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Andrej PREDIN

Kopenhagen in energetika?

Konferenca v Kopenhagen-u se je končala s pravno nezavezujočim dogovorom. Obljubljene so milijarde pomoči revnim državam kot pomoč pri boju proti globalnemu segrevanju, vendar pa konkretnih ukrepov za zmanjšanje toplogrednih emisij ni v dogovoru. Prav tako v dogovoru ni nobenih konkretnih številk, določeno je le, da je potrebno globalno segrevanje omejiti pod dve stopinji Celzija glede na predindustrijsko obdobje. Države so pozvane, da do februarja 2010 naznanijo svoje zaveze za omejitev izpustov v naslednjih desetih letih, do 2020. Prav tako ni sprejetih nobenih dolgoročnejših ciljev do leta 2050. Na konferenci je sodelovalo 192 držav pogodbenic Okvirne konvencije ZN o podnebnih spremembah (UNFCCC).

Izpusti se v največji meri nanašajo na energetsko področje pridobivanja električne energije, predvsem iz termoenergetskih sistemov. Veseli smo lahko, da se je Kitajska, kot ena večjih onesnaževalk okolja, ki mimogrede ni podpisnica Kyotskega protokola, uspela prebiti med skupino najnaprednejših držav, ki gradijo nove termoenergetske postroje po principu integriranega kombiniranega cikla - uplinjanja premoga oz. IGCC (Integrated Gasification Combined Cycle) z zajemanjem CO_2 izpustov. Trenutno gradi dve napredni postrojenji in sicer Shenhua in GreenGen (Science, Sept. 2009, Vol. 325). Shenhua skupina elektrarn, ki bo kot stranski produkt zajela 3,6 milijona ton ogljikovega dioksida na letni ravni in jih bo skladiščila v bližnjih rezervoarjih pod tlakom. Ta uskladiščeni CO_2 bo uporabljen za iztiskanje težke nafte na površino, pri tem pa bo velik del CO_2 ostal v nepropustnih zemeljskih plasteh. Drugi projekt, GreenGen, ki ga je Kitajska vlada odobrila junija prejšnjega leta, bo skonstruiran po IGCC tehnologiji v Tianjin-u. Namesto klasičnega sežiga premogovega prahu pod tlakom je izbrana IGCC tehnologija, ki omogoča lažji zajem CO_2 že med uplinjanjem premoga in lažji zajem CO_2 po zgorevanju v plinskih turbinah. Tehnologija je bila razvita v sodelovanju s Standfordsko Univerzo iz Palo Alta v Kaliforniji, v okviru programa Obnovljivega energetskega razvoja. V kolikor bodo uspešni, bo to vodilni ogljiko-zajemni termoenergetski projekt v svetu. Do leta 2011 pričakujejo zagon 250 MW bloka. Dodatni 450 MW blok pa je predviden za zagon do leta 2016. Predviden je zajem preko milijon ton CO_2. Zajeti CO_2 bodo uporabili v spremljevalni kemični industriji, kjer bodo iz odpadlih vod in različnih odpadlih polimerov pridobivali sintetično nafto. Na ta način želi Kitajska prodreti z zaključeno tehnologijo zajemanja CO_2 in s proizvodnjo sintetične nafte v svet kot gonilna sila na tem področju. Njeni plani so res visoki, saj želijo v končni fazi zajeti preko 3,2 milijarde ton CO_2 na Kitajskem.

In kaj počne Evropa, naša Slovenija, kot najnaprednejša skupina okoljsko zavednih držav, podpisnic Kyotskega protokola?!

Copenhagen and energy technology?

The Copenhagen conference ended with a legally non-binding agreement in which billions of euros in promised aid to poor countries to help fight global warming were pledged, but with no agreement on concrete measures to reduce greenhouse emissions. There are no numbers in the agreement, only the conclusion that it is necessary to reduce global warming by two degrees Celsius (with reference to the pre-industrial period). By February 2010, all countries are invited to announce their commitments to limit emissions over the next ten years, i.e. to 2020. No long-term objectives for 2050 were made. The conference had 192 states parties participating in the UN Framework Convention on Climate Change (UNFCCC).

CO_2 emissions are mostly from electricity production, mainly from thermal power systems. We are pleased that the China, as a major polluter of the environment (and not a signatory to the Kyoto Protocol), is building new thermal installations on the principle of an integrated gasification combined cycle – IGCC with captured CO_2 emissions. They are currently building two advanced plant through Shenhua and GreenGen (Science, Sept. 2009, Vol. 325). The Shenhua Group plants will have a by-product of 3.6 million tonnes of carbon dioxide on an annual basis, which will be stored in nearby pressurised tanks. The stored CO_2 will be used for the extrusion of heavy oil to the surface, while most of the CO_2 will remain in non-porous layers of earth.

The second project, GreenGen (approved in June last year by the Chinese government) will be constructed with IGCC technology in Tianjin. Instead of conventional pulverized coal pressurised combustion, it will use IGCC technology, which facilitates the capture of CO_2 during coal gasification and the post-combustion capture of CO_2 in gas turbines. The technology was developed in collaboration with the University of Stanford in Palo Alta, California, under the renewable energy development program. If successful, this will be the leading carbon-capture thermal power plant project in the world. By 2011, a 250 MW block is expected to start; an additional 450 MW block is estimated to start in 2016. Over one million tonnes of CO_2 will be captured. The captured CO_2 will be used in the chemical industry, where they will extract various synthetic polymers and synthetic oil from the waste water. The intention is to enter China with complete CO_2 capture technology and the production of synthetic oil in the world as a driving force in this area. Its plans are so ambitious, because ultimately they want to capture over 3.2 billion tonnes of CO_2 annually in China.

However what are the actions of Europe, of Slovenia, proclaimed as a pioneering group of environmentally conscious countries, who are signatories to the Kyoto Protocol?!

Krško, January 2010

Andrej PREDIN

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PUPILS' WASTE MATERIALS AND ECOLOGICAL AWARENESS IN A DESIGN AND TECHNOLOGY CLASS IN SLOVENIAN ELEMENTARY SCHOOLS

KOMUNALNI ODPADKI IN EKOLOŠKO OSVEŠČANJE OTROK PRI POUKU TEHNIKE IN TEHNOLOGIJE NA OSNOVNIH ŠOLAH

Katja Cilenšek[ℜ] and Janez Jamšek

Keywords: awareness, ecological problems, ozone hole, greenhouse effect, acid rain, water pollution, air pollution, waste materials, separate collection of waste materials

Abstract

Rapidly melting glaciers, stronger and more frequent storms, and food and water shortages are only some of the climatic problems that Earth is experiencing increasingly frequently. For further action in stopping the consequences of global warming, it is necessary to increase pupils' educational awareness, i.e. to present them all possible known solutions to ecological problems and to teach them to exercise critical judgment regarding these issues. Teachers should be acquainted with current ecological problems and their consequences. Therefore, it was goal to discover the level and situation of ecological awareness of Slovenian pupils. By using a questionnaire, we examined 12- and 14-year old elementary school pupils as well as their teachers for the subject of Design and Technology. The purpose was to establish their knowledge of ecology and the level of teachers' effort to increase the pupils' ecological awareness. We reviewed the Design and Technology curriculum to discover to what extent it is related to ecology. We further attempted to identify the correlation between the teacher's instruction according to the curriculum and the pupils' ecological knowledge. These

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questionnaires were designed to determine to what extent the pupils understand ecological issues, whether they were taught them at school or learned them outside the scope of school curriculum. What do they know about ecological problems, waste materials and their separate collection, why do waste materials cause so many problems and are the pupils interested in ecology at all? We were also interested whether it was possible to connect the ecological awareness of pupils only with the curriculum, and how consistent teachers are when teaching Design and Technology according to the curriculum. In this paper, we present the questionnaire results from which it can be determined that whereas pupils' ecological awareness knowledge is good, their comprehension is rather poor. With this in mind, we propose possible actions to strengthen their ecological comprehension.

Povzetek

Prekomerno taljenje ledenikov, pogostejši in močnejši viharji, pomanjkanje vode in hrane, itd. so samo nekatere klimatske težave današnjega sveta, ki se kažejo v vedno večji meri. Za delovanje v smeri zaustavljanja ekoloških posledic, je neobhodno vzgojno osveščanje, učenje kritičnega razmišljanja ter predstavitev obstoječih možnih rešitve učencem. Z aktualnimi ekološkimi problemi in njihovimi posledicami je potrebno najprej seznaniti učitelje. S tem namenom smo skušali ugotovitvi trenutno stopnjo in stanje ekološke osveščenosti učencev. Anketirali smo učence 2. in 3. triade v osnovni šoli, prav tako tudi učitelje Tehnike in tehnologije z namenom ugotoviti njihovo poznavanje ekologije in prizadevanje približati jo učencem. Pregledali smo v kolikšni meri se navezuje učni načrt Tehnike in tehnologije na ekologijo in ugotavljali povezavo med učenčevim znanjem ekologije ter učnim načrtom in delom učitelja. Z anketnimi vprašalniki smo ugotavljali koliko učenci poznajo ekološko problematiko, ki se je učijo pri predmetu Tehnike in tehnologije, ali poznajo ekološko problematiko izven okvira šole - ali vedo kaj o ekoloških problemih, o odpadkih in njihovem ločevanju, zakaj odpadki povzročajo probleme ter ali učence ekologija sploh zanima. Zanimalo nas je tudi ali se z učnim načrtom Tehnike in tehnologije lahko dobro ekološko osvešča in ali se učitelji držijo striktno učnega načrta, ko obravnavajo to temo. Ugotavljamo, da učenci dobro poznajo ekološko problematiko iz učnega načrta, imajo pa težave pri razumevanju ekoloških problemov. Vedo, kaj je ločevanje odpadkov in pomen ločevanja. Ekologija jih zanima, učitelji pa so mnenja, da je ekološko osveščanje nujno. Kar nas lahko skrbi je to, da se z dosedanjim učnim načrtom Tehnika in tehnologija ne da dobro ekološko osveščati in da se učitelji pri obravnavi te snovi v večini držijo striktno učnega načrta. Znanje učencev je pogojeno z učiteljevim trudom in učnim načrtom, zato je potrebno osveščati v osnovnih šolah in poiskati pomanjkljivosti v učnih načrtih, ki obsegajo to tematiko. S tem namenom podajamo predloge za dvig ekološke osveščenosti učiteljev/učencev.

1 INTRODUCTION

Technology is currently one of the biggest causes of pollution. As such, it is necessary to indicate so. In recent years, it has been noticed that pupils in Slovene primary schools showed a lack of interest in ecology, which resulted in their low ecology awareness. By "ecological awareness" we primary mean waste products and their separation, knowledge of current ecological problems and pupils' general interest in ecology. The pupils' lack of concern for ecology was our primary motivation for discovering whether they realize how much technology affects the environment and whether they know what kind of ecological problems it causes. Since

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technology is most directly related to the Design and Technology (DT) subject in primary schools, we have focused our study on the DT curriculum [1].

DT is an obligatory subject in Slovenian primary schools from the 6th to the 8th grades. It is insufficient in its coverage of ecological issues and topics. As such, it is not able to ensure necessary ecological awareness. Ecological problems are currently gaining increasing importance in our everyday life. The DT curriculum no longer seems reflect this. Consequently, primary school teachers should aim to stimulate pupil's interest in ecology to increase ecological awareness. There are many different areas where this aim could be achieved. The most direct is related to the subject curriculum. It is in our interest to discover how DT contributes to the pupils' ecology awareness, i.e. to determine the correlation between DT teachers' work, pupils' knowledge and DT curriculum.

There are other potential areas where ecological awareness could be investigated, such as, DT field trips related to ecology, optional subjects in ecology and other school activities. Nevertheless, the pupils' ecological awareness could be achieved most effectively if the majority of schools would decide to become eco-schools; such schools follow the eco-document statements [2]. The most successful way of achieving eco-school pupils' ecological awareness is when the "eco-content" is integrated into the curriculum of different school subjects and class lessons.

2 ECOLOGY IN PRIMARY SCHOOL

In Slovenian primary schools, ecology is taught from the 1st to the 8th grade. In first, second and third grades, it is included in the curriculum of the school subject entitled "Let's Get to Know the Environment" [3]. Pupils learn about nature, how it works and its changes. They develop an attitude to nature, people's interference in nature and an awareness of responsible behaviour with the environment. In the 4th and the 5th grades, ecology is included in the curriculum of the school subject "Science and Technology" [4]. Pupils in the 4th grade learn about the separate collection of waste materials for the first time. They develop knowledge regarding regulated landfills and learn that waste products can be used for raw material. In the 5th grade, pupils learn about polluted water and the importance of clean water. They also learn about types of contaminants of water and air. In the 6th, 7th and 8th grades, ecology is in the DT curriculum [1]. In the 6th grade, pupils learn about recycled paper and its impact on forests and the environment. In the 7th grade, pupils learn about the positive and negative consequences of plastic materials, how production affects the environment, the role of people in those problems and the possibilities of saving electrical energy. In the 8th grade, pupils are taught about metals, engines and their impact on the environment. Ecology can be also found in other school subjects. In Science 7 (7th grade) [5], topics such as the decay of wood, the water and air pollution are studied. Ecological problems are discussed in the Citizenship and Ethics class (8th grade) [6].

Currently, ecological problems affect increasing numbers of people everywhere. Therefore, it is necessary to introduce them to younger generations of people. Regarding this, we present in brief the (I.) ecological problems and (II.) waste materials collection to clarify our specific ideas for addressing these topics. They are also dealt with in the third section of this paper.

(I.) Ecological problems. One such problem is the degradation of forest land. The main factors of this problem are fire, acid rain and storms. Since the year 2000, more than 7.3 million ha forests have been disappearing from the surface of the Earth every year [7]. The second ecological problem, which is connected to the first one, is desertification. In one year, deserts can expand by 60 000 km^2 [8]. The ozone hole is also one of the biggest global problems. In 2006, the international meteorological organization discovered that the ozone hole over Antarctica measures 29.5 million km^2 [9], which is the largest hole ever. The greenhouse effect is one of the most serious ecological problems for environmentalists. One of the consequences of the greenhouse effect includes the powerful storms that hit Slovenia in 2008; wind speeds reached 216 km/h [10]. Acid rain is another problem. It has harmful effects on plants, aquatic animals, and infrastructure. It is mostly caused by emissions of sulphur, nitrogen, and carbon compounds that react with the water molecules in the atmosphere to produce acids [11]. The last two ecological problems are water pollution and air pollution. Water pollution affects drinking water, rivers, lakes and oceans all over the world. This consequently harms human health and the natural environment. The primary cause of this problem is heavy metals from industrial processes. Air pollution is also caused by industry and traffic. The quality of air has improved in Slovenia in last 15 years. In 1992, we exceeded the maximum permitted value of sulphur dioxide in the air on 38 days; in 2004, this occurred only once [12].

(II.) Separate collection of waste materials. Separate collection of waste materials is one way of improving our environment. We can select paper, glass, metal, plastics, textiles, electronics, and organic waste. Recycling involves processing used materials into new products to lessen the consumption of raw materials, to save energy, to reduce air and water pollution, to lower greenhouse gas emissions, to reduce the consumption of natural resources (like water, air, wood etc.), to diminish the amount of waste on the landfills, etc. Slovene primary school pupils must know this particular school topic in order to increase ecological awareness.

3 PUPILS' ECOLOGICAL AWARENESS LEVELS

Slovene primary school pupils' ecological awareness levels were examined. The main purpose of the study was determining both the pupils' levels of both knowledge and interest in ecological issues and how their ecological knowledge correlates with their age (the difference between the 6th and 8th grades). Ecological awareness was studied under the subject of DT, which is obligatory from the 6th to 8th grades. Therefore, pupils entering the subject in the 6th grade and leaving it in the 8th grade and their technology teachers were the subject of the study. Although technology topics are integrated into other subjects in lower grades, we have focused only on DT since the correlation to the study can be determined most directly.

3.1 Method

Technology teachers and pupils aged from 12 years to 14 years (6th and 8th grades) were surveyed. For this purpose, we prepared two questionnaires: one for the pupils and one for the teachers. An additional aim was to discover whether the students' knowledge is related to the teachers' teaching. For this purpose, the questions in both questionnaires were related.

The questionnaire for the pupils consisted of 26 questions, divided into four topics. The questionnaire was the same for both grades, except for one question (the 3rd). In the 6th grade, pupils do not learn about electricity; therefore, for them the 3rd question was about wood

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coating. Each question had a one-choice answer. The first topic was related to the DT curriculum [1]. It includes questions from the curriculum and its aims concerning ecology. With these questions, we tried to examine whether pupils understand the ecological issues that they were taught at school. As there are only some ecological objectives covered in the DT curriculum, we were interested in the second topic to determine whether pupils are familiar with a larger scale of ecological problems and if they understand them. The third topic focused on the separate collection of waste materials. We were interested in the extent to which pupils are familiar with this topic and (if they are) whether they separate waste materials correctly. The aim of the fourth topic was to examine pupils' interest in ecology.

The questionnaire for the teachers was similarly divided into four topics, and contained 42 questions. The intention of the first topic was to discover the teachers' opinions regarding the ecological aims of the DT curriculum [1], whether it increases pupils' ecological awareness, whether it sufficiently emphasises ecological problems, to what degree teachers follow curriculum requirements regarding ecology and how much they emphasise ecological topics. The second topic concerned current ecological problems. We wanted to learn of teachers' opinion regarding pupils' knowledge of ecological problems, whether they emphasise ecological problems and discuss them during teaching, even if there is no such aim in the curriculum. In the third part, we discuss the collection and separation of waste materials. As there is no material regarding waste materials in the curriculum, we wanted to establish whether pupils are taught this topic in class or not. In the final topic, we inquired to what degree of pupils' ecological awareness the school should be obliged to be taught and to what degree teachers should favour it. We wanted to discover whether teachers think that the school makes sufficient effort for the ecological awareness of their pupils, whether they think this awareness is necessary and effective, and finally what their attitude towards ecology is.

3.2 Results

Pupils aged from 12 years to 14 years (6^{th} and 8^{th} grades) and their technology teachers were interviewed; in total 155 pupils, 90 of whom were boys (58 %) and 65 of whom were girls (42 %), which represents about 0.3 % of the last three years of the primary school population in Slovenia. Five technology teachers were interviewed: four female and one male. Three different primary schools, one of them being an eco-school, participated in the research. A comparison of the results for the eco-school and the other two schools, the results of the 6^{th} and 8^{th} grade pupils, and finally the results of male and female pupils are also given.

3.2.1 Pupils ecological awareness

Results are given according to the topics (I.-IV.), as in the questionnaire.

Curriculum (Topic I.). The results showed that pupils know the importance of the wood for humanity, the importance of recycling, the importance of waste paper collection and which forms of producing electricity cause the most damage to the environment. Figure 1 shows the percentage of correct answers to Question No. 2. Clearly, the majority of the pupils answered correctly.

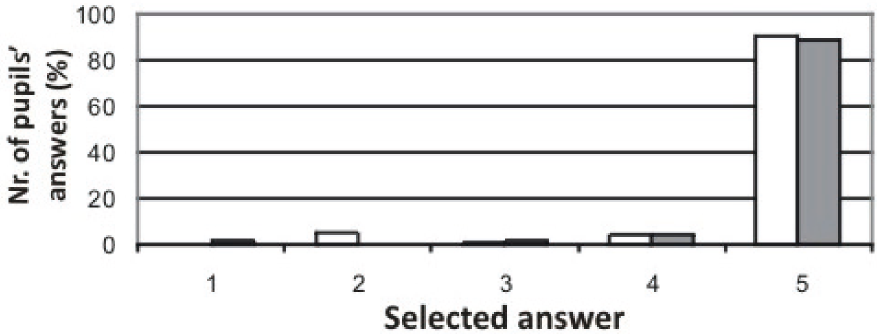

Figure 1: *Pupils percentage of correct answers to Question No. 2 (What does it mean if we say that the products are recycled?), white column 6th and grey column 8th grade pupils, where possible answers were: 1 – we destroy waste products by burning them; 2 – we take these products to waste by bicycle; 3 – the products, that we do not use any more, we use for another purpose; 4 – no answer and 5 – the products that are used and thrown away are remade and used for similar products.*

Current ecological problems (Topic II.). Pupils know the cause of the water (rivers and seas) pollution, what acid rain is, what causes air pollution, what are possible solutions for air pollution and the destruction of forests. Pupils do not know what the greenhouse effect is, what the solutions are for diminishing of the ozone hole, greenhouse effect and for water pollution. Figure 2 shows the percentage of correct answers to Question No. 10. It can be seen that pupils had less knowledge than in the first topic as correct answers (No. 3) were hardly over 50 % for the 6th grade as well as for the 8th grade.

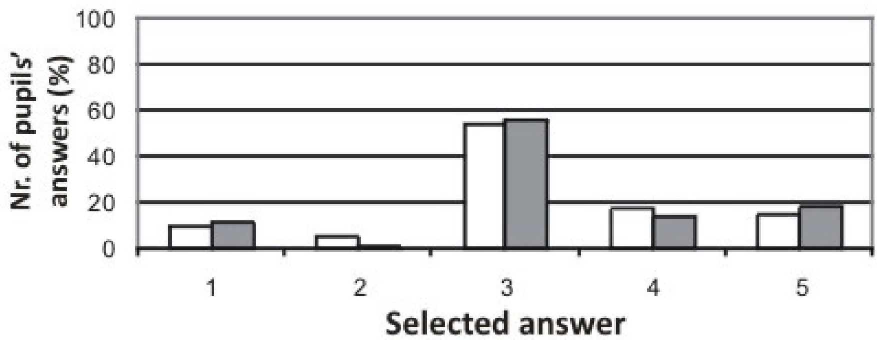

Figure 2: *Pupils percentage of correct answers to Question No. 10 (Choose the correct answer), white column - 6th and grey column 8th grade pupils, where the possible answers were: 1 – the ozone hole is the increase of the concentration of ozone in the air.; 2 – the Earth is cooling down; 3 – traffic, industry and household are air polluters; 4 – the greenhouse effect is caused by the solar rays that make the Earth warmer and 5 – no answer.*

Waste materials and their separate collection (Topic III.). This showed that pupils know what separate collection of waste materials is (84 % in the 6th grade and 88 % in the 8th grade), whereas they do not know what the main waste material problem. In their opinion, illnesses

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caused by waste materials are a greater problem than waste materials' excessive accumulation and a decreasing number of landfills.

Ecological awareness (Topic IV). The results showed that pupils are interested in ecology (62 % in the 6th grade and 67 % in the 8th grade). They learn about this subject not only at school, but also from television, in discussions with their parents and in different magazines. It is very positive that the most students think that they can do something to reduce pollution themselves. Figure 3 shows the percentage of answers to the question No. 18. It can be seen that most answers show that pupils are interested in ecology.

Results comparison. (A) Firstly, we compared the results gained from eco-school and regular school pupils. Eco-school pupils show greater levels of knowledge than the regular ones in most inquiry questions. Moreover, in their teachers' answers the difference of importance given to the ecology was also observed. Eco-schools favour ecology in such a way that eco-themes are incorporated in every school subject and also during teaching.

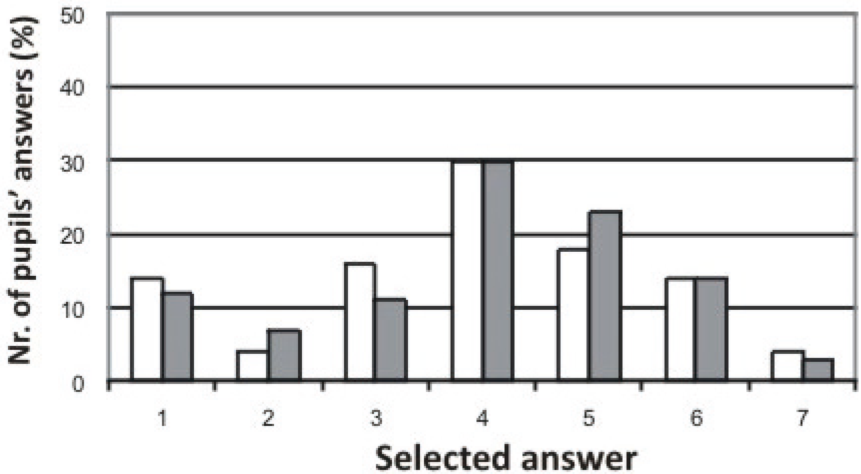

Figure 3: *Pupils percentage of answers to Question No. 18 (Are you interested in ecology?),* white *column - 6th and grey column 8th grade pupils, where possible answers were: 1 – I am not interested in ecology.; 2 – I am only very slightly interested in ecology.; 3 – I am a little interested in ecology.; 4 – I am somewhat interested in ecology. ; 5 – I am interested in ecology; 6 – I am very interested in ecology and 7 – no answer.*

(B) Secondly, a comparison of 6th and 8th grade pupils' results was done. Interestingly, 6th grade pupils' results for the curriculum part of the questionnaire were better than for the 8th grade. Although the difference is not enormous, it is distinct. We can interpret the difference with the fact that pupils have already discussed some ecological topics in the 1st to 5th grades and are therefore already aware of some ecological problems. This might be the reason that pupils in the 6th grade are more familiar to these topics than pupils in the 8th grade, who may have already forgotten some lessons. Teaching goals in the 6th grade related to ecology are the forests' influence on the environment, the importance of waste paper collection, the difference between recycled and ordinary paper, and the significance of wood coatings. The curriculum part questionnaire questions are closer to the teaching goals of DT for the 6th year.

Consequently, the topics are more familiar to 6^{th} grade pupils. In the second and the third part, where the questions concern ecological problems in general, the answers in the 8^{th} grade were better than those in the 6^{th}. This could be due to the fact that pupils in the 7^{th} and 8^{th} grades already learn about ecological problems in other school subjects (Citizenship and Ethics, and Science 7). They learn about the wood decay and water/air pollution.

(C) Finally a comparison between boys and girls pupils was also preformed: No significant gender differences were observed.

3.2.2 Technology teachers' opinion

Results are presented along with Topics I.-IV. from the questionnaire.

Curriculum. All interviewed teachers think that the DT curriculum is not sufficiently precise regarding its ecological aims. That is why each teacher interprets it in his/her own way; as a result, they do not teach it uniformly. They always add something to the aims. Sixty percent of the teachers think that DT curriculum does not sufficiently increase the pupils' awareness.

Ecological problems. Sixty percent of the teachers teach the ecological problems in the DT class, while 20 % teach them only during DT field trips, and 20 % do not teach them at all.

Waste materials and their separate collection. As with ecological problems, we asked teachers the same questions about the separation of waste materials. Eighty percent of them teach separation in class, while 20 % only warn their pupils about separation. Two schools practise separate collection of waste materials; one does not. Sixty percent of the teachers also separate the waste materials in class.

Ecological awareness. All the teachers strongly emphasize ecological problems; all of them also teach pupils to save water and electricity, and 80 % would run an ecological group. Schools also organize lectures about ecological problems, excursions to a landfill of waste materials and different ecological activities.

4 SUMMARY AND CONCLUSIONS

The principal finding was that pupils understand the ecological issues . Nevertheless, their knowledge is in high correlation only if the topics were curriculum-related. They know what the separate collection of waste materials is and how significant it is. However, it seems that Slovenian pupils can recall facts taught, but lack understanding of them. They do not understand the nature of the ecological problems. The teachers' opinion is that pupils are interested in ecology and that ecological awareness is presently very important.

Analysis results extent the fact that with the present DT curriculum we cannot increase the present pupils' ecological awareness. Pupils' knowledge is highly correlated with teacher's effort and curriculum. Renewing DT curriculum seems to be an answer as this would stimulate teachers more towards ecology issues. The study further showed that DT textbook writers and technology teachers always come from originate current and valid subject curriculum [1]. Although this can be very effective and goal-oriented for DT teaching, it also has weaknesses. This is why they are not inclined to new topics and are not a part of the curriculum. One such topic is ecology related to DT. The textbook authors rarely include ecological topics in the textbooks, as they follow the curriculum directives. Teachers also teach fewer ecological topics

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also due to the lack of time that was a result of a reduction of DT hours during last major curriculum renovation. Consequently, pupils do not gain sufficient knowledge to care about ecology. Therefore, it is necessary to include more goals and activities related to ecological topics, in the 6th year, to the very beginning of the DT curriculum.

Although waste product materials are usually included in project making in DT (mostly due to the reason that they are very inexpensive) they could be used more. Nevertheless, teachers do not explain the importance of waste material. Here, an example of a waste product materials book would be of a great help for DT teachers. Further, pupils in lower classes should read books on ecological problems for home reading; we suggest the titles in the following references [13-19]. Because of the lack of awareness of the main ecological problems, we suggest that higher level pupils should find the latest news concerning the effects of global warming and the reasons for it on the internet, in textbooks and newspapers for their homework.

Furthermore, teacher's think that the DT curriculum is not precise enough regarding the ecological aims. Therefore, it would be necessary to make the current ones more specific and to add more ecological issues to the DT curriculum. For example: naming some actual ecological problems; explaining the reasons and describing solutions for ecological problems. One suggestion is that teachers could also introduce speaking activities. Every pupil (or in pairs) should choose an ecological problem and describe the reasons for it, its consequences and possible solutions. In this way, pupils could learn about all current ecological problems. Consequently, they would be more competent to act in favour of the environment and nature. Also on the 22nd of April, Earth Day, an ecological topic could be prepared on every school. It could be chosen by pupils. Schools could organize a lecture on the topic, pupils could prepare posters, draw pictures, make different items, watch a film, etc. Everything should be in connection with the chosen topic.

To gain greater ecological awareness every school, whether an eco-school or not, proper material should be provided for pupils. There are many interesting books for primary school [14-19], that would develop pupils' understanding of ecological problems. We discovered that schools organize different ecological activities. In one of those activities, pupils from lower and higher classes should take care of the school environment. That is how they would theoretically and practically get to know the meaning of the protection of nature.

The results showed that pupils also had problems on the third topic. It would be meaningful to add some themes on the separate collection of waste materials to the DT curriculum. For instance: naming what sorts of waste materials are known; explaining the meaning of separate collection; describing the route of the waste material from home to its final disposal; explaining what recycling is and drawing the sign for it; naming the reasons why waste materials cause problems; explaining why waste incineration is not suitable for destroying waste materials. Only 60 % of the teachers separate waste materials in class. Every school should promote separating waste materials and thereby serve as an example for the pupils. Every class should likewise have its own bins where they could separate rubbish. Such bins could be made by pupils with the help of their teacher in DT classes.

For better understanding of this problem, it is necessary to annually prepare an excursion to a waste-materials centre. Their guides would show the centre to the pupils and explain to them why the centre exists, how it works and talk about global warming, the greenhouse effect, waste materials, their separation and other topics. Every pupil would then have to report on what had been learned and what was the most interesting. The teachers would thus have insight to what is more and what is less interesting for the pupils. To emphasize the responsibility for material separation, there should be an annual waste paper school collection event. At the same time, other waste materials (old batteries, for instance) could be collected. We suggest organizing a class lesson about this topic to explain to the pupils the importance of this activity.

To increase the pupils' ecological awareness, we suggest that schools enter an eco-quiz. This is a team competition for the 6^{th} to 8^{th} grades of Slovene eco-schools. Last year, the topic was waste materials, energy and climate change. Pupils should also teach the adults (parents, aunts, uncles etc) by preparing an eco-newspaper, in which they would write about various ecological problems.

Our world depends on our youth, which is why ecological awareness should start with them. If they understand the problems of the globe and act in favour of nature and (consequently) of humanity, they will serve as a good example to coming generations. And we will begin to live in co-existence with our green world.

References

[1] **Amand Papotnik et al.: "***Učni načrt -Tehnika in tehnologija„* Ministrstvo za šolstvo, znanost in šport, Zavod RS za šolstvo, 2002

[2] To respectfully and responsively treat all living creatures, to persist in their healthy way of life, to take care of school area and its surroundings neatness and cleanness, to economize water, energy and raw materials usage, to collect and separate waste materials, to contribute to cleanness of water, air and soil, to respectfull treat food and drinking water, to take part in school, regional, national and international ecological activities, to widen their ecological knowledge, and to inform the public about their ecological activities and achievements.

[3] **Dušan Krnel et al.:** *Učni načrt - Spoznavanje okolja,* Ministrstvo za šolstvo, znanost in šport, Zavod RS za šolstvo, 2001

[4] **Janez Ferbar et al.:** *Učni načrt - Naravoslovje in tehnika*, Ministrstvo za šolstvo, znanost in šport, Zavod RS za šolstvo, 2001

[5] **Naravoslovje 7:**

[http://www.mss.gov.si/fileadmin/mss.gov.si/pageuploads/podrocje/os/devetletka/predmeti_obvezni/Naravoslovje_7_obvezni.pdf]

[6] **Državljanska vzgoja in etika**

[http://www.mss.gov.si/fileadmin/mss.gov.si/pageuploads/podrocje/os/devetletka/predmeti_obvezni/Drzavljanska_vzoja_in_etika_obvezni.pdf]

[7] **Degradation of forest land:**

[http://www.rtvslo.si/modload.php?&c_mod=rnews&op=sections&func=read&c_menu=12&c_id=93350]

[8] **Grega Merela** and others*: Pomagajmo ohraniti svet, Programsko gradivo za ohranitev narave*, Zveza tabornikov Slovenije, 1994

[9] **Ozone hole:** [http://www.rtvslo.si/modload.php?&c_mod=rnews&op=sections&func=read&c_menu=9&c_id=121808]

[10] **Brane Šalamon:** *Takšna neurja smo si zakuhali sami,* NeDeljski, Nr. 30., 2008

[11] **Acid rain:** [http://en.wikipedia.org/wiki/Acid_rain]

[12] **Eva Ančnik** and others**:** Kazalci okolja *2005,* Ministrstvo za okolje in prostor, Agencija republike Slovenije za okolje, 2006

[13] **Albert Gore:** *Nazaj k ravnovesju,* Bohinj, Inštitut za ekološke alternative, 1994

[14] **Jernej Fefer:** *Predelajmo koristne odpadke*, Vrhnika, Okoljevarstveno svetovanje, 2004

[15] **Jernej Fefer:** *Nejc obišče center za ravnanje z odpadki*, Vrhnika, Okoljevarstveno svetovanje, 2003

[16] **Jernej Fefer:** *Jaka pomaga naravi*, Vrhnika, Okoljevarstveno svetovanje, 2002

[17] **Jernej Fefer:***Kaj se dogaja na planet Zemlja?*, Vrhnika, Okoljevarstveno svetovanje, 2006

[17] **Isaac Asimov:** *Zakaj odpadki povzročajo probleme?* , CO LIBRI, 1996

[19] **Larry Gonick** and **Alice Outwater:** *Okolje v stripu,* Tehniška založba Slovenije, 2001

Nomenclature

Ha hectare

km^2 square kilometre

km/h kilometres per hour

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KEY PROVISIONS OF EU'S THIRD ENERGY PACKAGE

GLAVNE DOLOČBE TRETJEGA ENERGETSKEGA PAKETA EVROPSKE UNIJE

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Key words: electricity, natural gas, internal market, EU, ownership unbundling, transmission system operator, exemptions

Abstract

The EU adtoped the third energy package last July with the aim of creating an internal market for electricity and natural gas in the EU. The package consists of three regulations and two directives. Slovenia and other Member States must implement the directives into their national law by 3 March 2011, the date from which the regulations will also be directly applicable. The key provisions of the package concern (i) effective unbundgling of energy production and supply from network operations; (ii) the regime for exemptions; (iii) certification of transmission operators under the control of non-EU countries; (iv) stregthenthing the role and duties of national regulatory authorities; (v) the establishment of the Agency for the Cooperation of Energy Regulators and (vi) the establishment of European Networks of Transmission System Operators for Gas and Electricity. This article examines these provisions in turn.

Povzetek

Evropska unija je julija lani sprejela tretji energetski paket z namenom vzpostaviti enotni evropski trg s plinom in električno energijo. Slovenija in druge države članice EU morajo do 3.

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marca 2011 prenesti TEP v domači pravni red. Ključni elementi TEP-a so: (i) dejansko ločevanje dejavnosti dobave in proizvodnje od delovanja omrežja; (ii) režim izjem od pravil ločevanja; (iii) certificiranje operaterjev pod nadzorom tretjih držav; (iv) krepitev vloge in dolžnosti nacionalnih energetski regulatorjev; (v) ustanovitev Agencije za sodelovanje energetskih regulatorjev na nivoju EU in (vi) ustanovitev Evropskih mrež operaterjev prenosnih sistemov za električno energijo ter za plin prek katerih bodo operaterji sodelovali na ravni Skupnosti.

Najpomembnejše določba TEP določa da države članice morajo od 3. marca 2012 naprej zagotoviti dejansko ločevanja prenosa električne energije ali plina od pridobivanja ali dobave električne energije oziroma plina ter odpravo vseh navzkrižij interesov med proizvajalci, dobavitelji in operaterji prenosnih sistemov, imajo na voljo eno izmed naslednjih treh možnosti dejanskega ločevanja: lastniško ločevanje, samostojni operater sistemov in neodvisni operater prenosnega sistema.

Ne glede na to, za katero opcijo ločevanja se država članica odloči mora domači regulator imenovati in certificirati operaterje prenosnih sistemov v skladu z določili TEP-a in o tem obvestiti Komisijo. Direktivi uvajata dva različna postopka za certifikacijo operaterja glede na državljanstvo osebe, ki ga nadzira. TEP uvaja strožje pogoje za certifikacijo operaterjev, ki jih nadzirajo podjetja ali države zunaj EU. V skladu s členom 11 obeh direktiv bodo namreč morali operaterji, ki so v večinski lasti ali pod nadzorom podjetja ali države zunaj EU, od 3. marca 2013 delovati v skladu z zgoraj omenjenimi pravili ločevanja ter še dodatno dokazati, da odobritev certificiranja ne bo ogrozila zanesljivosti oskrbe države članice in Skupnosti z energijo.

TEP ne uvaja bistvenih sprememb glede izjem od pravil dejanskega ločevanja. Na podlagi 36. člena direktive o plinu se lahko novi povezovalni plinovodi, obrati za UZP in skladišča večjega obsega izvzamejo iz določil glede dejanskega ločevanja, obveznosti zagotovitve dostopa tretjim osebam ter dostopa do skladišč itd. pod pogoji, ki med drugim vključujejo: (i) da se z investicijo poveča konkurenca pri oskrbi s plinom in zanesljivost oskrbe; (ii) da raven tveganja dovoljuje izvedbo investicije samo v primeru odobritve odstopanja; ter (iii) da je infrastruktura, ki se gradi, vsaj pravno in funkcionalno ločena od operaterja, ki jo gradi. Pogoji in postopek odobritev izvzetja za nove enosmerne čeymejne daljnovode so določeni v členu 17 direktive o električni energiji in so podobni že omenjenim pogojem, ki veljajo za nove plinske infrastrukture.

Naloge regulatorja so v TEP razširjene in zdaj vključujejo promocijo enotnega energetksega trga EU; razvoj ustreznih čezmejnih prenosnih zmogljivosti; razvoj konkurenčnih in pravilno delujočih regionalnih energetskih trgov; določanje in odobritev tarif; ter spremembo pogojev po katerih operaterji določajo dostop do skladišč, vključno s spremembo tarife. Pristojnosti regulatorja so tudi okrepljene. Kot minimum mora imeti regulator naslednje pristojnosti: (i) izdajanje zavezujočih odločitev, (ii) izvajanje preiskav glede delovanja energetskih trgov, (iii) izrekanje učinkovitih, sorazmernih in odvračilnih kazni energetskim podjetjem, ki ne izpolnjujejo obveznosti iz direktiv, (iv) reševanja sporov med vertikalno intergriranimi podjetji ("VIP") in operaterji prenosnih omrežij, (v) odobritev vseh sporazumov med VIP in operaterji prenosnih omrežij ter (vi) možnost zahtevati od operaterjev prenosnih omrežij, operaterja sistema skladišč ter operaterjev distribucijskih sistemov, da spremenijo svoja določila in pogoje dostopa, vključno s tarifami.

Pomebna novost, ki jo uvaja TEP, je ustanovitev Agencije za sodelovanje energetskih regulatorjev. Evropska agencija bo prevzela naloge Evropske skupine regulatorjev za električno energijo in plin, ampak njena vloga ne bo samo posvetovalna. Sedež Agencije bo v Sloveniji.

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1 INTRODUCTION

After nearly two years of political wrangling between the EU Commission ("EC"), EU Parliament and the EU Council, the Third Energy Package ("TEP") was adopted in summer of 2009. The TEP represents the third bundle of legislation adopted at the EU level since 1986 with the aim of creating a fully integrated single European gas and electricity markets[i].

The TEP is comprised of the following three regulations and two directives[ii]:

- Regulation of the European Parliament and of the Council establishing the Agency for the Cooperation of Energy Regulators ("ACER Regulation");
- Regulation of the European Parliament and of the Council Amending Regulation 1228/03/EC on the conditions of access to the network for cross-border exchanges in electricity ("Electricity Regulation");
- Regulation of the European Parliament and of the Council Amending Regulation 1775/05/EC on the conditions of access to the natural gas transmission networks ("Gas Regulation" and together with the Electricity Regulation, the "Regulations");
- Directive of the European Parliament and of the Council concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC ("Gas Directive"); and
- Directive 2009/73/EC of the European Parliament and of the Council concerning common rules for the internal market for electricity and repealing Directive 2003/54/EC ("Electricity Directive" and together with the Gas Directive, the "Directives").

This article will in turn discuss the key provisions of TEP concerning:

1. Effective unbundling energy production and supply from network operations;
2. Exemptions from Unbundling;
3. Certification of Transmission System Operators ("TSO");
4. Powers and obligations of National Regulatory Authorities ("NRA");
5. Establishment of the Agency for the Cooperation of Energy Regulators ("ACER"); and
6. Establishment of European Networks of Transmission System Operators for Gas and Electricity ("ENTSOs").

2 UNBUNDLING

The Second Energy Package required network operation to be legally and functionally separated from supply and generation or production activities. Forcing the break-up of vertically integrated energy companies – ownership unbundling ("OU") - was the essential pillar of the EC's initial draft of TEP. Integrated energy companies, which dominate the EU energy market, however, strongly (and successfully) resisted OU.

Instead of OU, the TEP requires Member States to "effectively unbundle" transmission of energy from the production and supply of energy from 3 March 2012. Member States can

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choose from one of three "effective unbundling" options: OU, Independent System Operator ("ISO") and Independent Transmission Operator ("ITO").

2.1 OU Option

Under this option, vertically integrated energy undertakings[iii] ("VIU") are required to separate legal ownership of their high-voltage (high-pressure for gas) transmission company (i.e. the transmission system operator) from their production and supply interests.

2.1.1 Ownership unbundling requirements

Article 9 of the Directives requires Member States to ensure that from 3 March 2012:

1. each owner of the transmission system network is certified as a transmission system operator ("TSO")(see Art. 9(1)(a))[iv];
2. the same person(s) cannot exercise direct or indirect control over the TSO or the transmission system and at the same time control or exercise any right in respect of undertakings performing any function of supply or production of gas or electricity or vice versa (see Art. 9(1)(b));
3. the same person(s) cannot appoint members of the supervisory board or other bodies representing the TSO or the transmission system and directly or indirectly control or exercise any right in respect of undertakings performing any function of supply of gas or electricity (see Art. 9(1)(c)); and
4. the same person(s) cannot be a member of the supervisory board of the TSO or the transmission system or bodies representing them and of any undertaking performing the function of production and supply of gas or electricity (see Art. 9(1)(d)).

The requirement of ownership unbundling goes much further than might seem at first, as energy production and supply companies are no longer permitted to "control" or "exercise any rights over" transmission networks. The term "control" is very broadly defined in Article 2(36) of the Gas Directive to mean "any rights, contracts or other means which ... confer the possibility of exercising decisive influence on an undertaking, in particular by: (a) ownership or the right to use all or part of the assets of an undertaking; (b) rights or contracts which confer decisive influence on the composition, voting or decisions of the organs of an undertaking"[v]. Article 9(2) defines "exercising rights over an undertaking" as (a) the power to exercise voting rights; (b) the power to appoint members of the supervisory board or other bodies legally representing the undertaking; or (c) holding of a majority share. Additional requirements regarding *inter alia* the protection of commercially sensitive information and the prohibition of transfer of staff employed by the TSO to the VIU are set out in Article 9(7) of the Directives[vi].

Given the strictness of the unbundling requirement, which seems to prohibit even portfolio investments, it is perhaps not surprising that the industry strongly resisted this option. It will be interesting to see whether any country, besides the UK, adopts this option[vii].

2.1.2 Tasks of the TSO

The tasks of the TSO are set out in Article 13 of the Gas Directive and include:

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1. Operate, maintain and develop under economic conditions secure, reliable and efficient transmission to secure an open market;
2. Refrain from discriminating between system users or classes of users, particularly in favour of its related undertakings;
3. Provide other TSOs sufficient information to ensure the transmission of gas takes place in a manner compatible with the secure and efficient operation of the interconnected system;
4. Provide system users with information needed for efficient access to the system;
5. Build sufficient cross-border capacity to integrate European transmission infrastructure accommodating all economically reasonable and technically feasible demands for capacity and taking into account security of gas supply;
6. Ensure that the rules adopted for balancing the transmission system are objective, transparent and non-discriminatory;
7. Comply with minimum standards for maintenance and development of the transmission system should those be set by a Member State; and
8. Ensure that the energy it uses to carry out its functions is procured in accordance with transparent, non-discriminatory and market-based procedures.[viii]

2.1.3 What steps need to be taken by VIUs?

In order to comply with the OU option, a VIU must either (i) divest of the high-voltage/high-pressure network assets or the production and supply assets, or (ii) split the shares of the VIU into shares of a network entity and shares of the remaining supply and production entity so long as, in each case, the surviving entities fully comply with applicable OU rules.

2.1.4 Who do the requirements apply to?

The above-discussed OU requirements apply to VIU, existing at the time the Directives entered into force. By inference, going forward any merger or acquisition that would result in breach of Article 9(1)(a) to (d) of the Directives will not be permitted. Under Articles 10(3) and (4) of the Directives, a TSO has an obligation to inform the relevant national regulatory authority of, and such authority has an obligation to monitor on its initiative, the continued compliance with Article 9 requirements.

2.2 Independent System Operator ("ISO") Option

Under this option, a VIU can retain ownership over its network transmission assets, provided that an unrelated ISO performs all of the duties of the TSO. In other words, a separate legal entity must perform the technical and administrative management of the transmission system[ix]. Such a separate legal entity must be designated an ISO by the Member State and approved by the EC[x]. Very few Member States have expressed an interest in adopting this option.

2.2.1. ISO Requirements

In order to be designated an ISO, an undertaking must comply with conditions set out in the Directives, of which the key conditions are as follows. First, the candidate ISO must demonstrate that it complies with the requirements of Article 9(1)(b) to (d), discussed in Section

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1.1.1 above. Second, the candidate ISO must demonstrate that it has at its disposal the required financial, technical and other resources to carry out the tasks of TSO. Third, the candidate ISO must have undertaken to comply with a 10-year network development plan, which is monitored by the regulatory authority.

2.2.2. Tasks of ISOs

The tasks of an ISO are set out in paragraph 4 of the Articles 14 and 13 of the Gas and Electricity Directives respectively and include: granting and managing third-party access, ensuring long-term ability of the system to meet reasonable demand through investment planning, and planning the construction and commission of new infrastructure. Rather than prohibiting VIU's involvement in the above-mentioned activities, the Directives prohibit it from being "responsible" for these activities.

2.3 Independent Transmission Operator ("ITO") Option

The ITO option was introduced during the Second Reading of TEP in the European Parliament as a compromise to ensure its adoption by the EU Council.

Pursuant to this option, the TSO can remain part of the VIU, provided certain requirements concerning independence as set out in the Directives are complied with. The following are the key provisions that are meant to ensure the "effective unbundling" of an ITO.

1. The ITO is required to be set up as a separate legal entity[xi], and in particular, must own the transmission network assets[xii], cannot share premises with the VIU, must have a separate corporate identity[xiii], must not share the same information technology ("IT") or security access systems, or use the same consultants, legal advisers or auditors[xiv] as the VIU.
2. Pursuant to Article 18(3) of the Directives, the VIU's subsidiaries that generate or sell energy must not have any direct or indirect shareholding in the ITO.
3. Article 18(6) and (7) requires that all commercial agreements and arrangements between the ITO and VIU are at arm's-length and subject to the prior approval of the NRA.
4. The management of an ITO is to be appointed by the Supervisory Body rather than the VIU[xv].
5. This Supervisory Body must include representatives of the VIU and third-party shareholders.
6. The Supervisory Body is to have decision-making authority over issues such as the level of the ITO's indebtedness and the amount of dividends distributed to the shareholders of the TSO.
7. The majority of the ITO's management and/or members of other administrative bodies must not have advised or have had any business relations with the VIU or the shareholder who has a controlling interest therein for three years before their appointment[xvi]. The remainder of the ITO's management and/or members of other administrative bodies may have held such positions, provided any such positions were terminated at the latest six months before appointment with the ITO. A minimum four-year lock out period applies in the reverse case scenario[xvii].

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8. No member of management or employee of the ITO may have any interest, business relationship or hold any position in any part of the VIU or in its controlling shareholder or receive any remuneration therewith[xviii].
9. The ITO must appoint a compliance officer whose responsibility is to ensure that discriminatory conduct is excluded and a compliance procedure, previously approved by the NRA, is complied with[xix].

To ensure an ITO's compliance with the above requirements, the NRA is able to impose fines of up to 10% of its turnover.

This option has sought to reduce the scope for conflict between the interests of the ITO and VIU. However, it should be noted that the ability of a VIU to influence the decision making of the ITO is not entirely removed. Article 20 of the Directives enables a VIU to appoint half of the members minus one of an ITO's Supervisory Body. Since this body appoints the management of an ITO, the ability of a VIU to influence ITO's management remains. Furthermore, a VIU continues to able to guide and influence, via its representatives of the Supervisory Body, an ITO's 10-year network investment plan.

3 REGIME FOR EXEMPTIONS AND DEROGATIONS FROM UNBUNDLING

TEP does not introduce significant changes to the regime for exemption and derogations .

3.1 Exemptions for Gas Infrastructure

Article 36 of the Gas Directive sets out the general rules pursuant to which a "major[xx] new natural gas infrastructure" that is, major new interconnectors, LNG facilities and storage facilities, may be exempt from OU, third-party access and/or regulated tariffs rules. The exemption regime also applies to "significant increases in the capacity of existing infrastructure" and "modifications of such existing infrastructure which enable the development of new sources of gas supply"[xxi].

An exemption may be granted by NRAs in the above three instances provided that: (i) the investment enhances competition in the sources of natural gas supply and enhances the security of supply; (ii) the risk associated with such investment must be such that the investment would not take place unless an exemption was granted; (iii) there must be at least legal and functional unbundling of the infrastructure to be exempt; (iv) charges must be levied on users of such infrastructure (i.e., the infrastructure may not be funded by general tariffs); and (v) the exemption must not detract from (a) the existing level of competition or the effective functioning of the internal natural gas market, or (b) the efficient functioning of the regulated system to which the infrastructure is or will be connected[xxii].

An exemption is to be granted by an NRA on a case-by-case basis. It can cover all or part of the infrastructure and must be for a defined period of time that is, it cannot be granted indefinitely. In addition, an NRA can make it conditional on non-discriminatory access being granted to the exempted infrastructure.

When the infrastructure in question is located in the territory of more than one Member State, ACER may submit an advisory opinion to the NRAs concerned[xxiii]. If the involved NRAs have not reached an agreement within six months from the date exemption was sought or upon a joint request from the relevant NRAs, ACER is authorised to decide upon an exemption request after consulting with all of the parties involved[xxiv].

The NRA or ACER, as the case may be, is required to notify the EC of any request for exemption, as well as of any decision made in respect thereof. The EC has two months[xxv] from the date of receipt of such notification to direct the NRA or the ACER, as the case may be, to amend or withdraw the decision to grant an exemption.

3.2 Exemption for New Electricity Interconnectors

New high voltage electricity cross-border interconnectors may also secure an exemption from certain provisions of the Electricity Directive and the Electricity Regulation. The conditions and the procedure to secure such an exemption are set out in Article 17 of the Electricity Directive and are similar to those mentioned above for new gas infrastructures.

3.3 Temporary Derogation

The Gas Directive and Gas Regulation also provide for a temporary derogation in respect of take-or-pay contracts in circumstances in which a natural gas entity would encounter serious economic and financial difficulties absent such derogation because of existing contractual commitments[xxvi].

3.4 Derogations for Emergent and Isolated Markets

The Gas Directive and the Gas Regulation provide for specific derogations for emergent and isolated markets of Estonia, Latvia, Finland, Cyprus, Malta, Luxembourg and Greece[xxvii]. In addition, under the Electricity Directive, Cyprus, Luxembourg and Malta benefit from derogations as emergent and isolated markets[xxviii].

4 CERTIFICATION OF TSOS

Regardless of the unbundling option chosen by Member States, NRAs are required to certify that TSOs comply with the requirements set forth in the Directives. Once so certified, a Member State must appoint the TSO and notify the EC.

The Directives introduce two different procedures for certification of TSOs depending on the nationality of the person controlling the TSO. The EU has been criticised, by Russia in particular, for imposing more stringent certification requirements on non-EU controlled TSOs.

4.1 Control by EU Nationals

TSOs controlled by an EU energy undertaking or EU state must be certified by the relevant NRA before it is designated as a TSO. In addition, the certification of an ISO must be approved by the EC. The requirements regarding certification are set out in Article 10 of the Directives and Article 3 of the Regulations.

TSOs are required to notify the NRA of any transactions which may affect their compliance with Article 9 requirements concerning control[xxix]. In addition, Article 10(4) of the Directives imposes on NRAs an ongoing responsibility to monitor compliance by TSOs of their obligations under the Directives.

4.2 Control by Third Countries

Article 11 of the Directives sets out the procedure for the certification of a TSO controlled by non-EU nationals or non-EU states ("Third Countries"). Such an undertaking must demonstrate that (i) it complies with Article 9 requirements regarding control; and (ii) that its certification as a TSO will not put at risk the security of energy supply of the relevant Member State and the Community.

In assessing the risk to EU's security of supply, an NRA is required to (i) examine any agreements existing between the Community and the Third Country, (ii) any other agreements signed by Member States with the Third Country and (iii) other specific facts of the case and the Third Country concerned.

In order to ensure that the interests of the EU as a whole are protected rather than the narrow interests of the particular Member State from whom certification is sought, Article 11(5) of the Directives requires NRAs to request an opinion from the EC before certification and take "utmost account of the [EC's] opinion". Moreover, Article 11(3) makes clear that the NRA may consider rights and obligations existing under bilateral investment or other agreement with the Third Country only "in so far as these rights and obligations are in compliance with Community law".

4.3 Process of Certification

Pursuant to Article 10(5) of the Directives, NRAs are required to adopt a decision regarding TSO certification within four months of a request being made. If a decision refusing certification is not given within this period, certification is deemed as granted.

The NRA must submit its certification decision to the EC, which will examine it and deliver its opinion to the NRA within two months of receipt. Within a period of two months after the expiry of the period granted to the EC, the NRA is required to adopt a final decision regarding certification.

Member States have until 3 March 2013 to implement the provisions of the TEP concerning certification of TSO controlled by Third Countries.

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5 POWERS AND DUTIES OF NATIONAL REGULATORY AUTHORITIES

Numerous studies have revealed that the majority of NRAs are failing to exercise their powers robustly to ensure the creation of the EU single market and are subject to political interference[xxx].

5.1 NRAs to be Legally and Functionally Independent

In an attempt to strengthen NRAs, Articles 38(4) of the Gas Directive and 35(4) of the Electricity Directive oblige Member States to "guarantee the independence" of NRAs. In particular, a NRA must be set up as a separate legal entity and its staff must act independently of any market interest and must not seek or take instructions from the government or any other public or private entity. In addition, Articles 38(5) of the Gas Directive and 35(5) of the Electricity Directive require that members of the board of NRAs be appointed for a fixed term of between five and up to seven years, renewable only once.

5.2 Duties of NRAs

The duties of NRAs have been enlarged under TEP and include the promotion of the internal EU energy market; the development of appropriate cross-border transmission capacities to meet demand and enhance the integration of national markets; co-operation at one or more regional levels; developing competitive and properly functioning regional energy markets; fixing and approving tariffs; and requiring storage system operators to modify the terms and conditions of storage including tariffs[xxxi].

It should be emphasised that NRAs now have an express duty to promote the single EU energy market and develop competitive and properly functioning regional energy markets. As such, an NRA which promotes the interests of its own national market or fails to take steps to develop appropriate cross-border transmission capacities will be in breach of its obligations under the Directives.

5.3 Powers of NRAs

Pursuant to paragraphs 4, 5 and 8 of Articles 40 of the Gas Directive and 37 of the Electricity Directive, Member States must ensure that NRAs are granted powers which enable them to efficiently and expeditiously carry out their duties. At the very least, such powers must include the power to: (i) issue binding decisions, (ii) carry out investigations into the functioning of the energy markets, (iii) impose effective proportionate and dissuasive penalties on energy undertakings which fail to comply with their obligations under the Directives; (iv) act as a dispute settlement authority between VIU and TSO in respect of any complaints; (v) approve all commercial and financial agreements between VIU and TSO and (vi) require TSOs, storage system operators and distribution system operators to modify their terms and conditions of access including tariffs.

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6 ESTABLISHMENT OF ACER

One of the key changes introduced by TEP is the establishment of the Agency for the Cooperation of Energy Regulators (also known as "ACER"). ACER will take over from the European Regulators Group for Electricity and Gas ("ERGEG"). Unlike ERGEG, however, ACER will have separate legal personality and have its own staff and budget.

ACER will start working in March 2011. Slovenia has been selected as the seat of ACER. Until the premises become available in Slovenia, ACER will operate from Brussels.

6.1 Role of ACER

The role of ACER is much broader than that of ERGEG, whose role was simply advisory. ACER will *inter alia* provide the framework for cooperation between NRAs, issue advisory opinions concerning exemptions of cross-border new gas infrastructure, grant exemptions for cross-border energy infrastructure where NRAs cannot agree, draft framework guidelines ("FGs") on the basis of which ENTSOs will prepare network codes ("NCs") under the Regulations and advise the Commission on the NC[xxxii]. In addition, it is tasked with identifying gaps in the 10-year investment plans that are to be drawn up by ENTSOs. Finally and importantly, ACER will advise the EC regarding NRAs compliance with TEP and, in particular, with FGs adopted under the Regulations.

It should be emphasised that as an agency for cooperation, ACER's powers and mandate are limited. Consequently, ACER cannot be considered to be a fully fledged EU energy regulator.

6.2 ACER's Structure

ACER is to be managed and represented by a director and will have an Administrative Board and a Board of Regulators. The Administrative Board will be comprised of nine members, two appointed by the EC, two by the European Parliament and five by the EU Council[xxxiii]. The Administrative Board will appoint the members of the Board of Regulators and the Director and will adopt the work programme for ACER. The Board of Regulators of ACER will be made up of representatives of NRAs and one representative of the EC who will have no voting rights[xxxiv]. The Board of Regulators is tasked with providing opinions to the Director before his/her adoption of opinions, recommendations and decisions referred to in Articles 5 to 8 of ACER Regulation, as well as with providing guidance to the Director in the execution of other tasks[xxxv]. The members of the Board of Regulators must discharge their obligations independently of the interest of the NRAs which appoint them[xxxvi].

The setting up of ACER represents the first step towards the adoption of legally binding NCs. These are to be adopted pursuant to the Regulations. FGs and NCs are seen as key to the creation of the EU energy market. To date, guidelines adopted by ERGEG have been voluntary in nature. The following process is envisaged for the adoption of binding NCs under the Regulations: ENTSOs are to prepare them and submit them for consideration by ACER and EC; upon such review, the EC can propose their adoption through comitology. Once adopted, the NC will become legally binding on Member States and energy companies.

At present several pilot projects are underway for the adoption of FGs concerning gas capacity allocation,, electricity grid connection, electricity capacity allocation and congestion management.

7 ESTABLISHMENT OF ENTSOS

In a further step to ensure better coordination of activities of TSOs, the TEP establishes two new European associations: the European Network for Transmission System Operators for Electricity and the European Network for Transmission System for Gas (together referred to as "ENTSOs").

These associations have taken over from GTE+ and the Electricity TSO. Under the Regulations, ENTSOs are (i) to take the lead in drafting NCs, (ii) prepare the non-binding Community-wide 10-year network development plan, (iii) adopt common network operation tools to ensure co-ordination of network operation in normal and emergency conditions and (iv) make summer, winter and long system adequacy forecasts.

As discussed in Section 6 above, ENTSOs are expected to play a pivotal role in the process of adopting binding NCs, which are seen as key to the creation of the single energy market.

8 CONCLUSION

The much-awaited TEP should remove serious barriers to competition in the energy market and create a single EU energy market. However, many in the sector are sceptical for the following reasons. First, by bowing to the pressure exerted by certain Member States, it has been argued that the half measures adopted in respect of unbundling mean that integrated companies will continue to maintain a firm grip on transmission networks. In particular, the ITO option, introduced at the last minute during the Second Reading of the TEP in the EU Parliament, is likely to prove inadequate in addressing the conflict of interest between those of VIU and the TSO, which was identified as the key impediment to the creation of a competitive and single EU market. Second, the broad discretion given to NRAs and Member States in implementing the TEP further undermines the likelihood of the TEP achieving the set objectives. Since, as numerous studies have shown, in the majority of Member States NRAs are not free from government interference, a grant of such broad discretion will in practice permit NRAs to continue to promote national energy interests over those of the EU as a whole. Third, it is feared that the exemption to unbundling and third party access discussed in Section 2 will become a rule rather than an exception, thereby further undermining the TEP's objectives of creating a competitive energy market. Fourth, there is concern that the third country certification requirements for TSOs discussed in Section 4 breach the European Community's World Trade Organisation obligations, as well as the obligations of Member States under the Energy Charter Treaty and bilateral investment treaties. Fifth, the TEP fails to spell out the interplay between it and EU's climate and renewable energy package adopted earlier in 2009. There is a potential for inconsistencies between the two packages for the resolution of which no guidance has been provided. Finally, the TEP has been criticised for failing to include other stakeholders in the various associations set up thereunder. The TEP provides for discussion to take place between the TSO, NRAs and the EC. Calls have been made for network users, energy traders and distribution system operators to also be included in these discussions.

For the above reasons, many in the market believe that the TEP will do little to create a single EU market. It is too early to tell whether they will be proven right.

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[i] The term "energy" will be used in this article to refer to both gas and electricity.

[ii] OJ L 211, 14 August 2009. The complete text of TEP can be found on http://eur-lex.europa.eu/JOHtml.do?uri=OJ:L:2009:211:SOM:EN:HTML [English version].

[iii] A vertically integrated undertaking is defined in Article 2(19) of the Gas Directive as a "natural gas undertaking or a group of natural gas undertakings where the same person or the same persons are entitled, directly or indirectly, to exercise control, and where the undertaking or group of undertakings perform at least one of the functions of transmission, distribution, LNG or storage, and at least one of the functions of production or supply of natural gas. An equivalent definition is set out in Article 2(21) of the Electricity Directive.

[iv] For further details on certification process see Section 4.

[v] An equivalent definition is set out in Article 2(34) of the Electricity Directive.

[vi] It should be noted that, except for paragraph 1, all other provisions of Article 9 must be complied with if a Member State opts for ISO or ITO instead of the OU option. For further detail see paragraph 8 of Article 9 of the Directives.

[vii] Only the UK has unbundled TSO from the undertakings which generate or supply electricity and gas. The National Grid Plc is a listed company in which as at the time of writing this paper no single shareholder's interest exceeds 5%.

[viii] Similar tasks are accorded to TSOs in Article 12 of the Electricity Directive.

[ix] For further details see Article 14 of the Gas Directive and Article 13 of the Electricity Directive.

[x] See paragraph 1 of the Articles 14 and 13 of the respective Directives.

[xi] See Article 17(3) of the Directives.

[xii] See Article 17(1)(a) of the Directives.

[xiii] See Article 17(4) of the Directives.

[xiv] See Article 17(5) of the Directives.

[xv] See paragraph 1 of Article 19 of the Directives.

[xvi] See Articles 19(3) of the Directives.

[xvii] See Article 19(7) of the Directives.

[xviii] See Articles 19(4) and (5) of the Directives.

[xix] See Article 21 of the Directives.

[xx] The term "major" is not defined in the Gas Directive.

[xxi] See Article 36(2) of the Gas Directive.

[xxii] See Article 36(1)(a) to (e) of the Gas Directive.

[xxiii] See Article 36(4) of the Gas Directive.

[xxiv] Ibid.

[xxv] This period can be further extended, see paragraph 9 of Article 36.

[xxvi] See Article 48 of the Gas Directive.

[xxvii] See Article 49 of the Gas Directive.

[xxviii] See Article 44 of the Electricity Directive.

[xxix] For details see Section 2.1.1.

[xxx] For example see Datamonitor's Market Competitive Index reveals significant variation in national regulators' independence across the EU27, http://www.europeanenergyreview.eu/data/docs/Viewpoints/

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datamonitor_en090430.pdf.

xxxi See Article 39 of the Gas Directive and Article 36 of the Electricity Directive.
xxxii For details see Articles 5 to 8 of the ACER Regulation.
xxxiii See Article 19 of the ACER Regulation.
xxxiv See Article 11(1) of the ACER Regulation.
xxxv See Article 12 of the ACER Regulation.
xxxvi See Article 11(6) of the ACER Regulation.

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EFFECTIVE ENERGY USE IN PUBLIC BUILDINGS – AN EXAMPLE OF ACTIVITIES AT MUNICIPALITY OF VELENJE UČINKOVITA RABA ENERGIJE V JAVNIH STAVBAH – PRIMER AKTIVNOSTI MESTNE OBČINE VELENJE

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Keywords: Effective energy use, environmental projects, energy efficiency assesment, information control system, energy accounting online, Velenje

Abstract

Municipality of Velenje (MOV) is attentive to current environmental problems and challenges; therefore it focuses its activity and actions towards efficient use of energy and use of renewable energy resources. It joined numerous project, strategic as well as execution oriented ones. Raising the awareness of the people – service users, employees and general public – is also very important. This paper presents a project Future Public Energy, which received support from EU INTERREG IIIA Cross-border cooperation programme, Slo/Hun/Cro programme. Within this project we carried out the energy-efficiency assessment of buildings, introduced informational controlling system, developed and introduced energy bookkeeping for public buildings and executed several actions for raising awareness of users, motivating the public for efficient energy use.

Povzetek

Mestna občina Velenje v skladu z aktualnimi okoljskimi problemi in izzivi usmerja svoje delovanje in ukrepanje tudi na področje učinkovite rabe energije in rabe obnovljivih virov energije. Pristopila je k številnim projektom, tako strateškim kot izvedbenim. Zelo pomembno je seveda tudi osveščanje ljudi - uporabnikov storitev, zaposlenih in tudi širše javnosti. V prispevku je podrobneje predstavljen projekt Future Public Energy, ki je bil sofinanciran v okviru Programa

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1 INTRODUCTION

The rise of energy use, dependency upon foreign energy sources, environmental consequences of fossil fuel overuse present various problems. In Municipality of Velenje (MOV) we are well aware of the importance of efficient energy use, the use of renewable energy resources, and the need for to diminish environmental impact of different harmful emissions. The ever-growing use of energy, accompanied by high energy costs represents an ever larger part of operational costs. We are confident that every individual can, with its thoughtful action and a way of life incorporate small changes in their every-day routine errands, contribute to the mitigation of all negative effects. The improvement in energy efficiency represents one of the possible measures combating the negative effects of greenhouse gas emissions on the climate and a way of meeting the goals set by different international environmental obligations. Energy saving is also a way of diminishing energy dependency on foreign countries for energy sources. The concern for the environment in which we all live is also a concern for the quality of the living conditions, life and personal health.

The paper presents the activities of Municipality of Velenje, which are related to raising the awareness of citizens and employees about the efficient use of energy, reduced use of energy, reduction of traffic emissions and monitoring the quality of the air.

1.1 Environmental projects of MOV

The environmental projects that we executed or took part in in recent years are:

- the introduction of distance cooling;
- sanitation of public lighting system;
- introduction of public city transport;
- ecological information system;
- construction of the 2nd phase of Central wastewater treatment plant of Šaleška valley;
- Ekosan and Euresun;
- Future Public Energy and others.

2 FUTURE PUBLIC ENERGY

The paper will focus on the Future Public Energy project, which was executed by MOV together with a consortium of partners (Municipality of Ptuj, Velenje School Centre, ZRS Bistra (Ptuj), Municipality of Varaždin, and city of Čakovec) within the framework of EU INTERREG IIIA Cross-border cooperation programme Slovenia – Hungary – Croatia 2004-2006.

The aim of the project was to establish basic foundations for long-term action for efficient use of energy in public buildings. Buildings and their users are responsible for almost 50 % of all CO_2 emissions all over the world, so they are one of the cornerstones for the creation of sustainable environmental development (Boček et al., 2007) By implementing several pilot measures and through use of knowledge in information transfer and different dissemination tolls and public events we endeavour to influence the rise of "energy culture and awareness" of general public as well as community of experts.

By introduction of modern organizational investment measures and methods for reducing energy usage we endeavoured to improve economy and efficient use of energy in public sector, thus reducing pollution of the air. In the project we have chosen four areas in Savinjska and Podravska region and in Varaždin and Medžimurje municipalities, in which we raised awareness and trained users of public buildings through the use of seminars, conferences and other dissemination tools. In this way we ensured a permanent transfer of knowledge and information across citizens of bordering regions.

The goals of the project were:

- to lower CO_2 emissions;
- to lower the use of energy use in public buildings;
- to raise awareness and motivate people for efficient energy use by using visual means (stickers);
- to establish an internet energy use bookkeeping (online energy accounting);
- to introduce a control system for the current use of energy (in public administration buildings in Municipality of Velenje, Ptuj and Varaždin).

The following activities were executed in the project:

- assessment of energy efficiency of public buildings;
- establishment of informational control system;
- development and implementation of internet energy use bookkeeping;
- raising the awareness of users and motivating them for a more efficient energy use

2.1 Energy efficiency assessment of buildings

Within the activities of the project we carried out a full energy efficiency assessment of public administration buildings of Municipality of Velenje in Municipality of Ptuj. On the basis of these results we proposed organizational and investment (maintenance and technical) measures for reducing the use of energy and achieving better energy efficiency and the use of other natural resources.

A large majority of public buildings, especially older ones, have in principle a big potential for more efficient use of energy. Even without larger investments in these buildings and by practicing a rational use of energy and better organization one can lover the use of energy by 10%. With this we have in mind especially energy for heating, electric energy and water. By restructuring the organization of work and with suitable awareness of users of those buildings one could save an additional 5 % of energy. Experts agree that with suitable technical measures and additional investments the potential of efficient energy use could add up to 30 %.

2.1.1 Energy efficiency assessment of public administration building of MOV

The aim of the energy efficiency assessment of public administration building of MOV was to analyse the existing energy efficiency state regarding heating, the use of hot and cold water and the use of electric energy. We tried to locate energy inefficient places of the building and propose measures for improvement. The results of this investigation also provided a basis for construction and implementation of energy controlling system.

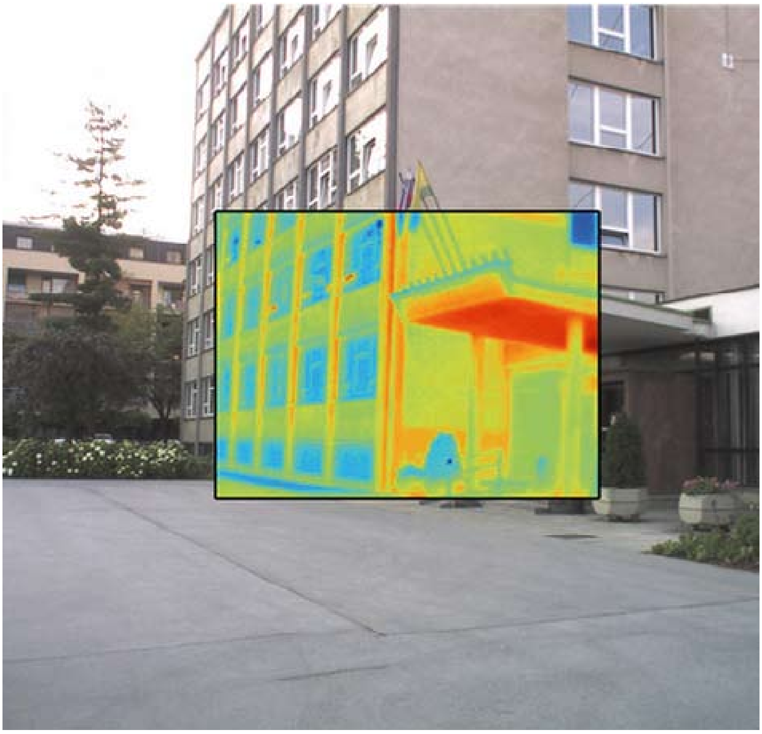

***Figure 1**: Thermal vision of MOV administration building*

The building was built in 1960 and consists of 6 storeys, a hall and a conference hall. Net surface of the building is 2000 m^2; a heated volume is 5700 m^3. The building has a modern, gas-filled windows built in and it is heated out of two sources – distance heating system and electric energy (Energetska študija…, 2007).

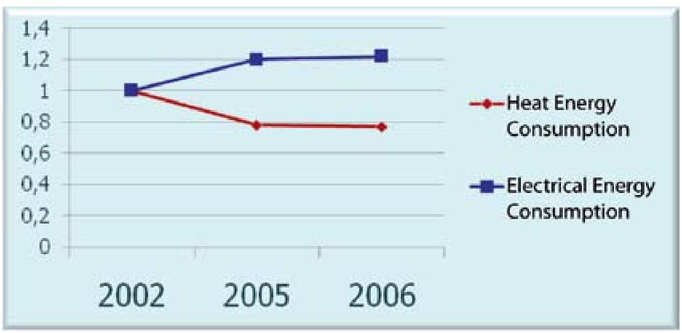

***Figure 2:** Comparison of the energy number of heat energy and of the electric energy use for MOV administration building*

The use of heat energy decreased after 2002 (when new windows were built in). The use of electric energy has increased, which is consistent with a general trend of its increase (Figure 2). On the basis of building energy use classification the building belongs into category of average buildings, which have ample energy saving potential (Energetska študija…, 2007).

ENERGY SOURCES AND ENERGY PARAMETERS	UNIT	2002	2005	2006
JOINT ENERGY USE	GJ	2206	1949	1925
HEAT ENERGY	MWh	495,3	400,4	390,4
ENERGY NUMBER OF HEAT ENERGY Eop	kWh/m2a	247	186	182
ELECTRIC ENERGY	MWh	117,5	141	144,3
ENERGY NUMBER OF ELECTRIC ENERGY Etn	kWh/m2a	55	66	67
ELECTRIC PEAK POWER	kW	509	570	584
ENERGY NUMBER OF ELECTRIC PEAK POWER Epk	W/m2a	237	265	272
CONSUMPTION OF COLD WATER	m3	1221	1865	1452
CO_2 EMISSIONS	T	232	211	234

Figure 3: *Comparison of the energy use in years 2002, 2005 and 2006 for MOV administration building (Energetska študija…, 2007)*

Energy saving potential of the MOV administration building is above all in the envelope of the building (windows, façade renewal, and external shades), heating system (construction of a central air conditioning unit) and interior lightning (lights with sensors).

On the basis of this analysis we proposed organizational (daily monitoring and measuring of energy usage, implementation of web based energy usage bookkeeping, raising the awareness of users about the use of different energy kinds, better coordination of the time of activities, implementation of a suitable natural air ventilation) and investment measures (construction of a central air conditioning unit, reconstruction of lighting, renovation of the building outer envelope).

The measures proposed would reduce the energy use by 155 MWH per year, which would mean 5.300 € savings and 61 tons less CO_2 emissions. By achieving such results the building would classify as an energy economical building (Energetska študija…, 2007).

2.1.2 Preliminary assessments of public buildings

Besides thorough assessment of energy efficiency we also carried out a large number of preliminary energy efficiency assessment of public buildings. Results of the analisysy display the level of energy efficiency and provide the basis for an Internet based energy tracking, allowing for continuous monitoring of energy use in public buildings, ability to take appropriate action, and thus becoming a viable technology for financing through various renovation and implementation funds. Comparison of Energy indicators was used to assess the potential

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savings. During the building analysis in order to perform proper comparisons objects were divided in four categories:

- minor public facilities,
- major public facilities,
- schools, education institutes, libraries,
- sport facilities.

Selected comparative indicators for public institutions were:

- energy consumption per m^2 of net area (number of energy E),
- energy consumption based on the structure's age,
- energy consumption based on total number of employees,
- energy consumption per employee,
- energy consumption according to the number of users and employees in public institutions,
- energy consumption according to energy and CO_2 emissions,
- cost of energy per m^2,
- cost of energy per person.

The consumption of electricity and heat are treated separately. The merger of electricity and heat (amount) were made only when the costs of energy consumption were compared in a single indicator (eg unit/m2).

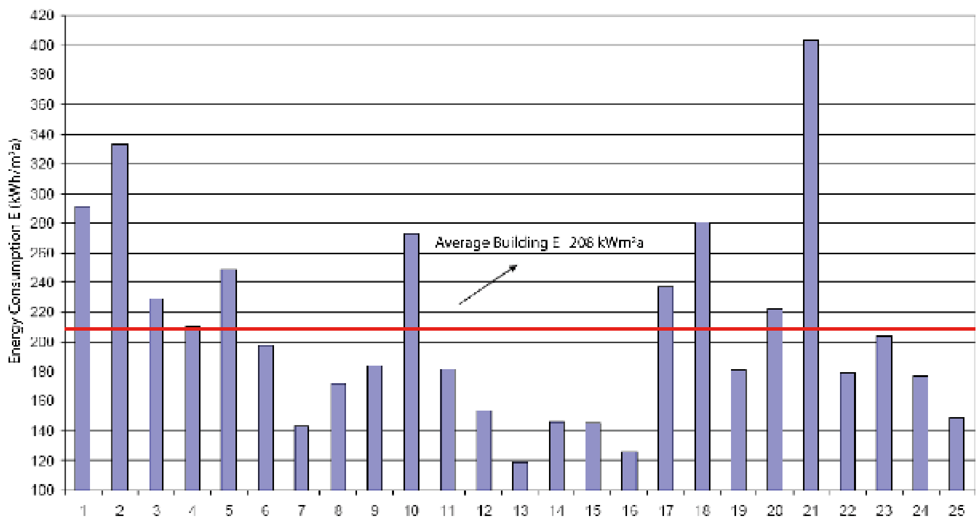

Figure 4: *Comparison of energy numbers E in all treated buildings in Velenje (Boček et al., 2007)*

The overall comparisons of all the buildings (Figure 4) show that high schools are most energy efficient (marks on the graph: 13 - 17, and 2), while elementary schools are the least energy efficient (marked on the graph: 1 and 3). We found that energy efficiency is not as dependent on the age of the buildings. Buildings constructed between 1961 and 1970 in some cases turned out to be more energy efficient than some of the slightly newer ones. The most effective ones were of course modern buildings.

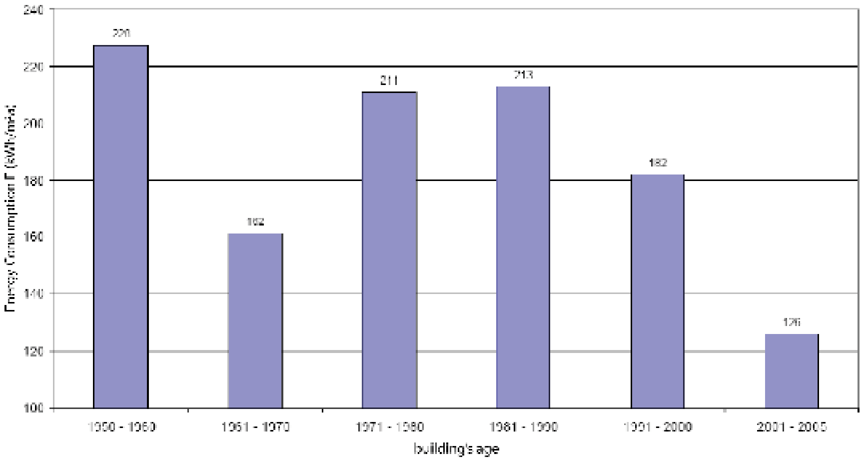

Figure 5: *Energy consumption of buildings according to age (Velenje) (Boček et al., 2007)*

The overall comparison of 25 public institutions in the Municipality of Velenje was carried out according to the following indicators:

- classification of buildings according to the energy consumption,
- classification of buildings according to energy consumption and the number of staff,
- classification of buildings according to energy consumption per user,
- classification of buildings according to the energy cost per user,
- classification of buildings according to the cost of energy per m^2.

Each building has been classified on a scale of 1 to 25 (1 best value and 25 the worst) in relation to each indicator. The overall comparison was made out of the sum of points from all five indicators.

Overall comparison showed that the high schools are the most energy efficient. Technical upgrades to buildings such as heating systems, windows, doors, lighting systems and energy management efforts contributed to such a result. Most buildings' energy managers lack the money for the necessary investment in equipment. Most of the buildings have not been renovated since the time of construction and still continue to use obsolete equipment.

2.1.3 Measures to reduce energy use

Reducing energy consumption can be achieved through organizational, maintenance and technical measures, which are naturally associated with different levels of financial contributions.

Organizational measures that can bring about energy savings of up to 5% with low cost of implementation for an example are:

- monthly monitoring of energy consumption (online energy accounts),
- awareness and education programs on energy efficiency,
- the introduction of proper natural ventilation,
- proper use of lighting during the daylight.

Small investment measures that with regular maintenance can significantly contribute to reducing electricity consumption are:

- improvements in building envelope, carpentry, interior and exterior trim maintenance, repair or installation of shades
- establishment of central and local regulation of the heating system
- optimization of lighting systems; installation of energy efficient lighting
- improvements in management and maintenance of air conditioning systems; installation of simple software automation

Major investment technical measures that at the same time bring greater energy savings and in addition to energy efficiency contribute to a better human habitation (better lighting, better air conditioning ...) (A comparative study ..., 2007).

Technical measures are:

- improvements in building envelope, replacement of doors and windows, installation of thermal insulation roller blinds or shutters, installation of building thermal insulation
- heating system improvements; installation of central heating systems; replacement of boilers, burners, use of alternative energy sources, calorimeter installation...
- improvements in electricity consumption; balancing off take from the public electrical grid, installation of energy efficient lighting
- -improvement in the ventilation and cooling systems; installation of central monitoring and control systems, heat recovery, and preheating of intake air.

2.2 Information Control System

An information control system for monitoring and targeting energy consumption was set up in the Municipality of Velenje based on the results of energy overview of administrative buildings. Data gathering and processing system for automatic display of energy use and cost evaluation allows for central monitoring, energy control, and process optimization in pilot structures (Ferlin, 2008).

2.3 Energy Accounting Online

Online energy accounting is a basic tool of energy management and represents the capture, processing and archiving of data related to the purchase and consumption of fuels and energy (Energy study ..., 2007). There is a regular monthly inspection and comparison of energy bills that provide energy consumption tracking data. Implementation of energy accounts forces the user to think about energy consumption and ways to reduce it. At the same time it allows for supervision of energy consumption and measures taken by the user such as renovations of heating systems, windows, lighting, and employee training. It shows the amount of spent energy in each time period and the effects of implemented measures such as regularly switching off lights in offices, corridors and toilets that contribute to reducing electricity costs to a few percent.

2.4 Raising awareness of users and promotion of energy efficiency

There is a series of external factors that have an impact on energy consumptions, such as variable weather conditions, large temperature fluctuations, energy prices, structure and mindset of users. User awareness on ecological impact of efficient energy usage and use of renewable energy sources plays a significant role on energy consumption. Regular warnings, education, and emphasis on more economical use of energy contribute to changing usage habits and conservation. With this in mind we organized lectures, set up a website www.futurepublicenergy.eu, issued an energy manual and brochures. Users were directly encouraged to save energy at work with warning labels on switches, taps, radiators, and computers (Figure 6).

Figure 6: *Sticker example meant to encourage heat conservation*

3 RESTRUCTURING OF VELENJE MUNICIPAL BUILDINGS

Municipality of Velenje shortly after the building overview began the implementation of certain investment measures to reduced energy use and increased efficiency.

The purpose behind reconstruction of administrative building was the replacement of obsolete installations and reduction in energy consumption for heating and lighting.

Heating during the winter months was inefficient; radiators were built into the wooden ledges with broilers that were too small to facilitate passage and heating of air (Krajnc, 2008); subsequently heating the outer walls. During the summer months the building was very hot due to high temperatures often causing disruptions during work hours. After renovations space heating and cooling was handled by convectors, while the primary source of heating continue to be warm water from the city distant heating system (Krajnc, 2008). Hot wastewater was used for cooling without the use of electricity during the process, indirectly helping to reduce of CO2 emissions from fossil fuel power generation. Since natural water is used this process is environmentally sound.

In addition to renovation of heating and cooling systems an upgrade to lightning system was carried out as well. New low power (2x36 W, 1x85 W, 1x36 W) parabolic light fixture were installed capable of power regulation while corridors and toilets were fitted with motion sensors.

The reconstruction of the lighting system energy saving estimate is 30 MWh of electricity per year, representing around 20% of total electricity use (Krajnc, 2008).

With the reconstruction of the lighting and heating system MOV will reduce consumption of electricity and heat, increasing energy use for cooling (Krajnc, 2008). Working conditions will be improved, especially during the summer months when work hours were disrupted several times due to excessive heat. Cooling with convectors is also more economical and energy efficient way of cooling.

Cooling power needed for the administration building MOV is 150 kW. For the average office air conditioning system should use about 3.5 kW, which is the same as if you had installed 40 air conditioners, but the efficiency in distant heating is better.

In the next stages other buildings in the community: Cultural Center, Administrative Unit Velenje, Court Building, Red Hall and others, will be connected to the same distant cooling system. Only estimated negative effect of distant cooling system establishment is the noise from the cooling tower. This problem was addressed by placement of the facility outside densely populated areas.

4 FIRST RESULTS

Improvements in energy usage are expected in the longer term. Results for the time period from September 2007 to January 2008 and September 2008 to January 2009 show that the heat energy consumption decreased by 13%, even though the rising prices of thermal energy (€ / MWh) increased by 4% (Figure 7). This is encouraging because decrease in consumption was not a result of rising prices helping to reduce the release of CO_2 due to power generation.

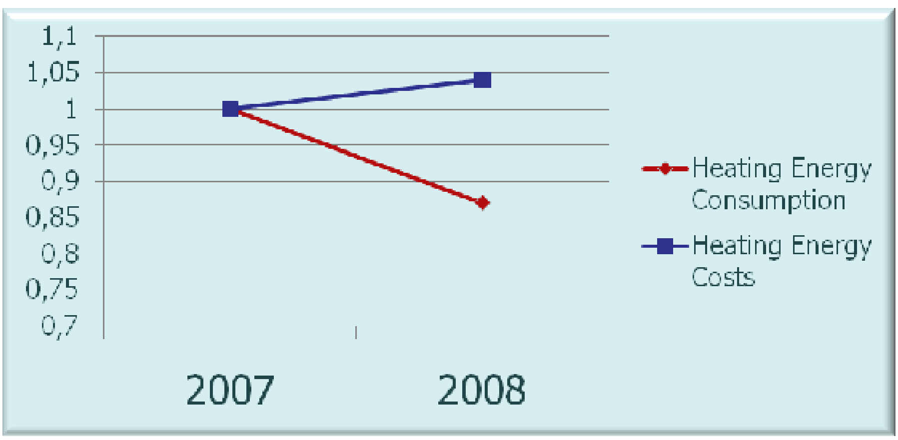

Figure 7: *Comparison of heating energy consumption and its costs before and after the reconstruction.*

Consumption of electricity in the comparable period increased for 1.7%. It is encouraging that the increased consumption occurred during off-peak periods and was reduced during what would normally be peak times. Despite the satisfactory results the cost of electricity due to rising prices increase by as much as 47% (Figure 8). Because of this we are also pleased that power consumption is not significantly.

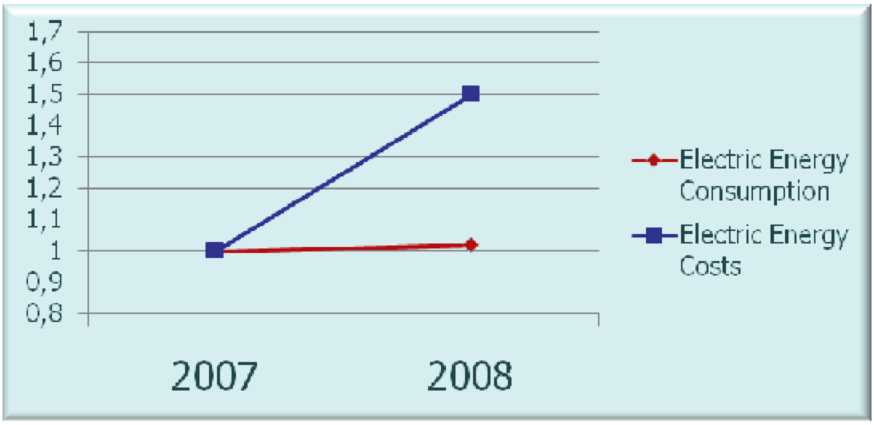

Figure 8: *Comparison of electric energy consumption and its costs before and after the reconstruction*

5 CONCLUSION

Municipality of Velenje is a part of Šalek Valley still representing its "energy pool". We are very well aware of the importance of environmental protection due to the past negative effects of mining. Projects that were carried out in the field of efficient energy use and the promotion in the use of renewable energy sources represent the foundation for further activities in this area. We have set ourselves a goal to become the most energy aware and energy efficient municipality in Slovenia. To facilitate this goal several strategic documents have been adapted representing the blueprint for implantation of concrete projects. The city of Velenje will with the signing of the Convention of Mayors for Reduction of Energy Consumption join the other European cities that made sustainable development of municipalities as an important priority.

Online energy account management, completed building energy consumption overview, established energy management system at the municipality level, are the foundation necessary for acquisition of founds from Cohesion Found for reconstruction of public buildings. Therefore our further activities are going to be aimed at investment measures in public buildings that are in greatest need of improvement; to further increase awareness of both employees and citizens on the efficient use of energy; investment into a efficient urban public transportation; and reduction of CO2 emissions.

References

[1] **Boček, J., Matjaž, R., Ferlin, D., Karničnik, M., Krajnc, B.:** *Primerjalna študija energetske učinkovitosti javnih zgradb Mestne občine Velenje in Mestne občine Ptuj. Benchmarking analiza.* Zavod Energetska agencija za Savinjsko, Šaleško in Koroško. 58 pages., 2007

[2] *Energetska študija vzorčnih javnih zgradb.* Upravna stavba Mestne občine Velenje. Upravna zgradba Mestne občine Ptuj. 2007. http://www.futurepublicenergy.si (citied 16.6.2009)

[3] **Ferlin, D.:** *Do učinkovite rabe energije v javnih zgradbah skozi projekt Future Public Energy.* (personal archive), 2008

[4] **Krajnc, B.:** *Daljinsko hlajenje in sanacija zgradbe MO Velenje*. Sinergija. p. 9., 2008

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ENERGY EFFICIENCY OF FUZZY APPROACH IN CONTROLLING TRAFFIC SIGNALIZATION

ENERGETSKA UČINKOVITOST MEHKEGA PRISTOPA PRI UPRAVLJANJU PROMETNE SIGNALIZACIJE

Tea Vizinger[1], Janez Usenik[2]

Keywords: crossroads, traffic signalization, control, fuzzy logic, energy efficiency

Abstract

An important element of traffic signalization in crossroads is controlling them in such a way that contributes to effective flow of traffic, especially in large cities and in rush hours. There are many possibilities for optimal and simultaneous controlling; one of them is the usage of fuzzy logic. In this article, we are dealing with the fuzzy approach of optimization controlling traffic signalization in crossroads. The general theoretical part of creating such a system is introduced and an algorithm of fuzzy inference, which is appropriate for such controlling, is deduced. The algorithm is applied to an intersection in Maribor, where extensive jams are frequent occurrences. The fuzzy approach in controlling traffic signalization based on introduced algorithm in this crossroad was shown to be efficient, i.e. it achieved fundamentally better traffic flow. Of course, in this way, we are achieving multiple effects: because vehicles spend less time at crossroads, the drivers waste less time, vehicles use less fuel, which affects on energy efficiency and costs of transport; there are also fewer negative effects on environment than usual.

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Povzetek

Upravljanje prometne signalizacije v križiščih je pomemben element, ki prispeva k pretočnosti prometa, še zlasti v urbanih naseljih in še posebej v prometnih konicah. Možnosti optimalnega in sinhronega upravljanja je več, med njimi je pomembna uporaba mehke logike. V tem prispevku obravnavamo mehki pristop pri optimizaciji upravljanja prometne signalizacije v križišču. Predstavljen je splošni teoretični del v postopku kreiranja sistema, izpeljan je algoritem mehkega sklepanja, ki je primeren za takšno upravljanje. Ta algoritem je bil uporabljen na konkretnem križišču v Mariboru, kjer sedaj prihaja do velikih zastojev. Mehki pristop pri upravljanju prometne signalizacije se je v tem križišču izkazal za učinkovitega, saj na osnovi predstavljenega algoritma dosegamo bistveno boljši pretok prometa. Na ta način seveda dosegamo multiplikativne učinke: ker vozila v križišču stojijo bistveno manj časa, ga porabijo manj tudi vozniki, vozila porabijo manj goriva, kar vpliva na energetsko učinkovitost in s tem na stroške prevoza, mnogo manj so zaradi tega tudi aktivni negativni učinki na okolje.

1 INTRODUCTION

Flexible, fast, independent, ecologically and energy efficient transport by car is still the most effective means of transport for many activities. Large amounts of cars in urban areas are produce congestion, burden roads, damage the environment and cause unnecessary and expensive usage of fuel. The largest bottlenecks on traffic networks are at crossroads, where congestion occurs the most often. In recent years, many crossroads have been replaced with roundabouts, where crossing roads from different directions does not occur. Because of this, roundabouts enable faster and safer flow of vehicles. Certainly crossroads in the urban areas will remain unchanged for a long time and care must taken to make safe traffic that will be energetically and environmentally efficient. Traffic signals have long been the standard way of managing crossroads. Of course, traffic signals must be placed well, synchronised and controlled, so that they will be able to contribute to the efficiency of the urban road network.

Traditional controllers of traffic signalization at crossroads manage time intervals considering the current traffic circumstances. Controllers, with the help of sensors, gain data that are often incomplete, because controllers do not obtain information from the environment as well as human beings. Traffic systems are exceedingly complex, because of the large number of stochastic variables. Because of this, it is difficult to create an accurate and highly efficient exact mathematical model that will offer all necessary information for controlling based on data gained in real time. In such a situation, the use of fuzzy logic is expected and reasonable.

The fuzzy approach is becoming increasingly important and also efficient by controlling traffic signalization in crossroads. In this paper, we present an original fuzzy approach for managing traffic signalization. The model was made by studying an intersection in Maribor, which can be used as a demonstration example for all similar crossroads.

The structure of the article is as follows: in the first two chapters, the researched problem and the analysis of the problem are presented, and then the structure of the model, which includes all standard procedures in the fuzzy approach, is assigned. Following that, we perform and analyse in detail the numerical example for controlling traffic signalization on a crossroad in Maribor.

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2 CONTROLLING TRAFFIC SIGNALIZATION

Controlling traffic signalization in crossroads is a very demanding task, because the goal of this process is to efficiently eliminating congestion in traffic, which is a problem in major parts of cities throughout the world. The number of vehicles on the road is increasing from day to day and the controllers of road architecture must follow these trends. Well-planned traffic signalization certainly contributes to greater effectiveness of the road network, which is important from all viewpoints: economic, security, ecological, sociological etc.

In the literature, there are three main goals in the frame of searching optimum in process of controlling traffic signalization in crossroads: a) maximum safety, b) minimal delays and c) minimal negative consequences on environment. Each of these criteria always implicitly contains maximal economic effects. With increased safety, the number of traffic accidents is decreasing, leading to a reduction in material damage; with minimal delays, the time that we spend in traffic decreases; with minimal negative consequences for environment, the amount of exhaust gases reduces and so on. The afore-mentioned goals of controlling traffic signalization can significantly increase traffic flow.

The general aim of efficient initiation and the optimal activity of traffic signalization is in reducing and eliminating confrontations within crossroads. So it is necessary to efficiently coordinate the allocation of very limited time and place for larger numbers of vehicles.

2.1 Control procedures

The procedures of controlling traffic signalization in crossroads are based along two axes, Davol [1].

The first way is based on the handling response of the system to the conditions in traffic. In this case, we are referring to pre-timed, actuated and adaptive procedures. Among newer procedures of controlling traffic signalization in crossroads to this area, we also place the fuzzy approach and with this one use of a fuzzy inference.

The second way deals with the approach of controlling traffic signalization in crossroads from the view of the strategy that we are using in this purpose. In this, we divide three basic kinds of controlling traffic signalization at crossroads: a) isolated, b) arterial and c) network controlling. In this paper, we consider the model of an isolated controlling of crossroads. Under the concept "isolated and self-dependent crossroad," we understand the situation when traffic goes through this crossroad independently of other intersections. Thus, we are considering only one crossroad, whose signalization is not connected with other intersections. The controlling algorithm in such a case is more primitive and has more possibilities for controlled strategies.

2.1.1 Pretimed procedure

In controlling based on fixed time intervals, it presumed that the length of cycle and each phase are constant. The cycle of controlling traffic signalization in crossroads is presented in all phases or intervals (green, yellow and red) in sequence. The cycle is finished when the first phase starts again. Data on traffic density through an actual crossroad show the setting of optimal length of cycle and incidence of individual phase. The optimal length of cycle is calculated by Webster's formula, Cheng et al., [2], that denotes a minimum of common delays for known traffic overflows:

$$C = \frac{1,5L + 5}{1 - Y} \tag{2.01}$$

In (2.01): *C* – the optimal minimum delay cycle length (s),
L – total lost time within the cycle (s),
Y – the sum of critical phase flow ratios.

In Webster's equation, it is also assumed that the effective green time of each phase is in the ratio of their respective *Y* values, Chang et al. , [2]. So, for the calculation of the *Y* value, we firstly calculate the degree of saturation for each critical phase by dividing the demand by the saturation flow, FHWA, [3].

The key attribute of pre-timed control is that the logic is not demand-responsive, but signals operate without regard to fluctuations in traffic demand. Thus, each direction of roadway receives certain duration of green/red signal regardless of the actual number of vehicles.

2.1.2 Actuated procedure

Procedures working with the perception of vehicles are determining time intervals based on real-time data. Built-in sensors that measure the load (i.e. weight) passing over the crossroads are enabling suitable time lengths of individual phases and cycles and, with that, are presenting optimal adaptation to traffic circumstances within the crossroads.

The most common feature of actuated control is the ability to extend the duration of the green interval into advanced defined maximum determined time limit during times of greater traffic flow in a particular direction (Figure 2.01).

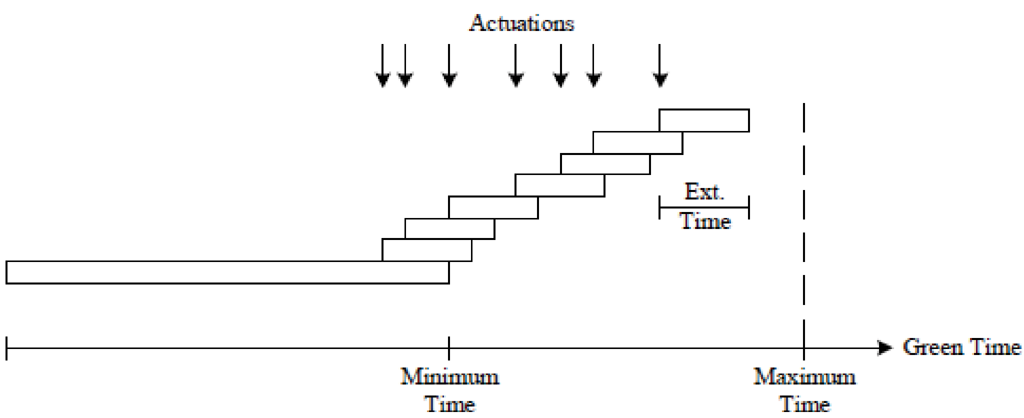

Figure 2.1: *Green interval extension of an actuated phase*

According to Figure 2.1, Davol, [1] controlling of the system requires three parameters: 1) the minimum green time, 2) the extension time and 3) the maximum green time. Regardless of

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demand, green is retained for at least the specified minimum duration. If, within this time, sensors detect any additional approaching vehicles, the duration of the green interval extends appropriately. This procedure can occur as long as the extension time does not reach the maximal value of the duration of the green time. The duration of the green interval is terminated for one of two reasons: when sensors do not detect more approaching vehicles or when extensions are taking more or the maximum time in advance of the ordered duration of the green interval.

The extension time is usually set in such a way that every additionally detected vehicle has enough time to pass the distance from detector to crossroad. The extension time can also be set to vary as a function of the elapsed green time (Figure 2.2). A variable extension length is often used in cases in which detectors are located a long distance from the intersection. Longer extension is desirable at the start of the green light interval, because we want to ensure that all detected vehicles cross the intersection. However, as the duration of the interval is approaching the maximum value, use of the green light becomes shorter in order to not extend the additional interval unnecessarily, Davol [1].

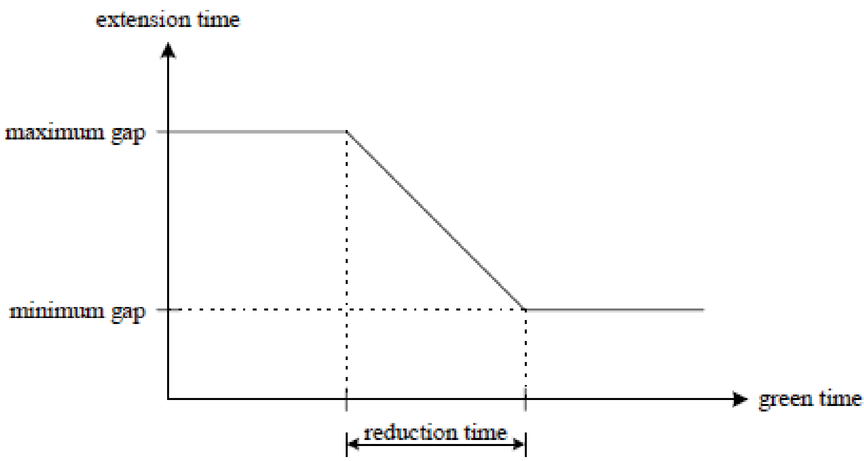

Figure 2.2: *Function of the extending green signal*

The elementary purpose of controlling with the perception of vehicles is to eliminate traffic congestion so that the vehicles that are approaching the green light are allowed to cross the intersection without the unnecessary stopping. The main disadvantage of this approach is that it considers only vehicles approaching a green light and not waiting vehicles on the red light.

2.1.3 Adaptive procedure

With the implementation of methods of mathematical optimization, we have to deal with adaptive controllers, which like actuated procedures respond to changes of densities of traffic flow in the real time. The main difference between both approaches is that adaptive controllers take into consideration changes of density of traffic flow from all directions and not just in the direction of the green signal. This procedure also considers others important criteria, like changes of interval duration of the green light because of the maximal throughput of vehicles and the minimum of traffic jams. The choice of an appropriate optimization method is based on

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logical selection of dedicated function. In Nittymäki [4] the optimization strategy, which uncovers a minimum of common delays of vehicles, is considered. The result is shown in Equation (2.02).

$$T=\left\{\left[\delta_N+\delta_S-q_N\frac{1-\frac{\delta_N}{s_N}}{1-\frac{q_N}{s_N}}-q_S\frac{1-\frac{\delta_S}{s_S}}{1-\frac{q_S}{s_S}}\right](a+r_{NS}+l_{NS})\right\}-\left\{h\left[n_W+n_E+\sum_{i=1}^{k_W}q_W+\sum_{i=1}^{k_W}q_E\right]\right\} \tag{2.02}$$

In the first segment of equation (2.02), we consider additional vehicles that are able to cross the intersection during the extension and, in the other segment, the vehicle column that occurs because of the extension within the transverse direction.

In (2.02): *T* – controlling function, difference in delay (s),
h – evaluated extension of the time interval length (s),
δ_I – expected number of vehicles that will cross intersection in next *h* seconds,
q_I – flow density of vehicles in next *h* seconds (number of vehicles/hour),
a – length of yellow phase (s),
r_I – length of next red phase (s),
I_I – time spent during accelerating beyond end of red phase (s),
n_I – number of vehicles that are waiting (stand in front of red light),
k_I – time required for releasing the column (s),
I – index of approaching the vehicles to crossroad, where N, S, E, W are describing the variables North, South, East, West.

2.2 Chronology of classical procedures of controlling signalization

Signalled controlled systems for urban streets began to be devised with the development and use of automobiles. The year 1928 saw the introduction of a flexible-progressive pre-timed system. Municipalities quickly accepted these pre-timed systems and widespread installation followed in virtually every U.S. city by Dunn Engineering Associates [5]. Mass installations were arranged with simplicity, reliability and relatively low cost. The main problem of the controllers was in limitations of flexibility, because counting and predicting of traffic flow is quite complicated.

The evolution of actuated controllers started between 1928 and 1930. Americans developed pressure detectors, which worked only in isolated crossroads. In 1952, they gained real success with the development of an analogue computer control system. Flexible time intervals for individual parts of day were replaced with controlled algorithms that adapted to actual conditions in traffic. With this system, they were also able to connect isolated crossroads in a signalled network.

In 1960, a pilot study using a digital computer to perform centralised control functions was conducted in Toronto, Dunn Engineering Associates, [5]. In 1964, IBM[3] started with an even more in-depth development of a traffic system controlling, which helped to reduce traffic jams, delays and accidents. In 1967, FHWA[4] started with its Urban Traffic Control System (UTCS), whose purpose was especially in testing and evaluating of advanced strategies for controlling traffic. The amount of traffic information that was obtained from this period radically influenced the development of traffic control signals throughout the world. In Toronto, computer supervision of over 885 crossroads was established by 1973. Systems based on the perception of vehicles are still in use nowadays, but their main disadvantages are that they react only to flowing traffic, so with this they are adapting to a past situation, working responsively and not proactively, Malej, [6].

Research into software and models for digital computers and microprocessors began in the 1970s. The TRRL[5] in Great Britain developed the advanced centrally controlled traffic system named SCOOT[6], which was implemented in the 1980s in cities in England and in North America, Dunn Engineering Associates, [5] . The system works based on a mathematical model of traffic flow and progressively changes the parameters of signalization, Malej, [6]. SCATS[7], developed in Australia, was also put into place in many cities in the world. However, SCATS does not use a mathematical model of traffic prediction, but uses the degree of saturation for entry data and does not include direct optimization according to specific measures of efficiency. The difference between these systems is also shown in the setting up of detectors, as SCATS anticipates placing sensors next to stop lines at entry connections of each intersection, while SCOOT foresees placing sensors farther, i.e. before crossroad. These systems require the mass installation of responsive control systems, with the use of adaptive techniques of controlling and are still implemented today among most contemporary systems for controlling urban signalization.

The development of traffic signalization in crossroads is demonstrated in Figure 2.03, Dunn Engineering Associates, [5].

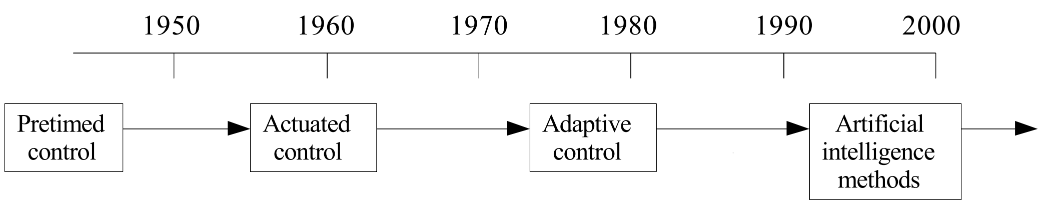

***Figure 2.3:** Chronological overview of controlling traffic signalization*

The experiences gained indicate that the efficiency of reducing traffic jams, delays, fuel consumption and emissions depends on both effective control systems and on effective traffic signalization control. Even better effects are achieved with the use of the fuzzy logic approaches and artificial intelligence that appeared in the 1990s.

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[3] International Business Machines
[4] Federal Highway Administration
[5] Transport and Road Research Laboratory
[6] Split, Cycle and Offset Optimization Technique
[7] Sydney Coordinated Adaptive Traffic System

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3 FUZZY APPROACH IN CONTROLLING TRAFFIC SIGNALIZATION

Fuzzy logic systems originated from a desire to model human experiences, intuition and behaviour in decision systems, Zimmermann, [7]. The original idea of the possibility of making decisions that are based on inaccuracy and about qualitative information in connection with descriptive linguistic rules was first introduced by Lotfi Zadeh, Usenik, [8]. The combination of imprecise logical rules within the strategy of controlling was termed "approximately or fuzzy inference." He introduced fuzzy logic for the first time in 1965. He concluded that common quantitative techniques of a system analysis were highly inappropriate for humanistic systems and viewed them as incompatible principles, stating, "When the complexity of a system increases, does our ability to pass accurate and important statement reduce until the limit value reaches the level in which accuracy and significance have almost reciprocal exclusive features", Zadeh, [9].

Fuzzy logic allows reasoning (inference) based on imprecise data and on their very efficient uses. Sets of fuzzy rules and verbal descriptions of strategy and treatment within the procedure of controlling allow the creation of exceptionally efficient algorithms, by which we infer in the decision area. The general advantage of such a fuzzy approach is the possibility of initiation and using rules based on experience, intuition, inventiveness and ingenuity, Usenik, [10].

3.1 Theoretical bases of fuzzy approach in controlling traffic signalization

The problem of controlling intersections has been studied by many experts. The first article that tried to solve this problem with use of fuzzy logic was written by Papis and Mamdami in 1977, Teodorović and Vukadinović, [11]. For an isolated signalised crossroad of two one-way streets they developed a model of controlling that was based on linguistic controlled instructions, with the use of fuzzy inference. They compared the results of the model using fuzzy logic with the results of the classic approach and discovered that results are better with the use of fuzzy logic. Their research had a set of activities that would imitate the work of an actual provider in crossroad, i.e. a police officer. They were also derived from a real situation, i.e. when a police officer is directing traffic at an intersection of two one-way streets. In this situation, a police officer was guiding traffic in one direction for some time and for some time in other direction. What kind of criteria did the officer use in such decisions? At which moment did he decide to change the direction of the traffic flow? Certainly the time and number of vehicles that were waiting to cross the intersection have influence on the police officer's work. The officer probably noticed that large number of vehicles was accumulating from one side and he decided to let them through the crossroad. He might also have been influenced by the fact that small number of vehicles were already waiting to cross the intersection for a relatively long time. Thus, in the process of the officer's decision, concepts like "small," "large" or "quite a lot of" number of vehicles that are waiting and "short," "middle," "long" or "very long" waiting times and similar are occurring. These are the concepts by which fuzzy logic operates, Teodorović and Vukadinović, [11].

With fuzzy controlling of traffic signalization at a crossroad, we are modelling the actions of a skilled police officer, who knows very well how to lead the traffic flow through crossroads in order to minimise waiting. The development of rule systems should therefore proceed in cooperation with experienced planners of traffic signalization in crossroads. With a systematic approach in this sense, it is possible to deduce a functional controlled algorithm of traffic signalization for any isolated intersection, Niittymäki, [4].

3.2 Structure of fuzzy controlling traffic signalization

Controlling traffic signalization in crossroad is a very difficult assignment with many conflicting intentions. Efficient traffic systems must appropriately balance the traffic flow in order to prevent the occurrence of long waiting queues. To the planners of controlling systems the most problems are with difficult crossroads with many streets and more roadways.

In the classic controlling of traffic signalization at a crossroad, signals are changing at constant time intervals or based on receiving information in the direction of the green light, which is certainly not optimal solution. The exact mathematical models for such complex systems are very complicated, but we can radically simplify the procedures by using fuzzy logic.
The fuzzy logic method is a more democratic way of controlling, because information about the traffic situation from the directions of green and red lights is considered. With typical detectors, the principle of extending the green light are assigned to one or the opposite direction of crossroad with the perception of a larger number of vehicles, but with the fuzzy approach we can also terminate an active signal if the vehicle column of the opposite direction is long enough. From this perspective, the fuzzy logic method is a multi-objective method.
With the fuzzy approach, there are only a few entry parameters. The fuzzy controller is changing the duration of time intervals. Thus, it constantly gathers information (Figure 3.01), evaluates conditions on individual roadways and chooses the most appropriate option to complete the current phase and go to a more suitable phase or to extend the current phase, Nittymäki and Könönen, [12].

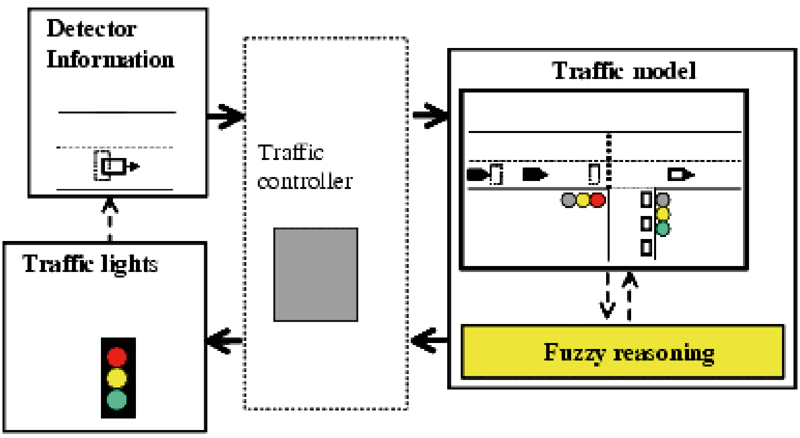

Figure 3.1: *System structure for controlling signalization,* (Source: Laboratory of Transportation Engineering)

The fuzzy process of controlling traffic signalization at a crossroad is a combination of the following concepts: current traffic circumstances, gaining of sharp values of measured amounts, modelling of traffic circumstances, a traffic controller in which the procedures of fuzzification, fuzzy inference and defuzzification and controllers actions are occurring.

3.3 Fuzzy approach procedure of controlling traffic signalization, construction of the model

Construction of a fuzzy system generally takes several steps: selection of decision variables and their fuzzification, establishing the goal and the construction of algorithm (base of rules of fuzzy reasoning), inference and defuzzification of the results of fuzzy inference. A graphic presentation of a fuzzy system is given in Figure 3.02, Usenik, [8].

The entire system demonstrates the course of inference from input variables against output and it is built on a base of "if-then" fuzzy rules. The fuzzy inference consists of three phases:

1. Fuzzification
2. Fuzzy inference
3. Defuzzification

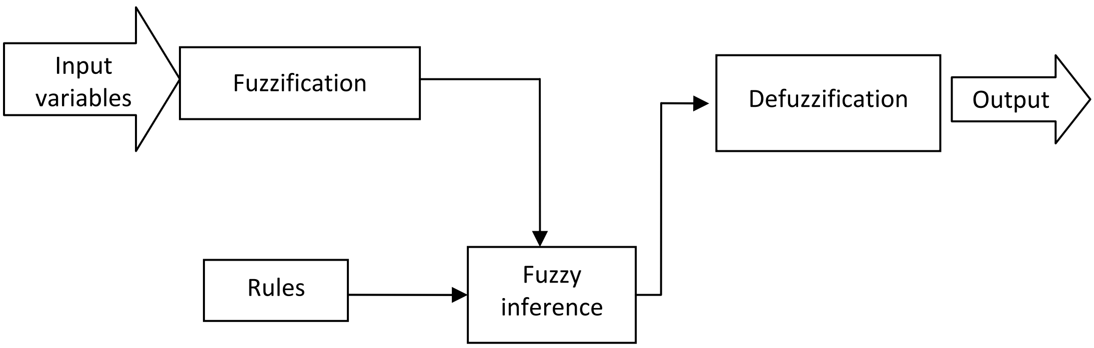

Figure 3.2: *Elementary elements of fuzzy system*

In this article, we will model a fuzzy system, by which we gain optimal lengths of green light duration for an individual road; following that, we will give a practical example.

3.3.1 Variables at fuzzy approach of controlling traffic signalization

First, we determine all input and output variables of the system. With controlling traffic signalization, the input variables are usually the following: duration of time cycle, length of column at a red light, number of vehicles approaching the crossroad in the direction of a green light etc. For output variables, we can set e.g. probability of change of current time cycle, the duration of the green light etc. By constructing the algorithm for an actual crossroad, we chose

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"the traffic flow from individual directions" and for output "the duration of the green light for each road" for entry variables.

3.3.2 Setting up goals

The main goals in controlling traffic signalization are: flowing traffic, safety, environmental protection, and energy efficiency. Furthermore, we also have some other goals such as delays, waiting time, share of stopping, crash risk, emission levels etc.

3.3.3 Fuzzification

It occurs very rarely that input values in the system are already fuzzy, because usually we have to deal with numerical data from sensors. So for fuzzy inference, it is necessary to transform sharp input values to fuzzy ones, which is done in the procedure of fuzzification.

To the input and output parameters within this phase, we assign membership functions. The choice of fuzzy sets and linguistic variables has a huge influence on the sensitivity of a controlled system, but there is no accurate procedure for this, Ross, [14]. Most often a procedure of trials and errors is used, which will also be used in our practical example.

For each linguistic expression, we must to determine relevant fuzzy set. In the case below, we used the set of triangular, trapezium, Z and S forms.

3.3.4 Fuzzy inference

Fuzzy inference is a process in which a certain conclusion / resolution is derived from a set of fuzzy statements.

In addition to linguistic variables, there are basic widgets of a fuzzy logic system as well as sets of rules that define the behaviour of system. With the assembly of a base of rules, the question always appears of how to get rules. Usually this is written down as a base of knowledge within shape of "if-then" rules by an expert for a definite system based on his own knowledge and experiences. An expert must also define entry and exit fuzzy functions, their shape and position. However, it often occurs that his knowledge is not sufficient and he cannot define an adequate number of rules. Therefore, the procedures of forming or supplementation to the base of rules based on available numerical data were developed, Šafarič and Rojko, [15].

With fuzzy inference, we must put all values and facts in a definite order and connect them to the procedure of inference execution, so that will be feasible with a computer. This order is given as a list or system of rules, in Table 3.01, Virant, [16]:

Table 3.01: *General record of rule list*

rule 1	**If** $X_1 = A_{11}$ **and** $X_2 = A_{12}$ **and** …… **and** $X_n = A_{1n}$ **then** $Y = B_1$
rule 2	**If** $X_1 = A_{21}$ **and** $X_2 = A_{22}$ **and** …… **and** $X_n = A_{2n}$ **then** $Y = B_2$
…	…
rule m	**If** $X_1 = A_{m1}$ **and** $X_2 = A_{m2}$ **and** …… **and** $X_n = A_{mn}$ **then** $Y = B_m$

Each rule has its left and right side, between one and the opposite side is the mnemonic “then.” The left side consists of presumptions of the form $X_1 = A_1, X_2 = A_2 \dots X_n = A_n$ and relates to the self-dependent variables, and the right side relates to searched variable Y. The results of inference are linguistic values of the output variable. To such rules, where entries and exits are linguistic values described with fuzzy sets, we also appoint Mamdami rules, Ruspini et al., [17].

3.3.5 Defuzzification

In procedure of defuzzification, fuzzy output variables are changed into numerical values. There are many procedures for defuzzification, which give different results.

With the “Center of Maximum” method (acronym CoM), the weighted average of maximums that belongs to individual membership functions is calculated. With the “Center of Area” method (acronym CoA) for sharp or output values, the focus of character that we have obtained with fuzzy inference is taken. With the “Mean of Maximum” method (acronym MoM), the output is the highest degree of output fuzzy membership functions.

In systems for controlling traffic signalization at crossroads, the most commonly used methods are the Center of Area and the Center of Maximum. In algorithm in the following section the CoM method is used.

4 FUZZY APPROACH IN CONTROLLING TRAFFIC SIGNALIZATION OF SELECTED CROSSROAD

To build a general fuzzy model of controlling traffic flow for every crossroad is, in fact, impossible. However, it is possible to define general assumptions and to predict behaviour, but its implementation requires examining the characteristics of the actual crossroad.
In our article, we will limit ourselves to a crossroad in Maribor, where we will accomplish essential improvements with the use of fuzzy logic. We must first analyse each chosen crossroad to determine the traffic flow and current controlling procedure. After this, we can attempt to model the system for fuzzy controlling. Firstly, we define all basic component elements of the system and then transmit the base of knowledge in the form of membership functions and rules. Finally, we will optimise the system, so that we will obtain actual optimal results.

4.1 Example

As an example of the use of fuzzy controlling traffic signalization, we chose a crossroad in Maribor, where the Proletarskih brigad road (Road A, hereafter) and Ljubljanska street (Road B) are crossing. Road A is a four-lane road and Road B is a two-lane road (Figure 4.01). It is a crossroad of two of bidirectional roads with primitive two-phase signalization with a system of coordination that works with fixed time intervals.

Figure 4.1: *Location of chosen crossroad (Source: Google maps 2009)*

For an analysis of activity or implementation of traffic flow within this crossroad, we have gained data from Directorate for Roads of the Republic Slovenia, and information about the controlling of traffic signals we have obtained at the operator.

Additionally, we made measurements in fieldwork with the help of a video camera. Video tapes were recorded on June 26, 2008. We observed two parameters: 1) length of column waiting at a red light and 2) number of vehicles approaching a green signal. We observed all roadways on areas approximately 20m before the crossroad.

Within the observed time the duration of individual cycle takes 100 seconds. On Road A, a red light takes 42 seconds, a yellow signal in overlap from red to green takes 1 second; a green light takes 54 seconds and a yellow signal at overlap from green to red takes 3 seconds. On Road B, a red light takes 67 seconds, a yellow signal at overlap from red to green takes 0 seconds; a green light takes 30 seconds and a yellow signal at overlap from green to red takes 3 seconds. On Road B, the duration of the green light is close to optimal, because vehicles could leave the crossroad within majority of measured intervals. Vehicles that turn left had some problems; some of them even needed to wait for the next green signal. But on Road A the duration of the green light is approximately 20 seconds too long, because within this time only some vehicles drove through green light, whilst on Road B there was already a column of several more cars (Figure 4.02).

On Road A, the operator tried to achieve a continuous flow of traffic via synchronised lights with the current pre-timed system of arterial coordination. In some intervals they succeeded, but the density of traffic flow on this road is changing so greatly that controlling with fixed time intervals does not function optimally.

We expect that traffic through this crossroad will function better with a coordination system using fuzzy logic. Time intervals could be shortened by at least 20 percent, which results in a faster changing of cycles. Consequently, vehicles and pedestrians have more frequent possibilities for crossing the roadway.

Figure 4.2: *Snapshot of situation in which a column of vehicles is waiting unnecessarily*

4.2 Defining the structure of model

We divided the course of system construction into five basic steps.

4.2.1 Selection of input and output linguistic variables

In first step, we selected all input and output variables of the system; our system contains four major input variables:

- *"south"* – number of vehicles from southern side,
- *"north"* – number of vehicles from northern side,
- *"east"* – number of vehicles from eastern side,
- *"west"* – number of vehicles from western side

and one output linguistic variable

- *"the duration of the green signal,"*

which denotes the duration of green light for each road.

4.2.2 Setting up goal and structure of the system

In Figure 4.03, we demonstrate a fuzzy system structure for controlling traffic signals on an actual crossroad. Connections between elements of system present the flow of data through the system.

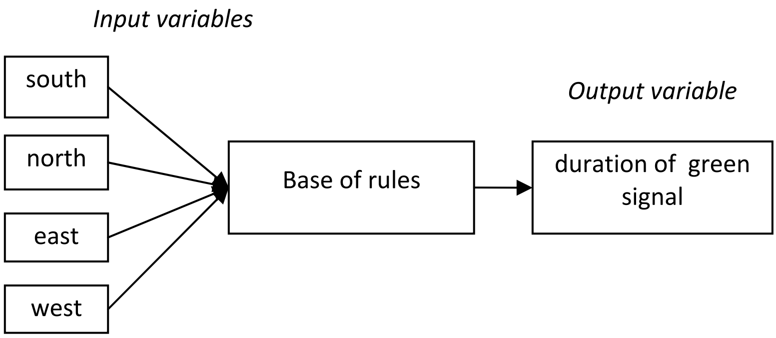

Figure 4.3: *Structure of fuzzy logic system for controlling traffic signalization*

The goal of optimal controlling of signalization of a crossroad is to achieve the traffic with the least possible stopping and waiting (i.e. the traffic with minimal disturbances).

4.2.3 Fuzzification

During fuzzification, the sharp numerical input is transformed into soft linguistic values. In Figures 4.0 – 4.08, we present the variables of the system, their membership functions and characteristics.

From observations on this crossroad and from data gathered from the Directorate of Roads of Republic Slovenia, we choose the maximal number of approaching vehicles in each direction in one cycle. Out of this, a two-lane road can obtain values up to 20 vehicles in each direction per cycle and a four-lane road can occupy values up to 40 vehicles in each direction per cycle. These numerical values were divided into three possible fuzzy numbers, named "small," "middle" and "many." Besides calling the previously mentioned numbers and others as "short" and "long," we also initiate linguistic values like "very short," "middle long" and "very long."
On the X axis, the number of approaching vehicles from each direction is defined; on the Y axis, the membership functions to individual variables that can obtain values between 0 and 1 are defined. With this, value 1 characterises the perfect affiliation and value 0 incomplete memberships.

Let us take for example the middle number of vehicles on Figure 4.04. First, we may notice that perfect membership to this variable occupies the values on the interval from 8 to 13 vehicles. We may also notice that values that are smaller than 4 and larger than 16 do not belong to this variable. The vehicles that obtain the value on the intervals from 4 to 8 and (on the other side) from 13 to 16 belong to middle variable with the incomplete affiliation. The calculation procedure of the affiliation to each variable is listed below.

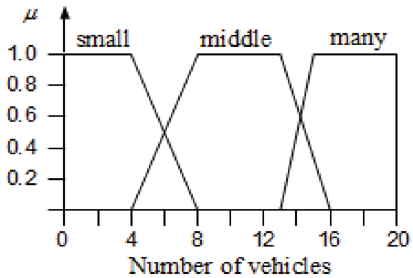

Figure 4.04: "South"

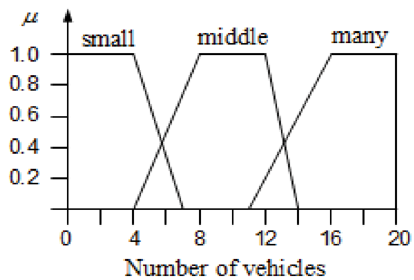

Figure 4.05: "North"

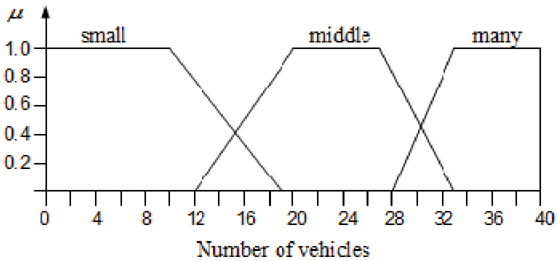

Figure 4.06: "East"

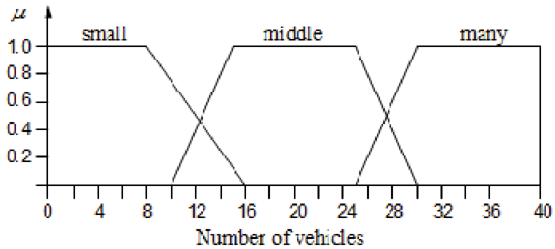

Figure 4.07: "West"

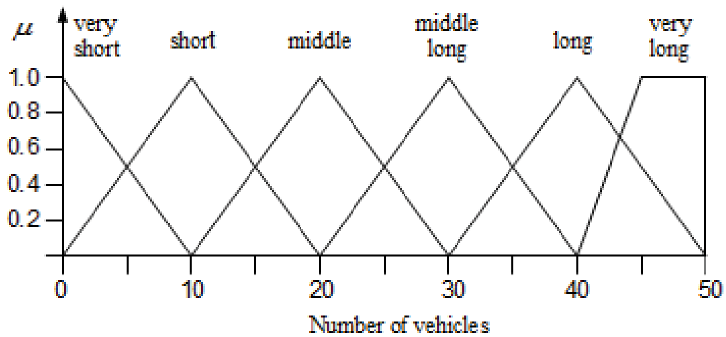

***Figure 4.8:** "Duration of green signal"*

4.2.4 Creating algorithm within process of fuzzy inference

The entire system of fuzzy inference is implied in the block (base) of rules. The situation for which rules are planned is described by the entry part of rules and the response of the fuzzy logic system on a given situation is described by the outcome. The weights[8] that are giving larger or smaller meaning to individual rules are associated to rules. In our case, all rules are equally weighted with a weight of 1, so they are equivalent.

We initiate the processing of rules with a procedure of aggregation. With this, we use an operator minimum as a generality of the linguistic conjunction AND. The implication is using general multiplication, and in this case at accumulation we used an operator maximum.

[8] In the program fuzzyTech, weights are appointed DoS (Degree of Support)

The goal and output of our model is continuous traffic, which means the least possible number of waiting vehicles at the crossroad and the least possible number of stoppings. We enter logic into a system of rules that is predictable in such case: if a small number of vehicles approaches a green signal, the duration of the green light should be short, if a middle number of vehicles are approaching, the duration should be middle or middle long, if many vehicles are approaching, the duration should be long or very long.

For input variables, we defined three possible conditions and with these, 81 theoretical rules (3×3×3×3). We selected only 49 rules, by which we could describe actual situations of activity within the crossroad. In Table 4.1, we list some of these rules.

Table 4.1: *Some rules for calculation of the duration of the green light*

	IF				THEN	
#	*"South"*	*"north"*	*"east"*	*"west"*	DoS	*"time"*
1	small	small	small	small	1	short
25	middle	middle	middle	middle	1	middle long
27	middle	middle	many	middle	1	long
29	middle	many	small	small	1	middle long
49	many	many	many	many	1	Very long

4.2.5 Defuzzification

Fuzzy output variables are changed into sharp numerical values in the procedure called defuzzification. As already mentioned, there are many methods of defuzzification that generally give various results. In our example, we used the "Centre of maximum" method that calculates the weighted average of maximums that belongs to individual membership functions, Ross[14].

$$Y = \frac{\sum i \left(\mu_{RESULT,i} \times Y_i \right)}{\sum i \, \mu_{RESULT,i}}; \qquad (4.01)$$

μ_i - membership of element to individual fuzzy value

y_i - middle of maximum for each fuzzy value

4.3 Numerical example

4.3.1 The duration of green light on Road B

On Road B, 10 vehicles from southern side of crossroad crossed and from northern side 15. On Road A on eastern side on a red light, three vehicles waited and one on the western side. Using the membership functions of input variables, we have:

- *"South"* (Figure 4.04) is 10 *middle* vehicles with membership degree 1.
- *"North"* (Figure 4.05) is 15 *many* vehicles with membership degree 0.8.
- *"East"* (Figure 4.06) is 3 *small* vehicles with membership degree 1.
- *"West"* (Figure 4.07) is 1 *small* vehicle with membership degree 1.

We can define membership degree to an individual fuzzy set in different ways. The simplest is certainly to read the degree from graph, but it is not most reliable. More accurate are numerical calculations and especially the use of a suitable software tool, such as the program FuzzyTech.
Let us consider how we obtained the membership degree 0.8 for input variable "*North.*"

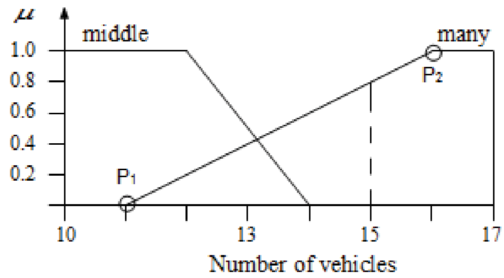

Figure 4.9: *Membership degrees to fuzzy sets for input variable "North"*

As we have already demonstrated in Figures 4.04-4.08, the variables "North" and "South" can obtain values up to 20 vehicles in each direction per cycle. If approximately seven vehicles approach the traffic light, this means something "small." If roughly five to 15 vehicles are approaching, we have tasks with at something like a "middle" level. And if more than 12 vehicles are approaching, we may say that we are dealing with the fuzzy number "many."
As we can observe from Figure 4.09, the number 15 means the middle number of vehicles with membership degree zero and many number of vehicles with membership degree 0.8. However, to claim with certainty that this degree is really 0.8, we have to confirm it analytically.

Two non vertical points are determining precisely one straight line with equation $y = kx + n$. Through points P_1 (11, 0) and P_2 (16, 1) on figure (4.09) passes the straight line $y = \frac{1}{5}x - \frac{11}{5}$, from which we derive for $x = 15$ the value $y = 0.8$.

In the fuzzification procedure of sharp numbers, we obtained that from "South" approaches a *middle* number of vehicles with membership degree 1, from "North" *many* vehicles with member

ship degree 0.8, from "East" a *small* number of vehicles with membership degree 1 and from "West" a *small* number of vehicles with membership degree 1. To these data, Rule Number 29 is corresponding, which says: IF the number of vehicle from "South" is *middle* AND from "North" *many* AND from "East" *small* AND from "West" *small* THEN the duration of the green light should be *middle long*.

The rules within this case are derived from the input conjunction AND that gives special feature to individual rules and represents the intersection of fuzzy sets. The intersection of two fuzzy sets is defined with the following, Ross, [14]:

$$\mu_{A \cap B}(x) = \min\left\{\mu_A(x), \mu_B(x)\right\} \tag{4.02}$$

The concrete result of the fuzzy inference is:

$$\mu_{N \cap S \cap E \cap W}(x) = \min\left\{0.8, 1, 1, 1\right\} = 0.8; \tag{4.03}$$

Where N, S, E, W describe the input variables "North," "South," "East," and "West." According to (4.03), the duration of the green light should be middle long with membership degree 0.8. With the CoM method, considering the membership functions, we obtain:

$$Y = \frac{30 \times 0.8}{0.8} = 30 \tag{4.04}$$

The duration of the green light on Road B should be 30 seconds. This value equals the present value of the duration of the green signal. This value is also optimal, because Road B is empty at this time. Problems occurred when more than 15 vehicles from one direction wanted to cross the intersection; in particular, if many of them were turning left.

4.3.2 Length time of green light on road A

On Road A: from the eastern side of the crossroad, 30 vehicles are transported and 19 from western side. Road B has on the southern side at a red light waited 10 vehicles and on the northern side 11. Using the membership functions of input variables we have:

- "South" (Figure 4.04) is 10 middle vehicles with membership degree 1.
- "North" (Figure 4.05) is 11 middle vehicles with membership degree 1.
- "East" (Figure 4.06) is 30 many vehicles with membership degree 0.4 and middle vehicles with membership degree 0.5.
- "West" (Figure 4.07) is 19 small vehicles with membership degree 1.

Let us see how we have obtained the membership degrees to fuzzy numbers for the input variable "*East*" in case of such information.

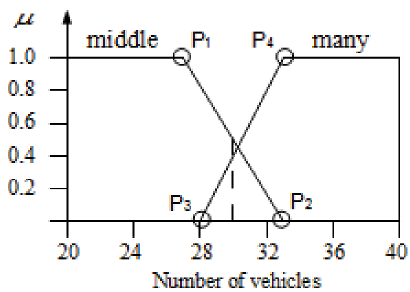

Figure 4.10: *Membership degrees to fuzzy sets for input variable "East"*

First, let us calculate the membership degree for the *middle* number of vehicles. From Figure 4.10, we can notice that through points P_1 (27, 1) and P_2 (33, 0) passes the straight line $y = -\frac{1}{6}x + \frac{33}{6}$, from which we derive for $x = 30$ the value $y = 0.5$.

For *many* vehicles we can notice from Figure 4.10 that through points P_3 (28, 0) and P_4 (33, 1) passes the straight line $y = \frac{1}{5}x - \frac{28}{5}$, from which we derive for $x = 30$ the value $y = 0.4$.

The result of fuzzification says that from "South" approaches a *middle* number of vehicles with membership degree 1, from "North" *middle* with membership degree 1, from "East" *many* with

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membership degree 0.4 and *middle* with membership degree 0.5 and from “West” *middle* with membership degree 1. These data corresponds to rules numbers 25 and 27.

Rule number 25: IF the number of vehicle from “South” is *middle* AND from “North” *middle* AND from “East” *middle* AND from “West” *middle* THEN the duration of the green light should be *middle long*.

Rule number 27: IF the number of vehicle from “South” is *middle* AND from “North” *middle* AND from “East” *many* AND from “West” *middle* THEN the duration of the green light should be *long*.

According to Equation 4.03, we obtain the following results of fuzzy inference:

$$\begin{aligned} &\text{Rule number 25:} \quad \mu_{N\cap S\cap E\cap W}(x) = \min\{1, 1, 0.5, 1\} = 0.5 \\ &\text{Rule number 27:} \quad \mu_{N\cap S\cap E\cap W}(x) = \min\{1, 1, 0.4, 1\} = 0.4 \end{aligned} \tag{4.05}$$

So, the duration of the green light should be *middle long* with a membership degree of 0.5 and *long* with a membership degree of 0.4. With the CoM method, considering the membership functions, we obtain:

$$Y = \frac{30\times 0.5 + 40\times 0.4}{0.5+0.4} = 34.444 \tag{4.06}$$

The duration of the green light on Road A should be 35 seconds long. This value is optimal, because Road A has mostly emptied in 30 seconds and within the remaining time only a few vehicles crossed this intersection.

The duration of the first cycle would thus amount 69 seconds, if we also add 4 seconds for yellow signals. With this, we would achieve a quicker turning of cycles and consecutively less congestion.

4.4 Optimization

When the system structure is set and all elements of the system are defined, the model must also be tested and checked for its fit to data and for producing the desired results. However, in our case we have tasks with relatively simple optimization, because we have limited the problem to concrete conditions. We simplified the system enough that it is well defined and gives the desired results.

At optimization, we are verifying the entire definition area of input data. This is four-dimensional space $D_N*D_S*D_E*D_W$, where D_N, D_S, D_E and D_W are by queue definition areas of variables North, South, East, West.

For each point of the definition area, we check whether the system is giving the desired result and if this result is logical. If we are not satisfied with the results, we can change any of the membership functions or any of fuzzy inference rules.

Graphic tools can also demonstrate system activity. Such a graphic demonstration immediately shows us the response to a change of data or change in definition of the system elements. The system optimises the method of trials and errors (removing the mistakes).

Figures 4.11 and 4.12 demonstrate system imaging in three-dimensional space, with the program FuzzyTECH. In Figure 4.11, the situation on Road B is presented. We have calculated that this road requires 30 seconds of green light in order to empty the roadways from south and north. In Figure 4.12, the situation on Road A is presented. We have calculated that 35 seconds of green light signal is required in order to empty the east and west roadways. From both figures we can obtain that calculated times are optimal and that all vehicles will manage to leave the intersection until last second of the green signal.

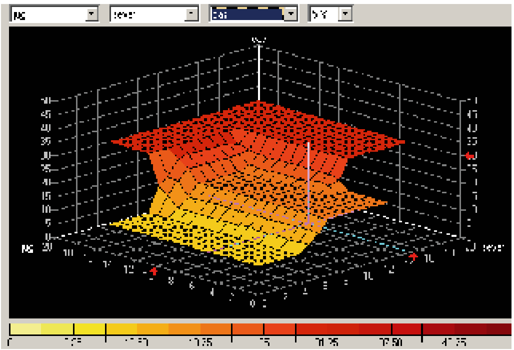

Figure 4.11: *Road B, Source: FuzzyTech 5.54d*

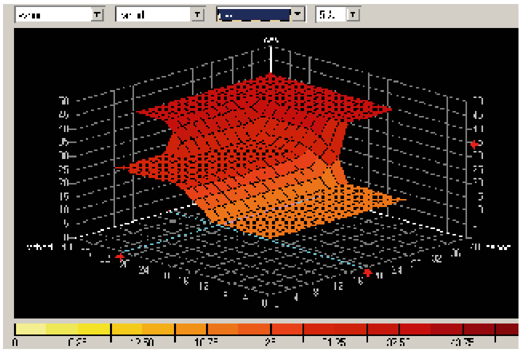

Figure 4.12: *Road A, Source: FuzzyTech 5.54d*

4.5 Results

We tested the acquired model with the help of simple simulation in the program Microsoft Excel. We used the information gathered with the help of a camera and collected data from Directorate of the Republic Slovenia for Roads.

In Table 4.02 we see the initial zero cycle, because for the duration of the first green light on Road A there are a significant number of vehicles that are waiting for this green signal. We have calculated the green light duration for Road B by considering all vehicles passing through this green light on one side and vehicles waiting on Road A on the red light on the other side. We have also calculated the green light duration for Road A by considering all vehicles passing through this green light on one side and vehicles waiting on Road A on the red light on the other side.

Table 4.02: *Activity simulation of fuzzy logic model*

	Road B				Road A			
cycle #	Signal	South	North	Time	signal	East	West	Time
0	RS GS				GS RS	3 W	1 W	
1	RS GS	10 W	11 W 4 A	30s	GS RS	27 A 1 W	18 A 1 W	35s
2	RS GS	8 W 2 A	12 W 2 A	30s	GS RS	38 A 3 W	24 A 3 W	40s
3	RS GS	3 W 3 A	6 W 4 A	20s	GS RS	19 A 4 W	19 A 3 W	30s
4	RS GS	10 W 5 A	7 W 6 A	26s	GS RS	23 A 3 W	25 A 1 W	36s
5	RS GS	7 W	8 W 3 A	20s	GS RS	18 A 5 W	20 A 5 W	30s
6	RS GS	7 W	12 W 2 A	30s	GS RS	18 A 9 W	23 A 8 W	36s
7	RS GS	8 W 3 A	14 W 3 A	30s	GS RS	30 A 5 W	13 A 6 W	40s
8	RS GS	2 W 2 A	12 W	20s	GS RS	24 A 6 W	31 A 3 W	33s
9	RS GS	10 W 1 A	5 W 4 A	20s	GS RS	13 A 5 W	14 A 2 W	30s
10	RS GS	10 W	8 W 3 A	20s	GS RS	24 A 3 W	19 A 1 W	33s

Legend:

W – vehicles that are waiting on a red light

A – vehicles that are approaching to green signal

RS – red signal

GS – green signal

South – number of vehicles from southern side

North – number of vehicles from northern side

East – number of vehicles from eastern side

West – number of vehicles from western side

Time – the duration of the green light on individual road

We must add the four-second duration of yellow signals to the duration of the green signal, i.e. one second at the overlap from a green to a red light and three seconds at the overlap from red to a green light. The average duration of one cycle, in measured ten cycles, amounts 63 seconds, which is 37 seconds less than the present duration of a cycle. This means that instead of two so long cycles as we have now, we could have three. The traffic would be faster and larger congestions would not be occurring. In Table 4.02, we are dealing with values smaller in at least 20 percent of the cases, because some vehicles, which are waiting for green light 20 seconds or more, could pass the crossroad in the previous cycle. The fuzzy approach in controlling traffic signalization works precisely with shorter cycles, which is also bringing advantages to pedestrians, because the possibility of safely crossing the road is greater.

4.5.1 Energy efficiency of the model

Through the examined crossroad, 34,654 vehicles passed (on 13.1.2005) from 5am to 9pm. From crossroad analysis and from Table 4.02, we observe that about 30 % of vehicles did not have to stop at the traffic light; the remaining 70% (24,257 vehicles) had to stop at the traffic lights.

The waiting times of vehicles are quite variable. Some of the vehicles needed to wait just a few seconds, while others waited 30 seconds. Within our analysis, let us assume an average waiting time of 5 seconds, which is definitely the lower limit based on our observations.

All vehicles that had to stop at a traffic light because of a red light, in total spent 33.69 hours (24257 vehicles$\cdot 5s$).

Let us also look at these eventual time savings from aspect of fuel consumption. Each of waiting vehicles need to stop on a traffic light and after stopping had to again drive off. Personal vehicles use between one and two litres of fuel per hour when idling, but other vehicles (lorries, buses) use much more. We selected a minimal consumption of 1.7 litters of fuel per hour.

The amount of used fuel at driving off (departing) strongly varies and is especially dependent of engine type, driving styles, etc. From this, we chose for consumption at driving off an average of middle range of vehicles, which current consumption at driving off is 30-40 *l*/100*km*. We have round this value a bit upward, because we must not forget heavier vehicles. So an average consumption at driving off was taken to be about 0.0004 *l/m* for all vehicles.

The way that a vehicle passes at accelerating from 0-50 *km/h* in average equals 30 *m*. This means that each vehicle that must stop at a traffic light at driving off on average uses 0.012 *l* of fuel (30 *m* * 0.004 *l/m*). If we add up to this also 0.0024 *l* that vehicle uses while driving, we get 0.14 *l* of used fuel for one vehicle on the 13th of January 2005.

On this crossroad on the afore-mentioned day, 24,257 vehicles stopped. This means that vehicles used 24,257*0.014 l = 339.598 l of fuel because of breaking and stopping. Within one year, if we do not consider weekends, this totals a surprising 339.598*250=84,899 l of fuel.

If we take, for example, that we have in Slovenia 100 such crossroads, this unnecessary consumption already rises to 84,899*100 = 8,489,900 *l* of fuel, which at current prices means more than nine million euros.

We want to emphasise that the above result of fuel consumption was obtained using the minimum values. Thus, the consumption may be even greater.

5 CONCLUSION

The fuzzy approach to controlling traffic signalization is increasingly used, but this area is still heavily debated, especially because of some incorrect perceptions. Fuzzy logic is appropriate, because a combination of expert knowledge and verbal communication enables the proper setup of a system that imitates the human strategy of controlling.

In this article, we have described a fuzzy system whose base of linguistic variables and rules forms a suitable output value of traffic controller. The fuzzy controller system is based upon a fuzzy base of rules that changes according to traffic situations. For the construction of a fuzzy system and for specifying the rules, an expert knowledge that system could imitate human decision making is required.

On a crossroad in Maribor we presented the possibility of controlling traffic signalization and we have obtained solutions that are much better than existing ones. When planning fuzzy controlling, we have limited ourselves on four input variables and one output linguistic variable. In spite of a quite simple system, the structure results are more than adequate.

The fuzzy approach in controlling traffic signalization is enabling smaller delays within traffic, fewer vehicles stopping on crossroads and consequently lower fuel consumption. A fuzzy controller is much more effective than all others with regards to all three main goals of controlling signalization: minimum delays, maximum security and minimal negative consequences for the environment. It is also important that fuzzy logic systems are more transparent than classic ones (which mean easier maintenance).

References

[1] **Davol, P.A.:** Modelling of traffic signal control and transit signal priority strategies in a microscopic simulation laboratory; Master's thesis in transportation. Massachusetts: Massachusetts Institute of Technology, 2001.

[2] **Cheng, D., Messer, C.J., Tian, Z.Z., Liu, J.:** Modification of Webster's minimum delay cycle length equation based on HMC 2000. Texas A&M University; 2000. Paper submitted to the transport research board for presentation and publication at the 2003 – Annual meeting in Washington, D.C.

[3] **FHWA:** Signal timing on a shoestring. Washington: Federal Highway Administration, 2006. [URL: *http://ops.fhwa.dot.gov/publications/signal_timing/03.htm*]

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[4] **Niittymäki, J.:** Fuzzy Traffic Signal Control – Principles and Applications. Doctoral Thesis. Helsinki: Helsinki University of Technology, 2002.

[5] Dunn Engineering Associates In association with Siemens Intelligent Transportation Systems: Traffic control systems handbook. Washington: Federal Highway Administration, 2005.

[6] **Malej, A.:** Samoučeče upravljanje za učinkovito mestno prometno signalizacijo; Doktorska disertacija. Ljubljana: Ekonomska fakulteta, 2007.

[7] **Zimmermann, H.:** Fuzzy Set Theory and its Applications. Boston: Kluver Academic Publishers, 1996.

[8] **Usenik, J.:** Mehka logika in Nevronske mreže; Gradivo v virtualnem učnem okolju. Celje, Krško: Fakulteta za logistiko, 2008a. [URL: http://estudij.fl.uni-mb.si/file.php/50/gradiva/mehka_logika.pdf] [URL: http://estudij.fl.uni-mb.si/file.php/50/gradiva/NEVRO_01.pdf]

[9] **Zadeh, L. A.:** Fuzzy Sets. Information and Control, Vol. 8, 1965.

[10] **Usenik, J.:** Fuzzy approach in process of multiple-attribute decision making, JET Journal of Energy Technology, Volume 1 (2008b), p.p. 43-58.

[11] **Teodorović, D., Vukadinović, K.:** Traffic Control and Transport Planning – A Fuzzy Sets and Neural Networks Approach. Boston: Kluver Academic Publishers, 1998.

[12] **Niittymäki, J., Könönen, V.:** Traffic Signal Controller Based on Fuzzy Logic. SMC2000 Conference Proceedings, 2000 IEEE International Conference on Systems, Man & Cybernetics. Nashville, Tennessee: IEEE, 2000.

[13] Laboratory of Transportation Engineering: [URL: http://www.tkk.fi/Units/Transportation/ITS/ENG/fusico.html].Helsinki: University of Technology. 23.09.2009.

[14] **Ross, J., T.:** Fuzzy logic with engineering applications, 2nd edition, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, England, 2004, reprinted 2005, 2007.

[15] **Šafarič, R., Rojko, A.:** Inteligentne regulacijske tehnike v mehatroniki. Maribor: Tehniške fakultete, Fakulteta za elektrotehniko, računalništvo in informatiko, 2007.

[16] **Virant, J.:** Uporaba mehke logike v sodobnih sistemih. Ljubljana [i.e.] Radovljica: Didakta, 1992.

[17] **Ruspini, H.E., Bonissone, P.P., Pedrycz, W.** (Editors in Chief): Handbook of Fuzzy Computation, Institute of Physics, Publishing, Dirac House, Temple Back, Bristol, UK, 1998.

[18] Google maps, 2009: [URL: http://maps.google.com/]. 13.10.2009.

[19] fuzzyTECH 5.54d Professional Edition. Inform Software Corporation.

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THERMOPHYSICAL PROPERTIES OF REFRIGERANTS - THEORETICAL CALCULATIONS IN COMPARISON WITH DATA FROM DYNAMIC LIGHT SCATTERING (DLS)

TERMOFIZIKALNE LASTNOSTI HLADIL- TEORETIČNI IZRAČUN V PRIMERJAVI Z LASERSKIMI METODAMI

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Abstract

Currently, the use of refrigeration mixtures is rapidly increasing. This paper features a mathematical model of computing the velocity of sound, thermal diffusivity and viscosity of the boiling liquid and the saturated vapour of pure HFC refrigerants R134a, R 125, R143a, R32, and R152a. The model contains all important molecular contributions (translation, rotation, internal rotation, vibration, intermolecular potential energy, and the influence of electron and nuclei excitation). The constants necessary for the computation like the characteristic temperatures of rotation, electronic state etc. and the inertia moments are obtained analytically by applying the knowledge of the atomic structure of the molecule. The vibration constants are obtained using

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a modified Urey-Bradley force field. We simultaneously developed a mathematical model for the calculation of the thermodynamic properties for HFC mixtures, e.g., for the binary azeotropic mixture R507 (50 % R125, 50 % R134a), the binary zeotropic mixture R410A (50 % R32, 50 % R125), and for the ternary zeotropic mixture R404A (44 % R125, 52 % R143a, 4 % R134a) with the help of classical and statistical, equilibrium and non-equilibrium thermodynamics.

There are several methods for computing the influence of anisotropic potentials. In this paper, the Lucas-Gubbins model was used, which yields favourable results in practical computations for a large number of components and within a relatively wide range of densities and temperatures. We consider rigid nonlinear molecules with the assumption that all anisotropic interactions are scalars. The multipole expansion is terminated at the octopole term. Intermolecular repulsion interaction is modelled by the Lennard-Jones r^{-12} law. The induction interactions are formulated with the isotropic polarizibility approximation. Intermolecular interactions are limited to the third-order term, cross terms between intermolecular interactions are not considered. In this paper, models will be presented obtained on basis of the pure theory (hard sphere, Lennard-Jones etc.) from the Chapman-Enskog theory and as well as on the basis of the background functions for transport properties for pure fluids. These functions are presented as sums of the form for the temperature-dependent dilute gas contributions and the terms for the temperature and density dependent excess contributions. The analytical results obtained with non-equilibrium statistical thermodynamics are compared with experimental data and empirical equations on the basis of experimental results. The analytical results for the viscosity are again compared with the experimental data obtained with dynamic light scattering and the agreement found was very good.

Povzetek

Uporaba zmesi različnih hladilnih snovi skokovito napreduje.Tako lahko danes hladilne zmesi uporabljamo na področju hlajenja, toplotnih črpalk, solarne tehnike in klimatizacije. Prav zato inženirji in projektanti hladilnih naprav potrebujejo računalniške programe kjer ahko izračunajo termofizikalne lastnosti poljubnih zmesi hladil. Članek obravnava matematični model izračuna hitrosti zvoka, termićne difuzivnosti in viskoznosti zmesi hladil.

V članku so obravnavane čiste hladilne snovi R134a, R 125, R143a, R32, and R152a. Matematični model obravnava vse prispevke kot so na primer translacija molekul, rotacija molekul, notranja rotacija atomov v molekuli, vibracija atomov, modmolekulkarne sile…. Zelo pomemben je vpliv medmolekularnih sil, v tan amen smo posplošili Lucas-Gubbinsov model. Vse potrebne konstante za izračun so izračunane analitično. Prav tako so v članku obravnavane zmesi kot je na primer azeotropska zmes R507 (50 % R125, 50 % R134a), binarna zeotropska zmes R410A (50 % R32, 50 % R125), in ternarna zeotropska zmes R404A (44 % R125, 52 % R143a, 4 % R134a) na osnovi klasične in statistične termodinamike. Prav tako lahko z omenjenim modelom izračunamo termodinamične lastnosti hladil poljubnih zmesi.

Analitični rezultati so primerjani z eksperimentalnimi rezultati dobljeni na osnovi laserske DLS (Dynamic-Light Scattering) metode. Laserska DLS metoda je najnatančnejša eksperimentalna metoda za termodinamične veličine. Primerjava rezultatov kaže na zelo dobro ujemanje rezultatov.

1 INTRODUCTION

Dynamic light scattering (DLS) is a unique diagnostic tool for the determination of a variety of thermophysical properties of fluids, using an essentially identical experimental setup. In contrast to conventional methods, most of which work with macroscopic gradients according to the desired quantities, DLS provides information on the thermophysical properties of fluids in macroscopic thermodynamic equilibrium. In the following, only some general aspects of the underlying theory of DLS from bulk fluids and the application of this method to fluid surfaces are discussed. For a detailed and comprehensive description, the reader is referred to specialized literature [1,2].

In binary fluid mixtures, thermal diffusivity and mutual diffusivity can essentially be determined simultaneously from the linewidth of the Rayleigh line, governed by microscopic fluctuations of temperature and concentration. Whether it is possible to determine signals simultaneously from concentration and temperature fluctuations is mainly governed by the relative difference of the refraction indices of the mixture components and their concentration. For the refrigerant mixtures studied in this paper, the refractive indices of the pure components have comparable values [3,4,5] so that from the Rayleigh component of scattered light a signal from only temperature fluctuations associated with thermal diffusivity can be resolved. Additionally, information about sound velocity and sound attenuation can be obtained from the Brillouin lines of the spectrum, which are shifted in frequency with respect to the incidental light and which are caused by pressure fluctuations. Information about surface tension and kinematic viscosity can be derived from light scattering by surface waves, which are caused by the thermal movement of molecules, resulting in so-called ripplons.

The optical and electro-optical parts of the experimental setup used for the determination of sound velocity are shown (in a top view) on the left side of Fig. 1. For performing light scattering from bulk fluids, the scattering volume, which is determined by the intersection of the incident beam and the axis of observation (dashed line), is located in the middle of the vessel. The principle of the scattering geometry that allows scattering by surface waves is shown schematically (in a front view) on the right side of Fig. 1. In this case, the detected scattering volume is located at the interface between the liquid and vapour phase under saturation conditions. The basic modification of the setup on the left side of Fig. 1 for the realization of surface light scattering experiments was to mount the pressure vessel in a vertical position.

As a light source, either an argon ion laser (λ_0 = 488 nm) or a frequency-doubled continuous wave Nd:YVO_4-laser (λ_0 = 532 nm) were used. The laser-power was up to 300 mW when working far from the critical point, and only a few mW in the critical region. For the determination of sound velocity, a reference beam shifted in frequency by an opto-acoustic modulator was added to the scattered light. Scattered light was detected by two photo-multiplier tubes (PMTs), and the cross-correlation function was calculated with a digital correlator. A more detailed description of the experimental setup can be found in [6].

According to the analysis of the manufacturer (Solvay Fluor und Derivate GmbH, Hannover), the refrigerant samples used had a purity of 99.7 % for R125, 99.98 % for R134a, and 99.99 % for R143a. According to the specifications of the manufacturer, the refrigerant mixtures had a minimum purity of 99.5%. The uncertainty in the composition for the binary mixture R507 is certified for each component within ± 1% wt. For the ternary mixture R404A, the uncertainties in the composition are ± 2 % wt. for R125, ± 1 % wt. for R143a, and ± 2 % wt. for R134a. All refrigerant samples were used without further purification.

The samples were filledinto an evacuated cylindrical pressure vessel (volume ≈ 10 cm^3) from the liquid phase to avoid decomposition, which is relevant in particular for the refrigerant R404A, which represents a near-azeotropic mixture. The temperature of the pressure vessel, which is placed inside an insulated housing, is regulated through resistance heating and measured by calibrated 25-Ω or 100-Ω platinum resistance probes with an uncertainty of ± 0.015 K. The temperature stability was better than ± 0.002 K during one experimental run. For each temperature point, typically six measurements at different angles of incidence were performed. For temperatures below room temperature, the insulating housing was cooled to about 10 K below the desired temperature in the sample cell with a lab thermostat.

With the experimental setup, the saturated vapour sound velocities of the binary and ternary mixtures, R507 and R404A respectively, have been determined with an overall uncertainty smaller than ± 0.5 % [7]. With the exception of the region closer to the critical point, the total uncertainty of the liquid kinematic viscosity data is estimated to be better than ± 1 % for all refrigerant samples [8].

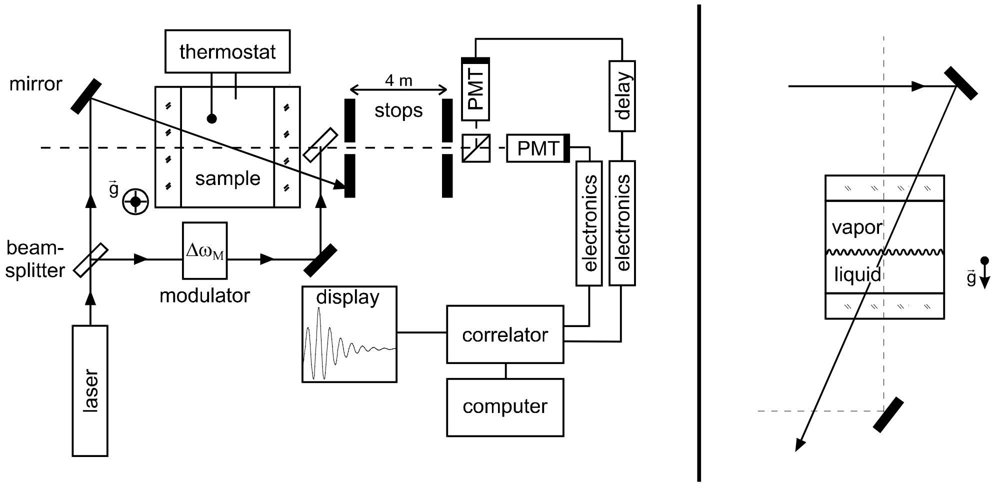

Figure 1: *Experimental Setup: Optical and Electronic Arrangement*

2 COMPUTATION OF THERMODYNAMIC PROPERTIES OF THE STATE

To calculate thermodynamic functions of state, we applied the canonical partition function [13]. Utilising the semi-classical formulation for the purpose of the canonical ensemble for the N indistinguishable molecules the partition function Z can be expressed as follows:

$$Z = \frac{1}{N!h^{Nf}} \int .. \int \exp\left(-\frac{H}{kT}\right) \cdot d\vec{r}_1 d\vec{r}_2 .. d\vec{r}_N d\vec{p}_1 d\vec{p}_2 .. d\vec{p}_N \tag{2.1}$$

where f stands for the number of degrees of freedom of an individual molecule, H designates the Hamiltonian molecule system, vectors $\vec{r}_1, \vec{r}_2 .. \vec{r}_N$ describe the positions of N molecules and $\vec{p}_1, \vec{p}_2 ... \vec{p}_N$ momenta, k is the Boltzmann`s constant and h is the Planck`s constant. The canonical ensemble of partition function for the system of N molecules can be expressed by:

$$Z = Z_0 Z_{trans} Z_{vib} Z_{rot} Z_{ir} Z_{el} Z_{nuc} Z_{conf} \tag{2.2}$$

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 intermolecular potential energy (conf).

Utilising the canonical theory for computing the thermodynamic properties of the state, these can be calculated in the following way [13]:

Pressure $p = kT\left(\frac{\partial \ln Z}{\partial V}\right)_T$,

Internal energy $U = kT^2\left(\frac{\partial \ln Z}{\partial T}\right)_V$,

Free energy $A = -kT \cdot \ln Z$, Entropy $S = k\left[\ln Z + T\left(\frac{\partial \ln Z}{\partial T}\right)_V\right]$, (2.3)

Free enthalpy $G = -kT\left[\ln Z - V\left(\frac{\partial \ln Z}{\partial T}\right)_V\right]$,

Enthalpy $H = kT\left[T\left(\frac{\partial \ln Z}{\partial T}\right)_V + V\left(\frac{\partial \ln Z}{\partial V}\right)_T\right]$,

where T is the temperature and V is the volume of the molecular system. Except for the configurational integral, the computation of the individual terms of the partition function and their derivatives is given in the works of Lucas [13]; Gray and Gubbins [15], and McClelland [14].

In this paper, our interest is focused on the calculation of speed of sound. The speed of sound refers to the speed of the mechanical longitudinal pressure waves propagating through a medium. It is a very important parameter in the study of compressible fluid flows and in other applications (acoustic resonance level gauge).

The propagation of sonic waves for real fluids is almost in all cases nearly isentropic. Therefore, we can calculate the isentropic speed of sound for a real fluid c_0:

$$c_0 = \sqrt{-V^2\left(\frac{\partial P}{\partial V}\right)_{S,\psi} \frac{1}{M}}, \tag{2.4}$$

where *M* is the molecular mass, *S* is the entropy and ψ is the molar concentration.

INTERMOLECULAR FORCES

Molecules are composed of positive and negative charges. According to Coulomb's law of electrostatics, the charges interact, and the interaction energy between the molecules in the system is called intermolecular energy. Hence, we say that intermolecular forces are of electrostatic nature.

The analytical computation of intermolecular potential is extremely complex [16-20]. As far as certain simple systems are concerned, the problem is can be solved, although the equations thus obtained are highly complicated. This is why further analytical solutions of a configuration integral are exceptionally difficult. In general, the assumption for the sum of repulsive (rep) and attractive (att) force is sufficiently accurate. If the intermolecular potential is denoted by u, then the equation below can be written as:

$$u = u_{rep} + u_{att} \tag{2.5}$$

The occurrence of the **repulsive force** is associated with the Pauli exclusion principle. If two molecules approach one another within a very short distance, so that the electronic clouds of both molecules begin to coincide, certain electrons in the molecule have to move to higher energy levels due to the exclusion principle, made possible only through the supply of sufficient energies, resulting in the occurrence of the repulsive force.

Intermolecular potential

Attractive intermolecular potential consists in general of three parts:

a. *Multipole- or electrostatic force potential*, which occurs due to the manifestation of static permanent dipole, quadrupole and multipole moments or asymmetrical distribution of the charge in molecules. In this case, the summation of Coulomb's interactions between positively charged nuclei and negatively charged electrons of a certain molecule with the adequate charges of another molecule gives (in general) a certain value of intermolecular energy. The interactions between molecules possessing multipole moments result in attractive forces, which are dependent on the orientation of molecules in space. The distribution of charges can generally be described or denoted by multipole molecule moments. Fig. 2 illustrates some of the lowest rates. A neutral atom with a negative cloud centre of gravity coinciding with the centre of gravity of a positive nucleus has a zero dipole moment. The first rate of multipole moments is called the **dipole moment** and is created if the centres of gravity of positive and negative charges fail to coincide. It is represented by a partial positive and negative moment δ at a certain distance r, which creates the moment rδ. In many cases, the molecules have no dipole moments due to the symmetry of charges. Nevertheless, they can have even higher rates of multipole moments, such as quadrupole and octopole moments.

In general, multipole moments can be written as tensors in the Cartesian coordinate system [13]:

Molecule charge: $q = \int \rho \cdot d\vec{r}$

Dipole: $\mu_\alpha = \int \rho\alpha \cdot d\vec{r}$

Quadrupole: $\theta_{\alpha\beta} = \frac{1}{2}\int \rho\left(3\alpha\beta - r^2\delta_{\alpha\beta}\right)d\vec{r}$ (2.6)

Octopole:

$$\Omega_{\alpha\beta\gamma} = \frac{1}{2}\int \rho\left[5\alpha\beta\gamma - r^2\left(\alpha\delta_{\beta\gamma} + \beta\delta_{\gamma\alpha} + \gamma\delta_{\alpha\beta}\right)\right]d\vec{r}$$

$\delta_{\alpha\beta} = 1, \text{if } \alpha = \beta; \ \delta_{\alpha\beta} = 0, \text{if } \alpha \neq \beta$.

Higher rates may be defined as well, but they are rarely used in calculations.

b. ***Induction force potential*****.** The neutral atom with the negative electron cloud centre of gravity coinciding with the centre of gravity of the positive nucleus has no dipole moment. If, for example, such an atom is approached by another atom with the dipole moment, the dipole moment $\vec{\mu}_{ind}$ is induced in it, proportional to the electric field of the dipole moment $\vec{E}$:

$$\vec{\mu}_{ind} = \alpha\vec{E}\ . \tag{2.7}$$

The described phenomenon is called polarization. The constant α is called the polarization constant. The polarization effect occurs also when two molecules with multipole moments approach one another (Fig. 3).

In general, the polarization constant in the system of molecules with multipole moments is a tensor [16-18]. The analytical calculation of tensor components of the polarization constant is very complex. In practical computations, we usually satisfy ourselves by the mean polarization constant:

$$\alpha = \frac{1}{3}\left(\alpha_{xx} + \alpha_{yy} + \alpha_{zz}\right). \tag{2.8}$$

The electrostatic and inductive potentials occur in cases of polar molecules, where the potential energy is not dependent on the distance only, but on the influence of the orientation of molecule in space.

c. ***Dispersion force potential*** occurs both in polar and nonpolar molecules. It results from time-varying dipole moments. In most cases, the potential of dispersion forces represents the most important element. In general, an example of nonpolar molecules can be expressed by the following relation:

$$u_{disp} = \frac{C_1}{r^6} + \frac{C_2}{r^8} + \frac{C_3}{r^9} \tag{2.9}$$

Table 3 and Fig. 4 illustrate the influence of multipole, dispersion, inductive and repulsive forces on thermodynamic properties of the state at the intermolecular distance r. Table 3 is especially

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interesting as it shows the impact of multipole, inductive and dispersion forces, varying considerably with different molecules of coolants. The influence of multipole forces is the highest with water as the coolant medium (R 718), representing even today one of the major problems in calculating the thermodynamic functions of state.

In general, one may establish the following:

1. The effect of inductive forces is very low in almost all cases. With certain high-polar molecules, however, the effect of multipolar forces very often equals the magnitude rate of the dispersion forces.
2. The computation of thermodynamic properties and state using isotropic potentials is sufficient for nonpolar and low-polar molecules.
3. For the computation of thermodynamic properties and the state of high-polar molecules, primarily in the area of liquids, the theory of anisotropic potentials must to be taken into consideration.

INFLUENCE OF LENNARD-JONES INTERMOLECULAR POTENTIAL

a) Johnson-Zollweg-Gubbins (JZG) model [21]

For a real fluid, the Johnson-Zollweg-Gubbins (1993) model based on molecular dynamic and Monte Carlo simulations with the Lennard-Jones intermolecular potential can be used. The MBWR EOS contains 32 linear parameters (x_i) and one non-linear parameter (γ) (see Table 4).

On this basis [21,17], we can express configurational free energy A_{conf}:

$$A_{conf}^{*} = \sum_{i=1}^{8} \frac{a_i \rho^{*i}}{i} + \sum_{i=1}^{6} b_i G_i \ , \qquad (2.10)$$

where the coefficients a_i, b_i and G_i are presented in Table 1. The coefficients a_i and b_i are solely functions of the reduced temperature T^*, the coefficients G_i are functions of the reduced density ρ^* and of the nonlinear adjustable parameter γ.

$$\rho^* = \frac{N\sigma^3}{V}, \qquad T^* = \frac{kT}{\varepsilon}, \qquad A_{conf}^{*} = \frac{A_{conf}}{N\varepsilon}$$

$$F = \exp\left(-\gamma \rho^{*2}\right) \qquad , \gamma=3$$

where A_{conf} is reduced configurational free energy, σ and ε are Lennard-Jones parameters.

Impact of anisotropic potentials on thermodynamic functions of state

There are several methods for computing the influence of anisotropic potentials [9-27]. In this paper, those models were used that yielded favourable results in practical computations for a large number of components and within a relatively wide range of densities and temperatures.

b) Lucas-Gubbins's model (LG) [13,14,28,33,34]

Lucas-Gubbins's model deals with the perturbation expansion around Lennard-Jones's intermolecular potential. The total intermolecular potential can be written as a sum of the Lennard-Jones's intermolecular potential (LJ) and the potential, which also takes into account the orientation of a molecule in space (p):

$$u_{12}(r_{12},\omega_1,\omega_2)=u_{12}^{LJ}(r_{12})+u_{12}^{p}(r_{12},\omega_1,\omega_2) \tag{2.11}$$

In Eq. (11), r_{12} s the distance of the centres of gravity between the molecules 1 and 2, ω_1 and ω_2 are orientations of both molecules in space, which may be expressed with Euler's angles ϕ,ϑ,χ. The reference part u^{LJ} can also be written as a certain mean intermolecular energy at the distance r_{12}:

$$u_{12}^{LJ}(r_{12})=\langle u_{12}(r_{12},\omega_1,\omega_2)\rangle_{\omega_1\omega_2}=\frac{\int u_{12}(r_{12},\omega_1,\omega_2)d\omega_1 d\omega_2}{\int d\omega_1 d\omega_2} \tag{2.12}$$

Now suppose that the sum of intermolecular potential energy is:

$$U_{conf}=\sum_{i<j}u_{ij}=\sum_{i<j}u_{ij}^{LJ}(r_{12})+\sum_{i<j}u_{ij}^{p}(r_{12},\omega_1,\omega_2) \tag{2.13}$$

Using the perturbation expansion around the reference potential, one can then write the configuration effect to the free energy as:

$$\frac{A_{conf}}{Nk_BT}=\frac{A^{LJ}}{Nk_BT}+\frac{A^{\lambda}}{Nk_BT}+\frac{A^{\lambda\lambda}}{Nk_BT}+\frac{A^{\lambda\lambda\lambda}}{Nk_BT} \tag{2.14}$$

The free energy of Lennard-Jones's fluid A^{LJ} was calculated using Johnson-Zolweg-Gubbins's (JZG) model [21].

We consider rigid nonlinear molecules with the assumption that all anisotropic interactions are scalars. The multipole expansion is terminated at the octopole term. Intermolecular repulsion interaction is modelled by Lennard-Jones r^{-12} law. The induction interaction is formulated in the isotropic polarizibility approximation. Intermolecular interactions are limited to the second-order term, cross terms between intermolecular interactions are not considered. The configurational free energy is then given by:

First order terms:

Inductive forces:

$$\left(A^{\lambda}\right)^{ind}=-4\pi N\rho\alpha\left(\mu^2\right)\frac{J(6)}{\sigma^3}-6\pi N\rho\alpha\left(\theta^2\right)\frac{J(8)}{\sigma^5} \tag{2.15}$$

Second order terms:

Multipole forces:

$$\left(A^{\lambda\lambda}\right)^{mult-mult}=\left(A(112)^{\lambda\lambda}\right)^{mult-mult}+2\left(A(123)^{\lambda\lambda}\right)^{mult-mult}+\left(A(224)^{\lambda\lambda}\right)^{mult-mult} \tag{2.16}$$

$$\left(A(112)^{\lambda\lambda}\right)^{mult-mult} = -\frac{2}{3}\frac{\pi N\rho}{k_B T}\frac{\mu^4}{\sigma^3}J(6) \tag{2.17}$$

$$\left(A(123)^{\lambda\lambda}\right)^{mult-mult} = -\frac{\pi N\rho}{k_B T}\frac{\mu^2\theta^2}{\sigma^5}J(8) \tag{2.18}$$

$$\left(A(224)^{\lambda\lambda}\right)^{mult-mult} = -\frac{14}{5}\frac{\pi N\rho}{k_B T}\frac{\theta^4}{\sigma^7}J(10) \tag{2.19}$$

If the intermolecular potential is restricted to the dipole-dipole term, Eq. (2.17) is the only contribution, while for quadrupolar (CO_2, C_2H_6, etc.) molecules; Eq. (2.19) is the only non-vanishing term. For tetrahedral molecules (CH_4, CCl_4, CF_4, etc.), the leading multipole term is the octopole-octopole and the corresponding contribution to free energy is:

$$\left(A(336)^{\lambda\lambda}\right)^{mult-mult} = -\frac{19008}{875}\frac{\pi N\rho}{k_B T}\frac{\Omega^4}{\sigma^{11}}J(14) \tag{2.20}$$

Dispersion forces

$$\left(A(202+022)^{\lambda\lambda}\right)^{disp-disp} = -\frac{32\pi N\rho}{5k_B T}\sigma^3\varepsilon^2\kappa^2 J(12) - \frac{16\pi^2 N\rho^2}{5k_B T}\varepsilon^2\sigma^6\kappa^2 L(662) \tag{2.21}$$

$$\left(A(224)^{\lambda\lambda}\right)^{disp-disp} = -\frac{10368\pi N\rho}{875k_B T}\sigma^3\varepsilon^2\kappa^4 J(12) \tag{2.22}$$

Third order terms:

$$\left(A_A{}^{\lambda\lambda}\right)^{mult-mult-mult} = 3\left(A_A(112;112,224)^{\lambda\lambda\lambda}\right) + 6\left(A_A(112;123;213)^{\lambda\lambda\lambda}\right) + 6\left(A_A(123;123;224)^{\lambda\lambda\lambda}\right) + \left(A_A(224;224;224)^{\lambda\lambda\lambda}\right) \tag{2.23}$$

$$\left(A_A(112;123;213)^{\lambda\lambda\lambda}\right) = \frac{8\pi N\rho}{25(k_B T)^2}\frac{\mu^4\theta^2}{\sigma^8}J(11) \tag{2.24}$$

$$\left(A_A(112;123;213)^{\lambda\lambda\lambda}\right) = \frac{8\pi N\rho}{75(k_B T)^2}\frac{\mu^4\theta^2}{\sigma^8}J(11) \tag{2.25}$$

$$\left(A_A(123;123;224)^{\lambda\lambda\lambda}\right) = \frac{8\pi N\rho}{35(k_B T)^2}\frac{\mu^2\theta^4}{\sigma^{10}}J(13) \tag{2.26}$$

$$\left(A_A(224;224;224)^{\lambda\lambda\lambda}\right) = \frac{144\pi N\rho}{245(k_B T)^2}\frac{\theta^6}{\sigma^{12}}J(15) \tag{2.27}$$

$$\left(A_B{}^{\lambda\lambda}\right)^{mult-mult-mult} = \left(A_B(112;112,112)^{\lambda\lambda\lambda}\right) + 3\left(A_B(123;123;224)^{\lambda\lambda\lambda}\right) + 3\left(A_B(123;123;224)^{\lambda\lambda\lambda}\right) + \left(A_B(224;224;224)^{\lambda\lambda\lambda}\right) \tag{2.28}$$

$$\left(A_B(112;112;112)^{\lambda\lambda\lambda}\right)=\frac{32\pi^3}{135}\left(\frac{14\pi}{5}\right)^{1/2}\frac{N\rho^2}{(k_BT)^2}\frac{\mu^6}{\sigma^3}K(222;333) \tag{2.29}$$

$$\left(A_B(112;123;123)^{\lambda\lambda\lambda}\right)=\frac{64\pi^3}{315}(3\pi)^{1/2}\frac{N\rho^2}{(k_BT)^2}\frac{\mu^4\theta^2}{\sigma^5}K(233;344) \tag{2.30}$$

$$\left(A_B(123;123;224)^{\lambda\lambda\lambda}\right)=-\frac{32\pi^3}{45}\left(\frac{22\pi}{63}\right)^{1/2}\frac{N\rho^2}{(k_BT)^2}\frac{\mu^2\theta^4}{\sigma^7}K(334;445) \tag{2.31}$$

$$\left(A_B(224;224;224)^{\lambda\lambda\lambda}\right)=\frac{32\pi^3}{2025}(2002\pi)^{1/2}\frac{N\rho^2}{(k_BT)^2}\frac{\mu^6}{\sigma^9}K(222;333) \tag{2.32}$$

When intermolecular potential is terminated at the dipole-dipole term, Eq. (2.29) is the only contributing term. Similarly, for quadrupolar fluids, Eq. (2.32) is the only non-vanishing term. For tetrahedral molecules with which the octopole-octopole potential is the lowest multipole term, the $(A_A{}^{\lambda\lambda\lambda})$ is zero and we can express contribution to free energy:

$$\left(A_B{}^{\lambda\lambda\lambda}\right)=\left(A_B(336;336;336)^{\lambda\lambda\lambda}\right)-\frac{221184\pi^3}{11375}\left(\frac{3533\pi}{737}\right)^{1/2}\frac{N\rho^2}{(k_BT)^2}\frac{\Omega^6}{\sigma^{15}}K(666,777) \tag{2.33}$$

The structural properties of the Lennard-Jones potential are introduced via J, L integrals expressed by:

$$\begin{aligned}
&J(n)=\int_0^\infty \frac{1}{r^{*n}}g^{LJ}r^{*2}\cdot dr^*,\\
&K(ll'l'';nn'n'')\\
&\quad=\int_0^\infty\int_0^\infty\int_{-1}^1 \psi_{ll'l''}g_3^{LJ}r_{12}^{*(2-n)}r_{13}^{*(2-n')}r_{23}^{*-n'}dr_{12}^*dr_{13}^*d(\cos\alpha)\\
&L(l;n,n')=\int_0^\infty\int_0^\infty\int_{-1}^1 P_l(\cos\alpha)g_3^{LJ}r_{12}^{*(2-n)}r_{13}^{*(2-n')}dr_{12}^*dr_{13}^*d(\cos\alpha),\\
&r^*=\frac{r}{\sigma}.
\end{aligned} \tag{2.34}$$

The J, K and L integrals are calculated by numerical integration over tabulated pair correlation functions. We calculated the J, K and L integrals with help of simple interpolation equations:

Nicolas-Gubbins-Street-Tildesley (LG)[28]: interpolation limit: $0\le\frac{N\sigma^3}{V}\le 1.2,\ 0.5\le\frac{k_BT}{\varepsilon}\le 6$,

In thermodynamic perturbation theory, we can obtain, from the properties of the real system, the Helmholtz free energy in powers of the perturbation potential (Eq. 14). When Eq. (14) is terminated at the third-order term, it is found that the results are good for moderate polar fluids but fail for strong dipoles (H_2o, NH_3…). Similar results have been found for quadrupole forces[27]. This is shown for a liquid state condition in Fig. Due to the slow convergence of Eq.(14), for strong multipole strengths, the following simple Pade approximation for the free energy can be found in the literature[6,28]:

$$\frac{A_{conf}}{Nk_BT} = \frac{A^{LJ}}{Nk_BT} + \frac{A^{\lambda}}{Nk_BT} + \frac{A^{\lambda\lambda}}{Nk_BT}\left(1 - \frac{A^{\lambda\lambda\lambda}}{A^{\lambda\lambda}}\right) \tag{2.35}$$

MIXING RULES

The thermodynamic properties of Lennard-Jones mixtures are obtained using the ome-fluid theory. The molecules interacting with Lennard-Jones potential have parameters σ and ε given by:

$$\sigma^3 = \sum_{\alpha,\beta} \psi_\alpha \psi_\beta \sigma_{\alpha\beta}{}^3 \ \varepsilon\sigma^3 = \sum_{\alpha,\beta} \psi_\alpha \psi_\beta \varepsilon_{\alpha\beta} \sigma_{\alpha\beta}{}^3 . \tag{2.36}$$

$$\sigma_{\alpha\beta} = \frac{\sigma_{\alpha\alpha} + \sigma_{\beta\beta}}{2}, \varepsilon_{\alpha\beta} = \sqrt{\varepsilon_{\alpha\alpha}\varepsilon_{\beta\beta}} . \tag{2.37}$$

The multipole moments with the next are represented [36,37]:

$$\sigma^3\varepsilon^2\mu^4 = \sum_{\alpha,\beta} \psi_\alpha \psi_\beta \sigma_{\alpha\beta}{}^3 \varepsilon_{\alpha\beta}{}^2 \mu_\alpha{}^2 \mu_\beta{}^2 \tag{2.38}$$

$$\sigma^3\varepsilon^2\theta^4 = \sum_{\alpha,\beta} \psi_\alpha \psi_\beta \sigma_{\alpha\beta}{}^3 \varepsilon_{\alpha\beta}{}^2 \theta_\alpha{}^2 \theta_\beta{}^2 \tag{2.39}$$

$$\sigma^3\varepsilon^2\Omega^4 = \sum_{\alpha,\beta} \psi_\alpha \psi_\beta \sigma_{\alpha\beta}{}^3 \varepsilon_{\alpha\beta}{}^2 \Omega_\alpha{}^2 \Omega_\beta{}^2 \tag{2.40}$$

3 RESULTS AND DISCUSSION

We have carried out calculations for pure refrigerants R125, R134a and R143a and refrigerant mixtures R404A and R507. The comparison of our calculations on the basis of statistical thermodynamics (JZG-LG model) with models obtained on the basis of the classical thermodynamics (Jacobsen-Lemmon (JL) model, the Tillner-Roth-Watanabe-Wagner model (TRWW), the Solvay package (S)) and experimental results (Exp) are presented in Tables 2,3,4,5 and 6 at saturated conditions.

Table 2 features the velocity of sound for pure refrigerants R125, R 134a and R143a as the function of relative deviation (RD) in the whole region important for refrigeration. The relative deviation of the JZG-LG model from the TRWW model is less than 1% for R125 and R 134a and less than 2% for R143a. The values are presented in the saturated vapour region.

Tables 3 and 4 show the average absolute deviation (AAD) and absolute deviation (AD) of the velocity of sound for R507 for the real gas region. The average absolute (AAD) deviation from the experimental data is less than 1% for JL, S and TRWW models; the JZG-LG model has AAD 1.05%. The best results in comparison with experimental data are obtained with the TRWW model with the maximum absolute deviation (AD) 0.3%. The analytical results obtained with statistical thermodynamics show very good agreement with experimental data and with the maximum AD 2.25 %. Somewhat larger deviations can be found in the near critical region due to a larger influence of the fluctuation theory and the singular behaviour of some thermodynamic properties at the near-critical condition.

Tables 5 and 6 show the average absolute deviation (AAD) and absolute deviation (AD) of the results for R404A between the analytical computation based on the statistical thermodynamics, classical thermodynamics and experimental data (Exp.). The average absolute deviation from the experimental data is less than 1% for the JL, S, TRWW and JZG-LG models. The best results in comparison with experimental data are obtained with the JL model with the maximum absolute deviation (AD) 0.79 %. The analytical results obtained with the statistical thermodynamics (JZG-LG model) show very good agreement with experimental data and with a maximum AD of 2.36 %.

Figures 5 and 6 feature the graphic course of the velocity of sound for refrigerants R404A and R507 in the whole region important for refrigeration calculated by JZG-LG model. The values are presented in the saturated vapour region.

Table 2: *Relative Deviation (RD) for R125, R134a and R143a.*

	RD (%)		
T (K)	R125	R134a	R143a
200	0.161681	-0.66667	1.689189
220	0.470219	-0.42553	0.390371
240	0.771605	0.760194	1.348748
260	1.006971	1.022495	1.806452
280	1.117318	1.227831	1.322751
300	0.599315	0.903405	1.533101
320	-2.9	-0.36284	0.995406
340		-0.70533	

RD= $(c_{0JZG\text{-}LG.}-c_{0TRWW})/c_{0TRWW}$

Table 3: *The Velocity of Sound c_0 for R507 Saturated Vapour*

			c_0 (m/s)		
T (K)	Exp.	JL	S	TRWW	JZG-LG
315.1	122.14	121.8	121.9	122.5	124.3
317.1	120.98	120.4	120.3	121	122.5
319.1	119.25	118.9	118.7	119.5	120.6
321.1	117.80	117.2	117	117.9	118.5
323.1	116.10	115.5	115.1	116.2	116.2
325.1	113.92	112.8	113.3	114.5	113.8
327.1	112.60	111.8	111.3	112.6	111.2
329.1	110.90	109.9	109.3	110.7	108.4

AAD	0.58	0.73	0.17	1.05

AAD=average absolute deviation $\sum\left|(\text{data}_{\text{Exp.}} - \text{data}_{\text{calc.}})/\text{data}_{\text{Exp.}}\right|/\text{no. of points}$

Table 4: *Absolute Deviation for R507 at Saturated Condition*

	AD (%)			
T (K)	JL	S	TRWW	JZG-LG
315.1	0.278369	0.196496	0.294744	1.768462
317.1	0.479418	0.562076	0.016532	1.256406
319.1	0.293501	0.461216	0.209644	1.132075
321.1	0.509338	0.679117	0.08489	0.594228
323.1	0.516796	0.861326	0.086133	0.086133
325.1	0.983146	0.544242	0.509129	0.105337
327.1	0.71048	1.154529	0	1.243339
329.1	0.1713	1.442741	0.180343	2.254283

AD=absolute deviation $\left|(\text{data}_{\text{Exp.}} - \text{data}_{\text{calc.}})/\text{data}_{\text{Exp.}}\right|$

Table 5: *The Velocity of Sound for R404A (Saturated Vapour)*

			c_0 (m/s)		
T (K)	Exp.	JL	S	TRWW	JZG-LG
318.1	122.1	122.7	122.5	122.5	123.3
320.6	120.2	120.4	120.5	120	120.5
323.1	118	118.8	118.4	118.5	118.3
325.7	115.8	116.3	116.1	117.5	116.6
328.1	113.5	114.4	113.8	115.8	114
330.6	111.3	111	111.4	111.3	109.9
333.1	108.4	108.4	109.1	110.9	106.6
335.6	105.6	106.1	107.4	106.4	103.1
AAD		0.41	0.48	0.93	0.98

Table 6: *Absolute Deviation for R404A at Saturated Condition*

	AD (%)			
T (K)	JL	S	TRWW	JZG-LG
318.1	0.4914005	0.3276003	0.3276003	0.982801
320.6	0.1663894	0.249584	0.1663894	0.249584
323.1	0.6779661	0.3389831	0.4237288	0.2542373
325.7	0.4317789	0.2590674	1.4680484	0.6908463
328.1	0.7929515	0.2643172	2.0264317	0.4405286
330.6	0.2695418	0.0898473	0	1.2578616
333.1	0	0.6457565	2.3062731	1.6605166
335.6	0.4734848	1.7045455	0.7575758	2.3674242

4 NON-EQUILIBRIUM THERMODYNAMICS

Accurate knowledge of the non-equilibrium or transport properties of pure gases and liquids is essential for the optimum design of the different items of chemical processing plants, for the determination of intermolecular potential energy functions and for the development of accurate theories of transport properties in dense fluids. Transport coefficients describe the process of relaxation to equilibrium from a state perturbed by the application of temperature, pressure, density, velocity or composition gradients. The theoretical description of these phenomena constitutes that part of non-equilibrium statistical mechanics that is known as kinetic theory.

KINETIC THEORY OF DILUTE POLYATOMIC GASES

The kinetic theory of dilute gases assumes a macroscopic system at densities low enough so that molecules move freely most of the time and interact only through binary encounters. Nevertheless, the densities are high enough to ensure that the effects of molecule-wall collisions can be neglected compared to those from molecule-molecule encounters. It is worth noting that in this paper the terms “dilute” or “low-density gas” represents a real physical situation, whereas the frequently used expression “zero-density limit” is related to results of a mathematical extrapolation of a density series of a particular transport property at constant temperature to zero density. This paper is predominantly concerned with the transport properties of fluids of practical significance. This means that attention is focused upon systems containing polyatomic molecules and upon traditional transport properties, such as viscosity and thermal conductivity. The ease of the practical evaluation of the transport properties of a dilute gas by means of these relationships decreases as the complexity of the molecules increases. Thus, for a pure monoatomic gas, with no internal degrees of freedom, the calculations are now trivial, taking minutes on a personal computer. For systems involving atoms and rigid rotors, the computations are now almost routine and take hours on work stations. For systems that involve molecules other than rigid rotors, the theory is still approximate and calculations are heuristic.

The background transport properties for pure gases are represented as sums of terms for the temperature-dependent dilute-gas contributions and terms for the temperature- and density-dependent residual contributions. Contributions for the critical enhancement are not included in these background functions.

From the Boltzmann equation, we can calculate transport properties for mono-atomic dilute gases not far from the Maxwellian [38-40]. This means that we treat transport phenomena with low temperatures or velocity gradients of the molecules. On this basis, we can express viscosity and thermal conductivity for a single-component gas:

$$\eta_0 = \frac{5kT}{8\Omega^{(2,2)}}\left(1+\frac{3}{49}\left(\frac{\Omega^{(2,3)}}{\Omega^{(2,2)}}-\frac{7}{2}\right)^2\right) \tag{4.1}$$

where M is molecular mass of the molecule, and $\Omega^{(l,s)}$ is the transport collision integral. For the Lennard-Jones intermolecular potential, it is almost impossibly obtain collision integrals analytically. Because of the difficulty of calculating these integrals, their values are usually taken from published tables. To make computerized calculations more convenient and to improve on the accuracy obtainable by linear interpolation of the tables, we used the Neufeld [4.2] at al. empirical formulation, obtained on the basis of numerical simulations and interpolation procedure.

$$\Omega^{(l,s)} = \frac{A}{T^{*B}}+\frac{C}{\exp\left(DT^{*}\right)}+\frac{E}{\exp\left(FT^{*}\right)}+\frac{G}{\exp\left(HT^{*}\right)}+RT^{*B}\sin(ST^{*W}-P) \tag{4.2}$$

This equation contains 12 adjustable parameters and is developed for 16 collision integrals.

For the calculation of the transport properties for polyatomic molecules in principle, a quantum mechanical treatment of processes is necessary to account for the changes of internal state. The fully quantum mechanical kinetic theory of polyatomic gases is based on the Waldman-Snider [40,41] equation and summarized by McCourt et al. Wang-Chang and Uhlenbeck and (independently) by de Boer (WCUB) formulated a semiclassical kinetic theory. The quantum mechanical theory has the advantage that it can treat the degeneracy of rotational energy states and is therefore able to describe the effect of magnetic and electric fields on transport properties. The disadvantage of this theory for practical application is that it is only formally established for gases with rotational degrees of freedom. In contrast, the semiclassical theory has the advantages that it treats all forms of internal energy and is the semiclassical limit of the quantum mechanical approach. In this paper, we used simple expressions for taking into account rotational contributions. Internal modes have, at relatively low temperatures, almost no influence on viscosity and relatively high influence on thermal conductivity.

The dilute gas viscosity is obtained from kinetic theory assuming that a Lennard-Jones (LJ) potential applies and using the expression:

$$\eta_0(\mathrm{T}) = 26.69579 \cdot 10^{-1} \frac{\sqrt{\mathrm{MT}}}{\Omega^{(2,2)*}\sigma^2}, \tag{4.3}$$

where η is in Pa s, M is the molecular mass in gmol^{-1}, T is in K, $\Omega^{(2,2)}$ is a collision integral and σ is the Lennard-Jones parameter.

1. Holland-Hanley model (HH) [43,44,45]. The viscosity of dense Lennard-Jones fluid is found using [43,44]

$$\eta(\rho,\mathrm{T}) = \eta_0(\mathrm{T}) + \eta_{ex}(\rho,\mathrm{T}) \tag{4.4}$$

where η_{ex} is excess viscosity due to high density contribution.

$$\eta_{ex} = 10^{-7} \exp\left(a_1 + \frac{a_2}{\mathrm{T}}\right) \mathrm{x} \left(\exp\left[\left(a_3 + \frac{a_4}{\mathrm{T}^{1.5}}\right)\rho^{0.1} + \left(\frac{\rho}{\rho_c} - 1\right)\rho^{1/2}\left(a_5 + \frac{a_6}{\mathrm{T}} + \frac{a_7}{\mathrm{T}^2}\right) \right] - 1 \right) \tag{4.5}$$

In Eq. (45), coefficients a_1... a_7 are empirical data dependent on substance.

2. In this paper, the Chung-Lee-Starling model (CLS) will be presented [50-52]. Equations for the viscosity and the thermal conductivity are developed based on kinetic gas theories and correlated with the experimental data. The low-pressure transport properties are extended to fluids at high densities by introducing empirically correlated density-dependent functions. These correlations use acentric factor ω, dimensionless dipole moment μ_r and empirically determined association parameters to characterize the molecular structure effect of polyatomic molecules κ, the polar effect and the hydrogen bonding effect. In this paper, new constants for fluids are determined.

The dilute gas viscosity for CLS model is written as:

$$\eta_0(\mathrm{T}) = 26.69579 \cdot 10^{-1} \frac{\sqrt{\mathrm{MT}}}{\Omega^{(2,2)*}\sigma^2} \mathrm{F_c} \tag{4.6}$$

The factor F_c has been empirically found to be [51]:

$$\mathrm{F_c} = 1 - 0.2756\omega + 0.059035{\mu_r}^4 + \kappa \tag{4.7}$$

where ω is the acentric factor, μ_r relative dipole moment and κ is a correction factor for the hydrogen-bonding effect of associating substances such as alcohols, ethers, acids and water.

For dense fluids, Eq. (6) is extended to account for the effects of temperature and pressure by developing an empirically correlated function of density and temperature as shown below:

$$\eta = \eta_k + \eta_p \tag{4.8}$$

$$\eta_k = \eta_0\left(\frac{1}{G_2} + A_6 Y\right) \tag{4.9}$$

$$\eta_p = \left[36.344\cdot 10^{-6} - (MT_c)^{.5} / V_C{}^{2/3}\right] A_7 Y^2 G_2 x \exp(A_8 + A_9 / T^* + A_{10} / T^{*2}) \tag{4.10}$$

$$Y = \rho V_c / 6\,,\, G_1 = \frac{1.0 - 0.5Y}{(1.0 - Y)^3} \tag{4.11}$$

$$T_c = \frac{1.2593\varepsilon}{k},\;\; V_c = \left(0.809\sigma\left(\dot{A}\right)\right)^3 \tag{4.12}$$

$$G_2 = \frac{\left\{A_1(1 - \exp(-A_4 Y)) + A_2 G_1 \exp(A_5 Y) + A_3 G_1\right\}}{(A_1 A_4 + A_2 + A_3)} \tag{4.13}$$

The constants A_1-A_{10} are linear functions of acentric factor, reduced dipole moment and the association factor

$$A_i = a_0(i) + a_1(i)\omega + a_2(i)\mu_r{}^4 + a_3(i)\kappa \text{ ,i=1,10} \tag{4.14}$$

where the coefficients a_0, a_1, a_2 and a_3 are presented in the work of Chung at al [50,51].

THE PREDICTION OF VISCOSITY OF GAS MIXTURES

For the determination of viscosity for dense gas mixtures, we have used a purely analytical model [39,40,54]. According to this theory, the viscosity of dense gas mixtures containing N components can be written in the form:

$$\eta = -\frac{\begin{vmatrix} H_{11} & \cdots & H_{1N} & \psi_1 \\ \vdots & & \vdots & \vdots \\ H_{N1} & & H_{NN} & \psi_N \\ \psi_1 & & \psi_N & 0 \end{vmatrix}}{\begin{vmatrix} H_{11} & \cdots & H_{1N} \\ \vdots & & \vdots \\ H_{N1} & \cdots & H_{NN} \end{vmatrix}} \tag{4.15}$$

$$H_{ii} = \frac{\psi_i{}^2}{\eta_i} + \sum_{\substack{j=1 \\ j\neq i}}^{N} \frac{\psi_i \psi_j}{2\eta_{ij} A_{ij}^*} \frac{M_i M_j}{(M_i + M_j)^2}\left(\frac{20}{3} + \frac{4M_j}{M_i} A_{ij}^*\right) \tag{4.16}$$

$$H_{ij}(j \neq i) = -\frac{\psi_i \psi_j}{2\eta_{ij} A_{ij}^*} \frac{M_i M_j}{(M_i + M_j)^2}\left(\frac{20}{3} - 4A_{ij}^*\right) \tag{4.17}$$

where ρ is the molar density, ψ_i and ψ_j are mole fractions of species i and j, and M_i and M_j are their molecular masses. A_{ij}^* is a weak function of intermolecular potential for i-j interactions. The symbol η_i represents the viscosity.

5 RESULTS AND DISCUSSIONS

Figures 5-14 show the deviation of the results for R134a, R143a, R125 and mixtures R507 and R404A in the real gas region and real liquid region between the analytical computation (HH-Holland-Hanley model, CLS-Chung-Lee-Starling model), and DLS experimental technique. In the saturated gas region, analytical results are compared with the REFPROP model (version 23-7). Tables 3 and 4 show the most important data for analytical calculation. The results for all models obtained by statistical thermodynamics shows relatively good agreement. The computed viscosity conforms well for both models, obtained by statistical thermodynamics. The CLS model yield surprisingly good results.

Somewhat larger deviations can, however, be found in the region of real liquid due to the large influence of the attraction forces, since the Lennard-Jones potential is only an approximation of the actual real intermolecular potential. The best results in the real liquid domain are obtained with the CLS model.

6 CONCLUSIONS

This paper presents the mathematical model for the computation of the velocity of sound in the fluid region.

For the real fluid, the Johnson-Zollweg-Gubbins model based on molecular dynamic and Lennard-Jones simulations and modified the Benedict-Webb-Rubin equation of state (MBWR) was applied. In this paper, multipolar and induction interactions are calculated with help of quantum mechanical calculation of the intermolecular energy function and the Lucas-Gubbins perturbation theory. The multipole expansion is terminated at the octopole term.

The analytical results are compared with the experimental data obtained with a dynamic light scattering technique, and they show a very good agreement.

The paper also presents the mathematical model for computation of viscosity in liquid and gaseous states.

The analytical results are compared with the dynamic light scattering and show relatively good agreement. In the region of real gases, the results are an equally good match.

References

[1] **D. Langewin**, *Light Scattering by Liquid Surfaces and Complementary Techniques*, Marcel Dekker, New York 1992.].

[2] **J. W. Schmidt and M. R. Moldover**, *J. Chem. Eng. Data* **39**, 39 (1994).

[3] **J. W. Schmidt, E. Carrillo-Nava, and M. R. Moldover**, *Fluid Phase Equil.* **122**, 187 (1996).

----

[4] **J. Yata, M. Hori, and T. Minamiyama**, *Proc. 11th Jap. Symp. Thermophys. Prop.*, pp. 111–114 (1990).

A. **P. Fröba, S. Will and A. Leipertz**, *Fluid Phase Equil*. **161**, 337 (1999)

[5] **P. Fröba, S. Will, and A. Leipertz**, *Int. J. Thermophys.* **22**, 1349 (2001)

[6] **P. Fröba, Dr.-Ing. thesis, Friedrich-Alexander-Universität Erlangen-Nürnberg 2001**

[7] **S.M. Walas**, *Phase Equilibria in Chemical Engineering*, (Buttenworth Publishers, Boston, 1984)

[8] **R.T. Jacobsen, R.B. Stewart, M. Jahangiri, S.G. Penoncello**, **31**:1161 (1986).

[9] **J. Li, R. Tillner-Roth, H. Sato, K. Watanabe**, Fluid Phase Equilibria, **161**:225 (1999).

[10] **E.W. Lemmon, R.T. Jacobsen**, International Journal of Thermophysics, **20**:825 (1999).

[11] **K. Lucas**, *Applied Statistical Thermodynamics* (Springer-Verlag, New York, 1992).

[12] **B.J. McClelland**, Statistical Thermodynamics (Chapman & Hall, London, 1980).

[13] **C.G. Gray, K.E. Gubbins**, *Theory of Molecular Fluids* (Clarendon Press, Oxford, 1984).

[14] **B.J. Moser**, Die Theorie der Intermolekularen Wechseelwirkungen und Ihre Anwendung auf die Berechnung von Verdampfungsgleichgewichten binärer Systeme, PhD Thesis (Universität Duisburg, Germany, 1981).

[15] **K. Shukla**, Fluid Phase Equilibria, **127**:1 (1997).

[16] **K. Shukla**, Fluid Phase Equilibria, **96**:19 (1994).

[17] **K. Margenau, N.R. Kestner**, *Theory of Intermolecular Forces* (Pergamon Press, 1969).

[18] **M. Rigby, E.B. Smith, W.A. Wakeham, G.C. Maithland**, *The Forces between Molecules*, (Clarendon Press, Oxford, 1986).

[19] **L.K. Johnson, J.A. Zollweg, K.E. Gubbins**, Molecular Physics, **78**:591 (1993).

A. **Müller, J. Winkelmann, J. Fischer**, AIChe Journal, **42**:231 (1996).

B. **Saeger, J. Fischer**, Part I, Fluid Phase Equilibria, **72** :41 (1992).

[20] **L. Luckas, K. Lucas, U. Deiters, K.E. Gubbins**, Molecular Physics, **57**:241 (1986).

[21] **A.L. Guevara, F. Benavides**, Molecular Physics, Vol. 89:1277 (2000).

[22] **D.E. Strogyn**, The Journal of Chemical Physics, **30**:4264 (1969).

[23] **J.S. Rowlinson**, The Journal of Chemical Physics, **19**:827 (1951).

[24] **J.S. Rowlinson**, The Journal of Chemical Physics, **19**:831 (1951).

[25] **W.P. Ameling, K.P. Shukla, K. Lucas**, Molecular Physics, **58**:381 (1986).

[26] **M.-J. Lee, J.-T.Chen**, Journal of Chemical Engineering of Japan, **31**:518–526 (1998)

[27] **D. Heinemann, M. Ripke, K. Lucas**, Fluid Phase Equilibria, **86**:15 (1993).

[28] **W.B. Sediawan, S. Gupta, E. Mc Laughin**, The Journal of Chemical Physics, **90**:1888 (1989).

[29] **Twu, K.E. Gubbins**, Chemical Engineering Science, **33**:879 (1978).

[30] **Twu, K.E. Gubbins**, Chemical Engineering Science, **33**:863 (1978).

[31] **J.L. Nicolas, K.E. Gubbins, W.B. Street, D.J. Tildesley**, Molecular Physics **37**:1429 (1979).

[32] **U. Weingerl, M. Wedland, J. Fischer, A. Müller, J. Winkelman**, AIChE Journal, **47**:705 (2001)

[33] **F. Bosnjakovic**, *Thermodynamics* (Tehnicka Knjiga, Zagreb, 1976, Croatia).

[34] **J. Millat, J.H., Dymond, C.A. Nieto de Castro**, *Transport Properties of Fluids* (Cambridge, University Press, 1996).

[35] **J.H. Ferziger, H.G. Kasper**, *Mathematical Theory of Transport Processes in Gasses* (North-Holland Publishing Company, London, 1972)

[36] **F. R.W. McCourt, J.J. Beenakker, W.E. Köhler, I. Kuscer**, I., *Nonequilibrium Phenomena in Polyatomic gases* (Clarendon Press, London, 1990).

[37] **S. Chapman, T.G. Cowling**, *The Mathematical Theory of Non-Uniform Gases* (Third Edition, Cambridge, University Press., 1970).

[38] **P.D. Neufeld, A.R. Janzen, R.A. Aziz**, The Journal of Chemical Physics, **57**:1100.

[39] **S.B. Kiselev, R.A. Perkins, M.L. Huber**, International Journal of Refrigeration, **22**:509 (1999).

[40] **S.B. Kiselev, M.L. Huber**, Fluid Phase Equilibria,**142**:253(1998).

[41] **M.J. Assael, N.K. Dalaouti, K.E. Gialou**, International Journal of Thermophysics, **5**:367 (2000).

[42] **M.J. Assael, J. Dalaouti, J.H. Dymond, E.P., Feleki**, International Journal of Thermophysics, **21**:367 (2000).

[43] **J.H. Dymond**, Fluid Phase Equilibria, **174**:13 (2000).

[44] **M.J. Assael, J.H. Dymond, M. Papadaki, P.M. Patterson**, Fluid Phase Equilibria, **75**:245 (1992)).

[45] **T. Kihara, T.**, *Intermolecular Forces* (University of Tokyo, John Wiley & Sons, Chichester, New York, Brisbane, Toronto, 1976)

Nomenclature

(Symbols) (Symbol meaning)

A ....free energy
AAD ....average absolute deviation
AD.......................absolute deviation
c_0.........................velocity of sound
CFC ....chlorofluorocarbons
CLS......................Chung-Lee-Starling
D ....hard sphere diameter
g..........................radial distribution function
H ....enthalpy, Hamiltonian
HH.......................Holland-Hanley
HFC ....hydroflurocarbons
h, $\hbar$ ....Planck constant
E..........................electric field
JZG ....Johnson-Zollweg-Gubbins
k_B ....Boltzmann consstant

LG .... Lucas-Gubbins
LJ......................... Lennard-Jones
N .... number density, number of molecules in system
p .... pressure, momentum
r .... intermolecular distance
R_m .... universal gas constant
S.......................... entropy
T.......................... temperature
T_c .... critical temperature
u .... intermolecular potential
U .... internal energy
V .... volume
V_c .... critical volume
α .... polarization constant
μ .... dipole moment
Ψ .... Molar concetration
θ .... quadropole moment
ω .... acentric factor
Ω .... octopole moment
ω .... orientation of molecule
σ .... Lennard-Jones parameter
ε .... Lennard-Jones parameter
η .... viscosity
μ_r .... relative dipole moment
κ .... correction factor for hydrogen bonding effect
Ω .... transport collision integral

Superscripts and subscripts

att............................ attraction
conf .... configuration
disp .... dispersion
ind .... induction
pot........................... potential energy
rep........................... repulsion
c .... critical condition

AUTHOR INSTRUCTIONS (MAIN TITLE)

SLOVENIAN TITLE

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Key words: (Up to 10 keywords)

Abstract

Abstract should be up to 500 words long, with no pictures, photos, equations, tables, only text.

Povzetek

(In Slovenian language)

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A title page consists of the main title in the English and Slovenian languages; the author(s) name(s) as well as the address, affiliation, E-mail address, telephone and fax numbers of author(s). Corresponding author must be indicated.

Main title: should be centred and written with capital letters (ARIAL **bold** 18 pt), in first paragraph in English language, in second paragraph in Slovenian language.

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Abstract: Abstract should be up to 500 words long, with no pictures, photos, equations, tables, - text only.

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[ℜ] Corresponding author and other authors: Title, Name and Surname, Tel.: +XXX x xxx xxx, Fax: +XXX x xxx xxx, Mailing address: xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx, E-mail address: email@xxx.xx

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Chapter examples:

1 MAIN CHAPTER

(Arial bold, 12pt, after paragraph 6pt space)

1.1 Section

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1.1.1 Sub-section

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$$c = \sqrt{a^2 + b^2} \quad (1.1)$$

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References

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Example of reference-1 citation: In text, Predin, [1], text continue. **(Reference number order!)**

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