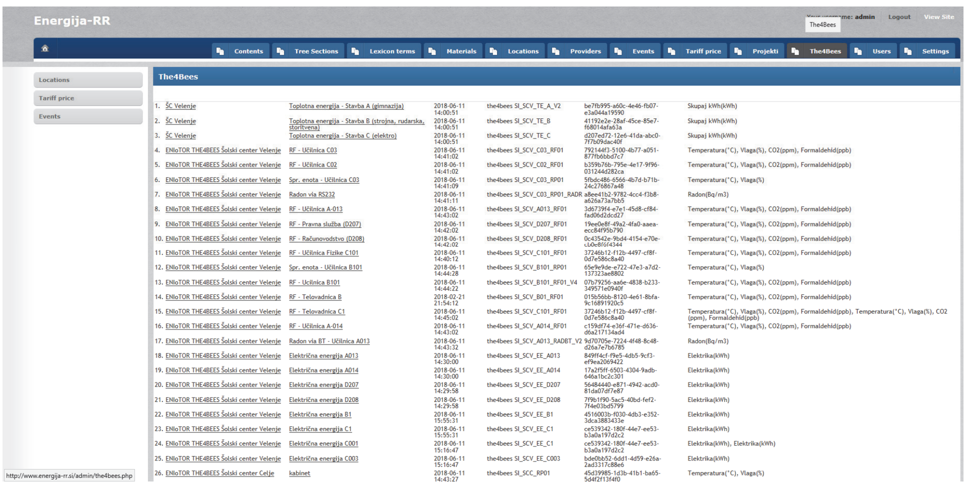

Figure 14: *Overview of data streams at energija-rr .si web interface for THE4BEES project*

For a visual representation of the gathered monitoring data, quick testing and demonstration, a second web interface is used, available at http://www.klima.beri.si. It allows for the effective monitoring of several locations and a quick overview of the data-sending activity.

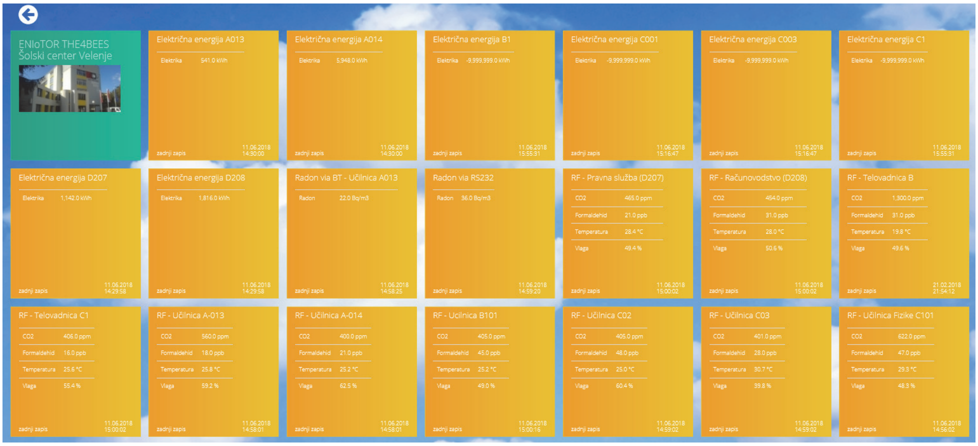

Figure 15: *Visual representation of sensors/measuring units, last measurements value and time*

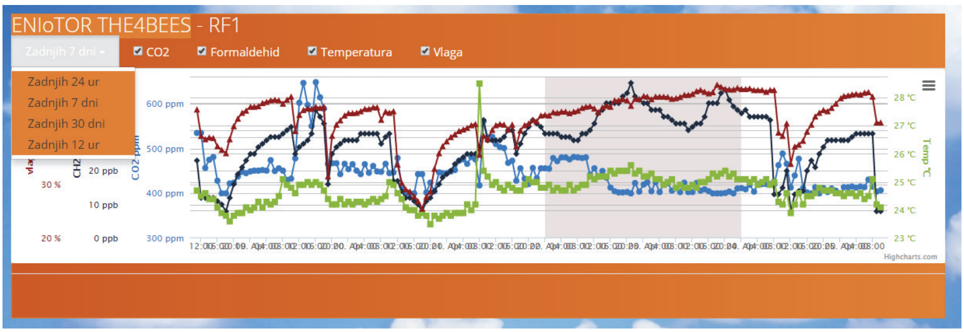

Figure 16: *Visual representation of monitoring data (microclimate and CO2)*

5 CONCLUSION

The demonstration pilot carried out within THE4BEES project was designed to influence the behaviour of persons involved in the educational process on the secondary and tertiary levels. The activities, as well as the general design of the monitoring network, were focused on addressing students. Although awareness-raising activities were carried out non-selectively for all persons related in any way to the educational process, particular focus was dedicated to actively engaging students with an acquired skill set that was/is relevant to the scope and activities of THE4BEES project. Specifically, the students that participated in the largest extent in the pilot activities had previous experience in electrotechnics, electronics, automation, computer programming or any of the multidisciplinary related fields. This approach was applied to achieve the greatest possible impact and multiplicator effect (students become teachers, mentors and ambassadors) of the co-creation activities. The core sensing network was developed and tested for the purposes of pairing data on energy use (pre-existing energy monitoring information system) with monitoring data on microclimate parameters and indoor air quality within six buildings (6 classrooms, 2 gymnasiums and 2 offices) of the School centre Velenje (ŠCV), located at Trg mladosti 3. The sensor equipment was primarily tested and calibrated on the premises of a dislocated unit, the Interbussiness educational centre (MIC) Velenje, located at Koroška cesta 62a, 3320 Velenje, where certain co-creation activities were carried out mostly due to great access to laboratory equipment (development, testing, programming, first calibration). Particular focus was attributed to measurements of indoor air quality, that is defined as a prerequisite and benchmark for monitoring and optimizing energy use with reference to existing health and safety standards. To this end, the developed sensing network measures indoor levels of carbon dioxide (CO_2), formaldehyde (H_2CO) and radon (Rn) gases. CO_2 was chosen due to its negative effects on concentration and overall learning ability. Formaldehyde and radon are highly hazardous gases that were assumed to be problematic in the context of energy renovation of the thermal envelope, which generally reduces the air exchange rate between the interior and exterior, causing in many cases increases of formaldehyde and other VOCs (volatile organic compounds).

Furthermore, radon is formed from radium in the uranium decomposition series within the earth’s crust and rises to the surface where it enters the atmosphere or accumulates in enclosed spaces, such as caves, mines and buildings. Velenje has a long tradition of lignite mining and has also been very active in energy renovation in previous decades. A combination of these two factors points to the potentially hazardous build-up of radon levels on the ground/lower storeys.

ŠCV is primarily focused on the practical aspects of learning, so that students can achieve higher professional and technical education that is very specifically focused on market and industry needs, while the dislocated unit MIC has become a centre of excellence and modern technologies; in its classrooms and laboratories students can achieve quality functional knowledge in the field of energy, computer science, mechanical engineering, business, ICT and so on. In addition, the MIC is located in the vicinity (on top) of an abandoned mine shaft, assumed (and later confirmed) to pose an increased risk of radon gas presence. In addition, the entire complex is constructed around an advanced energy technology learning and demonstration course (including solar PV, solar collectors, geothermal applications, nZEB-nearly zero energy buildings, wind turbine, etc.) that unites the learning process within one study visit for pilot participants about energy, from production to consumption.

With the intent of gaining a better understanding of the needs and requirements of educational institutions within the region as well as establishing a stronger platform for promoting policy adaptation, it was necessary to engage additional schools that were willing to carry out the activities of the project and consent to installing the sensor equipment and support the monitoring processes. To this end, measurements were carried out within the premises of three additional educational institutions, the School Centre Celje (ŠCC), School Centre Ravne na Koroškem (ŠCR) and the elementary school Črna na Koroškem (OŠ Črna). Students from the School Centre Celje and the School Centre Ravne actively participated in the co-creation labs as well as follow up activities. The elementary school Črna na Koroškem, in contrast, was included in the monitoring system as a test-site for determining and quantifying negative effects of improper energy renovation on indoor air quality as wider consideration of associated health risks. Each of the three associated partner schools was provided with a set of measuring equipment, containing one Arduino sensor box, one Raspberry Pi sensor box data/concentrator, and the external radon sensor.

Pilot participants of ŠCC have been carrying out monitoring and awareness-raising activities in a specially designed classroom for extracurricular activities, equipped for enthusiasts and tinkerers of the vocational programmes, as well as for preparing for themed school competitions. SCR has placed the monitoring equipment in a joint classroom frequently used for addressing school visitors, taking every opportunity to point out the importance of securing excellent indoor air quality and provide information about THE4BEES project. The elementary school Črna na Koroškem used the equipment to successfully identify the shortcomings (in terms of microclimate parameters and indoor air quality) of the recently completed energy renovation of their buildings. Each school that engaged in the pilot was characterized by strong support from their principals and will continue make measurement and build upon existing knowledge and experience. The management and coordination team of the Slovenian pilot consisted of four educators (two from the School Centre Velenje in charge of operating and maintaining the internal EMIS system of the organization as well as carrying out organizational and awareness raising activities associated to energy efficiency, as well as one mentor from ŠCC and one from ŠCR), two representatives of a local SME that was chosen in a public tender to supply the equipment and oversee/support the development process, two students from the technical college programme at ŠCV, that each developed their final diploma thesis on the topic of monitoring indoor air quality/energy use (one focused on the deployment of the sensor box-Arduino unit and the other on the data concentrator-Raspberry Pi unit) and participated in the co-creation activities as mentors to the students of the secondary vocational programmes in addition to the constant engagement from the side of project partners KSSENA and EZAVOD. The core group that participated in co-creation pilot activities consisted of 22 students from the schools mentioned above, age from 14-18 and male. The monitoring system and pilot activities, in general, were very well received by the participating students. There is clear opportunity to engage students in innovative co-creation activities as demonstrated by THE4BEES project to complement the traditional classroom (education vs regurgitation) approach. Presenting specific problems to the students has a positive effect in terms of presenting a challenge, providing a sense of accomplishment once it has been met.

A major issue with using innovative approaches to conveying complex messages is the prohibition of the use of electronic devices on school grounds. The potential of supporting the learning process by such devices (like mobile devices and free applications) is substantial; therefore, the experience of the Slovenian pilot clearly indicates that such bans should be re-defined or lifted all-together.

From the Slovenian pilot experience, the feedback functionality is an essential part of addressing energy users and should be expanded within future project activities. It was clearly demonstrated that further personalization of applied IT tools that would be tailored to the individual and would learn from their past behaviour (login, UI customization, customized level of thermal comforts, etc.) would be necessary to improve their ability to engage and impact behaviour on the level of final consumers. Visualization of complex data was seen as a key factor for effectively conveying the message to the students, particularly in the form of demonstrations and infographics. An approach similar to workout or learning applications would be welcomed (30-day workout program, Endomondo, Duolingo, etc.), whereby the user is confronted with challenges and alerts that are designed to produce internal motivation and action. The applications should also allow the comparison between the present and past performance in order to quantify and stress the improvement an individual was able to achieve. Comparison and competition, in general, are great ways to engage and motivate students (users in general) in energy virtuous behaviour. The issue remains to secure good comparability of data and clear rules that unify the efforts and activities of each participant, which is very difficult in the field of energy use. A good way forward would be to organize such competitions in the form of training "boot camps", where participants would be able to demonstrate their knowledge/behaviour in a comparable setting. It was found that for households the information that motivated energy consumers the most was not, for example, the amount of money they were wasting with unnecessary energy use, but that they were consuming more (having a more significant impact on the environment, in essence doing worse from a sustainable perspective) than their neighbours.

Finally, virtuous behaviour (once quantified) should be rewarded. The capability to motivate energy users by making them part of the energy savings would go a long way. Great success was demonstrated past initiatives, such as implementing the 50/50 methodology in schools; however, more efforts should be made to reward the individual responsible for the desired outcome, rather than the organization or the managing authority. In its current state, the legislation and administrative procedure is prohibitive in the sense that it does not to any extent define the structure for rewarding virtuous energy consumption behaviour amongst users and managers and does allow even the minimal flexibility in public budgets for such causes; therefore, this option was not further explored within the Slovenian pilot. Part of the financial savings could be reinvested in new electronic equipment that students could use to build gadgets and tools in their school electronics/robotics classes, especially equipment used for building and learning on the field of energy, energy measuring, and energy consumption. In this case, both learning and awareness raising could be achieved, but there would have to be consistent support from the school/managing authority. Newly obtained knowledge about the importance and impact of indoor air (understanding of the impact of indoor air quality and microclimate on cognitive ability and health) should be argued primarily on the level of energy renovation.

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CHARGING A CAR IN MOTION WIRELESSLY

BREZŽIČNO POLNJENJE AVTOMOBILOV V VOŽNJI

Dario Ležaić[2], Tihomir Mihalić[ℜ1], Andrej Predin[3]

Keywords: wireless on-the-road-charging, Dynamic charging, Li-Air, wireless tower, car body panels as energy storage system

Abstract

The concept is charging electric cars wirelessly, both stationary and in motion, via wireless modules prebuilt in roads or over energy towers that emit electrical energy through the air. The wireless charging of electric cars means there is a completely new obstacle for engineers: one that competes with conventional battery charging. The conventional charging of high capacity batteries is simple, because current travels along a wire that is made of metal and is a good conductor. However, how is it possible to transfer great amounts of electricity wirelessly through the atmosphere?

Povzetek

V članku je predstavljena ideja polnjenja električnega avtomobila statično in v vožnji, preko brezžičnih modulov, nameščenih v cesti, ki se napajajo preko energijskih stolpov, ki emitirajo energijo skozi zrak. Brezžično polnjenje električnih avtomobilov predstavlja popolnoma nov inženirski pristop glede na konvencionalno polnjenje električnih baterij. Namreč konvencionalno polnjenje baterij zahteva kovinske vodnike, ki so dobri prevodniki, ne omogočajo pa polnitve v gibanju avtomobila. Izziv pa je, kako emitirati večje količine energije brezžično in to višjih moči.

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1 INTRODUCTION

The Tesla company's conventional chargers can deliver about 120 kwh of energy and can charge a battery of 85kwh in approximately an hour. With new superchargers, it will be possible to deliver approximately 350kwh of energy; therefore, the speed of charging will triple, and the difference between charging electric cars (EC) and filling the tank of Internal Combustion Engines (ICE) cars will be greatly diminished. What about wireless charging? Power levels of 120 kwh for wireless technology are not presently possible because electric current that is running through metal conductors (made of metal with density of 8000 kg/m³) has enough particles on which to travel to the batteries. In contrast, air has 8000 times less density thus fewer particles on which the current can flow. This can be solved by using Tesla's coil for transforming high current of 500A and relatively low voltage of 120VDC and frequency into low current of just a few amps but very high voltage and frequency about 100kV and 50kHz; the specific parameters depend on the manufacturers and technologies used. That kind of current with high voltage and frequency travels faster through the air, carrying less "cargo" or less current; the current now can reach the batteries via the given amount of particles in air. The process of transforming voltage and current to the desired values and reversing it back again is fully automated and occurs beneath the car while parked over a charging station.

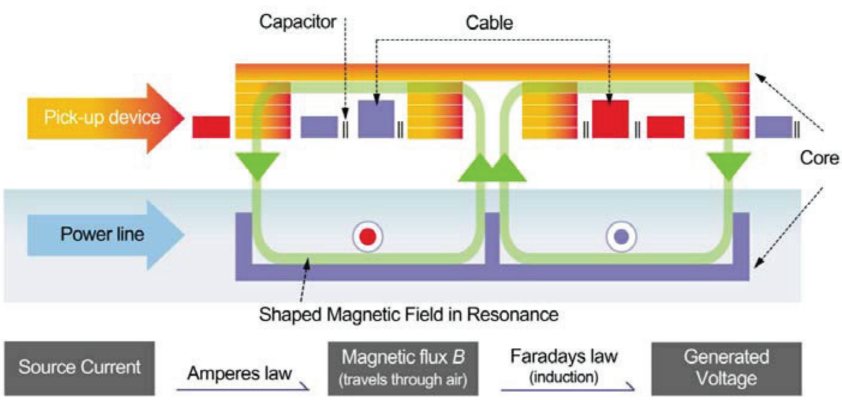

***Figure 1**: Wireless dynamic battery charging technology*

2 WIRELESS BATTERY CHARGING

This kind of energy transfer has great potential. The power of wireless charging varies in the range of 3.6 to 11 kWh depending of the manufacturer and the need of charging various battery types. With improvements of Qi (an open interface standard that defines wireless power transfer using inductive charging over distances) technology, somewhere between 22 to 25 kWh of energy is possible in the near future for the same battery capacity and device that is used now. An interesting idea for both static and dynamic battery charging is in a system of public transportation. Buses and trams have predetermined routes; therefore, installing wireless chargers in every station or every two stations can provide continuous battery charging and the overall battery capacity of used batteries can be reduced, which in the end reduces the high cost of manufacturing them. In this manner, wires hanging above tramlines could be removed, but electrical charging for all public transportation would remain possible.

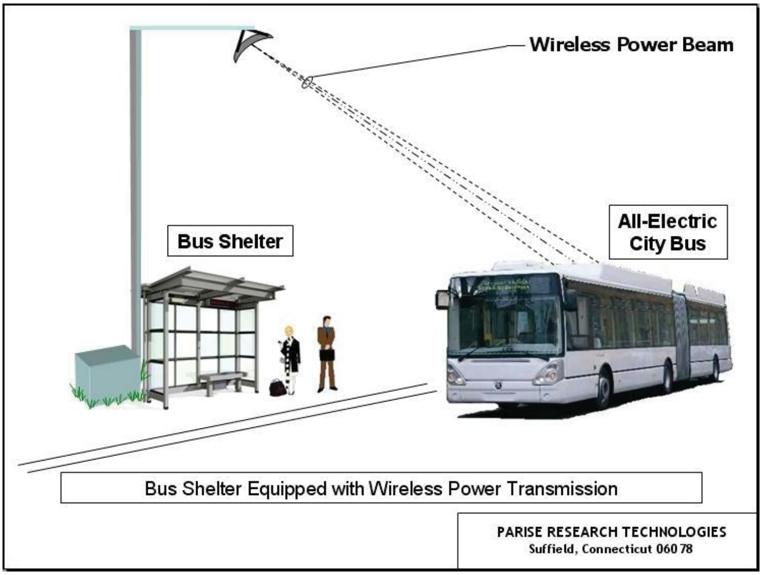

***Figure 2**: Diagram of using wireless charging technology in public transportation*

With the further development of solar panels, this number can be expanded, because every minute spent in sunlight means that the range is further extended; in combination with the wireless charging of cars in motion, market development and the buying of electric cars will be hastened. Furthermore, any excess energy that is produced could be sent back to the grid, thus reducing grid costs; it could also power nearby devices, such as mobile phones. This could provide added benefit to waiting passengers.

If we apply those ideas to cars we can discuss extending the ranges of Electric Cars. In particular, with current technology, solar panels with installed power of 4 kWh could give a radius of driving about 40 kilometres, which is enough to commute from home to work or from work to the nearest charging station. If the battery was completely drained when a driver arrived at work in the morning, this 40 km can help without any extra cost or worries; if the battery was at 50%, this extra 40 km safely guarantees the drive back home or even another, unplanned ride.

The latest achievement on the market is CED (Continuous Electric Drive technology), which was introduced by the car manufacturer Volvo. It already has a prototype, which will introduce this new engineering achievement to the public and it can be implemented in new vehicles very soon. Figure 3 shows Volvo's concept car with installed dynamic wireless charging technology.

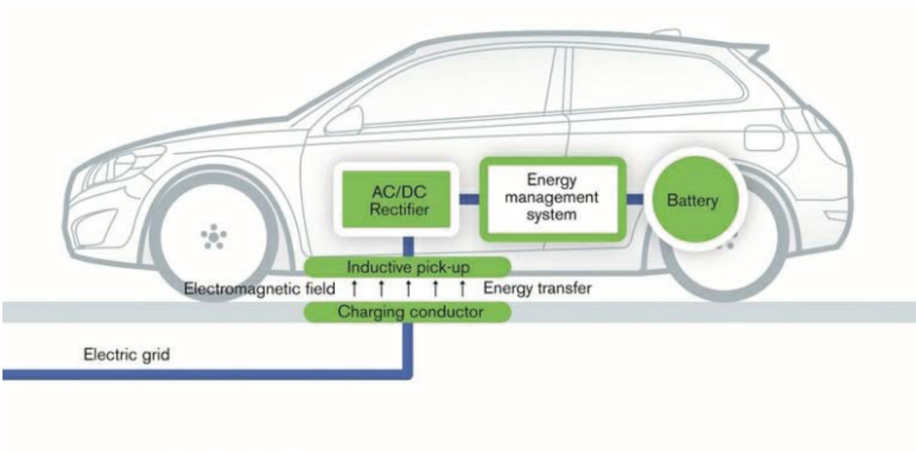

Figure 3: *Volvo's concept car with installed dynamic wireless charging technology*

Volvo has stated that its new prototype of electric car is ready for production and that it is fully adjusted for a dynamic wireless charging with a system called CED, which stands for Continuous Electric Drive. This technology is widely used in electric trams and railway systems in which a constant power supply to drive motors and batteries is used just to provide electric energy in emergency situations like gird failure or crashes; their capacity is just around a few kWh. However, with the CED system, engineers are adopting that idea to power the main motor for vehicle propulsion and to make it more efficient. Everything unnecessary will be removed and a smaller battery pack will be installed, which will be enough to power a car in non-charging areas; when it returns to the main grid, it will charge the battery fully and continue to use wireless power to move. By adopting this usage protocol, a car's range will be practically unlimited. This technology is very expensive today because of the necessity of installing thousands of kilometres of cables under the roads; it is technologically feasible, but a better solution may be found elsewhere.

Another idea is to build a tower that could broadcast energy like a TV tower broadcasts signals. An electric car consumes about 11 to 15 kWh of energy to travel a distance of 100 kilometres. Wireless technology which can deliver 11 kWh of power, which would be enough to provide driving over 90% of a given ride and only 10% would be covered by energy from the battery. This means that current electric cars with an average range of 150–160 kilometres could travel a distance of 1400 km with this new CED system. Of course, there is always a question of cost effectiveness for the previously mentioned system because this would require to completely reconstructing city roads to achieve this goal. With this in mind, perhaps building a one or few central towers to provide cars with electric energy would be a cheaper and better solution. Recent research shows that electric towers can send 10 kWh of electric energy in a radius of 500 metres; in this phase, a few towers to provide a whole city with enough power but in the future, range and power will grow so it will no longer be a problem.

The technology that is used in energy towers is based on microwaves. Microwaves, because of their ability to move through air at high frequencies, can deliver small amount of the energy in a given time but because of high frequency and the wider aspect of time when using more towers, greater amounts energy can be delivered.

Furthermore, another idea is to use the car's body panels as batteries, which will significantly lower the weight of current EC caused by the additional weight of batteries.

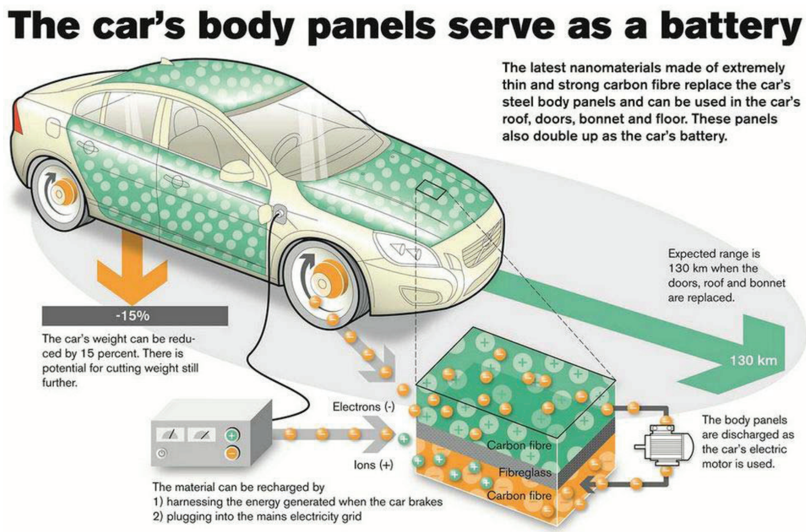

Figure 4*: Volvo's system to use car body panels to serve as energy storage.*

3 FUTURE DEVELOPMENTS

The race for new technologies and development never stops. If Volvo successfully implements its idea about using car body panels for energy storage, it would create a completely new perspective on how batteries look and how energy will be stored in the future. Conventional battery packs will become obsolete because there would be no need to use a plastic housing for battery cells. With this, a car's payload and usable volume will increase. The same thing happened with USB flash memory. At first USB flash drives had housing 10 times bigger than the USB connector, and now the USB connector is 4 times bigger than the rest of the device which can now store up to 10 times more data. The best solution for this system would be the usage of Li-Air batteries with great capacity and also usage of dynamic wireless charging to make cars lighter and to increase the range above 1000 km, body panels to store energy, and CED technology.

4 CONCLUSION

The vehicle production industry undoubtedly goes forward with new technologies. Now more than ever before, it is essential to reduce emissions of CO_2 in every way possible. Electric cars are very helpful in this situation because conventional cars produce large amounts of pollution. With the development of CED technology and fast battery-charging, electric cars become very attractive to buyers. The mass production of electric cars will lower their price, which is currently a significant obstacle to overcome when buyers decide which car to buy.

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Nomenclature

ICE	Internal Combustion Engine
EC	Electric car
CED	Continuous Electric Drive

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SLOVENIAN TITLE

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[1] **J. Usenik**: *Mathematical model of the power supply system control*, Journal of Energy Technology, Vol. 2, Iss. 3, p.p. 29 – 46, 2009

[2] **J. J. DiStefano, A.R. Stubberud, I. J. Williams**: *Theory and Problems of Feedback and Control Systems*, McGraw-Hill Book Company, 1987

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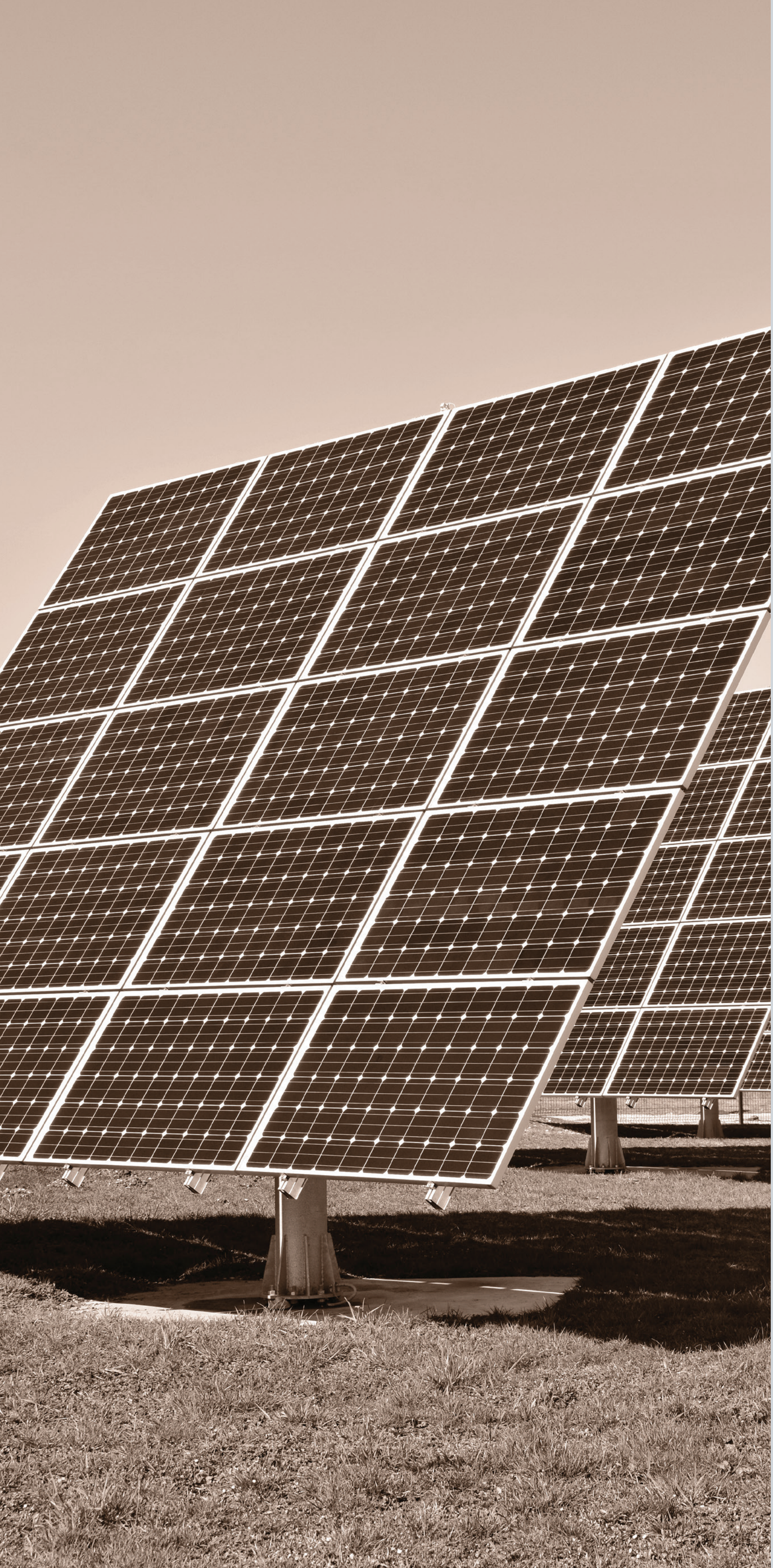

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