VIII ERGONOMICS

Agronomy Research **12**(3), 837–842, 2014

The microbiological environment in specific rooms of a university campus

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Abstract. The aim of this paper is to present the results of a microclimatic research focused on the microbiological contamination in different rooms of the campus of the Czech University of Life Sciences Prague with emphasis on bacteria and filamentous fungi, including presence of the allergenic genus *Cladosporium*. Attention is paid to the purpose of the rooms, ventilation or air-conditioning, and also to problems with the technological equipment installed and used in the rooms. In the frame of this research, were examined the indoor conditions in lecture rooms, the special breeding sections for laying hens and several parts of an experimental brewery. Different intensities of ventilation and air-conditioning influenced the quality of the indoor environment in the studied rooms during the year.

Key word: indoor air quality, bacteria, filamentous fungi, temperature, air humidity.

INTRODUCTION

The aim of this paper is to present the results of a microclimatic research focused on the microbiological contamination in different rooms at the Czech University of Life Sciences campus. The microbial contamination (bacteria and filamentous fungi including presence of the allergenic genus *Cladosporium*) as well as the main microclimatic parameters of the air (temperature and relative air humidity) were measured and evaluated in relation to the different performance conditions of the tested rooms. Attention is paid to the purpose of the rooms, ventilation or air-conditioning and also problems with the technological equipment installed and used in the rooms.

Many scientific and professional papers emphasize the influence of indoor climate on human health (Gorny & Dutkiewicz, 2002; Karwowska, 2003; Fisk et al., 2007) and on the comfortable feeling of inhabitants inside different buildings and rooms (Seppänen et al., 2006; Nõu & Viljasoo, 2011; Tint et al., 2012). There are also many research and scientific papers that have focused on the influence of microclimate on the health of animals and the efficiency of animal production (Chiumenti, 2004; Ledvinka et al., 2008; Rajaniemi & Ahokas, 2012; Sada et al., 2012). Majority of these papers pay the attention to the thermal conditions and the concentration of noxious gases. The problems of the welfare of laying hens are also emphasized in the EU Council Directive 99/74/EC; unfortunately, the issue of indoor air quality and ventilation are not mentioned.

Indoor environment can also play a rather important role in the relation to the quality and durability of a building (Sada et al., 2012). The effect and influence of moisture and air humidity as well as microbiological contamination by fungi is emphasized (Papez & Kic, 2013).

In the frame of this research, were examined the indoor conditions in lecture rooms, special breeding sections for laying hens and several parts of an experimental brewery. Different intensities of ventilation and air-conditioning influenced the quality of the indoor environment in the studied rooms during the year.

MATERIALS AND METHODS

This research work was carried out in different rooms of the campus of the Czech University of Life Sciences in Prague. In the frame of this research, were examined the indoor conditions inside a lecture room, special breeding sections for laying hens and several parts of an experimental brewery.

The lecture room M II has the capacity of 121 student places and is equipped with a comfortable air-conditioning (AC) system for ventilation, heating and cooling. It also includes a regenerative heat exchanger and humidifier for the winter period. The measurement was carried out during summer, autumn and winter periods, under different operational conditions.

Two sections of an experimental building for housing domestic animals were equipped with different technological equipment. The first section was equipped with a three-tier battery of cages housing 72 laying hens, and the second one (60 laying hens) with a typical floor housing technology of boxes on deep litter, corresponding with the alternative technology with nests etc. The microclimatic research covered all four periods of the year.

The brewery of the Czech University of Life Sciences in Prague, used for education and production of special traditional Czech beers according to the old traditional procedure, consists of separated rooms used for specific purposes, which need very special equipment and also require individual parameters of microclimatic conditions (Chladek, 2007). The microbiological conditions were controlled in the brew house, the section of wort cooling, the cellar room which is combined of the department of fermentation and maturation tanks, the energetic centre and a classroom for 32 students. The measurement of microbiological contamination was carried out during the winter.

The air samples for microbiological analyses were taken by the instrument Merck Mas-100 Eco, a microbial air sampler with the volume of 0.200 m^3 of air, and cultivated by PDA (potato-dextrose agar OXOID CM 139; 100%) and NA (nutrient agar OXOID CM 003; 100%). Colonies of microorganisms were evaluated after 5 days of incubation. Yeast and filamentous fungi were cultivated at 22°C, bacteria at 29°C. The captured microorganisms, which formed colonies on the culture media, were expressed as colony forming units per m^3 ($CFU \cdot m^{-3}$).

The temperature and humidity of surrounding air were measured by the sensor FH A646–2 including the temperature sensor NTC type N with an operative range from –30 to +100°C with accuracy of ± 0.1 K, and air humidity by a capacitive sensor with an operative range from 5 to 98% with accuracy of ± 2%. The sensors were connected to the data logger ALMEMO 2690–8.

RESULTS AND DISCUSSION

The principal results of the microclimate measurement and microbiological evaluation for different AC levels are summarized in Tables 1, 2, and 3. Table 1 contains the results about the microbiological contamination and air temperature (T) and relative humidity (Rh) in the lecture room during several periods of the year and with different operational conditions.

Table 1. Results of measurements in a lecture room at the Faculty of Engineering

Period	AC	Students	Fungi	*Cladosporium*	Bacteria	T	Rh
-	-	persons	CFU m^{-3} ± SD	CFU m^{-3} ± SD	CFU m^{-3} ± SD	°C	%
Summer	no	0	408 ± 19	293 ± 26	207 ± 28	23.3	39.4
Summer	yes	0	444 ± 126	356 ± 133	121 ± 45	22.2	43
Autumn	no	34 to 55	356 ± 93	48 ± 16	884 ± 149	25.3	50.4
Autumn	yes	17 to 55	324 ± 36	104 ± 15	308 ± 103	23.1	34.5
Winter	no	5 to 47	77 ± 23	9 ± 4	860 ± 121	22.3	32
Winter	yes	5 to 47	28 ± 7	7 ± 3	312 ± 61	22.9	20.2

SD – Standard deviation.

The summer measurement was in an empty lecture room without students. The concentration of bacteria was low and the air–conditioning (AC) was decreased. On the other hand, the concentration of filamentous fungi was increased by the AC operation, which is especially true for the allergenic fungi *Cladosporium* which the air conditioner brought into the internal environment from the outdoor air. There was a similar situation during the autumn.

The quality of indoor air in the classroom with students and without the function of AC during the autumn measurement was rather low, which is obvious from the high level of average temperature (25.3°C) and the strongly increased relative humidity to the average 50.4%., as none of the metabolic products of the persons surviving inside (energy, vapour, noxious gases, etc.) were ventilated out. Contamination of indoor air by bacteria was also rising with the number of students present to the average value of 884 CFU m^{-3} when the AC in the lecture room was out of order.

A positive influence of AC was recognised in the autumn measurement, when the AC was switched on. The indoor temperature was decreased to the optimum 23.1°C and the relative humidity was lower as well (average 34.5%). Thanks to the function of the AC the average concentration of bacteria also decreased from 884 CFU m^{-3} to 308 CFU m^{-3}. Unfortunately, the average concentration of the allergenic *Cladosporium* increased from 48 CFU m^{-3} to 104 CFU m^{-3}. The filtration of inlet air is not sufficient and this fungus was brought into the internal environment from outdoor air with inlet air.

There was a completely different situation in winter. As the day of the winter measurement was rather cold with snow, all surrounding surfaces including the area of air inlet were covered with snow and clean, without a source of fungi. It resulted in a very low concentration of all kinds of fungi inside the lecture room. The range of the quantity of fungi was between 30 and 785 CFU · m^{-3} in various educational rooms (Karwowska, 2003). Our results are in accordance with this author's.

From the measurement of bacteria, it is obvious that students are the main source of bacteria inside the lecture room. Gorny & Dutkiewicz (2002) reported a normal range of bacteria concentration between 88 and 4,297 CFU m^{-3}. Our results are in accordance with these authors. The AC which was installed in our lecture room significantly reduced the bacteria concentration inside the lecture room in autumn and winter as well.

Table 2 contains a summary of the results of the microbiological measurements and the air temperature and relative humidity in the building with two rooms used for the breeding of laying hens during several periods of the year. The levels of indoor contamination by microbes are very high; there are differences between both sections and also in the course of the year.

Table 2. Results of measurements in two sections for breeding of laying hens

Period	Housing	Fungi	Bacteria	T	Rh
		CFU m^{-3} ± SD	CFU m^{-3} ± SD	°C	%
Winter	Cages	32,476 ± 8,591	116,810 ± 14,457	19.0	45
Winter	Boxes	56,571 ± 14,875	194,333 ± 34,152	17.0	65
Spring	Cages	6,952 ± 1,238	73,892 ± 15,834	20.2	52
Spring	Boxes	10,190 ± 571	100,282 ± 11,876	19.1	61
Summer	Cages	5,036 ± 3,572	9,840 ± 8,625	22.3	68
Summer	Boxes	4,923 ± 3,661	76,435 ± 28,768	22.0	69
Autumn	Cages	5,869 ± 1,274	11,297 ± 2,708	20.4	50
Autumn	Boxes	4,310 ± 691	72,714 ± 2,786	19.6	64

SD – Standard deviation.

The situation was the worst in the winter, which was mainly due to little ventilation. During other periods of the year, at increasing outdoor air temperatures, contamination with bacteria and fungi occurs due to intensive reduction of ventilation of the indoor air. It is obvious from the results of the measurements that the situation in the section of the laying hens housed in the boxes on the floor was constantly worse. As the people working in the building are usually inside the building only for a very short time for housing the laying hens, the measurement of *Cladosporium* was not provided in these sections.

Table 3 contains the results of the microbiological contamination and the air temperature and relative humidity in five main parts of the experimental brewery. The lowest contamination by bacteria was in the brew house, where there is quite intensive ventilation due to removal of the excess heat generated during brewing. Intensive ventilation on the other hand causes an increased incidence of filamentous fungi, including *Cladosporium*.

Table 3. Results of measurements in five sections of the brewery

Room	Fungi	*Cladosporium*	Bacteria	T	Rh
	CFU m^{-3}	CFU m^{-3} ± SD	CFU m^{-3} ± SD	°C	%
Brew house	785 ± 25	150 ± 30	760 ± 90	21.2	31.7
Whirpool	500 ± 70	90 ± 20	1,135 ± 25	19.1	37
Cellar	685 ± 65	95 ± 5	1,120 ± 270	7.8	100
Energy centre	360 ± 160	60 ± 10	815 ± 155	20.5	75.1
Classroom	545 ± 105	95 ± 5	840 ± 40	22.1	29.4

SD – Standard deviation.

But the brewing process can also be the source of fungi. The highest incidence of fungi and bacteria in the brewery was in the cellar and whirlpool, which was caused by the technological processes. The concentrations of fungi and bacteria in both of these rooms are similar; although there are significant differences in temperature and relative air humidity.

The concentration of fungi and bacteria in the classroom was worse than in the studied lecture room, because this room is permanently connected to the brew house and the internal environment is directly influenced by its microclimate. More intensive ventilation of the special classroom connected to the brew house could, in this case, also improve the indoor microclimate.

CONCLUSIONS

The comparison of the results obtained from the measurements in different parts of the university campus shows that ventilation and air-conditioning also have a decisive influence on the quality of the indoor environment, in addition to the technological equipment and purpose of the room.

The indoor environment in the lecture room would be greatly improved by the use of better filters, which are able to capture finer particles, particularly allergenic *Cladosporium*. It is also important to ensure the necessary maintenance, especially well- timed replacement of filters after pollution.

The higher movement of the laying hens on the floor and the more complicated ventilation in the part of the housing section used for living (especially near the floor) cause permanently higher concentration of microbes than in the case of housing in cages. More intensive ventilation of the building would help to improve the quality of the indoor microclimate.

The brewery is a very special technology, which needs different rooms and very different microclimatic conditions. The results of the measurement show that different technological needs are respected in the operation of heating, cooling or air-conditioning in all sections of the brewery.

ACKNOWLEDGEMENTS. The authors are grateful and express many thanks to all colleagues who permitted the authors to carry out all measurements of microbiological environment in the specific rooms of the CULS Prague during the teaching or research period.

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Agronomy Research **12**(3), 843–850, 2014

Physical load analysis in hotel cleaning work

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Abstract. Hotel cleaning work is one of the physically demanding professions. Employees in hotel cleaning processes are subjected to compulsory work postures, frequent body, arm, and leg movements, awkward turns due to areas of restricted spaces or inappropriate work equipment. Such workload can result in health problems and deteriorate health. Therefore, the aim of the research was to determine the physical load for hotel office cleaning staff. 23 hotel cleaners, all female, participated in the investigation participated. For the physical load analysis, a questionnaire, the Key Indicator Method, the quick exposure check method, and heart rate monitoring were chosen. It was proved in this research that the work of hotel office cleaners corresponds to the category of light and moderate workload despite the fact that hotel office cleaners themselves consider the work process to be very intensive and physically demanding. Further studies are necessary in order to clarify the fatigue level and other social risks that can influence the physical workload of employees.

Key words: hotel cleaners, workload, ergonomics, shift work.

INTRODUCTION

Excessive workload can result in health problems and worsen health in the current changing labour market. In the European Union countries, musculoskeletal disorders (MSD) affect more than 40 million employees, comprising gross domestic product (GDP) costs of 0.5 to 2.0%. Almost 30% of employees in Latvia report an increase in physical workload (Woolfson et al., 2008). Musculoskeletal disorders are the most common form of work related ill health and forms 60–62% of the total number of work related disorders (Fit for Work, 2012). Awkward, extreme, or repetitive working postures have been referred to as the main risk factors of MSD in various industries (Silverstein et al., 1987; Bernard, 1997). Often the cause of MSDs can be not only awkward postures, but also hard manual work, which significantly affects the ability to work and quality of life for employees (Monteiro et. al., 2009; Picavet & Hoeymans, 2004). The problems include backache and slipped discs, upper limb disorders, tenosynovitis, pain, numbness, swelling, and tingling in the hands and wrists. It is known that psychosocial work conditions (i.e. work strain and social support) are significantly related to discomfort in different body parts after work (Jablonska et.al., 2006).

Hotel cleaning work is one of the physically demanding professions. Cleaners increasingly work under severe time constraints. In the same time, it should be emphasized that hotel cleaning work is very intensive, where employees are subjected to compulsory work postures, frequent body, arm, and leg movements, awkward turns due to areas of restricted space, or inappropriate work equipment. Other risk factors, such as chemicals, etc. are also relevant (Bell & Steele, 2011; Hsieh et al., 2013). This combined effect of risks dramatically increases the likelihood of MSD (EU-OSHA, 2009) that can influence the ability to work and quality of life for workers (Monteiro et al., 2009).

Hence, the aim of the research was to determine the physical load for the hotel office cleaning staff that is employed in office rooms, incl. conference rooms, hallways, shower rooms, toilets, and cloakrooms cleaning processes.

MATERIALS AND METHODS

Participants. Hotel cleaners were recruited from one of the medium-sized hotels in Latvia. 23 hotel cleaners participated in the investigation, all women with the average age of 42.6 ± 7.3 and length of service of 5.2 ± 2.4. The physical workload of hotel cleaning staff was analysed in 8 hour shifts in the following work processes:

- Manual toilet cleaning, using chemical cleaning products and cloths
- Manual shower cleaning, using chemical cleaning products and cloths
- Manual sink washing using chemical cleaning products and cloths
- Manual cloakroom cleaning, including cupboard, wall cleaning, using chemical cleaning products and cloths
- Hall and corridors floor cleaning with vacuum cleaner
- Conference room cleaning, including table, window, door cleaning and work with a vacuum cleaner, also manual cleaning using chemical cleaning supplies and wiping cloths (Fig. 1).

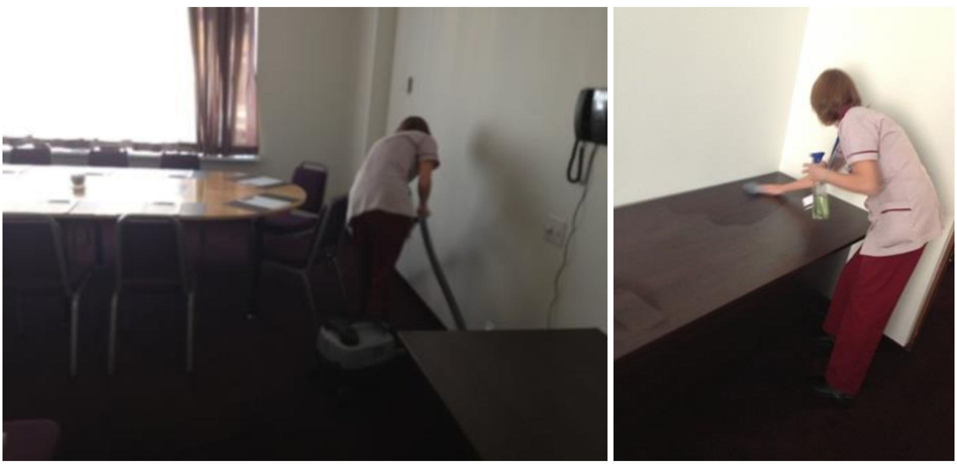

Figure 1. Conference room cleaning operations.

The inclusion criteria were: age, health status after mandatory examination, and full consent to participate in the study. The exclusion criteria were: acute pain in different body parts, cardiovascular diseases, undergone any muscular-skeletal surgery, having not attended the mandatory medical examination. Prior to the study, participants completed a questionnaire to find out the opinion of the workers about the ergonomics risks, work conditions and physical load impact on different body parts.

The Key Indicator Method (Steinberg, 2006; Klussmann et al., 2010) was used for assessment of the lifting, holding, carrying of heavy loads (KIM-LHC) as well as for manual handling operations (KIM-MHO).

The quick exposure check (QEC) method was applied in the research in order to carry out quick identification and assessment of the influence of the workload on the body parts of hotel cleaning staff (Brown, Li, 2003).

Heart rate monitoring (HRM) allowed to estimate the work heaviness degree depending on the workers' physical activity (intensity). The measurement was based on heart rate (HR) variation, which correlates with oxygen consumption and allows to quantify the objective energy expenditure for each work phases including short rest periods (Jackson et al., 1990). HRM was performed using the POLAR S810i™ Heart Rate Monitor device and the data processing software Polar Precision Performance.

Work heaviness in terms of energy expenditure was classified according to the classification scale shown in Table 1.

Table 1. Work heaviness classification in terms of energy expenditure (Mantoe et al., 1996)

Work heaviness category (WHC)		Energy expenditure	
NIOSH (USA) standard, ISO 28996		Male, kcal min^{-1}	Female, Kcal min^{-1}
Light work	I	2.0–4.9	1.5–3.4
Moderate work	II	5.0–7.4	3.5–5.4
Hard work	III	7.5–9.9	5.5–7.4
Very hard work	IV	10.0–12.4	7.5–9.4
Ultimate work	V	more 12.5	more 9.5

RESULTS AND DISCUSSION

The survey results show that employees in the hotel office cleaning work process are subjected to dynamic, static-dynamic work. All hotel cleaning staff (n = 23) noted that they lifted and moved no more than 5 kg heavy burdens in the process, and the frequency of lifting or moving heavy burden was up to 10 times per shift. At the same time, it was noted that everyday work involved chemical substances. In interviews, the hotel cleaning staff (n = 23) complained about intensive hand and leg movements, awkward postures: frequent bending, twisting, reaching, or crouching during the work process. The following main discomfort areas were marked: neck, shoulders, arms and hands, upper back, legs. The hotel cleaning stuff (n = 23) remarked that intensive work only took 3.8 ± 1.3 hours per shift.

The workload severity risk range for the activities involving lifting, holding, and carrying analysed for the hotel cleaning staff with the KIM-LHC method are summarised in Table 2.

Table 2. KIM-LHC method risk scores (RS), standard deviation (SD), risk range (R) for hotel cleaning staff (n = 23)

Work process	RS±SD	R I – V
Manual toilet cleaning using chemical cleaning products and cloths	4.3 ± 1.6	I
Manual shower cleaning using chemical cleaning products and cloths	4.5 ± 1.1	I
Manual sink washing using chemical cleaning products and cloths	5.2 ± 1.4	I
Manual cloakroom cleaning, including cupboard, wall cleaning using chemical cleaning products and cloths	4.9 ± 1.0	I
Hall and corridors floor cleaning with vacuum cleaner	8.7 ± 1.3	I
Conference room cleaning, including table, window, door cleaning and work with a vacuum cleaner, also manual cleaning using chemical cleaning supplies and wiping cloths	10.2 ± 1.3	II

The results in Table 2 shows that in various work processes, the workload for hotel cleaning staff is minimal and corresponds to risk degree I, since the maximum weight being lifted and carried is only 5 kg and the frequency does not exceed 10 times per shift. In the process of cleaning conference rooms, the risk degree corresponds to risk degree II (increased physical workload). That can be explained with more intensive work with vacuum cleaner, frequent arm movements, and it is in accordance with other authors' investigations (Bell & Steele, 2011). According to this method, the work hardness categories (or risk range) are: I – light work or low load situation ($RS < 10$); II – moderate work or increased load situation ($RS = 10…25$). If the risk range is II, physical overload is possible for persons older than 40 or younger than 21 years, newcomers in the job, or people suffering from illness.

The workload severity risk ranges R for manual handling activities analysed for hotel cleaning staff with the KIM-MHO method are summarized in Table 3.

Table 3. KIM-MHO method risk scores (RS), standard deviation (SD), risk range (R) for hotel cleaning staff (n = 23)

Work process	RS±SD	R I – V
Manual toilet cleaning using chemical cleaning products and cloths	8.1 ± 1.6	I
Manual shower cleaning using chemical cleaning products and cloths	7.4 ± 1.3	I
Manual sink washing using chemical cleaning products and cloths	7.9 ± 1.4	I
Manual cloakroom cleaning, including cupboard, wall cleaning using chemical cleaning products and cloths	8.2 ± 1.1	I
Hall and corridors floor cleaning with vacuum cleaner	8.6 ± 1.2	I
Conference room cleaning, including table, window, door cleaning and work with a vacuum cleaner, also manual cleaning using chemical cleaning supplies and wiping cloths	8.5 ± 1.7	I

After the assessment of manual handling activities, it can be concluded that in spite of frequent, repetitive hand movements in various operations, hotel cleaning stuff is subjected to risk range I (low workload) according to the KIM-MHO method results. Such result can be explained by the fact that each cleaning operation takes no longer than 15 minutes and rest time between operations is 15–30 minutes, sometimes even 45 minutes. It depends on the intensity of the office and conference events at the hotel.

The assessment of the influence of workload on body parts using the QEC method showed that the results do not coincide with survey results and other authors' investigations (Bell, Steele, 2011). The QEC exposure scores for the back, shoulder/arm, wrist/hand, neck have been categorised into 4 exposure categories: low, moderate, high, or very high (see Table 4).

Table 4. QEC method exposure scores (Brown & Li, 2003)

	Exposure level			
Score	Low	Moderate	High	Very high
Back (moving)	10–20	21–30	31–40	41–56
Shoulder/arm	10–20	21–30	31–40	41–56
Wrist/hand	10–20	21–30	31–40	41–46
Neck	4–6	8–10	12–14	16–18
Work pace	1	4	9	–
Stress	1	4	9	16

In the research, the highest exposure scores have been categorized into moderate exposure level for back (16.3 ± 1.9), shoulder/arm (18.1 ± 2.4), work pace (4.0 ± 1.1) and stress (4.0 ± 0.9). The wrist/hand movements were assessed as low exposure (14.2 ± 0.6) that is in accordance with the KIM-MHO results. The exposure scores investigated by the QEC are shown in Table 5.

Table 5. QEC method exposure scores for the hotel cleaning staff (n = 23) body areas

	Toilet cleaning	Shower cleaning	Sink washing	Cloakroom cleaning	Hall and corridors floor cleaning	Conference room cleaning
Back (moving)	18	18	18	18	18	18
Shoulder/ arm	18	22	18	22	18	18
Wrist/ hand	14	14	14	14	18	18
Neck	6	6	6	6	6	6
Work pace	1	1	1	1	1	1
Stress	1	1	1	1	1	1
Total score	66	70	66	70	70	70
Exposure level	Low	Low	Low	Low	Low	Low

In order to justify the results of the quantitative methods, the objective heart rate monitoring method was applied. The heart rates of the studied hotel cleaning staff was observed after 15 minutes of intensive work which comprised of several work cycles: lifting and moving weights, unsuitable work heights, bending, twisting, reaching or crouching, repetitive movements, rapid hand movements.

The calculation of the measurement revealed that the average hotel cleaner energy consumption was 3.2 ± 1.4 kcal min^{-1}. Hence, the level of work heaviness of the employees according to the work heaviness classification data corresponds to the risk level I (light work category). Hence, the HRM analysis confirmed the work heaviness categories according to the KIM, QEC methods. Table 6 summarises the results of heart rate monitoring and the indices of energy consumption.

Table 6. Hotel cleaning stuff heart rate (HR), Pearson's correlation (r), energy expenditure (E), work heaviness category (WHC)

Occupation	Heart rate monitoring			Average E ± SD, kcal/min	WHC
	Average HR ± SD, beats/min	Range HR, beats/min	r		
Hotel cleaners (n = 23)	82 ± 9.1	79–93	0.95	3.0 ± 0.6	Light work

Determining the differences of all hotel cleaners, it can be concluded that the heart rate increased only in case of elderly cleaners ($n = 7$; 45.2 ± 2.6), but not significantly during the conference rooms cleaning process when the conference breaks take place (10 –15 minutes). The average energy expenditure increased by approximately 1.2 ± 0.5 kcal min^{-1}, therefore increasing the work heaviness category but not higher than category II – moderate work (3.5–5.4 kcal min^{-1} for females). After taking the rest break, the heart rate returned to the normal level (60–70 beats min^{-1}).

In this investigation, it was proved that the work of hotel office cleaners corresponds to the light and moderate workload category despite the fact that hotel office cleaners themselves consider the work process to be very intensive and physically demanding. These results were based on mathematical calculations (KIM, QEC methods) and objective measurements (HRM), but are not completely in accordance with findings of other authors, where cleaning work is characterised by working under time pressure, poor work organisation, and high psychosocial risks (Woods et al., 1999; Bohle et al., 2004). It could be explained by the fact that the research was only oriented to investigating the workload of office cleaners, but not of hotel room cleaners whose workload is characterised by more compulsory work positions and movements (Hsieh et al., 2013). In such investigations, it is suggested to analyse the impact of physical load in combination with other work environment risks (chemicals, noise, vibration, ventilation, fatigue, etc.) that can worsen the influence of the physical workload on hotel cleaning stuff.

CONCLUSIONS

The quantitative and objective physical load analysis methods for hotel cleaning staff confirmed that the workload of hotel cleaning staff is only increased during the conference breaks when the job is most intensive. Further studies are necessary in order to clarify the fatigue level and other social risks (work organization, lifestyle, habits, etc.) that can influence hotel cleaners` physical workload and wellbeing.

ACKNOWLEDGEMENTS. This work has been supported by the project 'The development of up-to-date diagnostic and research methods for the risks caused by nanoparticles and ergonomic factors at workplaces', Agreement No. 2013/0050/1DP/1.1.1.2.0/13/APIA/VIAA/025.

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Agronomy Research **12**(3), 851–862, 2014

Transition to low carbon society. Evaluation methodology

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Abstract. The need to resolve environmental pollution and climate change issues stimulate the introduction of new legislation to further lead to technological progress in the sphere of renewable energy sources and green technology. Nonetheless, the impact of the fragmented though concrete results-oriented activities on human development and on the transition to a low carbon society is difficult to assess. The paper describes a combined methodology for evaluation of the combined efforts contributing to transition to a low carbon society. The methodology includes 11 modules and encompasses the main drivers of sustainability and the thinking of a low carbon society– policy development (legislation), education and research, projects and programmes, and interest groups (stakeholders), which includes such groups as decision-makers, industries, educators NGOs and society as a whole. The results of the comprehensive evaluation provides points from which development activities can be launched in order to form a resilient, low carbon future.

Key words: climate change, programmes, policy, education, stakeholders, capacity development.

INTRODUCTION

Low emission measures are frequently reviewed in terms of their technological characteristics: transfer to renewable energy sources, introduction of low emission fossil fuel technologies, integration of new biofuels in heating systems and transportation (Tutt et al., 2012; Barisa, et al., 2013; Beloborodko et al., 2013; Eisenhuber et al., 2013;). Duerinck (2012) analyze long-term models un their applicability as tools for measuring support of policy design to transition towards a low carbon society in 2050 for Belgium. The models analysed include: accounting models, which provide transparency and flexibility in examination of energy scenarios; macro-economic and econometric models that can be used from short- to medium- and long-term forecasts on the impact of policy; partial equilibrium models which present technologies in detail thus allowing for comparative analysis of different energy technologies.

Nonetheless, the difference between the impact assessment of these measures at the modelling and the development phase and at implementation are often very different and frequently, in the latter case (implementation and post-implementation phase), there is not an adequate assessment of the actual results and their impact on transition to a low carbon society.

In order to deduce what lifestyle changes would have the potential to impact transition to a low carbon society, Neuvonen et al., (2014) applied a backcasting scenario approach whereby first criteria are defined for the desirable future and then a series of feasible and logical steps are constructed that need to be followed from the present to that desirable future. Within their study, lifestyle backcasting made it possible to identify key actors and diverse lifestyles that support sustainability. The authors saw the communication of alternatives in lifestyles allowed those, dedicated to sustainable ways of living to expand their practices to created change on a wider scale. Similar testing to the backcasting scenario approach by Kok et al. (2011), Robinson et al. (2011), Vergragt & Quist (2011) explore the challenges in involving participants but the valuable role such an approach has. The need to have a broader look at the diversity of actors and governance in the backcasting approach which is so important in the complexity of reaching a resilient low carbon state, is noted by researches (Vergragt & Quist, 2011; Wangel, 2011a, 2011b; Király et al., 2013).

Struggles to provide accurate models which include climate policy development are discussed (Strachan et al., 2009; Calvin et al., 2012). The low carbon society methodology used by Kainuma et al. (2012) reviews potential at the country level which explore the links between policy development, and modelling the possibility to introduce reductions in emissions in critical sections of the economy, such as transportation. The low carbon society (LCS) modeling proves to be a highly integrated process which is challenging to apply due to the various actors, not always comparable data sets, necessity to illustrate both national-level and municipal-level contributions.

These intricate links and the necessity to manage the uncertainties related to their further development are discussed by Hughes et al. (2013). Since the pathway to a low carbon society is an environmental with multiple interested parties, very broad and ambiguous boundaries, long-range goals and resulting effects related to a variety of external factors, the assessment of the uncertainties is important to make sure that the scenarios and options developed and offered to policy makers are reasonable and manageable with a higher degree of certainty.

The vital importance of the policy-level contribution to succeeding in reaching low carbon societies is thoroughly reviewed by Söderholm et al. (2011) which included 16 quantitative scenario studies within their research. Under this review it is made clear that further studies need to establish more balanced synergy between quantitative and qualitative methods to better reflect the success of the dynamic relationship and influence of governance and policy instruments on developing a more sustainable society.

METHODS

A low carbon society is the definition which includes all levels and scales from each of us as individuals to the global level, that are united in the necessity to reduce impact on climate change and to adapt to the current climate changes we are already facing.

The methodology developed and presented in the paper for establishing a low carbon society allows us to progress towards this goal by applying evaluation

techniques. The methodology is illustrated with the aid of an algorithm (see Fig. 1) which contains 11 modules with which various types of the following are described:
- data bases (evaluation criteria, input data);
- assumptions and boundary values;
- projects and programmes;
- capacity development (education, training, informative seminars, etc.); stakeholders and interest groups (private and public sector, civil society organizations, municipal and national level interests, commercial and industrial sector).

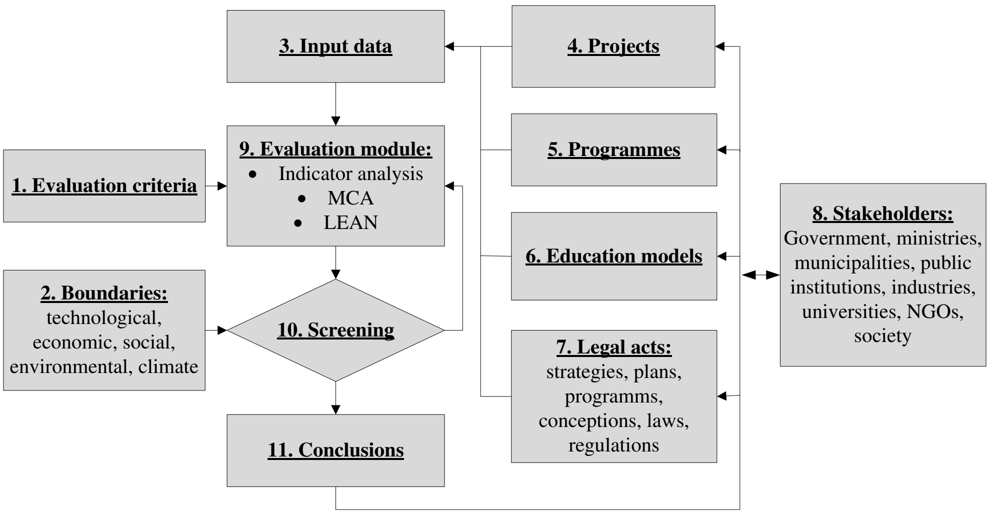

Figure 1. Algorithm for evaluation of transition to a low carbon society.

Module 1 'Evaluation criteria' include three-dimensional indicators which help to evaluate
- members of a low carbon society, beginning from each individual in society to the national-level government, the European Union (EU) and international players;
- activities of a low carbon society – projects, programmes, training, information;
- the evaluation of low carbon measures, comparison of results and conclusions, proposals, recommendations.

Module 2 'Boundaries' include restriction for the development of a low carbon society. These boundary restrictions cover several fields:
- technological – with innovative technological solutions that make is possible to reduce CO2 emissions in the energy sector, industry, agriculture, transport sector, households and the service sector;
- economic;
- social aspects;
- environment, including climate considerations.

Module 3 'Input data' that describe the current situation which include:

- information on taxes and policy (including fiscal) instruments;
- empirical models;
- data values.

Module 4 'Projects' include all types of projects implemented, including:

- on the global level;
- international;
- cross-border initiatives;
- national and municipal projects;
- institutional: projects implemented within local-governments, industry, agricultural companies, commercial enterprises, consulting and PR companies.

Module 5 'Programmes' include all types of programme that are implemented on several levels which have different goals, tasks and financial support (see Table 1).

Table 1. Description of 'Programmes' module

Level	Financing	Goals and tasks
Global	UN and its agencies World Bank EBRD Global Environmental Facility	security of global environment support to developing countries
Cross-border	EU	strengthening of cooperation among bordering countries resolution of cross-border environmental issues
Regional	EU European Economic Zone	resolution of regional environmental issues
National	State Research Programme Climate Programme Financing Instrument Latvian Environmental Protection Fund (LEPF) Grants for science National Support programmes	targeted for country-level environmental issues
Institutional	Enterprise developed support programes	targeted for sector-specific environmental issues additional motivation for private sector support in GHG emissions

Module 6 'Education models' include various forms of training, education with different objectives and goals (see Table 2).

Module 7 'Legal acts' include information and documentation on policy instruments with which it is possible to initiate activities which are directed towards low carbon solutions and measures. These include:

- strategies;

- programmes;
- action plans – recently, EU member states sign agreements with city mayors on reduction of CO2emissions. An important pre-condition to implement such agreements is the existence of energy action plans;
- concepts;
- laws;
- government regulations;
- municipal-level regulations.

Module 8 'Stakeholders' include all involved parties which can implement low carbon measures. Each of these interested parties has their own specific goals or objectives which produce their motivation on the individual-level, although the overall goal for the society is one.

Table 2. Description of 'Education models'

Organization/level	Target group	Form of training/education	Objectives and goals/tasks
Universities/ Higher education	Students, ministry representatives, local municipalities, industry, enterprises	Study courses, seminars, conferences	Scientifically based sustainability, including the development of low carbon technologies, education
Colleges/ Professional education	Students, ministry representatives, local municipalities, industry, enterprises, universities	Study courses, seminars, conferences, practice at enterprises	Sustainable use, development of low carbon technologies
Technical schools, trade schools/ Professional education	Students, ministry representatives, local municipalities, industry, enterprises, universities	Study courses, seminars, conferences, practice at enterprises	Sustainable use, applications of low carbon technologies
Schools/ General education	Colleges, technical schools, trade schools	Lessons, interest groups, seminars, summer schools	Basic concepts of sustainable use
Companies and NGOs	Ministry representatives, local municipalities, industry, enterprises, society	Study courses, seminars	Scientifically based sustainability, including the development of low carbon technologies, education

Module 9 The 'Evaluation module' includes several evaluation methods:

- simple indicator analysis – by choosing several 'transfer to low carbon' indicators, such as GHG emission factors and carbon intensity (tCO2 MWh-1), cost-efficiency (Euro (tCO2)-1), etc. Indicators currently applied measure unsustainable trends, for which actions can be identified to adjust these trends, however they do not help to define or secure sustainability. On the global level, the challenge is to find indicators of sustainability which can be used in evaluating dynamic systems, and which can help to show progress on multiple-levels: indicators that reflect global-level sustainability and against which national-level progress can be measured at the systemic level, and that on the individual level reflect progress and provide incentives to motivate further change towards sustainability. Thus, in evaluating the transition of society to one of low carbon, it is important also to develop appropriate project-level indicators that assess the results of a specific project or activity. The intensity of activities are concentrated on this level, as many systemic issues are reduced and fragmented to be resolved 'bit-by-bit' on the project-level. The evaluation and monitoring, however, of the results on this level does not always match the expectations and results to be stimulated and reached on the higher, systemic level of country- and global-level strategic goals and commitments. Due to the complexity of finding comprehensive indicators for sustainability which need to be relevant in the socio-economic and environmental context, often indicators are very specific to one sphere of specialization (Pissourios, 2013). At the same time, indicators should be oriented to five unified evaluation criteria: relevance, efficiency, effectiveness, impact and sustainability (Pissourios, 2013; Zvingule et al., 2013). Sustainability indicators are made even more complex by the different contexts in which they need to be relevant, and their values – independently comparable – governance, institutional frameworks and change, interpretations of sustainable development, etc. The perceptions of stakeholders also play a role as stakeholders are bound to interpret things differently, including what the indicators mean (Moreno-Pires & Fidélis, 2012; Mascarenhas et al., 2014).

- multi-criteria analysis (MCA). MCA is a widely used method for research on technical engineering, economic and social processes and has showed its high efficiency (Cruz, 2009; Park et al., 2011; Doukas, 2012; Jia et al., 2012; Kurka & Blackwood, 2013; Stewart et al., 2013; Liu & Rodríguez, 2014).
- environmental and energy management systems. The environmental management and energy management standards provide guidance for enterprises to develop programmes for minimizing their negative impact on the environment and optimizing energy consumption (Heras & Arana, 2010; Dörr et al., 2013; Testa et al., 2013). These systems are tailored to provide clear management through a plan-do-check-act principle with a view for continual improvement of the company's performance. The 'Check' aspect of the system is that which pertains very directly to evaluation, as companies are required to take both internal measures, and conduct independent audits to ensure that the programmes ('Plan') and their implementation ('Do') are in line with producing the desired, long-term effect on reducing pressures on the environment and climate change.
- LEAN management has been introduced in many sectors and has helped to improve results and competitiveness (Martínez-Jurado & Moyano-Fuentes, 2013). As interest in environmental issues increases from the regulatory framework and from stakeholders, the private sector needs to keep up. Thus, since lean management is an integrated management system (and fairly flexible in its ability to adapt to changing needs), increasingly there is interest to link it with environmental sustainability (see Fig. 2).

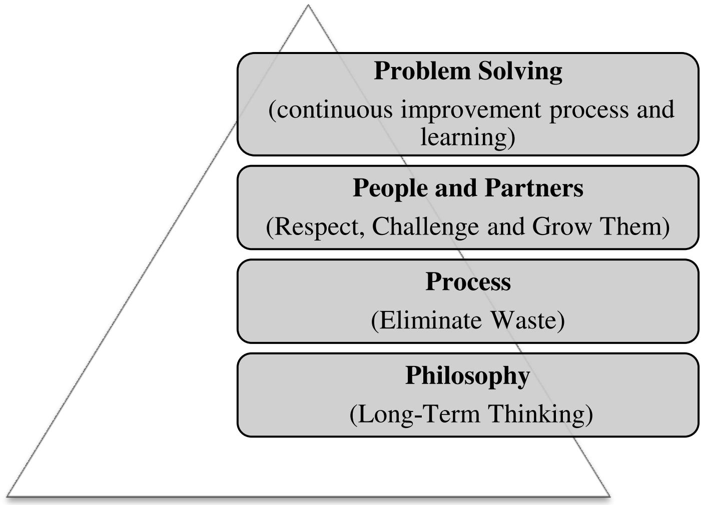

Figure 2. LEAN four aspects model (Liker's 4P model) (Dombrowski & Mielke, 2013).

Also Hajmohammad et al. (2013a; 2013b) argue that lean management and supply management impact on environmental performance via environmental practices.

Module 10 The comparative module ('Screening') is necessary in order to compare the results produced from the evaluation module to the border restrictions. Thus it is possible to determine or evaluation project and programmes on whether they have reached the defined conditions (boundary value indicators).
For instance, the results gained from the simple indicator analysis (IA) are compared with emission trading system (ETS) data. If ETS > IA, then the project has been successful, or – on the contrary, if ETS < IA, then the project has little value for impacting low carbon.

Module 11 The 'Conclusions' include essential parts for developing a low carbon society which is diverse and multi-layered

- Information on the results that have and have not been achieved by projects and programmes;
- Suggestions and recommendations that assist in developing a low carbon society on several levels;
- New projects and programmes can take into account the positive results of previous projects.

Table 3. Template for definition of evaluation results of transition to low carbon society

Information on the Component (Education, Policy, Projects and Programmes) Benefits	Shortcomings	Recommendations
…..	…..	…..

RESULTS AND DISCUSSION

The developed combined methodology is tested on the following components:

- Projects and programmes – cross border cooperation projects (ERDF, Interreg), national environmental programme (funded by the LEPF), EU IEE programme and corresponding projects (described in details in Blumberga et al., 2013; Zvingule et al., 2013).
- Education programmes – six higher education study programmes on Environmental science implemented in Latvian higher education establishments are evaluated. The results of an international audit of Latvian education study programs are used in the evaluation. The following indicators were used from the report: capacity of human resources, sustainability of the programme and financial sustainability.
- Policy – within the research, climate change policy was reviewed in particular. Climate change policy is an over-arching field which covers many sectors. A results-based approach will help to include in the evaluation both policy developed on the national level and also policy plans and actions related to other relevant sectors that may impact the goals set by the climate change policy. The evaluation is conducted presuming that climate change policy is an instrument which can help to steer the country to achieve its developmental goals. Thereby the policy shall provide information to those entities which are involved in the implementation of actions (civil servants, enterprises, society). It will also provide information on the activities which are vital for achieving sustainable development.

The relevance of each component to contributing to transition to low carbon society differs. The highest maximum theoretical potential to impact transition to a low carbon society for component ‘Projects and programmes’ is 10 points. This means that, if projects and programmes were implemented to their maximum potential, they would be well placed with their specifically, targeted goals, limited timeframe and focus area of activities to have large impact on changes in society as a whole. The theoretical potential of component ‘Education programmes’ is 8 points. The impact of education programmes can be large and can lead to sustainable results. The impact may be slower than direct actions on target sectors or policies; however the education programmes have the potential to impact to change the attitudes and ethics of a low carbon society. In Latvia’s particular case, the momentum of the current education programme is large – more than 50% of the goals have been reached. However, the lowest internal assessment has been for the criteria ‘sustainability’. The lowest theoretical potential is for the policy component which is attributed 4 points. Policy instruments are capable to bring results in initiating a transition, but policy instruments alone cannot maintain and monitor results in the long-term. In addition, the policy instruments which can support a transition to a low carbon society are inevitable fragmented across several sectors, periodic and not with an overall strategic or sustainable vision.

The results of the total evaluation of components are illustrated in Fig. 3.

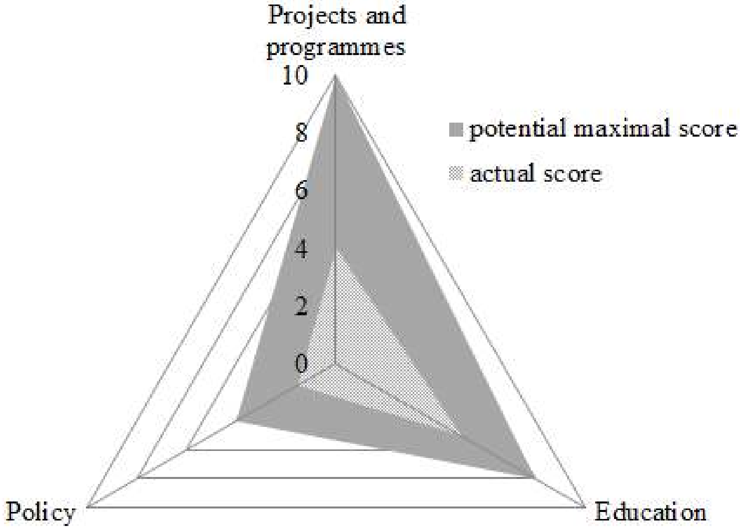

Figure 3. Results of the evaluation of Latvia's transition to low carbon society.

The actual score for each component, as illustrated above differs from the theoretical. In case of project and programmes, there are many contributed factors for the actual score (4 point) to be less than half of this component's theoretical impact. Primarily, this relates to the absence of results-oriented management of projects and programmed, which are primarily evaluated on their financial success in spending allocated budgets in the specified timeframe, and to the lack of replication of project ideas. In case of the latter, due to no formalized programme-level evaluation of project's successful results, best practices, there is no capture and transfer of knowledge from one project to other similar entities. This inability to capitalise on good results means that the potential impact of any project is limited to almost only the specific parties and enterprises directly involved in the project/programme. In case of education component, its actual score is 5 points, which is three points lower than the theoretical. Education programmes have the ability to improve their impact through more outreach activities to sectors external to their immediate institutions (industrial sector, commercial sector, municipalities, general public). The policy component has a score of 1.5 in comparison to its 4 points theoretical which is due to the limitations of policy to integrate its approaches across sectors and to engage various stakeholders in during policy development.

In summary, Latvia's journey towards a low carbon society is at half (almost 50%) of its theoretical possibilities.

CONCLUSIONS

A combined methodology for evaluation of transition to low carbon society has been developed which includes the main drivers of sustainability and a low carbon society – legislation, education and research, projects and programmes, as well as interest groups (stakeholders which include decision-makers, the industrial sector, educators, NGOs and society. The methodology has been tested to see the relevance of its application and its effectiveness in evaluating the sustainability of processes on the national, municipal and institutional levels. The results of the comprehensive evaluation provides points from which development activities can be launched in order to form a resilient, low carbon future. Such evaluations should be conducted ex-ante and ex-post in processes such as the development of country action plans (including in budget allocations) and strategic documents at the national level (both in sector and cross-sector strategies).

In further studies work needs to be done on improving the summarization of the evaluation method – in refining the point system for each component, and to expand the boundaries of the evaluation. Within the education component, it would be important to expand the study beyond the analysis of environmental programmes and also reflect the study programmes of other specialists. It would also be beneficial to review socio-economic projects and programmes that are not strictly related to the environment.

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Agronomy Research **12**(3), 863–874, 2014

Reducing exposure to extremely low frequency electromagnetic fields from portable computers

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Abstract. The relevance of this article can be described by the rapid development in computer technology which has resulted in widespread use of laptop computers. Consequently the population is now more exposed to the electromagnetic fields, emanating from such devices. The aim of this article is to test various intervention measures which would help to reduce the exposure. The authors focus only on the measures easily applicable by the general public. The effectiveness of the interventions is measured by reduced electric and magnetic field. This study focuses on the electromagnetic fields in the range of 50 Hz to 400 kHz. The importance of minimizing exposure to the electromagnetic fields is also stressed by the high level European bodies. Reduction of environmental risk factors, where possible, is in fact the corner stone of European occupational health legislation. The measurements are conducted using a novel 14-point model, covering the entire body of the user. Measurements from 46 laptop computer workplaces provided data about 156 unique exposure instances. The measurement results show that the least exposure scenario comprises of a laptop computer working on battery, having external input devices and display, the casing of the computer being properly grounded and power wires and adapters are positioned away from the user's body.

Key words: electromagnetic fields, ELF, extremely low frequency, computer, laptop.

INTRODUCTION

In this study, laptop personal computers (PCs) are in the focus from the aspect of electromagnetic fields (EMFs). Laptop computers produce a wide range of electromagnetic fields. The main source for EMFs from laptop PC's are 1) low and intermediate frequencies from power processing both inside (mainboard) and outside (power adapter) and 2) radio frequencies from wireless data transmission. This study deals with electromagnetic fields at the lower end of the spectrum, within a range from 50 Hz to 400 kHz. This encompasses extremely low frequencies (ELF), ultra-low frequencies (ULF), very low frequencies (VLF), low frequencies (LF) and some of medium frequencies as classified by the International Telecommunications Union (ITU)(ITU, 2005). This bandwidth was selected as, with the exception of radiofrequency fields, most all other electromagnetic emissions from mobile PC lay within that range. This study does not deal with EMF radiation utilized by PCs for wireless data transmissions (WLAN, 3G/4G etc.).

In this study different exposure scenarios were investigated, intervention measures applied and their efficiency measured. The selection criteria for intervention measures was based on easy applicability by PC users.

The relevance of the subject is prescribed firstly by the exponentially increased use of mobile computing devices in the past years, which in turn have increased the levels of EMFs in the working and learning environments.

The relevance can also be described, as the public is increasingly interested in reducing their exposure to the EMFs in everyday life. The danger from EMFs below the currently effective safety limits still remains debatable. The general precautionary principle, used in occupational and public health, however requires to reduce environmental risk factors to as low as possible. Therefore this study provides solutions on how to reduce electromagnetic fields from laptop computer use, and at the same time retain the functionality of a PC as a working and learning device.

Laptop computers, like any other electrical consumer products, must comply with the standards of electromagnetic compatibility which in turn would automatically ensure the compliance with the legal safety limits for the EMFs. Therefore it is highly unlikely that a modern PC would produce levels above of such safety limits.

However, as new data from dosimetric and clinical studies suggests, there may be other biological mechanisms induced by the electromagnetic fields that are currently unaccounted for in the safety limits (Bioinitiative report, 2007; 2012).

Although these newly proposed health implications cannot be unnoticed, a great uncertainty still exists amongst the scientific community. New biological effects are yet not well known and therefore there is a problem with replicating many of such studies. Also, it remains unclear, if the mentioned biological effects also have health consequences. Reports ordered by the EU have concluded: there is limited or inadequate evidence for such new effects (EFHRAN, 2010). The main aim of the legally established safety limits is to protect the public and workforce from levels of electromagnetic fields that are known to cause adverse health effects (ICNIRP, 1998; EP, 1999; EP&EC, 2004 and 2013).

Therefore, the lawmakers have not yet hastened to lower the safety limits but suggested the public and working people to follow a precautionary approach, until the science has made it more clear, what levels can be considered as harmful (EEA, 2007). The precautionary principle is voluntary in nature and prescribes that electromagnetic fields should be reduced to as low as reasonably possible. Also the current safety guidelines refer that the obligation of the employer is not only to assure the workplace's compliance with the limits but also to ensure that EMFs are reduced to the minimum. Special risk groups should also be considered – pregnant women and people wearing passive or active medical implants (EP&EC, 2013).

Whereas this study mainly deals with laptop PCs in office workplaces, there are many other places where people in work or in public are exposed to the EMFs. An international study done in several European countries, monitored peoples overall exposure to the EMFs, and it was found that the highest exposures were encountered in transportation vehicles (e.g. people using mobile devices simultaneously in a closed metal casket), followed by exposure in outdoor urban environments (wireless transmission antennas), and then in offices, followed by urban homes (Wout et al., 2010).

Modern office environment consists of a many EMF propagating appliances: some produce EMFs as a by-product (e.g. ELF EMFs from a PC); others use EMFs intentionally (e.g. wireless data link). Many of such types of products are new and not fully covered by compliance standards, therefore may create exposures to the EMFs that are currently unaccounted for in the guidelines (Kühn et al., 2007).

In the area of ELF and VLF EMFs, less research has been done in regard to mobile computers than in the domain of radiofrequencies. Whereas radiofrequencies in the portable PCs are created intentionally – to establish wireless data transmission link, low frequency EMFs can be considered as a side product of the operation of the PC. Computer components such as power supply modules, mainboard, video card, display, etc. all process signals and consume power which also generate electric and magnetic fields (MF) in the ELF and VLF range. Whereas the emanating magnetic field mostly depends on the processed electrical current, the strength of the electric field radiation is determined by the design and application of the portable PC. If the circuits and wires are enclosed in a shield and the casing is grounded, then the electric field values may be very low. Therefore, given that the laptop computers are with proper metal casing, the main factor determining the strength of the electric fields should be whether the casing is grounded or not (Fig. 1).

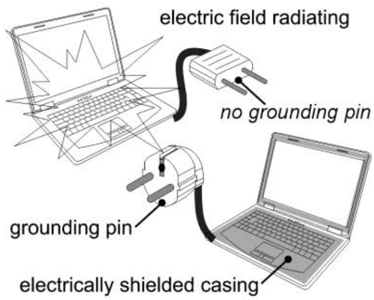

Figure 1. Plug type CEE 7/16 (left) is lack of the grounding pin, whereas plug type CEE 7/7 can ground the PC casing. Source: authors' drawing.

Frequencies of the electromagnetic fields produced by the laptop computers also vary from model to model. Besides typical sinusoidal waveforms, the EMFs have also an impulsive nature forming a complex waveform (Zopetti et al., 2011). Switching mode power supplies should be considered as main contributors to the impulse EMFs in the PC usage. A study by Zopetti et al. (2011) concluded that power supply units are the main source of high EMFs (Zopetti et al., 2011).

Bellieni et al. (2012) reported that next to the power supply unit, also the laptop PC's body itself (being in contact with a human body) gives off nearly the same levels of EMFs, and these can be higher than these found in the proximity of high tension power lines, transformers and domestic video screens (Bellieni et al., 2012).

The authors utilize a recently developed 14-point measurement protocol and a format of graphical representation, allowing easy understanding of the measurement results, by those not accustomed to the EMF issues. Unlike in some measurement protocols, where only one (maximum) reading is recorded from the worker's body position, this newly developed protocol provides better exposure assessment, picturing a detailed view of exposure levels in different body regions.

The aim of the paper is to identify high and low exposure scenarios, where various set ups of laptop computers, (including wiring) produce different exposure levels to the electromagnetic fields. This study is set to test the effectiveness of several intervention measures in actual office work environments. The results provide recommendations on how to use mobile computing devices by minimizing user's exposure to the EMFs.

A long term perspective of this study is to produce results that can be utilized in drawing up PC usage exposure assessment model. Such model is to use self-reported data (a questionnaire) of usage of electrical appliances and assess the exposure to various ranges of EMFs.

MATERIALS AND METHODS

In the ELF and VLF range of the electromagnetic spectrum, field strength measurements were conducted for both electric and magnetic fields. We investigated four factors that typically affect the exposure levels from laptop PC use in office environments: 1) battery or external power, 2) internal or external keyboard/mouse, 3) internal or external display 4) grounded or ungrounded casing and 5) distance to peripheral electrical wires and power adapter. Based on the combination of these determinants, tens of practically possible exposure scenarios could be deduced. Most common scenarios were selected for this study, as presented in Table 1.

Each of the exposure scenarios required a separate EMF measurement run. Scenario A, i.e. a PC setup without any intervention was studied first. A special wall socket plug was used to connect the laptop PC to external power without establishing a grounding connection for the PC casing. This would ensure comparable results for all PCs under testing, since some establish grounding via power supply unit. Secondly, intervention measures were tested independently from each other – only one determinant was changed (scenarios AG, AK, AW). Then, different combinations of interventions were tested. The authors selected the combinations that were most often used in practice.

Table 1. EMF exposure and intervention scenarios investigated in this study

Power source	Casing grounded	Ext.keyboard, mouse	Ext. monitor	Peripheral wiring, adapter
A	-	-	-	-
A	G	-	-	-
A	-	K	-	-
A	-	-	-	W
B	-	-	-	W
A	G	K	-	W
B	G	K	-	W
B	G	K	M	W

Abbreviations: A on external power source; B on battery power; K on external keyboard (otherwise on internal keyboard); M on external monitor (otherwise on internal monitor); G casing grounded (otherwise ungrounded); W wires routed away from body; (-) no intervention, which in case of 'peripheral wiring' means that power wires and/or adapters are right next to the body.

This study was set to investigate above mentioned exposure scenarios in actual work environments. Each workplace is unique by its laptop, peripheral devices and other inventory that makes up the overall electromagnetic field that the user is exposed to. While lab measurements are useful in determining the absolute exposure values and intervention effectiveness, the aim of the authors was to provide an overview of actual EMF levels present at places where office staff work daily. This allows encompassing also ambient EMFs, which are necessary to take into account when assessing the end result of an intervention. Perfect application of interventions can be achieved in the lab, but actual office environments are often confined by neighboring desks, preset wiring etc. that are likely to hinder the intervention outcome.

Fig. 2 describes exposure scenario A – laptop powered from a wall socket. This occurs most often when working with laptop PCs. Intervention BW would mean switching from external power (wall socket) to battery power. This would also remove the power adapter from the scene and create distance to any power wires.

Another intervention scenario, where external power is retained, would remove the power adapter and wires from beneath and next to the worker's feet (scenario AW). This means rerouting the adapter and wires to create maximum distance to them (usually 0.7 to 1.5 m).

Another intervention to increase user's distance to the EMF source (the PC), is using external keyboard and mouse (K). Also, connecting an external display unit to the laptop PC could result in additional distance (M). However, since external displays are also powered from the wall socket, secondary EMF source will be introduced into the scene.

Another way to reduce electric fields from the laptop PC, is to see that the casing is properly shielded and grounded (G). To make sure the shielding is adequate, in this study grounding was applied by two means: 1) connecting a grounding cable into laptop's USB-port's (Universal Serial Bus) grounding pin and 2) connecting power adapter's wall plug's third pin to ground (if applicable).

A new 14-point model of a human body (developed by Koppel) was used to conduct the measurements – altogether 14 points, distributed across the body, were measured for both electric and magnetic field (Fig. 2) (Koppel & Tasa, 2013). Unlike most workplace exposure measurements, where often only one reading is produced, encompassing 14 points, allows recording detailed readings. This in turn gives an overview of the exposure situation and to determine, which body regions are most exposed to the EMFs. Therefore intervention measures can be directed more efficiently.

The 14 p model is based on a sitting PC user, since the office personnel mostly spend their day behind the desk. On each of the 14 points, EMF meter was directed into different directions to obtain the strongest field reading. By going through the 14−point model, the whole body area was scanned The PC was set into operating mode, without any active software operations. The portable computers were on a chipboard office table. In case of power adapter and wires being positioned right at the worker's feet, point no 9 reading was taken right at the adapter/wires. Similarly point no 14 (the palms) reading was taken by scanning the PC casing for the highest field value. Therefore points no 9 and 14 represent the highest possible exposure point for the palms and the feet.

An average exposure was calculated based on the 14 points for each intervention. The results were grouped based on intervention scenarios. For each group average, maximum and minimum sets were determined, e.g. maximum of group A would indicate a PC that produced a highest average exposure across 14 points, in that group.

The equipment used for conducting the measurements, consisted of a low-medium frequency analyser ME3951A from Gigahertz Solutions, with a frequency span from 5 Hz to 400 kHz. Readings were taken in RMS (root mean square) values.

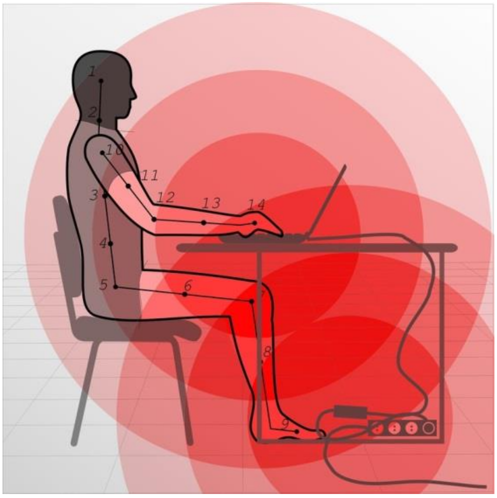

Figure 2. 14-point measurement model used in this study (Koppel, 2013), with exposure scenario A.

RESULTS

Altogether 156 unique exposure instances were investigated, each resulting in 14 readings for both electric and magnetic field (the entire sample consisted of 4,368 manually taken readings). Measurements were taken in office environments from 46 laptop PC setups.

Fig. 3 presents average, minimum and maximum values, classified per exposure scenario across the sample.

As this study conducted measurements for both electric and magnetic field, different propagation ways for these separate aspects of the electromagnetic field must also be taken into account when analyzing the results.

The highest exposure levels were characteristic to scenario A where no intervention was applied: 1) the laptop PC was connected to the wall socket, 2) using internal input devices (keyboard and mouse), 3) using internal monitor, 4) having an ungrounded casing and 5) with wires and power supply unit loosely positioned next to the user's body. For illustration purposes a PC was selected from the sample, that produced average field levels as compared to the rest of the sample, both in pre and post intervention measurements. Fig. 4 pictures a scenario A (no intervention) measurement for that PC.

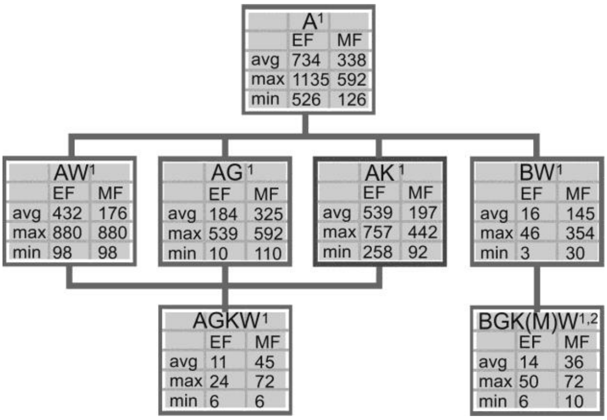

Figure 3. The effectiveness of various intervention scenarios, expressed as average (avg), maximum (max) and minimum (min) values for each intervention group's electric field (EF; V m^{-1}) and magnetic field (MF; nT); 1 see table 1 for scenario descriptions; 2 scenarios BGKW and BGKMW presented as one group due to their similarity in results.

Fig. 5 represents field strength values for the same PC when intervention scenario AGKW was implemented. The electric field strength as averaged over the body had decreased from 680 V m^{-1} (scenario A) to 9 V m^{-1} (scenario AGKV).

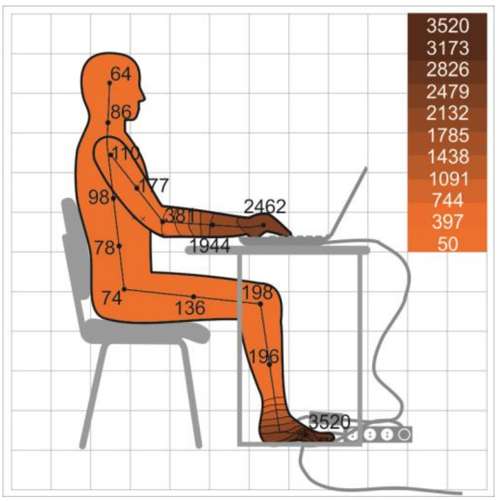

Figure 4. Scenario A for a selected PC, which represents typical field strength values for a computer without any intervention. Electric field values in V m^{-1}.

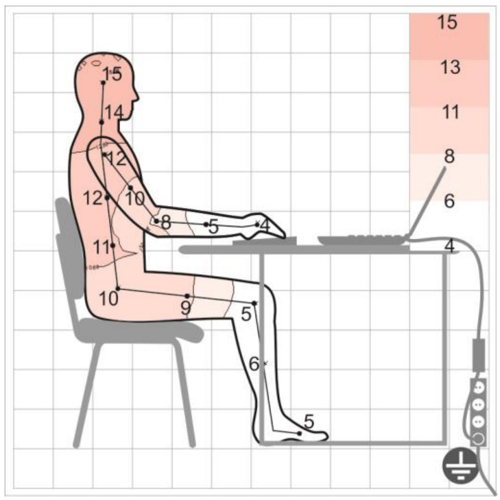

Figure 5. Scenario AGKV for the same selected PC, with typical field strength values for that intervention class. Electric field in V m^{-1}.

The first level intervention included testing each intervention measure separately (AW, AG and AK). Measurements indicated large variations in exposure levels across the sample. Any of the investigated four factors was seen to have a significant impact on overall exposure formation, but eventually did not produce satisfactory results alone itself.

Grounding the computer (AG) would somewhat reduce the electric field, but magnetic field remains unaffected due to the differences in propagation of these two fields.

Weakest electric fields we measured at the business class laptop PC's with an extra outer metal casing and with PC's casing properly connected to ground. Contrariwise, high E-filed levels were detected where the PC was lacking ground connection for casing. Such exposure scenarios are encountered in daily life where power plug lacks the third (casing grounding) connector (see Fig. 1) and if ground also cannot be established via external display unit or other peripheral device connected to ground.

Positioning of the PC's power adapter (AW) was also seen to largely increase the exposure levels. Often the adapters together with the wires were lying loosely on the floor, right next to or below the user's feet. Other peripheral wires, such as extension cords, while placed in close proximity of the user's body, were also measured to abruptly raise the exposure levels.

The usage of external keyboard and mouse (AK), was also seen to greatly affect the maximum exposure level. This can be explained by the user's increased distance to the PC if external input devices are used.

First significant reduction in electric field was noticed, when the laptop PC was on battery power and peripheral wires positioned away from the user's body (BW). Some PC models were seen to be unaffected irrespectively whether the PC was powered from the wall socket or from the battery. Whereas other models produced many folds greater exposure in electric field when connected to external power (AC). This is mainly to do with the PC mainboard's power module design, but also to do with the quality of switching power supply unit – whether the power adapter was equipped with adequate noise suppression filters or not.

Significant reduction of both electric and magnetic field could only be seen when multiple interventions were implemented simultaneously i.e. scenarios AGKW and BGK(M)W. Although BGK(M)W has a slightly lower magnetic field and AGKW with a bit lower electric field (see Fig. 3), the difference is marginal. Both scenarios produced satisfactory results and could be therefore recommended to the general public.

Involvement of external display unit, did not allow any significant change in EMF exposure, than using laptop PC's internal display. Although using an external display would allow placing the PC unit further away from the body, the external display unit also contains a live circuit itself which radiates EMFs.

The most exposed body parts were the user's hands and feet. Almost in all cases significant reduction in exposure could be achieved by utilizing external input devices (keyboard and mouse), since using the PC's internal input devices, places the user in close contact with the PC mainboard. Elevated exposure of the feet was encountered every time when the PC's power supply unit and/or peripheral power wires were arranged loosely, close to the user's body (most often the feet). The weakest exposure levels were detected in points 1 and 2 representing the head and neck.

CONCLUSIONS

This study has indicated that the user of a mobile PC can extensively control his/her exposure to the EMFs, without any significant extra effort or investment. Simple rearrangement of devices and adoption of new usage habits can reduce exposure to the EMFs even by factors of scale. Interventions, applied by this study, can broadly be divided to measures that reduce exposure by 1) increasing the distance to the EMF source, 2) shielding the EMF source and 3) using alternative power supply modes.

It was found that not all laptop PCs submit to interventions similarly. This is due to the PC design e.g. casing. Exposure levels are also dependent on the quality of accompanying power supply units. Some, cheap looking power adapters were seen to produce elevated levels of EMFs, both from the adapter itself, the power cable and consequently the PC unit. Few, good quality power adapters were equipped with a third wire for a casing ground – this effectively shielded the adapter, the power wire and the PC casing. Quality and design of a PC casing was also seen to be a determinant in how much electrical field was propagated out from the enclosure. The design of the PC also determines which parts of the PC radiate the most EMFs and whether the user is to be in close contact with these.

The overall conclusion - in order to effectively reduce the exposure levels, one should apply a combination of various intervention measures. Applying just one, may reduce some aspects of EMFs and/or reduce exposure only from a certain body area. The best reduction of EMFs was achieved when at least three intervention measures were applied: the whole body average exposure to the magnetic field was lowered by 89% (scenario BGKMW) and to the electric field by 99% (scenario AGKW).

As a general rule, the more distance were created between the user and the portable PC, the weaker the EMFs got. External input devices (mouse, keyboard) and output devices (monitor), together with rearrangement of power cords, can be viewed as means to create greater distance to the PC. The usage of such peripheral devices at the same time retains the full functionality of the PC or even improves it: 1) utilizing ergonomic mouse and keyboard alleviates ergonomic issues and allows better control of the cursor, 2) larger display reduces eye strain while images become larger and text more clear to read.

The results of this article are applicable for the general public, where users of mobile PC's seek to reduce the exposure to the EMFs. This study provides several ways, on how to reduce the EMF levels and to avoid excess exposure. However, the effectiveness of intervention measures should always be tested. As found in some instances in this study, some USB-sockets' grounding pin did not produce an effective grounding effect, whereas using other USB-port on the same computer achieved a good result. Also the power adapters may lack the third (grounding) pin or be of faulty design or working order.

DISCUSSION

The results of this study are in line with the work of Ekman et al. (2012), who also concluded a wide variation in the strengths of the electric field: the mean electric field of a PC was measured to lie between 10 and 678 V m^{-1}, with the maximum detected field of 1,050 V m^{-1}. For the PCs with high electric field, the underlying cause was the lack of grounding for the PCs casing (Ekman et al., 2012). The PCs with proper grounding were having electrical field strength tens of times lower. The main determinant was seen to be the power adapter unit, where some models were lacking a third pin for casing ground (Ekman et al., 2012).

This study found the strongest exposure to the MF to occur in point no 14 (the palms) and in point no 9 (the feet). Similar results were measured by Zopetti et al. (2011) and their follow up study by Bellieni et al. (2012), where magnetic field right at the power supply units was measured to be the strongest of the setup (from .28 to 4.7 µT RMS) (Bellieni et al., 2012; Zopetti et al., 2012). The authors of this study measured magnetic field at the same place (point 9 in scenario A) ranging from 30 to 3.6 µT. When analyzing the magnetic fields right at the laptop PC, Zopetti et al. (2011) recorded lower values (from .55 to 1.1 µT RMS) than this study (from .2 to 5.4, averaging at 2.7 µT for scenario A at point no 14) (Zopetti et al., 2012). This can be understood, as a difference in measurement setup - the height of the sensor from the object being measured. While this study scanned the computer at the height of ~1 cm, Bellieni et al. (2012) from a height of 5 cm. Also, this study used point no 14 to measure the EMFs from on top of the laptop PC i.e. palms, Zopetti et al. (2011) and Bellieni et al. (2012) measured from beneath the laptop PC, where they reported getting the highest readings. Therefore, considering the difference in measurement protocols, and acknowledging the concurrence of power supply unit measurements, the results of this study provide a good representation of the EMF levels produced by modern laptop computers.

Comparing our results from laptop PCs to desktop PCs, we would conclude that there is no difference in electric field. In this study points 3 and 4 from scenario AGKW averaged in 12 V m^{-1}, whereas Baltrenas et al. (2011) measured at the same relative body position 12 V m^{-1} in average for the desktop computers with LCD monitors and 15 V m^{-1} with CRT monitors (Christiane, 2011).

Measurements of magnetic field conducted in this study, were subject to fluctuations, due to variations in electrical power demand in neighboring facilities. Ambient magnetic field also varied from site to site. Since this study was conducted in actual work environments, such influences are inevitable even during the period when one laptop PC was investigated under various interventions. Per authors' evaluation, such variations in magnetic field remained mostly within the range of 40nT and therefore do not pose a role in comparing the exposure scenarios, except the multiple intervention scenarios AGKV and BGK(M)V. With the last two scenarios the magnetic field reaching the user's body from the PC was so low that remained below the ambient magnetic field level. Meanwhile, electric field, that is mostly shielded by walls, remained constant, unaffected by neighboring activities.

In order to completely control the workers' exposure to the EMFs, attention must also be paid to the elements of the work desk and any accompanying furniture. The focus should be on the arrangement of power cables and position of metal parts of the furniture. An ordinary power cable below the desk plate (at a distance of 3 mm from the worker's thigh) can produce an electric field of 40 kV m^{-1} on the surface of the skin (if the person is grounded) (Van Loock, 2007). Therefore, to minimize discomfort at the office desk, one should keep away from metal parts and electric wires (Van Loock, 2007). Van Loock recommends keeping a distance of at least 30 cm from the metal frame.

Complemented by authors' earlier work in the high frequency range of the EMFs (Koppel & Ahonen, 2013), the results of this study can be utilized in drawing up an exposure assessment model based on users' self-reported data (an online questionnaire). Although methodically questionnaire assessment is not as accurate as on-site measurements, a great number of people can be reached, who are interested in reducing their exposure to the EMFs. Such online-assessment model also serves as an educational tool since a vast portion of public are unaware of how the electromagnetic fields are propagated – a conclusion made by the authors after talking with the people from the workplaces. This finding is also supported by public studies which show that precaution as a way to manage EMFs has not been seen relevant for the majority of the public: they don't think about the measures (only 15% think) and they do not implement any measures (only 7% implement) (Christiane, 2011). Therefore, the authors emphasize the need to educate the public about electromagnetic fields as environmental risk factors.

With a diverse range of electrical office appliances and advancements in computer technologies, new methods of work have emerged e.g. working at distance via laptop. These developments have also brought along elevated levels of EMFs the worker today is exposed to. This paper has offered solutions on how to greatly reduce such exposure. The measures pointed out are both easy to implement and effective.

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Agronomy Research **12**(3), 875–880, 2014

Ergonomics slow down ageing and postpone ageing related diseases

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Abstract: For thousands of years, people have been interested in healthy ageing without diseases and in slowing down ageing. They are interested in longer-lasting youthful condition. Ageing is determined by physiology, biological ageing is accumulation of bodily changes that increase the possibility of death. There is no border line between ageing and age-related diseases, but a continuum from ageing to diseases. Longer health is good for a country's economy: social expenses are lower and people will retire later. Scientists have studied possibilities of postponing ageing for decades, but they have not found good solutions. In recent years, some attention has been paid to ergonomics. There is reason to conclude that ergonomics activities can be effective in slowing the pace of ageing. Ergonomics uses very different methods (psychological, physiological, physical, mathematical, etc.) for finding solutions, uses various professional skills (engineering, physiology, health sciences, psychology, etc.), and applies systems approach. Psychological knowledge can help solve many complex prevention problems. Our ergonomic research carried out in 1965−2000 in industrial enterprises in Estonia, Russia, Finland, and other countries also confirms these theoretical considerations. These studies have shown that it is possible to prolong good ability to work and health by up to 20 years. Ergonomics research can have potential in postponing age-related diseases, elucidation of new risk factors to health, and prolonging ability to work.

Key words: ergonomic research, ageing, health, ability to work, diseases, industrial enterprises, risk factors.

INTRODUCTION

When we hear something about ageing, it is usually about ageing-related changes in cells or in laboratory animals. In biology, ageing is mainly studied in short-living laboratory animals (Caenorhabditis elegans, Drosophila, Rodentia), and in connection with genetic problems. Ageing has been postponed several times in laboratory animals (C. Elegans, Drosophila). Despite the laboratory research of the basic biological mechanisms of ageing, these studies have given little information for knowledge about human ageing. Genetic knowledge has been used very little in practice for slowing ageing in human beings. It will probably be useful in the future.

Most scientific articles about ageing don't define what ageing is. Let us agree on the definitions. In this article, we speak about biological ageing on the level of the human organism, organismal ageing. Organismal ageing is accumulation of bodily changes that increase the possibility of death.

People have been interested in essential prolonging of youth and postponing of ageing and diseases for thousands of years. It has been a sweet dream. They do not believe that it is possible.

The aim of this article is to show that ergonomic research can have potential in postponing age-related diseases.

There has been small progress in developed countries: the average life expectancy is slowly increasing in the countries and is mainly increasing among older people. Health expectancy increases. Most prognoses of increases in the average life expectancy are moderately optimistic: 0.1−0.3 years every year.

At present, the average life expectancy of humans is 78−82 years in most developed countries. It is 89.63 years in Monaco according to World Factbook (2014) − the highest in the world. It was 76.2 years in Estonia (2012), a country that was classified as a developing country several years ago.

Studies of ageing in human beings are rarer compared to laboratory researches due to their complexity. People think that there is much scientific research on the issues of human ageing, but in fact, there is no intensive study: the funding of research of this complicated problem is limited. The current ageing research budget of the United States compares unfavourably with the United States chewing gum budget (Goldsmith, 2014).

At present, the average life expectancy in developed countries depends on multiple factors (accidents, deadly diseases, medical services), but first of all on biological ageing. Despite many studies, the situation of the ways and methods for postponing biological ageing is not clear.

There are three main groups of theories of human ageing (Goldsmith, 2014):

1. We age because of fundamental limitations, such as laws of physics or chemistry.
2. Modern non-programmed ageing theories: we age because our bodies do not try harder not to age.
3. Modern programmed ageing theories: we age because we possess what amounts to a suicide mechanism.

All these theories have a lot of proof.

At present, a researcher can often read that there are no methods for postponing (or slowing down) human ageing. However, the theoretical and experimental studies of many researchers (Kirkwood, 2005; de Grey & Rae 2007; Khaw, 2008; Fontana, 2009; Kristjuhan, 2010) show that modulating ageing is possible. The statistical data on increasing the average human life expectancy and health expectancy in parallel in various countries point to factors not related to genetics.

Age-related diseases develop from age-related changes (Kirkwood, 1999; Kirkwood, 2005). There is a continuum from ageing to diseases. The risk factors of age-related diseases are well-known. If we diminish the risk factors of age-related diseases, we decrease the pace of ageing. The time (years) of the onset of age-related diseases is the measure of ageing. There is a need for experimental studies showing prolonging of healthy years as a result improvement of working and living conditions.

MATERIALS AND METHODS

The ageing processes in humans occur slowly, from child's age to old age and death. The pace of ageing is not constant. Therefore, experimental studies to elucidate the influence of different working and living conditions on human ageing require several decades. This is complicated: working and living conditions are changing, people are changing their lifestyle, using various medicines, etc. We have not found such long-term experimental studies in the scientific literature. Such studies have probably not been carried out.

From 1965 to 2000 (Kristjuhan, 2010), we carried out ergonomic studies on healthy workers and made various recommendations to managers and workers in enterprises that were interested in improving working conditions and in better health of workers. Our ergonomic studies in the course of 35 years opened possibilities for us to assess changes in human ageing.

Our studies were carried out mainly through research contracts in Estonia, as well as in Finland, Sweden, Japan, Great Britain, Russia, and Moldova. The special ergonomics problems we studied were based on the wishes of managements. The subjects of the investigation (2,147 in total) were representatives of different jobs of light, dairy, automotive, and building materials industries (garment workers, shoemakers, weavers, spinners, metalworkers, engravers, sorters, smiths, bookkeepers, etc.). The physiological and ergonomics problems were studied in workshops where the environmental conditions were mostly satisfactory, corresponding to the international standards. Some workshops were noisy, but the workers wore antiphons. The studied groups included 30–50 male and female workers. Most studies were carried out three times during a shift, in the beginning, one-two hours after the beginning, and in the end of the shift, in the course of a few weeks. Several groups of workers were studied repeatedly.

We used a combination of methods, usable under the conditions of the enterprise, e.g. questionnaires, tests of the intensity of sensations and feelings of discomfort, critical flicker frequency, electromyography, reaction time testing, measurement of heart rate and blood pressure, exact measurements of limb perimeters, skin temperature, dynamometry, etc. We developed some research methods ourselves. We developed special devices for precise measurement of skin temperature (< 0.1°C) and limb perimeter meters for precise measurement (< 0.2 mm) of upper limbs in field conditions.

We developed a device for precise measurement of skin temperature in workshop conditions as there were no good technical solutions in the literature. The device was based on radiation measurement and was developed together with the Institute of Technical Termophysics of Kiev (Ukraine).

We developed perimeter gauges and calibrated rulers as the scientific literature does not offer practical methods for the measurement of small changes of limb perimeters (from 0.5 to 2.0%) in field conditions. The perimeter gauges consist of two or three millimetre wide measuring tapes and loads at their ends. The studied limb segment measured was supported so that it was horizontal. The measuring tape with loads was put around a marked place on the limb. The perimeter was measured with the help of a calibrated ruler. It was possible to find the localizations of physiological processes and their duration.

In our studies, we paid much attention to quantitative assessment of discomfort during working hours and after. By discomfort we mean antagonistic health effects that include many sensations and unpleasant feelings (aversion to activity, pain, being tired, itching, thinking about unpleasant things, etc.). Discomfort is an indication that something may be harmful: insufficient adaptation, stress, etc. It is information about very small changes to which most people usually do not pay any attention.

There are close associations between health and discomfort. The World Health Organization states that 'health is a state of complete physical, mental and social well-being.' Health is somewhat antagonistic to discomfort. Taking measures to alleviate discomfort can enable us postpone age-related disorders and consider individual aspects of ageing.

Subjective sensations are essential signals about something being wrong in the organism and the need to change the human activity or environment. Dozens of years ago, our experimental studies showed that subjective sensations mostly appear earlier than the changes registered by apparatus (Kristjuhan, 1985). An organism uses signals from the musculoskeletal system, but also from other organs that are under strain to avoid harmful activity.

We widely used 100 or 150 mm long visual analogue scales (VAS) for the assessment of discomfort sensations and feelings of fatigue in 4−11 body regions.

The author has worked out a chart of the human body that is divided into 100 regions for detailed analysis and quantitative assessment of fatigue and discomfort (Kristjuhan, 2010). Every region has specific reasons and physiological mechanisms of discomfort.

The chart (body map) takes into account the following:

- Spatial expansion of the symptoms of fatigue in different body regions
- Disposition of anatomical regions
- Symptoms of pathology of the musculoskeletal system
- Localization of symptoms caused by unfavourable changes in the visceral organ
- Spatial threshold of discomfort sensations
- Making the distinction between the regions of fatigue symptoms easy for workers
- Special role of upper extremities
- Maximum equality of the sizes of different regions.

Workers assessed the discomfort intensity in these regions on the 10-point scale (10 = intensity which disturbs work). Most workers found discomfort signs in 10–15 regions. Assessment in some small regions is not easy for workers, but possible and informative. Some Japanese scientists have distinguished as many as 104 anatomically identifiable parts of the body surface while studying fatigue (Kumaki, 1988).

Wilcoxon's matched pairs test was used in the discomfort studies and the *t*-test was used to assess most other ergonomics parameters.

In addition, qualitative research was also used: in discussions of ideas with workers and managers, taking into account continuous changes in lifestyle. We also used inductive strategies for finding solutions. Unfortunately, sometimes the optimal ranges of the physiological parameters that we needed were debatable in science.

RESULTS AND DISCUSSION

Ergonomics solutions

Our studies in enterprises were aimed at elucidating the most important health risk factors and their elimination. On the basis of the research data, we provided recommendations to managers and individuals: changing the technology, machine construction, colour of equipment and rooms, workstation design, new working zones, improving working conditions (parameters of noise, lighting, temperature, etc.), including music systems at the workplace, personal protective equipment (headsets, special shoes), work organization including work rotation and flexible work-rest schedules, corrective measures of workplace ergonomics, self-care procedures or doctor's visits, correct diet (optimum quantity of vitamin C, optimum calorie and sodium intake), changes in behaviour to decrease discomfort, preventive exercises, and improving labour productivity.

We developed some apparatus for preventing age-related diseases ourselves.

We developed a special apparatus for the prevention of leg fatigue: an air jet massage device. Most people working in standing position feel the fatigue of legs at the end of the work shift or in the evening. Simple measures like mechanical massage, periodic brief sitting down, physical exercise, and so on had no sufficient physiological effect. Hydro massage is effective but expensive: requires much room, water is splashed, and the devices may spread infectious skin diseases. The massage device developed by the authors is similar to the chair, in which a person sits and stretches his or her leg at a convenient 45° angle. The whole surface of the calf is gradually covered by the action of the air jet, making it possible to effectively combine the cooling and massage effects of the air jet with the physiological characteristics of the human body. After the air jet massage, the intensity of fatigue decreases significantly. Its effect lasted more than 50 min. Subjective fatigue symptoms in toes and heels which had less contact with the air jets practically disappeared (Kristjuhan et al., 1998).

Sometimes we recommended sets of exercises according to the peculiarities of work. In addition to the promotion of exercises, chronic disease prevention strategies were focused on reducing sitting time, e.g. creating workstations where work was possible in sit-to-stand workstations.

Postponing age-related diseases

The data about ageing were a by-product of our studies. When we studied the same workers during the second study period, we assessed the influence of our recommendations. We paid special attention to the time of the onset of musculoskeletal and cardiovascular diseases as well as changes in the ability to work. Comparison of the data received as a result of the research pointed to close connections between the environment, individual behaviour, and the ageing peculiarities in the human organism. Age-related changes and diseases appeared later, they were postponed up to 20 years when all recommendations were fulfilled (or in subjects who worked and lived in best conditions) compared to the persons who did not follow our recommendations. Consequently, ageing processes were slower.

Most scientific studies about prolonging the years of health and life by elimination of risk factors or adding a positive factor usually show a smaller effect, but they mainly concern a single factor. Increasing physical activity to the optimum is very widespread as an effective measure. According to Reimers et al. (2012), the data all 13 cohort studies on life expectancy in physically active individuals compared to that in physically inactive control subjects showed a higher life expectancy in physically active subjects, ranging from 0.43 to 6.9 additional years (average 34 years). A complex of various measures would be more effective.

Khaw et al. (2008) showed that the mortality risk for those with four compared to zero health behaviours (currently not smoking, not physically inactive, moderate alcohol intake (1−14 units per week), and plasma vitamin C > 50 mmol l^{-1}) was equivalent to being 14 years younger in chronological age. Improvement of working and living conditions can probably markedly prolong years of health and postpone age-related diseases.

CONCLUSIONS

Ergonomic research can have potential in prolonging ability to work. Our ergonomic research and practical implementations postponed age-related diseases up to 20 years.

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Agronomy Research **12**(3), 881–888, 2014

What is the priority in the problem of ageing?

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Abstract. What should we do to help solve the problem of postponing ageing? What is the priority? Let us define human ageing as accumulation of damage in the human organism that increases the probability of death. There are various problems of ageing: psychological ageing, biological ageing, etc. The central problem is biological ageing. If biological ageing is postponed, diminishing and postponing of diseases and increase in the older workers' ability to work are possible. People can stay healthy longer and countries save on social expenses. The problem of biological ageing is complex due to many different subproblems and adhering problems. Research in biological ageing is relatively poorly funded. Its funding and research depend on gaining public attention to this research. Many scientists think that there are no solutions for postponing ageing. Factually, no problem will be solved if we proceed from the assumption that the problem is not solvable. Researchers need popular support for the concept that ageing is a solvable problem. Higher public interest in biological ageing research compared to the present is possible through research of the causes of the average life expectancies of big contingents (countries, big population groups) and also interventions based on the risk factors of all-cause mortality. Studies of different causes of mortality in various countries may point to new risk factors to health and ageing. Interventions according to the known risk factors to age-related diseases can postpone these diseases and ageing markedly, by 10–20 years, and also increase the public interest in research in biological ageing.

Key words: biological ageing, biomedical gerontology, health, life expectancy, research priority, risk factors.

INTRODUCTION

Almost all organisms are ageing. Researchers have only not found ageing processes in a few animals: the sea anemone, hydra, etc. There was no need for the evolutionary process to develop organisms that will live forever. Long life of an animal has little species advantage.

Most people (excluding young, less than 15–18 years) do not want to be old. Many women use skin rejuvenation that can be achieved in a number of ways, ranging from laser, light and other energy-based treatments to chemical peels and other non-ablative methods. People older than 30–40 years sometimes dream about being young. At present, many ageing problems become increasingly important for governments of developed European countries in connection to population ageing.

People do not want to simply disappear. In spite of the small proportion of people who are uninterested in their health and therefore create problems for the medical industry, most people's activities are aimed at maintaining their health through better living and working conditions, better food and medical services. People want to use better homes, cars, clothes. Therefore, prolonging the period of healthy years (and life) is of the greatest importance (Kristjuhan, 2013).

At present, the percentage of older people in population is increasing and creating more problems for medicine. Most diseases of elderly people (cardiovascular diseases, Type 2 diabetes, cancer, arthritis, osteoporosis, dementia, Alzheimer, macular degeneration, glaucoma) depend, first of all, on the age of the subjects. Sarcopenia and general ageing-related muscle weakness are important limiting factors for the so-called successful ageing (McPhee et al., 2013). The percentage of pensioners also increases in population as countries have a fixed pension age, mostly 65 years, though in some countries this pension age has been increased during the recent years. Financial and social problems are topical in connection with funding of pension systems in developed countries: saving the previous level of the pension is difficult and often this level will be lower in the future. Nowadays, older people are working in enterprises more often than before and retire later. They are experienced specialists, but physically weaker compared to the young. Sometimes they need new knowledge and sometimes (depending on occupation and health) they need specific working conditions. The question of in what age their productivity is highest and when it begins to fall is important. The age of maximum productivity is quite high in the case of highly qualified specialists in intellectual work. University professors have maximum productivity in their fifties and sixties (Kristjuhan & Taidre, 2013).

The problem of ageing is a complex of many different subproblems and adhering problems and therefore solving some of them is a priority. The central scientific field is biomedical gerontology that is engaged in the biological processes of ageing. One of the world's pioneering researchers in the science of biological ageing, Tom Kirkwood (1999), says that ageing is one of the last great mysteries of the living world. Biogerontologists are interested in many problems of the biology of ageing, but first of all ways of slowing down biological ageing. Unfortunately, biomedical gerontology is badly funded. Professor Judith Campisi (2011, in interview by V. Glaser), a pioneer in researching controlling of cellular senescence, said: 'We need to gain more popular support for the concept that aging is a solvable problem.'

What is the priority in the problem of ageing? What should we do to help solve the problem of postponing ageing?

DISCUSSION

Fundamental problems at present

Biological ageing in humans, increasing mortality, begins from youth, but probably not with the birth. Mortality rate is often lowest in the age group 5–9 years in developed countries.

Factually, there are no widely accepted definitions for biological ageing. In experiments, the life expectancy of laboratory animals is widely used as a criterion of biological ageing, but the criterion of life expectancy is less used for ageing in human beings. Many other factors (e.g. diseases) are known which human life expectancy depends on.

There is also no widely accepted definition for diseases. It is not clear whether we should study biological ageing separately from diseases or as one continuum

(Blumenthal, 2003; Advances, 2013). There are thousands of centenarians and they are still dying of diseases, not of old age. Autopsies which have been performed on the very old always show a pathological cause of death. Disease prevention uses knowledge to decrease the morbidity associated with ageing. Distinction of ageing from diseases is difficult; it is separating undefinable from undefined (Evans, 1988). Kennedy and Minkler (1998) argue for a dialectical vision of ageing, wherein both able-bodied and disabled bodies are all parts of ageing. According to Ladiges et al. (2013), pathology assessment is essential to help define the progression of lesions associated with ageing; the real challenge is including it in ageing studies, because there is currently a lack of specialized expertise and resources. In the last few years, a new science geroscience has began to develop. The aim of geroscience is to examine how ageing contributes to disease (Advances, 2013).

Some scientists think that the first rate problem is how to measure ageing. However, the biomarkers of the pace of ageing are debatable despite many studies.

Many gerontologists think they need to know far more about the biology of ageing to slow down the ageing process. Other scientists think that there is no need for finding ways to slow down ageing. Maybe they are right. In the history of medicine, prevention of infectious diseases required different knowledge from the knowledge of disease mechanisms.

Most gerontologists think that modern biological theories of ageing in humans are falling into two main categories: the programmed and damage or error theories (Jin, 2010). Both groups of theories have pros and cons. The increasing number of centenarians is not simply due to an increase of the human life span as a consequence of improved economic, cultural conditions, and social/health care, but also the consequence of interaction of these factors with the genetic variability present in human populations, and environmental factors (Vasto et al., 2012). There is need a for balancing life-style and genomics research for disease prevention. Genetic and environmental factors, including diet and life-style, both contribute to cardiovascular disease, cancers, and other major causes of mortality, but various lines of evidence indicate that environmental factors are most important (Willett, 2002).

Speculative recommendations for postponing human ageing without any theoretical or experimental confirmation are very widespread. On the Internet, we can find a high number of anti-ageing remedies (herbs, adaptogens, antioxidants, hormones, vitamins, minerals, a lot of water, apple cider vinegar, etc.) but scientific confirmations of their efficiency can be found rarely.

Several modern biomedical fields have directly originated from rejuvenation and life extension research: 1) Hormone Replacement Therapy was born in Charles-Edouard Brown-Séquard's rejuvenation experiments with animal gland extracts (1889); 2) Probiotic diets originated in Elie Metchnikoff's conception of radically prolonged ’orthobiosis’ (c. 1900); 3) The development of clinical endocrinology owed much to Eugen Steinach's ’endocrine rejuvenation’ operations (c. 1910s–1920s); 4) Tissue transplantations in humans (allografts and xenografts) were first widely performed in Serge Voronoff's ’rejuvenation by grafting’ experiments (c. 1910s–1920s); 5) Tissue engineering was pioneered during Alexis Carrel's work on cell and tissue immortalization (c. 1900–1920); 6) Cell therapy (and particularly human embryonic cell therapy) was first widely conducted by Paul Niehans for the purposes of rejuvenation as early as in the 1930s (Stambler, 2014).

However, many scientists agree with Tosato et al. (2007) that no convincing evidence showing that administration of the existing ’anti-ageing’ remedies can slow down ageing or increase longevity in humans is available. Biological ageing is studied mainly in laboratory animals (translational biogerontology), but data of these studies are not easily usable in humans.

Are the practical problems of ageing financial?

A widespread opinion is that postponing human ageing and increasing the average life expectancy are very expensive, but factual data do not confirm that.

Most people are worried about their own longevity. They think much less about life expectancy in their country. It seems that it is far from their everyday problems.

A study comparing different life expectancies and Gross National Products (GDP, purchasing power parity, PPP) shows that sometimes the average life expectancy in poor nations is as long as in rich countries. According to World Factbook (2014), the average life expectancy in Jordan is 80.3 years, better than in the United States (78.6 years), but Jordan has much lower GDP (6.1 thousand USD per year) per person than the United States (50.7 thousand USD per year). Life expectancy in Kyrgyzstan is 69.75 years, nearly the same as in Russia (69.85 years), but Kyrgyzstan has much lower GDP (2,400 USD per year) than Russia (17.5 thousand USD per year). Economic recessions (extended declines in general business activity) despite the shortage of money often boost life expectancy (Kristjuhan & Taidre, 2012). Single factors (economy) probably have some role, but complexes of risk factors are more important. Complexes of health risk factors have been studied rarely as their study is difficult.

Studies of the causes of different life expectancies in various countries are rare. We know more about individual longevities and life expectancies of small groups of people rather than have a strong genetic aspect. Much attention is paid to the issues of the longevity of centenarians.

At present, national economies consider improving life expectancy to be a mere by-product of economic development, without any intrinsic value. The measures used to avoid deaths are mostly considered to be expenses (Kristjuhan, 2012).

Although human life is declared to be of high value everywhere, there is no intensive activity in research and practice for slowing down human biological ageing due to the complexity of the research and the difficulties with financing such projects. A part of this problem is misunderstanding of the effect of postponing ageing. Many people think of extended lives as extended illnesses and suffering. Factually, in countries where people have longer lives, people of the same age are healthier than in countries where life expectancy is short. The effect of prolonging life is very positive: more years in youthful condition, better health, longer health, lower morbidity, higher ability to work of the some age groups, better economy in countries, etc.

Postponing ageing in reality

Factually, at present, life expectancy and health expectancy increase together in most countries. At present, older people of the same age have better health than many years ago. The trends are towards less cardiovascular diseases and less disability (Khaw, 1997). The living and working conditions are better today compared to dozens of years ago. Khalyavkin and Yashin (2007) suggest that nonpathological senescence arises from unsuitable external influences, inadequate interaction of the organism with the environment. When biological ageing in humans is defined as accumulation of changes that increase the probability of death, many ways open for its postponing in reality.

Physicians sometimes think that life expectancy increases, but health deteriorates and diseases are even found in younger persons. They find infarctions in the myocardium and in the brain of younger persons than before. The main cause is that methods for diagnostics are becoming more sensitive. Using magnetic resonance imaging discovers many small infarctions and lacunar infarctions in brains that would not have become known before.

Practice of diminishing the risks of age-related diseases

Specialists in epidemiology and occupational health see a huge number of risk factors developing in highly developed countries as well. There are a great number of various risk factors for age-related diseases. Examples of the risk factors are obesity, big waist circumference, high body mass index (BMI), high blood pressure, low vitamin C content in food, tobacco consumption, binge drinking, sedentary lifestyle, high cholesterol, and diabetes. Many effects of these factors and their prevention are not clear. For example, there are different values of blood pressure: at home and in clinic. In a study of 438 patients (random selection), 170 (38%) normotension, 190 (43%) white coat hypertension, 10 (2%) masked hypertension (detected in at home measurements, but not in the clinical setting), and 68 (15%) sustained hypertension cases were detected (Helvaci & Seyhanli, 2006). White coat hypertension occurred more often than sustained hypertension. Avoiding and prevention of white coat hypertension is complicated. It depends very much on different psychological factors.

There are striking reserves to increase the average life expectancy and postponing ageing in highly developed countries. For example, 40% of men in Japan smoke and the Japanese use nearly two times more salt than the upper daily limit (6 g) recommended by the World Health Organization.

Some physicians think that they know almost everything about health risk factors. Factually, a very small percentage of risk factors have been studied in detail. For example, over 99% of the chemicals (cleaning products, cosmetics, clothing, etc.) in the market have undergone no comprehensive human and environmental risk assessment (REACH, 2005).

At present, we are only beginning to know the need for many components in our food and the actual situation – trace chemicals, antinutrients, etc. Small amounts of potentially harmful substances are found at some level in almost all foods. We are only just starting to understand nutritional patterns and their interaction with genetic and other forms of environmental exposure.

Several longitudinal studies have shown that taking into account some health risk factors and using interventions enable to postpone age-related diseases for 10-20 years. This saves social expenses significantly.

Ford et al. (2011) examined the relationship between four lifestyle behaviours (never smoked; healthy diet; adequate physical activity; and moderate alcohol consumption) and all-cause mortality in a national sample in the United States. They used the data from 16,958 participants aged 17+ in the National Health and

Nutrition Examination Survey III Mortality Study from 1988–2006. The rate of advancement periods representing the equivalent risk in the form of a certain number of years of chronological age for participants who exhibited all four high risk behaviours compared to those who had none were 11.1 years for all-cause mortality, 14.4 years for malignant neoplasms, 9.9 years for major cardiovascular diseases, and 10.6 years for other causes.

Khaw et al. (2008) examined the relationship between lifestyle and mortality in a prospective population study of 20,244 men and women aged 45–79 living in the general community in the United Kingdom with no known cardiovascular disease or cancer in a baseline survey from 1993–1997 and followed up in 2006. Participants scored one point for each health behaviour: currently not smoking; not physically inactive; moderate alcohol intake (1–14 units per week); and plasma vitamin C >50 mmol/l indicating fruit and vegetable intake of at least five servings a day, for a total score ranging from 0-4. The mortality risk for those with four compared to zero health behaviours was equivalent to being 14 years younger in chronological age.

Clarke et al. (2009) examined 18,863 men from 1967–70 and followed them for 38 years. Compared with the men in the lowest 5% of the risk score based on smoking, diabetes, employment grade, continuous levels of blood pressure, cholesterol concentration, and BMI, the men in the highest 5% had a 15-year shorter life expectancy from the age of 50 (20.2 *vs* 35.4 years).

Kopes-Kerr (2010) highlighted ten major studies on the effects of primary prevention. These studies demonstrate significant correlations between specific healthy lifestyle behaviours and decreases in major chronic diseases (e.g. diabetes mellitus, heart disease, stroke, and cancer) and all-cause mortality.

Studies showed that positive lifestyles (avoiding stress, blood pressure control, exercising, healthy food, etc.) do not entail much expenses and can have an impressive effect on health and life expectancy.

There are also many biogerontologists' suggestions on how to postpone ageing and increase human life expectancy. Rattan (2008) recommends applying hormesis in ageing research and a therapy which is based on the principle of stimulation of maintenance and repair pathways through repeated exposure to mild stress. A shortcoming of this method is that the value of the optimum level of mild stress is debatable. Kristjuhan (2006) recommended avoiding the risk factors of all-cause mortality from age-associated diseases and keeping away from sensations of discomfort.

Over 30 years, we have conducted ergonomic studies (we understand ergonomics as a scientific discipline concerned with understanding of interactions among humans and other elements in the human-machine-environment system) in industry workers. Data on ageing were a by-product of these studies. Comparing the data of the ability to work and health of the workers in optimal conditions with data of the workers who did not follow our physiological and ergonomics guidelines showed that it was already possible to postpone age-related diseases up to 20 years (Kristjuhan, 2010).

CONCLUSIONS

It is important to increase public interest in research of biological ageing. More public interest compared to the present is possible through research of the causes of the average life expectancies of big contingents (countries, big population groups) and also interventions based on the risk factors of all-cause mortality. Studies of the causes of different mortalities in various countries may point to new mechanisms and risk factors of health and ageing. Comparing the data of ability to work and health of workers in optimal conditions with data of workers who did not follow physiological and ergonomics recommendations showed that it was already possible to postpone age-related diseases up to 20 years.

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Agronomy Research **12**(3), 889–894, 2014

The impact of light conditions on identifying facial features

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Abstract. Biometry in the field of identifying people is a highly topical theme these days. The most widespread area is identification of a person on the basis of fingerprints, nevertheless scanners of the bloodstream, iris and retina in particular are undergoing development, as well as identification on the basis of facial features. In the case of scanners which distinguish people according to their face, user problems are appearing. One of these problems is the surrounding environment of the scanner device, in particular light conditions. According to tests, it is necessary to conduct identification of people under laboratory conditions, which is not acceptable from the user perspective. It is essential to consider this problem and to innovate and extend the system for identification on the basis of facial features. It is necessary for the system to react, if possible, with a minimal error rate and within the fastest response time. Through the help of testing light conditions, an improvement was achieved in the capability of identifying facial features, and at the same time a further modification was proposed to perfect the existing technology.

Key words: face, glow, identification, lighting, surrounding environment.

INTRODUCTION

Biometric identification systems are used in various versions, within both commercial and private infrastructure. Their identification was initially predominantly based on the systems of fingerprints, and they were used exclusively in buildings in which high demands were placed on security (chemical laboratories, government organisations, arms industry, etc.). Today, these systems are a part of our society and serve, for example, also for protecting data on flash disks, easier and more secure access to laptop computers, etc. Systems with extend ranges of biometric information focus on various other characteristic attributes of persons. These include, for example, scanners of the retina, iris, bloodstream of the hand, facial features, and last but not least tread.

In various cases, it occurs that the measured values show a relatively high error rate in the acceptance or rejection of a user, even in spite of the fact that the measurement was conducted under laboratory conditions. It is of fundamental importance to focus our attention on this problem and optimise the FAR and FRR values (Rabia & Hamid, 2009). Luminosity is one of the factors that strongly influence the values of FAR and FRR. And all research is based on this aspect.

MATERIALS AND METHODS

According to the recommendation of the manufacturer, tested scanners should be installed at a distance of 3 metres from the opposite window and at a distance of two metres from direct lighting. This lighting should be within the scope of 0–800 lux. Artificial lighting is within this range, for example a 100 W bulb at the distance of 2 m has a lighting intensity of only 35 lux. In the parameters of these scanners, it is stated that they can also be used as outside devices. This information is false, since the conditions of outside lighting are inappropriate for their proper functioning. This is due to the reason that even an overcast winter sky radiates a lighting intensity of 3,000 lux, whilst a sunny summer sky radiates a lighting intensity of up to 100,000 lux. From these values, it is evident that the use of scanners as outside equipment is inappropriate (Tan et al., 2009; Schwartz et al., 2012).

Measurement of the error rate of the systems which use facial features of a person for identification is relatively demanding. First of all, it is necessary to ensure the conditions stipulated by the manufacturer. Upon testing, the distances were set as stated in the instructions. The measuring panel was placed at the height of 1.2 m. Artificial lighting was also ensured at the distance of 2.2 m (Zhang, 2000; Schwartz et al., 2012).

The lighting intensity on the level of the scanning device was 270 lux, on average. The light which fell on the face (refraction from wall) had an average intensity of 70 lux. The scanned persons stood at the distance of 0.5 m from the scanner. A total of 78 subjects were measured, repeated 20 times. The measured persons were 17 women and 61 men within the age range of 22–29 years.

RESULTS AND DISCUSSION

The measurements were conducted on the scanners MultiBio 700 and iFace 302. Both devices are a combination of identification using code, fingerprint and scanning of facial features. The time of scanning the master template for the subsequent identification of persons was measured, as well as the number of erroneous acceptances and rejections of the user, or failure to read the user. The FAR and FRR values were subsequently calculated from these measurements, see Figs. 1 and 2. Fig. 1 shows the values measured on the scanning device MultiBio 700.

The probability of erroneous rejection (Zhang, 2000) on MultiBio 700:

$$FRR = (NFR/NEIA) \cdot 100\ [\%], \tag{1}$$

NFR – Number of False Rejections; NEIA – Number of Enrolled Identification Attempts; $FRR = (315/1560) \cdot 100\ [\%]$; $FRR = 20.19\%$.

The probability of erroneous acceptance (Zhang, 2000) on MultiBio 700 is determined by the relationship:

$$FAR = (NFA/NIIA) \cdot 100\ [\%], \qquad (2)$$

NFA – Number of False Acceptances; NIIA – Number of Imposter Identification Attempts; $FAR = (76/1560) \cdot 100\ [\%]$; $FAR = 4.87\%$.

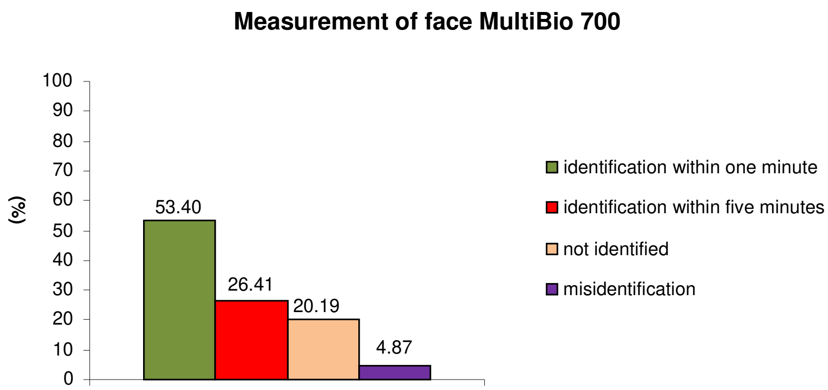

Figure 1. Identification capability of the MultiBio 700 biometric device.

Fig. 2 shows the measurements on the iFace 302 scanner, on which the resulting values were even less acceptable in comparison with the previous reader. A mere 53.4% of users were successfully read into the system and admitted into the building. Also, the value of more than 26% for both scanners, meaning successful identification taking up to 5 minutes, is highly uncomfortable from the user perspective.

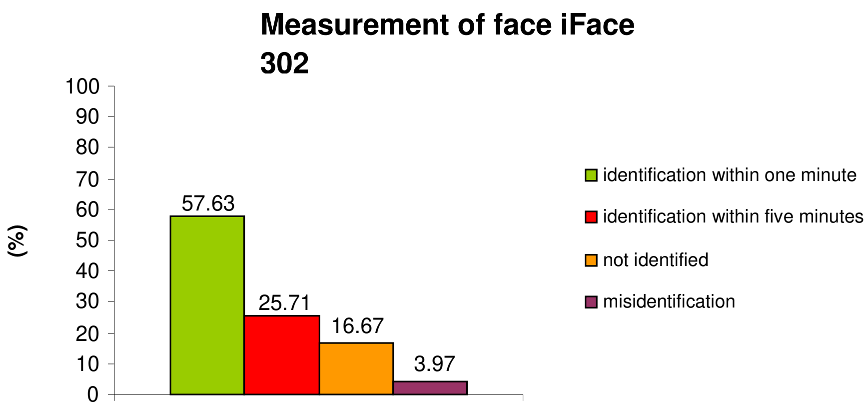

Figure 2. Identification capability of the iFace 302 biometric device.

The probability of erroneous rejection (Zhang, 2000) on iFace 302:

$$FRR = (NFR/NEIA) \cdot 100\ [\%],$$

$FRR = (260/1560) \cdot 100\ [\%]$; $FRR = 16.67\%$.

The probability of erroneous acceptance (Zhang, 2000) on iFace 302 is determined by the relationship:

$$FAR = (NFA/NIIA) \cdot 100\ [\%],$$

$FAR = (62/1560) \cdot 100\ [\%]$; $FAR = 3.97\%$.

From the calculations and their graphic expression, we can see that the percentage of erroneous rejections of users slightly exceeds the percentage of erroneous acceptances. However, both of these values are highly discomforting, and it is necessary to consider whether it is appropriate to use these systems for granting entry into important buildings. From the measured results, it is evident that it is continuously necessary to improve systems for identification on the basis of facial features.

A measurement was also conducted on the error rate of existing systems without an LED chiaroscuro, and with a chiaroscuro via a LED diode. The measurement was conducted on 78 subjects and with 20 periods. The measurement was completed after the elapse of one minute from the beginning of scanning at the latest. From the results presented in Fig. 3, it appears that the additional chiaroscuro of the LED diode accentuates the contours of the face and thereby increases the effectiveness of reading facial features, accelerating user identification.

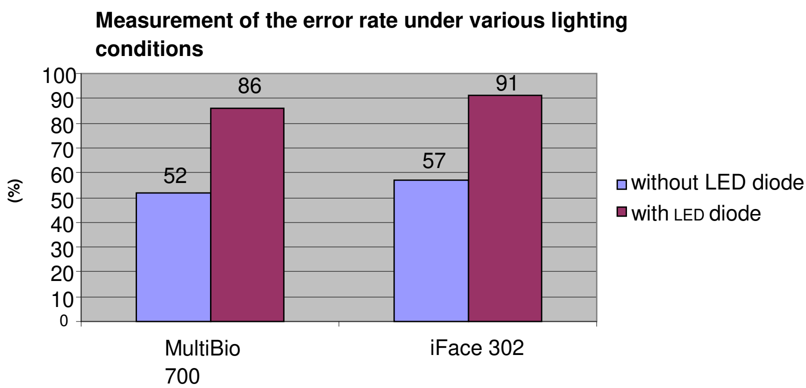

Figure 3. Identification capability under various lighting conditions.

The same photographs are show on Fig. 4. On the right side, there is photography with LED illuminator and on the left side without LED illuminator. The figure shows that the LED illuminator identification points are more visible. Due to this phenomenon, the success of correct identification is increased, as is evident from Fig. 3.

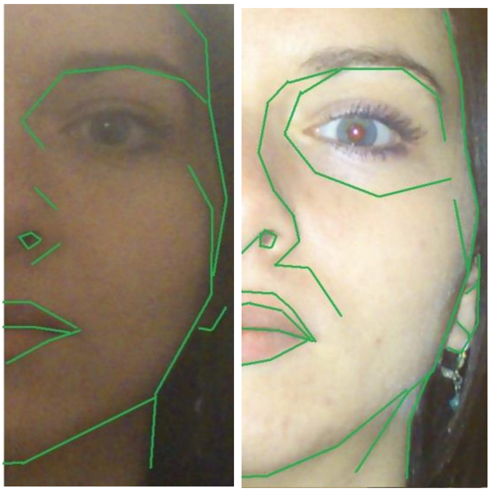

Figure 4. Identification capability under various lighting conditions.

DISCUSSION

Upon purchasing a biometric identification system, it is first of all necessary to consider how important the guarding of access is for the organisation or institution in question, since individual devices vary considerably in terms of price. For monitoring attendance or safeguarding a regular company, a higher quality fingerprint scanner is sufficient. This identification is very quick; the problem resides in very easy falsification of fingerprints. For superior protection, it is more appropriate to use systems which are tested in both laboratory and in regular conditions. These systems include, for example, readers of the iris, retina, bloodstream of the hand, etc. It is naturally mainly at the discretion of each company as to how much it intends to invest in protecting access and data. The measurements demonstrated an error rate and deficiencies of the two systems for reading facial features, and the only question is whether these deficiencies are a common feature of these biometric access systems.

CONCLUSIONS

The measured values demonstrated that identification on the basis of facial features is very imperfect. Two scanners from different manufacturers were tested, and the results were very similar. The determined error rate values in the case of both erroneous acceptance and erroneous rejection of the user were around 5%, which is a relatively high risk for the protection of valuable information and items.

Thanks to the conducted tests, modifications have been developed, which partially eliminate certain deficiencies of the tested systems. It was determined that with the help of a chiaroscuro the contours of the face are accentuated and sharpened better than with the existing systems, which do not have a chiaroscuro. It is necessary to constantly continue the development and innovations of biometric identification systems, since the present state is not yet error-free.

ACKNOWLEDGEMENT. This is a project supported by the Internal Grant Agency of the CULS (31170/1312/3119).

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Agronomy Research **12**(3), 895–906, 2014

Exposure to high or low frequency noise at workplaces: differences between assessment, health complaints and implementation of adequate personal protective equipment

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Abstract. Employees are exposed to high and low frequency noise which may cause different health effects. Hearing loss first occurs in the high frequency range, low frequency usually causes sleeping disturbances and annoyance. TES 1358 sound analyzer with 1/3 octave band was used to measure the equivalent sound pressure level, the peak sound pressure level, and the noise frequency spectrum at different workplaces. All the results were compared to Estonian and International legislations. High frequency noise was studied in metal, electronics and wood processing industries. The results showed that in several cases, the normative values were exceeded and the highest values appeared in the range of speech frequencies. Frequency analysis indicated that the noise level spectra at work stations of various machines differed in patterns. The low frequency spectra on a ship showed peaks in the frequency range of 50…1,250 Hz. Most employers provided workers with personal protective equipment against noise, but when selecting ear muffs, noise frequency had not been taken into consideration and therefore workers in the same enterprise used similar ear muffs. Knowledge of the prevailing frequencies assists to decide which ear protection should be used to avoid damage. An adequate hearing protector device can reduce the noise exposure significantly.

Key words: Noise, frequency analysis, PPE, occupational hazards.

INTRODUCTION

The human perception of sound is between 20…20,000 Hz. The ear is most receptive in the range of 500…8,000 Hz, so called acoustical window, even though the most sensitive range of hearing is 1,000…4,000 Hz (Salvendy, 2012) and the spectrum of human speech ranges in the frequency region of 250…6300 Hz (Cox & Moore, 1988).

Health effects from noise exposure have been studied by many researchers. Differences in complaints between low (20…500 Hz) (Alves-Pereira & Castelo Branco, 2007) and high frequency noise have been presented in several sources. Also it has been indicated, that hearing loss tends to occur in the range of high frequencies first (Salvendy, 2012). Industrial noise can mainly be characterized with high frequency noise, but also a considerable number of workers are exposed to low frequency noise on a daily basis. There is a general agreement that progression in hearing loss at frequencies of 500, 1,000, 2,000, and 3,000 Hz eventually will result in impaired hearing, i.e. inability to hear and understand speech (Johnson et al., 2001).

This is due to fact, that the range of 600…4,000 Hz has been considered to be the most important range for intelligibility (Savendy, 2012). For years there has been a debate considering the extra-auditory, subjective and biological effects – such as sleep disturbances, hypertension, noise-induced annoyance (Alves-Pereira & Castelo Branco, 2007), fatigue and lack of concentration. Also, complications in autonomic functions have been reported (in cardiovascular, endocrine and digestive systems), as well as problems with growth and immune system (Muzet, 2007). Noise induced complaints are distinguished by the frequency. For example, high frequency noise is mainly connected with hearing loss, hypertension and fatigue. Low frequencies are associated with different (often unexplained) problems such as feeling of annoying pressure or rumble in the ears (Walford, 1983). Recent studies also indicate that low frequency noise may have serious health effects such as sleeping disturbances (Waye, 2004), vertigo, stress, hypertension and heart rhythm disorders (Leventhall, 2003).

Studies have been conducted considering the subjective perception of loudness (loudness scaling) and objective measurements of auditory steady-state responses (ASSRs). Ménard et al., (2008) suggest, that the perception of sound with different frequencies (500 vs 2,000) differ insignificantly – test subjects have considered 500 Hz sound ‘comfortable’ if it is 59…62 dB hearing level (HL) and ‘loud’ if it is 76 dB HL or above. Yet it is indistinct whether the results of 2,000 Hz are really the same as suggested or differ approx. 10 dB as Allen et al. (1990) suggest.

According to Estonian regulations (EG, 2007), two action levels have been established. With the daily noise exposure level *(L_{EX}, 8 hours)* being between 80 dB(A) and 85 dB(A) hearing protection should be made available to employees who ask for it but it is not compulsory to wear. L_{EX} (8 hours) over 85 dB(A) employees must wear the hearing protection provided and employers need to offer training on correct use. The action values for ships (MSA, 2010) differ from the general values. The values for galleys and cabins vary from general ship values. The European Union (EU) directive (EC, 2003) introduces the similar concept of exposure limit values, taking into account the attenuation of the hearing protection, which cannot be exceeded. The exposure limit values correspond to an L_{EX} (8 hours) of 87 dB(A). No specific exposure limits according to octave band spectrum is provided. However, octave band analysis is necessary in selection of adequate personal protective equipment (PPE) as it is one of the most accurate methods to predict the attenuation of a PPE (Salvendy, 2012). The effectiveness of a PPE at different frequencies varies.

In order to reduce the negative effects of noise, adequate PPE is needed. There are four general types of passive hearing protection devices (HPD): earplugs, semi-insert or ear canal caps, earmuffs, and helmets. When selecting the most suitable PPE for each workplace, there is also a variety of parameters that need to be considered in addition to noise spectrum. In general, as a group, earplugs provide better protection than earmuffs below 500 Hz and equivalent or greater protection above 2,000 Hz. In the frequencies between, earmuffs have sometimes the advantage in attenuation (Gerges & Casali, 2007). If a PPE is provided with too little attenuation, protection might not be effective. On the other hand, too much reduction of the sound can have an isolation feeling which is risky, as employees may need to remove their PPE in order to communicate with colleagues. Also there is a danger in providing too much protection for listening out for safety warnings such as fire alarms or sirens from moving vehicles. A rule of thumb is not to reduce the level of sound at the ear below 70 dB(A). The adequate sound level at the ear is 70…75 dB(A) at the ear (National Research Council, 2010). Different action levels together with references are given in Table 1.

Table 1. Action levels of noise control with references

L_{EX}, dB(A)	Exposure time	Explanation	Reference
70 dB	24 h	Adequate to protect the most sensitive person at the most sensitive frequency	EPA, 1974
75 dB	8 h	Adequate to protect the most sensitive person at the most sensitive frequency (EPA, 1974), assuming that the remaining 1 hours are quiet. Equivalent sound level.	EPA, 1974
80 dB	8 h	Lower action value in EU: if daily noise exposure (8 hours/day) is 8 dB(A) or more, the employer shall make individual hearing protectors available to workers.	EC, 2003
85 dB	8 h	Higher action value in EU: if daily noise exposure (8 hours/day) is 8 dB(A), individual hearing protectors shall be used. It is also a widely used upper limit for exposure to hazardous noise in different countries including Estonia.	EC, 2003 EG, 2007
87 dB	8 h	Exposure limit value in EU: Above 87 dB(A), the employer is entitled to take immediate action to reduce the exposure to below the exposure limit values.	EC, 2003
90 dB	8 h	Exposure limit value in USA, Japan, Argentina.	I-INCE, 1997 OSHA, 29 CFR 1910.95

Comfort of PPE is crucial since PPE is only effective if it is worn by an employee continuously. During the fieldwork of our study many workers from different enterprises complained of the inconvenience of wearing a hearing protector. Individual preferences (e.g. wearing long hair, glasses or jewelry) and ear problems (e.g. irritation or earache) may affect the wearing of a hearing protection. It has been shown by Morata et al. (2001), that two of the reasons why workers did not wear their HPDs were (1) the interference with communication (70%) and (2) the interference with job performance (46%) by muffling certain sounds from machinery beyond detection. The working environment influences the choice of protectors as well – earmuffs may not be comfortable in high temperatures or humid conditions; earplugs may not be suitable for dusty environments, as the insertion of earplugs might be disagreeable due to possible absence of adequate sanitary conditions (Gerges & Casali, 2007).

The purpose of this study was to (1) analyze the spectrum of occupational noise; (2) give a literature review of the health complaints of workers who are exposed either to low or high frequency noise and (3) suggest the selection of adequate personal protective equipment (PPE) or other safety measures according to noise frequency.

METHODS

TES 1358 sound analyzer with 1/3 octave band was used to measure: (1) the equivalent sound pressure level; (2) the peak sound pressure level; (3) the noise frequency spectrum. The analyzer was held at a 1.55 m height from the floor, in the middle of a room or next to a working machine. Measurements with an A- and C-filter lasted for 30…60 seconds and were collected from different areas. All the results were compared to Estonian and International legislations.

The study was conducted on a research ship and in three industries - wood processing, metal and electronics. Noise from the machinery and equipment was measured and analyzed. The machinery and equipment used in companies were modern: either new or little-used. The ship on the other hand was built in 1974; its engine and auxiliary device had not been modernized.

RESULTS AND DISCUSSION

High frequency noise was studied in wood processing (company A), metal (company B) and electronics (company C) industries. The results showed that in several cases, the regulative norms were exceeded.

In wood processing industry, the exposure level normalized to a nominal 8 h working day varied from 72.8…90.9 dB(A). The highest noise levels were registered near the timber vats when the bench plane was in use (89.3 dB(A) and in the planing department (the bench planes operators' working stations (90.9 dB(A)). In other workplaces, the exposure levels did not exceed the Estonian existing norm – 85 dB(A), but in several places the results exceeded the second action level – 80 dB(A), when employer has to act on implementing safety control measures. The octave band frequency analysis (Fig. 1) of specific machines indicated that the noise spectra varied from one another in different frequency ranges.

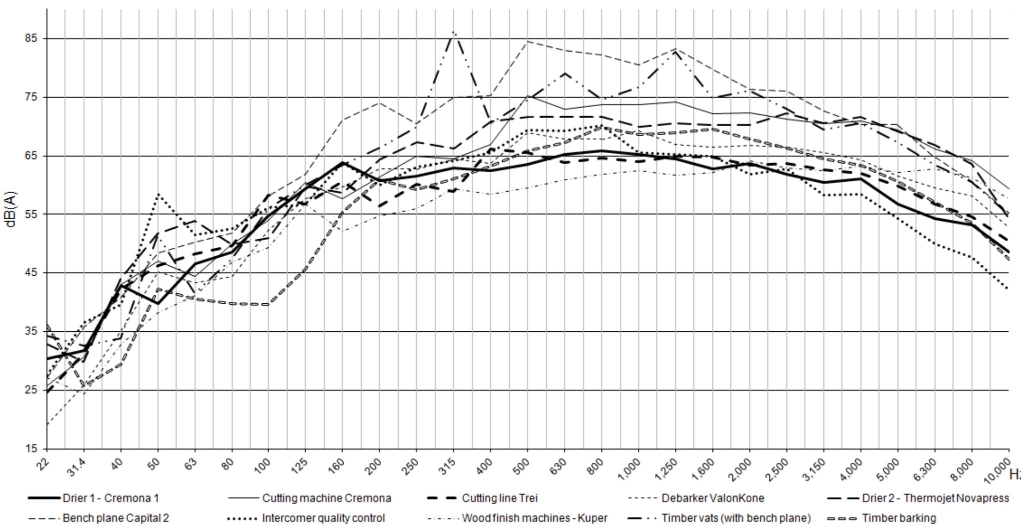

Figure 1. Noise frequency analysis, wood processing industry, Company A.

In many work stations in company A, the prevalent frequencies where the highest noise values appear are in the most sensitive range of human hearing (1,000…4,000 Hz) (Salvendy, 2012). Therefore the selection of most suitable HPD cannot be underestimated, for producing sufficient amount of attenuation. Also, the risk for overprotection has to be considered because it is crucial for the worker to hear safety signals and peers' warnings as many machines in wood processing industry involve sharp and rotating parts. Earmuffs or earplugs had been provided for company A workers. The selected PPE was with the highest attenuation number available to be sure they protect workers' hearing apparatus. The types and the attenuation data of the used HPD corresponding to frequency is presented in Table 2.

In company B (metal industry) the exposure levels normalized to a nominal 8 h working day were higher than in company A, varying from 84.1…100.4 dB(A). The highest noise level was registered in working station of Finnpower 6 punch press, but the measured noise levels depended on the material and workmode used.

Most machines in metal industry (except the punch press) produced high frequency noise, having peaks in 1,600…4,000 Hz, which is again in the sensitive range of human hearing (Fig. 2). In the enterprise B, only one sort of earplugs were available – EAR 3M E-A-Rsoft 'Yellow Neons'.

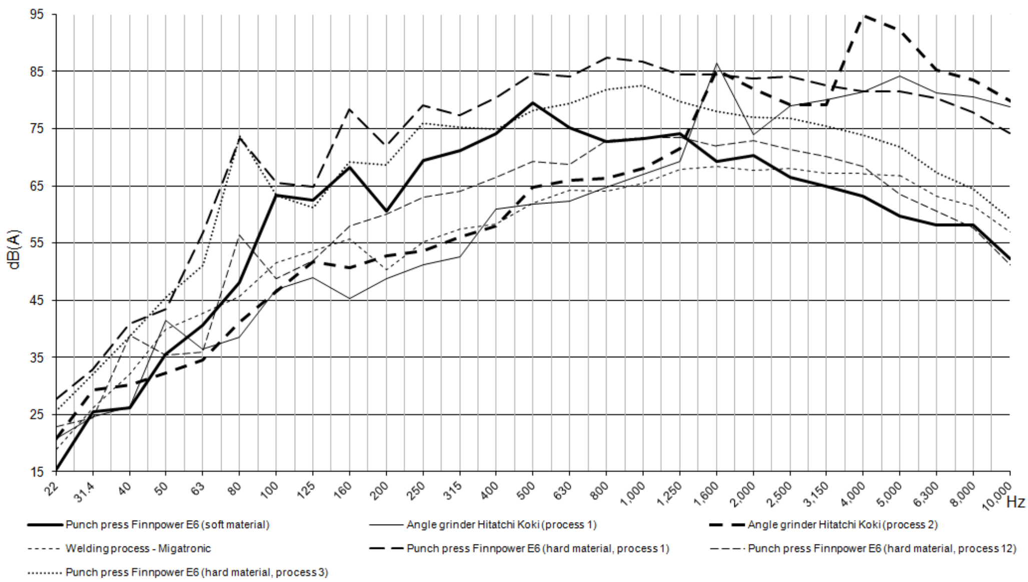

Figure 2. Noise frequency analysis, metal industry, Company B.

In company C the analysis was performed in a large production hall. Therefore, most of the workstations were influenced by noise produced by neighboring workplaces as the workstations were not separated. The exposure levels varied from 70.1 to 91.3 dB(A). All machines produced high frequency noise with clear peaks in the range of 500…6,300 Hz (Fig. 3). All employees of the company C owned similar earmuffs, the Peltor Optime 1^{TM} (3M, H510A), the same type was used in the company A.

Frequency analysis was also conducted on a fishing ship which was built in 1974. In the year 2009 the hold, galley and the main deck were renovated, but the other rooms were not modernized. The crew used earmuffs, but unfortunately it was not possible to identify neither the manufacturer nor the specifications of the earmuffs as the data was not identifiable anymore and the PPE itself was worn out.

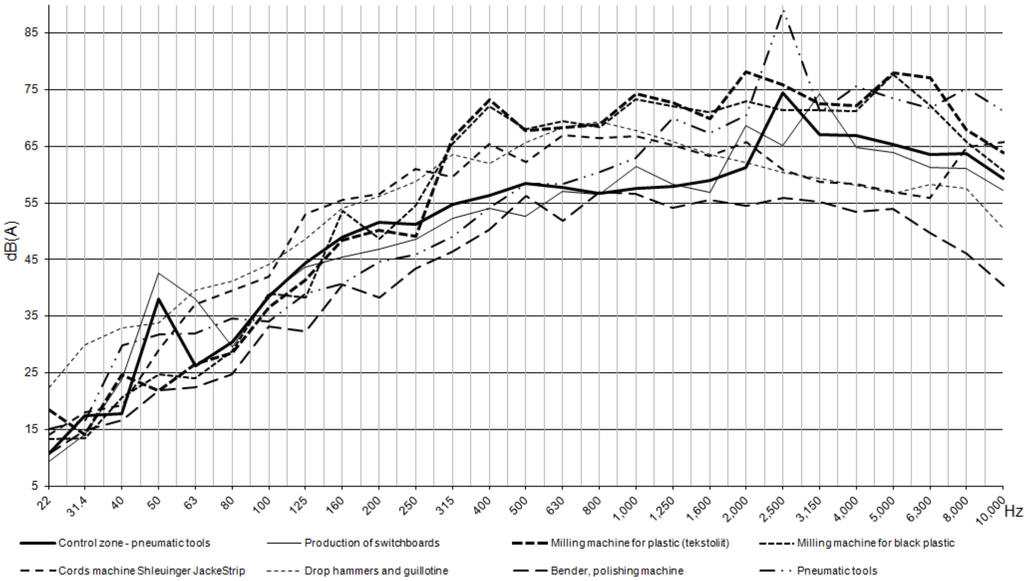

Figure 3. Noise frequency analysis, electronics industry, Company C.

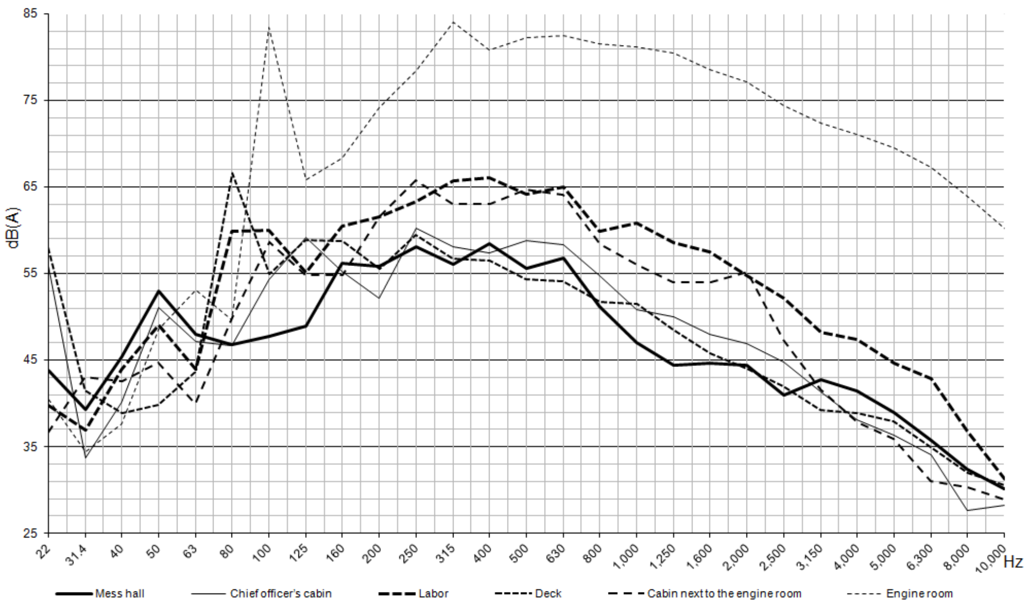

Figure 4. Ship, while anchored, noise frequency analysis.

The exposure levels normalized to a nominal 8 h working day varied from 42.0…101.4 dB(A) – the highest noise levels were measured in the engine room. On several cases (e.g. engine room, mess hall, cabins) the noise levels exceeded the national normative values. While anchored, the cabin next to the engine room had noise level of 72.1 dB(A) (peak at 250 Hz). The obtained result exceeded the 60 dB(A) normative value (MSA, 2010) by 12.1 dB(A). When sailing the noise level normative value was exceeded by 21.0 dB(A). Although the renovations done in 2009 did not include the crew's cabins, the noise measurements indicate that a widespread renovation is urgently needed. While anchored the engine room's noise level was 99.8 dB(A) (peak at 315 Hz) and during sailing 101.4 dB(A) (peak at 1,250 Hz). As there is no national normative value specifically for ship's engine rooms, the national general occupational noise normative value 85 dB(A) (EG, 2007) could be used. Our results correspond to the International Maritime Organization's recommended (IMO, 1981) values for engine rooms, which is 110 dB(A).

The 1/3 octave band frequency analysis showed that the auxiliary device (48 kW diesel generator) produced peaks in the range of 50…200 Hz, depending on the measurement point (50 Hz in mess hall, 100 Hz cabin next to the engine room). While anchored the occurring frequency range for the ship was 100…1,250 Hz (Fig. 4) and during sailing 80…400 Hz (Fig. 5). The figures indicate that most of the noise measured on the ship can be considered as low frequency noise.

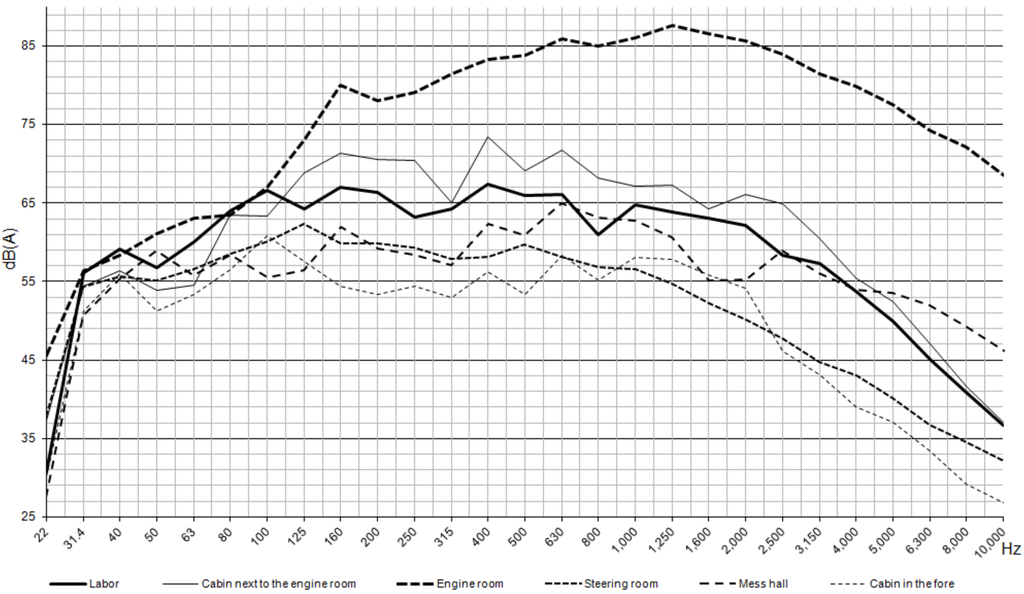

Figure 5. Ship, while sailing, noise frequency analysis.

Calculations of effectiveness of the PPE and selection of adequate PPE

Most employers provided workers with PPE against noise, but when selecting earmuffs noise frequency had not been taken into consideration and workers in the same enterprise used similar earmuffs. The current study resulted with counseling the enterprises on how to select the most suitable PPE for each workplace, based on the spectrum analysis.

For calculating the effectiveness of hearing protection the most common methods are: (1) Single number rating (SNR), (2) High, medium, low frequencies (HML) and (3) octave band method. In terms of accuracy in predicting the attenuation, the SNR method is the least accurate and the octave band is the most accurate, hence it is the preferred method (Salvendy, 2012).

Following octave band method, formula 1 was used to calculate the predicted level at the ear:

$$L'_A = \left(10\log \sum_{f=63}^{8000} 10^{\frac{L_f + A_f - APV_f}{10}} \right) + 4dB \quad , \tag{1}$$

where: L'_A – is the predicted A-weighted sound level at the ear; f – is the octave band centre frequency, Hz; L_f – is the measured octave band sound level in band f; A_f – is the frequency weighting for octave band f; APV_f – is the assumed protection value of the hearing protector for octave band f; 4 dB is added to allow for additional factors, such as badly fitted protectors.

The results are summarized in Table 2 and 3. As seen in Table 2, the L'_A values are much lower than the actual noise levels in the working places. It means that if workers wear HPDs properly and continuously during the working day, there is no high risk for hearing loss. However, while selecting earmuffs, not only the sufficient attenuation has to be considered, but also adequate hearing and understanding of the safety signals, peers' warnings and sirens from moving vehicles are crucial. Therefore, the sufficient level at the ear is 70…75 dB(A). Table 2 shows that in some workplaces, using earmuffs with a high attenuation value, could produce L'_A values as low as 42 dB (Bench plane Capital 2 in Company A) or 43 dB (welding process – Migatronic – in Company B). This however may lead to hazardous situations as workers may not hear safety warnings.

While selecting earmuffs and earplugs, in order to qualify according to other selection criteria as well, less attenuation can be recommended. While suppling the earmuffs and/or earplugs at least 2 different types should be provided in order to allow the employees to choose the most comfortable PPE. For example, instead of providing earplugs E-A-Rsoft 'Yellow Neons' (with SNR attenuation value of 36 dB), the company B can select E-A-Rsoft 21 (SNR = 21 dB) from the same manufacturer. The L'_A value would then be 70 dB for angle grinder Hitachi Koki workplace and 55 dB for welding workplace. For Punch press Finnpower 6, earplugs called E-A-R Pro-Seals would be effective with the L'_A value of 68 dB.

Company A may choose Earline 30214 model with SNR = 29 dB. Following the octave band method, the L'_A value for cutting machine Cremona would be 56 dB, the bench plane Capital 2 63 dB and for timber vats with bench plane 59 dB.

For company C, suitable earmuffs from the same company are for example Ultra 9000 (SNR = 22 dB), which gives following L'_A values: milling machine (textolite) 64 dB, milling machine (black plastic) 61 dB and pneumatic tools 61 dB.

To adjust the attenuation of an HPD to a particular noise problem (e.g. for different exposures in the same company), new earplug designs have been developed. Those may give the user some control over the amount of attenuation. These devices incorporate a leakage path that can be adjusted via a valve. One example is Variphone Earplug (NAL, 2007) which has the maximum attenuation of 34 dB, but can be reduced to 3 other levels: 30, 25 and 20 dB. Following octave band method, Variphone Earplug adjusted to 20 dB, is suitable for company A, having L'_A as follows: 64 dB for

Cutting machine Cremona, 72 dB for Bench plane Capital 2 and 65 dB for Timber vats with bench plane. Controlling the effectiveness of each octave band, the noise level by single frequency was not over 71 dB. When needed, the earplugs can be adjusted to 25 dB attenuation level.

Table 2 Attenuation of noise while using existent PPE (for all workplaces in companies A, B and C, noise level exceeding 85 dB(A))*

Co.	Work-place	PPE used	L_{EX}, dB(A)	L_L, dB(A)	L'_A, dB(A)	L_R, dB(A)
A	Cutting machine Cremona	PPE1	84.9±1.7	85	55	70…75
A	Bench plane Capital 2	PPE2	90.9±2.1	85	42	70…75
A	Timber vats with bench plane	PPE1	89.3±1.7	85	57	70…75
B	Angle grinder Hitachi Koki	PPE3	95.0±2.1	85	62	70…75
B	Welding process – Migatronic	PPE3	86.9±1.8	85	43	70…75
B	Punch press Finnpower 6	PPE3	100.4±2.2	85	61	70…75
C	Milling machine (textolite)	PPE2	87.8±1.7	85	55	70…75
C	Milling machine (black plastic)	PPE2	91.3±2.1	85	52	70…75
C	Pneumatic tools	PPE2	89.4±1.7	85	51	70…75

*Co. – company; L_{EX} – measured daily noise exposure level; L_L – noise level set by legislation; L'_A – the predicted sound level at the ear with attenuation; L_R – recommended level at the ear, derived from Table 1; PPE1 – Earline 30205 earplugs, PPE2 – Peltor Optime I earmuffs, PPE3 – E–A–Rsoft 'Yellow Neons'

In company B, Variphone Earplugs are effective when adjusted to 20 dB for working with angle grinder and in welding workplaces (L'_A respectively 74 dB and 55 dB). When adjusted to 25 dB the earplugs are effective for Punch press Finnpower 6 (L'_A: 71 dB). Controlling the effectiveness of each octave band, the noise level by single frequency was not over 71 dB in angle grinder and welding workplaces and 69 dB in punch press workplace.

In company C, adjustment to 20 dB is enough as the L'_A-s are 61 dB for milling machine (textolite), 62 dB for milling machine (black plastic) and 59 dB for pneumatic tools.

As the earmuffs used on the ship were unidentifiable, the octave band method was not applicable to evaluate the attenuation of the HPDs. Calculations with octave band method show that using a random HPD may not give the worker enough protection. When using E-A-R E-A-RFLEX 14 Earplugs (SNR= 14 dB) the attenuation is not enough in several cases when comparing to normative values or to the recommended noise levels at the ear (shown in Table 3). When using different earmuffs (ULTRA 9000 earmuffs SNR = 22 dB), the L_R is exceeded only in the engine room with

L'_A 73.8 dB(A). PELTOR^TM OPTIME^TM I – P3* earmuffs (SNR = 26 dB) will give the worker enough protection against noise but over attenuation problem arises. Despite the fact that each task needs individual HPD which can be provided, the renovation of the outdated parts of the ship are necessary.

Table 3. Attenuation of noise on a ship during sailing while using specific PPE

Work-place	L_{EX}, dB(A)	L_L, dB(A)	L'_A, dB(A) PPE 1	L'_A, dB(A) PPE 2	L_R, dB(A)
Cabin next to the engine room	81.0±2.0	60	67.6	54.9	60**
Engine room	101.4±2.2	110 85	81.2	67.7	70
Steering room	71.9±1.8	85	57.9	46.1	70
Mess hall	70.9±1.8	65	58.5	44.9	65**
Cabin in the fore	68.5±1.7	60	53.1	42.0	60**

L_{EX} – measured daily noise exposure level; L_L – noise level set by legislation; L'_A – the predicted sound level at the ear with attenuation; L_R – recommended level at the ear, derived from Table 1; PPE1 – E-A-R E-A-RFLEX 14 Earplugs (SNR=14 dB); PPE2 – PELTOR^TM OPTIME^TM I – P3 earmuffs (SNR = 26 dB)*
**According to the legislation (MSA, 2010).

There are several aspects to consider when implementing a plan for noise reduction in the workplace. This includes noise control, audiometry, training of staff, selection of appropriate PPE. Authors would like to emphasize that a PPE is only the 'first aid' measure until it is possible to reduce the noise exposure by other means such as engineering control methods or administrative controls. Even when selected and applied properly the effectiveness of hearing protection will always depend on human behavior.

The fact that employees wear ear protection does not necessarily mean that workers are protected against noise. The results of Kotarbińska & Kozłowski (2009) showed that for 18.7% of the tested workers wearing earmuffs the equivalent A-weighted sound pressure levels under earmuff cups were higher than 80 dB(A) and for 7.7% of workers higher than 85 dB(A). One reason for the higher noise level at the ear can be caused by incorrect usage of earmuffs. Therefore, knowledge of the prevailing frequencies assists to decide which PPE should be used to avoid ear damage.

The comparison of health effects from different noise frequencies has been brought out in the introduction section. Several researches have demonstrated that different frequencies produce different health complaints. In the current study, the specific complaints were not investigated and no questionnaire was conducted. This remains for the future research.

CONCLUSION

The general purpose of this article is to show that with a little application of knowledge the effectiveness of hearing protection can be increased significantly.

In all studied companies (A, B, C), workplaces existed, where exposure levels to noise were over 85 dB(A), which is the current normative according to Estonian legislation. In wood processing, metal and electronics industry high frequency noise dominated. On the ship, low frequency noise dominated. Until appropriate engineering controls are applied several workers have to use hearing protection devices.

The study demonstrates, that although conventional HPDs provide sufficient protection for most noise exposures, a potential disadvantage of over attenuation may emerge. The user's speech communication with peers can be disturbed due to the static nature of the attenuation. Also the risk to miss safety signals and warnings exists. In the current study, PPE with less attenuation or adjusted attenuation were recommended as it is important to assure that the extent of the attenuation of PPE does not overprotect the user.

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Agronomy Research **12**(3), 907–914, 2014

Utilisation of tactile sensors in ergonomic assessment of hand–handle interface: a review

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Abstract. Many ergonomic studies deal with comfort or try to find optimal parameters for tool design. Most of these studies also emphasise the importance of coupling between hand and handle. In order to collect objective data about hand–handle interface pressure, tactile sensors can be used. A trade-off between sensor dimensions, sensel density, robustness, and accuracy must be considered while choosing between commercial tactile sensors for ergonomic investigations. Based on literature from the last two decades, the main aspects of tactile sensors usage are highlighted.

Key words: hand–handle interface, force sensitive resistors, pressure mapping.

INTRODUCTION

Hand-handle interface is the link between the human and the equipment in a work system (Grandjean & Kroemer, 1997; ISO 26800). Therefore, the fit between the human hand and the tool handle is of particular interest of ergonomic intervention. Data about human abilities, limitations and variability must be quantified and applied to the design in order to improve compatibility between the two elements of the work system. Problems arise when trying to quantify experiences such as comfort. First, comfort is highly subjective; second, it is by nature a binary function; and third, human ability to make long term predictions about gripping comfort is doubtful. People tend to overestimate their tolerance of externally applied surface pressure to an extent that could cause tissue damage (Fransson-Hall & Kilbom, 1993). Moreover, the blood flow in the human palm does not correlate with the pressure-pain threshold (Johansson et al., 2002). Therefore, Strasser & Bullinger (2007) suggest a synergism of objective and subjective assessment methods, but assert that data from subjective methods is not reliable and concrete.

There are objective criteria for ergonomic quality assessment due to knowledge about pressure-pain tolerance (Fransson-Hall & Kilbom, 1993), pressure discomfort threshold values (Johansson et al., 1999), and the relationship between blood flow and externally applied pressure (Johansson et al., 2002). In the presence of such criteria, one could find sensors to satisfy said criteria.

Usability of the criteria for interface pressure measurement sensors can be summarized on the basis of Ferguson-Pell et al. (2000), Memberg & Crago (1997) and

Wang et al. (2007). In general, sensors should be: robust in construction, flexible and wearable by design (must not restrict movements or interfere with other sensors), small (≤10 mm in diameter), thin (1 mm thick), high in accuracy (in sense of linearity, hysteresis, repeatability, time constant, effects of temperature, humidity, or curved surfaces), range at least to 50 N, resolution 1 N, able to measure both shear and normal force, low cost, able to allow fast and easy calibration.

In this review, operational issues of capacitive tactile sensors and piezoresistive tactile sensors in hand-handle interface pressure measurement are examined.

Properties of the sensors

In the case of capacitive sensors, a pressure-sensing element (dielectric material between two layers of conductive material) is sandwiched by elastic synthetic layers. Pressure applied to the sensor will reduce the gap between the layers of conductive material and thus change the sensor's output. A piezoresistive tactile sensor consists of a layer of pressure-sensitive ink (pressure sensitive element), which is applied on conductive material (leads). The leads and the pressure sensitive element are then sandwiched by elastic synthetic layers. Only one manufacturer (Novel Gmbh, Germany) of capacitive sensors was mentioned in the scientific literature while three manufacturers (Tekscan Inc, USA; InterLink Electronics, USA; Verg Inc, Canada) were mentioned in the case of piezoresistive sensors.

Sensors for interface pressure measurement come either in the form of a single sensor or a sensor matrix. In case of a sensor matrix, flexible tactile sensors as thin as 0.1 mm are printed on polyester sheets either horizontally or vertically. When two sheets are laminated together, the intersections of horizontally and vertically printed tactile sensors create a sensing element (sensel). Therefore, most commercial sensor matrixes have higher sensel density than single sensor arrays. Utilisation of sensor matrixes also allows to acquire data about applied force, pressure and contact (see Fig. 1).

Sensors can be applied either on a tool handle, hand or a glove. A sensor matrix is usually shaped as a simple rectangle which limits its applications in hand-handle interface measurement. Handles are usually not shaped as simple cylinders. More complex handles will cause sensors to bend or wrinkle. Bending induced noise has been reported by Kutz et al. (2007), Wang et al. (2007) and Lemerle et al. (2008). Therefore, a more complex form of sensor is needed to conform with non-cylindrical or cone shaped handles. Both Novel Gmbh (Lemerle et al; 2008) and Tekscan Inc (Wang et al., 2007; Mastalerz et al., 2009; Vigouroux et al., 2011) produce sensor matrixes where the sensing regions are allocated so that they can be positioned individually. Regions allocated in such a way can be applied to a bare hand or a glove. An example of a sensor matrix with 18 sensing regions (Tekscan 4256) is shown in Fig. 2-B. Another approach is to use a trimmable sensor matrix. However, bending or wrinkling seems to be a concurrent phenomenon in the case of sensor matrixes.

Bending also affects single sensors. Jensen et al. (1991) reported a difference in sensor response between finger and flat surface applied sensors. Fergusson-Pell (2000) states that the effect of curvature becomes evident with radii greater than 32 mm. To avoid bending, it has been suggested to make sensors more rigid. For this purpose, an epoxy dome (Jensen et al., 1991), epoxy dome and base plate (Vecci et al., 2000), epoxy dome and steel base plate (Kargov et al., 2004; Pylatiuk et al., 2006), or fibreglass resin dome (Hall et al., 2008) are used. However, this approach could affect dexterity and be in conflict with sensor usability criteria defined above, but according to Jensen et al. (1991), the sensors were able to conform to the shape of the finger after attaching epoxy domes.

Calibration procedures are shown to have a significant impact on the resolution of the measurement system (Lemerle et al; 2008) and accuracy (Giacomozzi, 2007). Some researchers do not explain calibration methods clearly, but it is common to use a dynamometer (Radwin et al., 1992), known weights (Fellows & Freivalds, 1989; Komi et al., 2006), load cells (Bishu et al., 1993; Vecchi et al., 2000; Kong & Lowe, 2005), a laboratory scale (Kargov et al., 2004), a pneumatic calibration rig (Gurram et al., 1993; Buis & Convery, 1997; Wimer et al., 2004), or a pressure algometer (Hall 1997). Load cells seem to be the most user friendly option in the case of single sensors. The outputs of the sensor and the load cell can be measured simultaneously which allows for fast and easy data collection and linking. In order to simultaneously load and calibrate all sensels, a pneumatic calibration rig or a bladder should be used in the case of sensor matrixes. According to Tekscan's literature, a process of equilibration must be carried out prior to calibration. After equilibration, one could either proceed to calibrate the sensor matrix using known weights or continue to use a pneumatic calibration rig. However, calibration with known weights is reported to be time-consuming and sometimes uncalibrated raw sensor values are used (Hendrich et al., 2010).

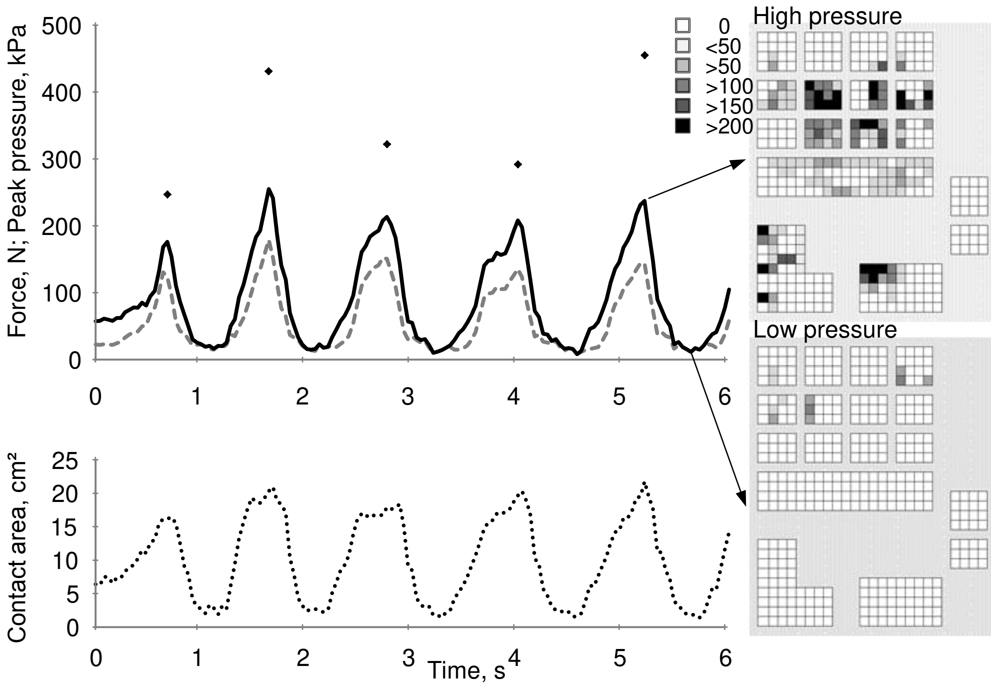

Figure 1. Sample analysis: work cycles (truns) while operating a screwdriver: dots – peak pressure on hand; solid line – force applied by whole hand; dashed line – force applied by fingers; dotted line – contact area; on the right, two GUI outputs are shown (high and low pressure frames), note that sensor regions correspond to Fig. 2-B (Own source, unpublished data).

A change in the sensor output in response to constant weight, force or pressure is called either 'drift' or 'creep'. Hollinger and Wanderley (2006) state that due to resistance drift, force-sensing resistors cannot be used in absolute measurements of force. Wang et al. (2007) are less strict and admit that 'measurement results are acceptable when the force value accuracy is not strictly required'. Komi et al. (2007) argued that drift should not be a problem in grip assessments as the locations and the magnitude of applied force change relatively quickly (see Fig. 1). Sensor output is also sensitive to temperature changes, but this is not a problem in a controlled laboratory environment.

Vecchi et al. (2000) found robustness to be a limiting factor of the Teskscan Flexiforce sensors' (single sensors) usage as the two layers of polyester come detached after numerous tests. Björing et al. (2002) experienced sensor breakdown, Fernandes & Chau (2008) had problems with acquisition of software and unspecified data loss was reported by Lowe and Kong (2007). Therefore, missing or corrupt data is a rare occasion.

Vecchi et al. (2000) conclude that Tekscan Flexiforce sensors 'can overcome some of the common problems of the FSR sensors, especially in terms of linearity, repeatability, and time drift'. Specification of the Tekscan Flexiforce A201 allows $< \pm 3\%$ error in linearity, $< \pm 2.5\%$ in repeatability and drift, $< 5\%$ per logarithmic time scale. Fergusson-Pell et al. (2000) found the drift of 1.7–2.5% per logarithmic time scale, while Hollinger & Wanderley (2006) reported 10.3–11.4% and 4.1% drifts in a period of 240 and 1200 s, respectively. Fergusson-Pell et al. (2000) and Hollinger & Wanderley (2006) used sensors with a different range, therefore, it could be speculated that the drift in case of the Teskcan Flexiforce A201 could also depend on the ratio of applied weight to maximum range. Sensor output reached the level of 97.3% from the stable value in 300 s and 98.5% in 600 s (Fergusson-Pell et al., 2000), but 90% in 450 s (Hollinger & Wanderley, 2006). However, this matter needs further investigation.

Sensor mounting

In order to ensure quick evaluations, it is advised to attach sensors on a glove rather than palmar skin. This approach will allow the researcher to perform calibrations before the arrival of the test subject. Obviously one glove size does not fit all. It has been suggested that for precise measurement the glove should be tailored for the test subject (Castro & Cliquet, 1997). However, using three different sizes (Lu et al., 2008) is a more practical approach. Moreover, glove thickness has been proven to reduce grip force (Wimer et al., 2010). Also, it can be extracted from Pylatiuk et al. (2006) that accurate positioning can be ensured by attaching sensors directly to skin. Moreover, Castro & Cliquet (1997) point out that people do not use gloves while performing everyday tasks. Lowe et al. (2007) noted that in industrial settings workers wear gloves and changing the normal work gloves for their 'force glove' is not a problem. In conclusion, one should critically analyse whether to attach sensors directly to palmar skin or to gloved hand.

The number of single sensors used in ergonomic assessment ranged from four (Radwin et al., 1992) or five (Pylatiuk) to 20 (Kargov et al., 2004; Lowe et al., 2006; Pylatiuk et al., 2006) sensors. There were 29 different sensor locations found in 19 settings (Fig. 1-A). However, Fellows & Freivalds (1991) and Pylatiuk et al. (2006)

used two different settings in one study. Therefore, these 19 settings were extracted from 17 different studies.

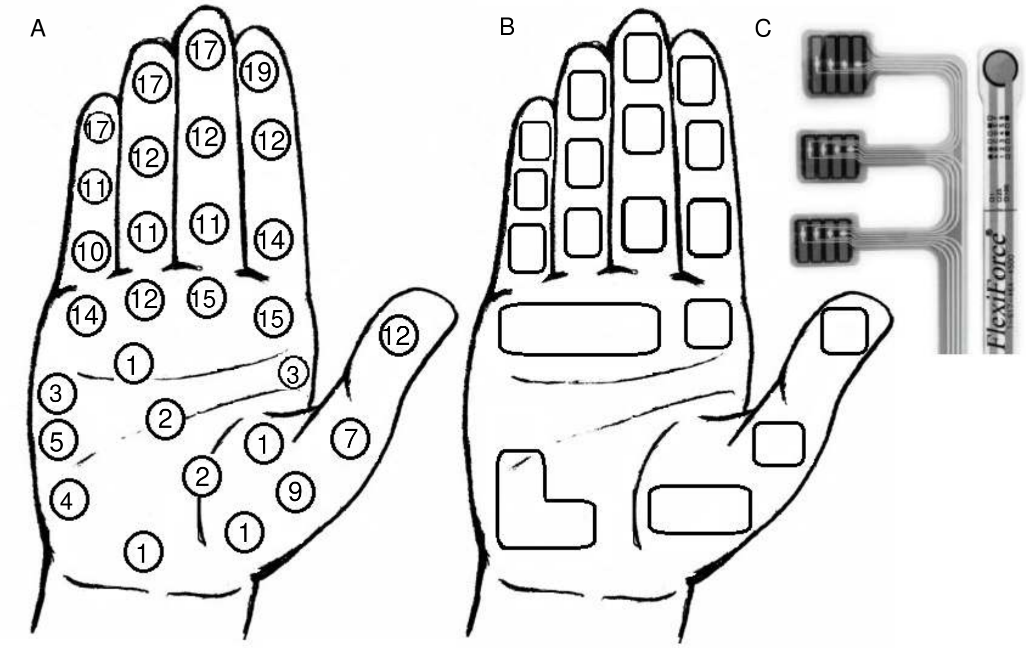

Figure 2. A) Distribution of the sensors, circles represent sensor locations in ergonomic studies, the numbers inside each circle represent the number of times the sensor location was used in 21 different settings; B) Locations of sensor regions of Tekscan 4256 (leads are now shown); C) Comparison of Tekscan sensors, three regions of 4256 (left) and Flexyforce A201 (right).

The number of sensors used in the study depends on the research object. The experiments of Radwin et al. (1992) and Pylatiuk et al. (2006) used four and five sensors, utilized pinch grip, and attached sensors only to distal phalanxes. A good example of a well-constructed measurement instrument is shown in a series studies by Kong (Kong & Freivalds, 2003; Kong & Lowe, 2005a; Kong & Lowe, 2005b; Lowe et al., 2006; Kong et al., 2007; Lowe et al., 2007a; Kong et al., 2008). The measurement instrument can be adjusted according to the researchers' needs by changing the number or locations of the sensors. Most studies by Kong et al. utilize 16 sensors (distal, medial, and proximal phalanxes and metacarpals of four fingers), settings with 12 or 20 sensors were used only once. Unique sensor locations are used in the studies of Hall (1997) and Björing et al. (2002) – only those two studies positioned sensors in the middle of the palm. Meanwhile, sensors were attached to the distal phalanx of the index finger in all measurement settings. The reason behind the relative unpopularity of the mid-palm area is mainly the object studied. In case of simple cylinder handle, the transverse metacarpal arch is not in contact with the handle, this is also demonstrated by Strasser & Bullinger (2007). However, in case of curved longitudinal contour, it may also be due to a connectivity issue. In order to attach a sensor in the middle of the palm area, the leads of the sensor must cross some other area on the subject's hand. It could restrict movement, impair dexterity, or interfere with other attached sensors which would conflict with the usability criteria.

Only a few studies reveal the reasoning behind chosen sensor locations. In the case of Fellows & Freivalds (1989; 1991), a pilot study was used. One had to grasp the tool handle after one's hand was dipped in finger paint. Areas of higher pressure were determined visually by change of paint coating on hand. Bishu et al. (1991) refers to an unpublished dissertation. Yun et al. (1992) refer to the above mentioned Fellows & Freivalds. Hall (1997) used the following criteria: 1) 'locations were expected to be exposed to pressure'; 2) locations had to coincide with a previous study about pain pressure threshold; 3) locations on the hand had to be evenly distributed.

Thenar region and the skinfold between the thumb and index finger are claimed to be the most sensitive areas of the hand (Fransson-Hall & Kilbom, 1993). However, according to the visualisation in Fig. 2-A, these areas tend to be underrepresented in ergonomic studies. There is no 'one and only' setting of sensor placement. If sensors (or sensor regions in case of sensor matrix) are attached to a glove, some of the hand surface remains uncovered. Thus, measured values tend to be underestimated (Kong & Lowe, 2005b).

CONCLUSIONS

Examples from scientific literature allow to conclude that state of the art pressure measurement sensors satisfy the criteria of usability. There are issues like sensor drift in curved surfaces that need further investigation as most ergonomic assessments deal with curved rather than plain surfaces. Attention should be paid to sensor selection. A trade-off between robustness, sensel density, sensor dimensions and wrinkling or induced accuracy loss is specific to handle geometry. A simple wet finger paint gripping test is most helpful for better understanding about hand-handle interface. Finally, interface pressure measurements are not yet an everyday tool for ergonomics research, but there is great potential for it to become one.

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Agronomy Research **12**(3), 915–924, 2014

Musculoskeletal symptoms, and perceived fatigue and work characteristics in supermarket cashiers

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Abstract. Working in the sitting position is often regarded as a cause for discomfort and pain in the musculoskeletal system. The aim of the present study was to evaluate musculoskeletal symptoms in different body regions in association with the perceived fatigue and work characteristics in supermarket cashiers, who are predominantly working in the sitting position. The subjects were 67 female supermarket cashiers with the mean (± *SD*) age of 33.5 years, body mass index (BMI) of 23.8 ± 0.4 kg m^{-2} and the working time of 9.7 hours a day. All subjects completed the standardized Nordic Questionnaire and self-administered questionnaire concerning cashier's work, bio-demographic variables and fatigue. The results of this study indicated that 86.6% of subjects reported experiencing discomfort at least in one body area. Musculoskeletal symptoms in the last 6 months were localized primarily in the lower back and neck regions (67.2% and 53.7%, respectively) and in the last 7 days also in the lower back (44.8%) and equally in the neck and wrist (40.3%). Correlation analysis showed that low back pain (LBP) perceived during the last 7 days was associated with knee pain ($r = 0.44$, $p < 0.001$). Last 6 months LBP was associated with shoulder ($r = 0.35$, $p < 0.01$) and neck pain ($r = 0.43$, $p < 0.001$) during last 6 months. On the other hand, no significant correlation emerged between LBP, fatigue and work characteristics (physical and mental fatigue after workday, rushing and monotony at work). From the cashiers, 80.9% had experienced rushing at work, while the majority of them (89.6%) felt physical fatigue after the workday, and 62.7% reported their work being monotonous. Approximately one-half of the subjects (49.3%) practiced recreational sport in their free time. It was concluded that in supermarket cashiers the highest prevalence rate of discomfort and pain was emerged in low back and neck, and they perceived rushing and monotony at work and physical and mental fatigue after the workday. Recreational sport can be recommended as a preventive activity for avoiding discomfort.

Keywords: discomfort, musculoskeletal symptoms, supermarket cashier, perceived fatigue, sitting position.

INTRODUCTION

Working for a long time in the sitting position is called 'forced position'. It has been suggested that prolonged working in forced position causes musculoskeletal disorders (MSDs) (Pensri et al., 2010). The European Agency for Safety and Health at Work has reported that in the European Union the relative prevalence rate of MSDs is the highest among service workers, and shop and market sales employees (Schneider et al., 2010). In Estonia, forced position is the main cause of occupational diseases according to the Estonian Health Board (2012).The field of service and sales holds the second place in the occurrence of occupational diseases in Estonia. In 2012 many cashiers claimed an occupational disease due to working in forced position. MSDs are also the main symptoms of work-related diseases (Estonian Health Board, 2012). The causes and occurrence frequency of MSDs among cashiers in Estonia has not been researched so far.

Working as a cashier in a supermarket does not usually require any specific skills – most cashiers are secondary school graduates –, and their income is low to moderate, depending on the sum of working hours. Cashiers' work conditions have received minimal attention and no specific measures have been taken for preventing work-related injuries. The work is monotonous and the employees are frequently exposed to manual handling tasks, such as lifting goods of different weight, and experience stress, especially at rush hours in the store. Cashiers' work is mentally fatiguing (Åhsberg, 2000; Vasseljen et al., 2001; DiDomenico & Nussbaum, 2008), while they manage cash and card payments, requiring extreme accuracy. Supermarket cashiers work for the whole day at the counter in the sitting position. They are affected by MSDs, because their body muscles are forced into one position at working time (Baron et al., 1992; Forcier et al., 2008). Previous studies have indicated that constant sitting affects mostly the neck and lower back region (Lehman et al., 2001; Beladev & Masharawi, 2011). Research results on musculoskeletal symptoms among supermarket cashiers have generally reported neck, shoulder, upper-limb and back pain (Baron et al., 1992; Lehman et al., 2001; Vasseljen et al., 2001; Violante et al., 2005), but also ankle-foot symptoms (Pensri et al., 2009). The most frequently affected body region is followed by low back (Violante et al., 2005), knees, hips, shoulders, head/neck, upper back, wrist/hands and elbows (Pensri et al., 2009).

Musculoskeletal symptoms, as work-related musculoskeletal discomfort and pain in different body regions are common complaints in individuals whose occupations are characterized by repetitiveness and monotonous work (Bernard, 1997). A screening examination performed by the occupational health care service on Swedish workers established that monotonous work was positively associated with neck and shoulder pain (Bernard, 1997), and repetitive tasks can be responsible for the high prevalence of lower back, neck and shoulder symptoms among cashiers (Lundberg et al., 1999). This is in accordance with a study that was also conducted in Sweden, showing the high prevalence (70%) of neck and shoulder pain during last 6 months (Rissen et al., 2002). Neuromuscular fatigue and discomfort are commonly perceived by cashiers in shoulder, low back and neck muscles (Nõu et al., 2011), cumulative local muscle fatigue may lead to potential risks for MSDs (Ma et al., 2013). Supermarket cashiers are generally known to be an at-risk population for MSDs (Forcier et al., 2008). However, the association of musculoskeletal symptoms with work-related characteristics in cashiers has not been well studied.

The aim of the present study was to evaluate the musculoskeletal symptoms in different body regions in comparison with perceived fatigue and work characteristics in supermarket cashiers who are working in sitting position.

MATERIALS AND METHODS

Subjects

Sixty-seven females, working as checkout cashiers in supermarkets, aged from 18 to 63 years (with mean ± *SD* age: 33.5 ± 12.8 years) participated in this study. The anthropometric and work experience characteristics of participants are presented in Table 1. The majority of the subjects (64) were right-handed.

Table 1. The anthropometric and work experience characteristics of participants (n = 67)

	Mean ± *SD*
Age (years)	33.5 ± 12.8
Height (cm)	165.4 ± 6.0
Body mass (kg)	65.1 ± 11.3
Body mass index (kg m^{-2})	23.8 ± 0.4
Years of work experience as a cashier (years)	5.3 ± 5.3
Working hours per day (hours per day)	9.7 ± 2.5
Working hours per week (hours per week)	37.2 ± 8.5

The subjects participated in the research voluntarily and the selection of cashiers was random. Approval for the study was obtained from the managers of the supermarkets, and from the Ethics Review Committee on Human Research, University of Tartu. Written informed consent for participation in the study was obtained from all participations.

Questionnaire

Cashiers received a self-administrated comprehensive questionnaire. In this study we used questions about demography (age, gender, height/weight), employment information (working experience as a cashier, number of daily and weekly working hours), psychosocial and work characteristics (fatigue, rushing at work, job dissatisfaction, monotony of work), and frequency of any exercise.

To assess MSDs were used the questions similar to the ones in The Nordic Questionnaire (NQ) (Kuorinka et al., 1987). NQ evaluates the frequency of musculoskeletal symptoms such as pain, tingling and/or numbness in six body regions (low back, neck, shoulder, elbow, wrist/hand, and knee) in two time periods: the previous seven days and the previous six months. A simple figure with six particular body parts in the questionnaire helped answerers to evaluate their MSDs.

The questionnaires were filled in at the workplace or at home. The subjects wrote the values of height and body mass themselves and the body mass index ($kg \cdot m^{-2}$) was calculated.

Statistical analysis

Means and standard derivations (± *SD*) of mean were calculated. Mann–Whitney *U*-test was used to determine differences in musculoskeletal symptoms. Linear correlations were calculated to observe the relationship between the received characteristics. A level of $p < 0.05$ was selected to indicate statistical significance.

RESULTS

The questionnaire was completed by 67 (55%) of the cashiers invited to take part in the research. All cashiers worked at the counter most of their work time. The mean number of hours worked per day was 9.7 ± 2.5 hours and per week 37.2 ± 8.5 hours, and 16.4% cashiers worked for more than 40 hours per week. All were female, with the mean age of 33.5 ± 12.8 years. The majority of them (38.8%) had worked as a cashier for 1–5 years, 32.8% for more than 5 years, and 25.4% for less than one year.

The majority of subjects (86.6%) reported experiencing discomfort and pain at least in one body area in the last 6 months, and 71.7% in the last 7 days (Table 2). Approximately 68.7% of participants had experienced musculoskeletal discomfort and pain at ≥ 2 anatomical sites in the last 6 months, and 56.8% in the last 7 days. Of those who reported pain in the last 6 months, 17.9% reported symptoms at ≥ 4 anatomical sites. Three body sites of pain per participant occurred most frequently both in the last 6 months and 7 days (23.9% and 20.9%, respectively).

Table 2. The number of body sites with musculoskeletal pain in the last 6 months and last 7 days ($n = 67$)

Number of body sites with pain	Last 6 months (%)	Last 7 days (%)
0	13.4	28.3
1	17.9	14.9
2	11.9	20.9
3	23.9	20.9
4	17.9	7.5
5	9.0	1.5
6	6.0	6.0

Musculoskeletal symptoms in the last 6 months were localized primarily in the lower back and neck regions (67.2% and 53.7%, respectively) and in the last 7 days also in the lower back 44.8% and equally in the neck and wrist 40.3% (Fig. 1).

The share of complaints about discomfort and pain in shoulders during the last 6 months was 43.3%, in the last 7 days 28.4%. In the 6-month period there was a high prevalence of discomfort and pain in the knee (38.8%), throughout the last 7 days it was 25.4%. Fewer complaints occurred in the elbow region. Subjects perceived significantly more discomfort and pain during the last 6 months compared to the last 7 days in low back (67.2% vs 44.8%, respectively; $p < 0.01$), in the neck (53.7% vs 40.3%, respectively; $p < 0.05$), and in the knee (38.8% vs 25.4%, respectively; $p < 0.05$).

Correlation analysis demonstrated that the last 6 months LBP is associated with 6 months neck pain ($r = 0.43$, $p < 0.001$) and with last 7 days neck pain ($r = 0.32$, $p < 0.01$) (Table 3). Last 7 days LBP is associated with last 6 months knee pain ($r = 0.39$, $p < 0.001$) and 7 days knee pain ($r = 0.44$, $p < 0.001$). Last 6 months LBP is associated with 6 months shoulder pain ($r = 0.35$, $p < 0.01$).

Last 7 days shoulder pain is associated with last 7 days elbow pain ($r = 0.44$, $p < 0.001$) and last 6 months elbow pain ($r = 0.36$, $p < 0.01$). Last 6 months elbow pain is associated with 6 months wrist/hand pain ($r = 0.36$, $p < 0.01$) and 6 months knee pain ($r = 0.31$, $p < 0.05$). Last 7 days elbow pain is associated with last 7 days knee pain ($r = 0.48$, $p < 0.001$), and last 7 days wrist/hand pain ($r = 0.54$, $p < 0.001$), and last 6 months wrist/hand pain ($r = 0.38$, $p < 0.01$). Significant correlation was noted between discomfort and pains in six different body regions occurring during the last 6 months and 7 days.

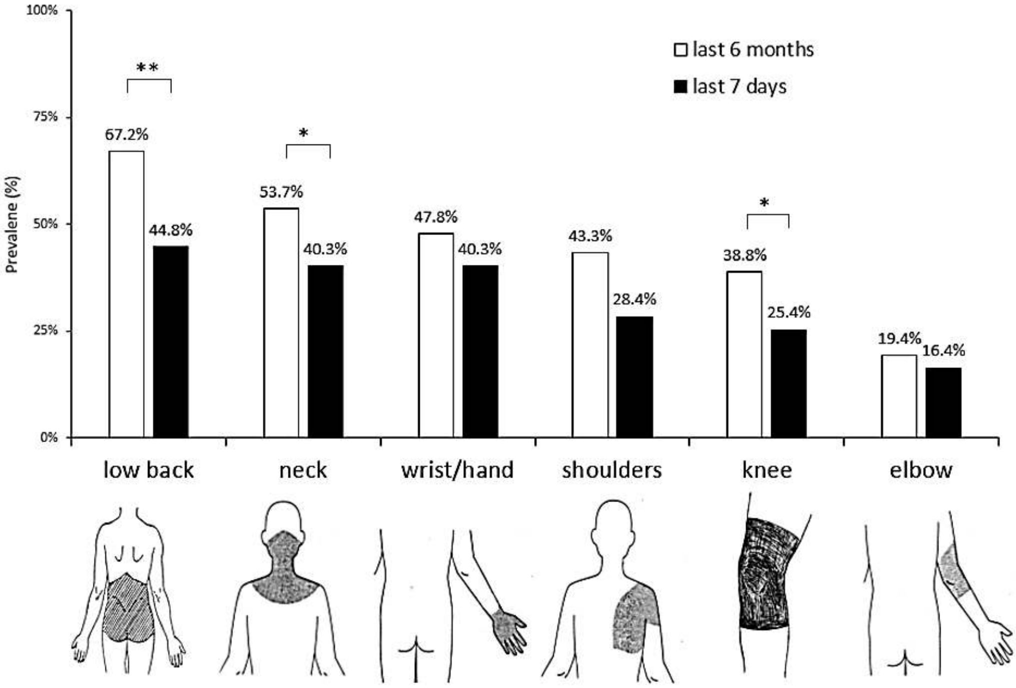

Figure 1. Prevalence (%) of musculoskeletal discomfort and pain in different body regions in the last 6 months and 7 days ($n = 67$); $*p < 0.05$; $**p < 0.001$.

During the workday, 80.6% of volunteers perceived rushing, while most of them (89.6%) felt physically fatigued after the workday and 76.1% felt mentally fatigued (Fig. 2). Despite being fatigued, 74.6% of cashiers are satisfied with their work, whereas 62.7% reported that their work is monotonous.

Table 3. Correlations between self-reported pain and discomfort in different body regions during last 6 months and 7 days in supermarket cashiers ($n = 67$). *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Variable	Low back, 6 months	Low back, 7 days	Neck, 6 months	Neck, 7 days	Shoulders, 6 months	Shoulders, 7 days	Elbow, 6 months	Elbow, 7 days	Wrist/hand, 6 months	Wrist/hand, 7 days	Knee, 6 months	Knee, 7 days
Low back, 6 months	1											
Low back, 7 days	0.44***	1										
Neck, 6 months	0.43***	0.23*	1									
Neck, 7 days	0.32**	0.18*	0.76***	1								
Shoulder, 6 months	0.35**	0.24*	0.27*	0.33*	1							
Shoulder, 7 days	0.09	0.30**	0.12	0.23*	0.59***	1						
Elbow, 6 months	0.10	0.01	0.08	0.14	0.26*	0.36**	1					
Elbow, 7 days	0.05	0.17	0.01	0.05	0.18	0.44***	0.70***	1				
Wrist/hand, 6 months	0.16	0.10	0.23*	0.31*	0.19	0.13	0.36**	0.38**	1			
Wrist/hand, 7 days	0.19	0.12	0.21	0.26*	0.20	0.23*	0.44***	0.54***	0.80***	1		
Knee, 6 months	0.30**	0.39***	0.19	0.16	0.17	0.25*	0.31**	0.23*	0.22	0.10	1	
Knee, 7 days	0.19	0.44***	0.13	0.15	0.18	0.24*	0.41***	0.48***	0.34**	0.22	0.66***	1

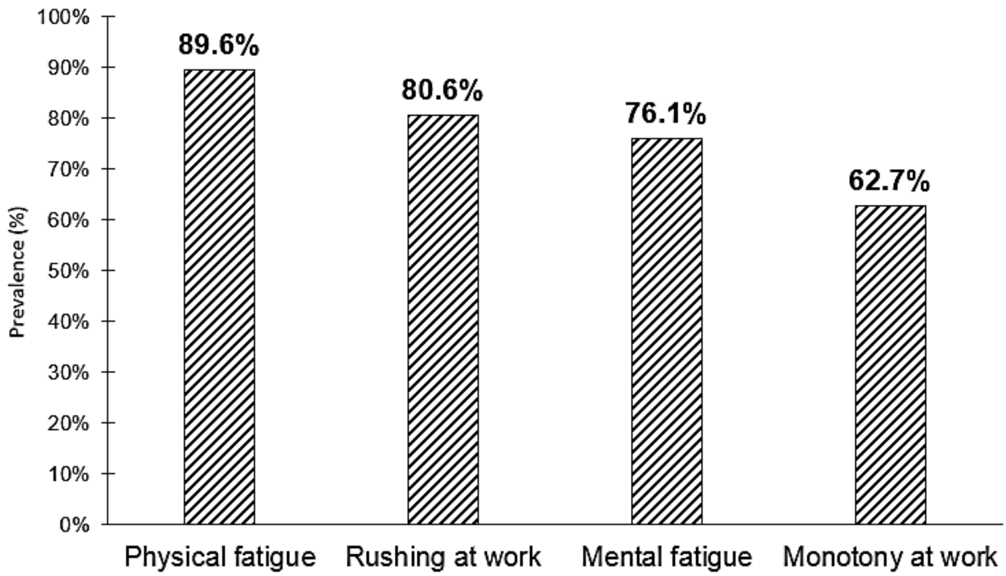

Figure 2. Prevalence (%) of subjectively perceived fatigue and work characteristics (*n* = 67).

No significant correlation was noted between discomfort, and fatigue and work characteristics (physical and mental fatigue after the workday, rushing and monotony at work), and between discomfort and work experience characteristics.

Approximately one-half of the subjects (49.3%) practised recreational sport in their free time, mainly running and aerobics. 34.3% of participants practised sport for 1–2 hours per week, 10.4% for 3–4 hours per week and for more than 4 hours per week only 4.5% of cashiers.

DISCUSSION

This study revealed, similarly to several other studies (Baron et al., 1992; Bernard, 1997; Lehman et al., 2001; Violante et al., 2005; Forcier et al., 2008; Pensri et al., 2009; Pensri et al., 2010; Beladev & Mashaeawi, 2011) that musculoskeletal symptoms are common among supermarket cashiers.

Participants in this study appeared to work the same or shorter hours during the week compared to their colleges in other countries. Cashiers in Estonia work on an average for 37 hours per week, while sales workers in the United Kingdom work an average 38–40 hours per week (Wardle et al., 2000). Cashiers in Thailand work on an average even 60 hours per week (Pensri et al., 2010). Despite the working hours per week are shorter in Estonia compared to Thailand, the working hours per day are similar – in our study cashiers worked on an average 9.7 hours per day, in Thailand 10.2 hours per day. Our study revealed that 16.4% of cashiers worked for more than 40 hours per week. The cashiers' income also depends on the number of working hours, so in order to earn more, the employees agree to do longer hours. However, prolonged work duration may place supermarket cashiers at high risk of musculoskeletal symptoms that was evidenced by their high prevalence rate.

Based on the self-reported musculoskeletal symptoms, the results of our study demonstrated that the majority of the subjects (86.6%) reported experiencing discomfort and pain at least in one body area in the last 6 months, and 71.7% in the last 7 days. Musculoskeletal discomfort and pain in the last 6 months in low back (67.2%) region indicated the highest prevalence of cashiers. The employees reported the high prevalence of neck (53.7%) and wrist/hand (47.8%) pain, the lowest prevalence was perceived in the elbow (19.4%). The prevalence of musculoskeletal discomfort and pain was higher in the last 6 months compared to the last 7 days in all body regions, whereas significant differences emerged in low back, neck and knee region. Consequently, chronic musculoskeletal symptoms prevail in cashiers over episodic symptoms. Our results are similar to the earlier data published by different authors. The United Kingdom Health and Safety Executive reported that out of cashiers who experienced work loss in one year due to musculoskeletal health problems, the occurrence percentages of affected body regions were low back (32%), wrist (28%), neck (21%) and shoulders (21%) (Lehman et al., 2001). Another study revealed that 57% of supermarket cashiers experience lower back pain, during a year (Spiers, 2003). Yet another study demonstrated that employees working in the sitting position are high prevalence in neck (56.7%) (Tsauo et al., 2007). In Thailand, a survey revealed that elbow pain (3%) is lowest in saleswomen who are standing for prolonged stretches of time (Pensri, et al., 2009). The occurrence of musculoskeletal symptoms in the elbow region seems to be lower compared to other often measured body regions in different worker categories, including cashiers.

In the present study, we found a very strong relationship between the last 6 months LBP and neck pain. Our data indicated that the last 7 days LBP is strongly associated with knee pain and 6 months shoulder pain. This means that LBP prevalence is associated with discomfort and pain in other body regions. Our study revealed that 86.6% of participants experienced discomfort and pain in 1–6 body areas, and most frequently three body sites of pain occurred per participant. Working in the sitting position caused more discomfort in low back and neck region, working in the standing position resulted in discomfort in lower limbs, and discomfort emerged also in knees.

This study demonstrated that approximately 90% of cashiers felt fatigued after the workday. The indicators of rushing at work (81%) and mental fatigue (76%) were also remarkably high. We found no significant relationship between discomfort and subjectively evaluated fatigue and work characteristics (physical and mental fatigue after the workday, rushing and monotony at work). The study of Lundberg et al. (1999) revealed that physical workload was not correlated with discomfort and mental fatigue of cashiers in Sweden. However, Skov et al. (1996) reported significant associations between neck, shoulder and low back symptoms and a range of psychosocial risk factors in salespeople in Denmark. Fatigue after the workday occurs due to reduced blood flow to muscles, therefore employees working in the sitting position and not doing physical hard work, feel highly fatigued at the end of the workday. Cashiers are socially active, their work is intensive, requiring verbal communication with many customers. This explains the high rate of cashiers' mental fatigue. The work of supermarket cashier includes the handling of a large number of items during the work shift, implying repetitive movements of the shoulders, arms and hands/wrists, and a high work rate. The work is associated with a high prevalence of disorders in the low back, neck and upper extremity (Kjellberg et al., 2012), as proved the results of this study. This study also revealed that cashiers are exposed to monotony at work (63%). Monotonous work, working in forced position and repetitiveness can cause MSDs (Bonfiglioli et al., 2007).

According to the results of this study, discomfort is not correlated with work experience characteristics. This finding contrasts the results of a previous study by Pensri et al. (2010), who reported significant association between the average working hours per day, working hours per week and prevalence of lower extremity symptoms. In our study all cashiers worked in the sitting position. This work posture puts high pressure on low back muscles and the correlation between working experience and discomfort could be possible. Cashiers in the Thailand study were exposed to prolonged standing, which requires the continuous contraction of number of muscles in the legs (Pensri et al., 2010).

Our study indicated that approximately one-half (49.3%) of subjects practiced recreational sport in their free time, mainly for 1–2 hours per week. Recreational sport is a good preventive activity to avoid discomfort (Hildebrandt et al., 2000).

In conclusion, the highest prevalence of musculoskeletal symptoms was noted in low back and neck regions, whereas the lowest prevalence was noted in elbow region. Cashiers perceived obvious physical and mental fatigue after the workday, rushing and monotony at work. The musculoskeletal symptoms in lower back region are significantly related with symptoms in other body regions (neck, knee, shoulder). This study indicated significantly higher prevalence of chronic musculoskeletal symptoms (reported during the last 6 months) in low back, neck and knee region compared to episodic musculoskeletal symptoms (reported during the last 7 days). However, no significant relationships emerged between musculoskeletal symptoms and perceived fatigue and work characteristics in this study.

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Agronomy Research **12**(3), 925–934, 2014

Air quality as an important indicator for ergonomic offices and school premises

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Abstract. The health risk assessment model for office rooms contains the physical indoor air factors and the risks connected with the use of computers. Four comfort classes have been postulated. Indoor air quality is the main risk factor at workplaces such as office rooms and schools besides non-ergonomic use of computers. High levels of carbon dioxide (CO_2) could be observed due to poor ventilation systems and inadequate air exchange due to inoperable windows. Overcrowded classrooms could also be the reason for a high CO_2 level. Lowering the occupancy and increasing the breaks between classes could alleviate the high CO_2 concentrations in schools and offices. The data of Estonian investigators are analyzed. Experiments for determination of the adequacy of ventilation rate and the respective build-up of CO_2 are carried out by the authors of the paper.

Key words: ergonomic workplace, indoor air, carbon dioxide, schools, offices.

INTRODUCTION

There are numerous hazards in the work environment (low temperatures, draught, high concentration of carbon dioxide, noise, etc.) that affect office workers and can damage the peripheral and central nervous system. Different hazardous factors (indoor climate, static posture, etc.) are influencing on the computer-workers. Workers and students spend about half of their waking hours at work or school (Koistinen et al., 2008). Therefore, the adequate air quality in schools and workplaces is a top priority for facility managers and building operating managers. The study of Myatt et al. (2002) found a relationship between sick leave absences and carbon dioxide concentrations in office buildings.

Computer-workers are under pressure as increasing amounts of work have to be done within limited time. Intensive use of computers causes major health problems like tissue damages, imbalance in blood flow, formation of the carpal tunnel syndrome (Oha et al., 2010). The interaction between the body and the work environment is complicated and four important systems (central nervous, automatic nervous, endocrine, and immune) are involved in this network (Raja et al., 1996). Stuffy air, noise, temperature, lighting deficiency might be the supplementary risk factors for developing musculoskeletal disorders (MSDs) and psychosocial stress at workplaces

(Tint et al., 2012a). The main physiological and psychological stress factor is a poorly designed workplace (Tint & Traumann, 2012b).

Stressors like time limits, too much work demanded by the employer are considered to be the factors that can cause fatigue in upper extremities (Feuerstein et al., 2004; Kulin & Reaston, 2011; Panari et al., 2012).

If improvement methods in the working environment are implemented, the level of stress of workers has to decrease.

The increasing amount of computer work and workers in the society is a supplementary source for developing the MSDs. The workload is increasing, but the working conditions are not developing so fast. The preventive measures in occupational safety and health are often not used as these measures cause supplementary costs for the employers (Tint et al., 2010). An investigation of 295 computer workers (Tint et al., 2014) showed that Estonian computer workers assess their health status as considerably high. They are optimistic in solving the problem that the monotonous work with computers will continue and believe that their health status in the future will stay on the same level using the steadily enhanced rehabilitation means. Considering the fact that people begin to work with computers at ever younger age, according to the current investigation, more MDSs are observed by young people (< 40 years of age) than by older workers (> 40 years of age). The positive result is that 43.4% of older workers consider their health status good. Vision disorders were diagnosed for groups A and B almost at the same rate. It shows that eyes get tired and the eyesight is worsening already at a young age.

In occupied rooms, including classrooms, the concentration of carbon dioxide (CO_2), a colourless, odourless gas, can be used as an indicator of the ventilation rate per occupant and the removal of pollutants in the air (Geelen et al., 2008). Indoors, complaints of poor air quality are unusual if CO_2 concentrations are under ca. 700 to 800 ppm. The carbon dioxide emissions from a medium-sized human doing easy physical work are estimated to be around 20 L h^{-1} (Laht, 2010).

If the occupancy and ventilation rate are stable enough, the time required to reach a steady state depends on the ventilation time constant which is the reciprocal of the air exchange rate of the space (e.g., if the air exchange rate is 0.4 h^{-1}, the time constant is 2.5 h). To reach a carbon dioxide concentration of 95% of the steady state value, a period of three time constants with a stable occupancy and ventilation rate could be required (Seppanen et al., 1999).

According to current Estonian legislation, the concentration of carbon dioxide considered to be hazardous is 5,000 ppm or 0.5%. The Estonian standards connected to building construction state that the maximal amount of carbon dioxide in rooms can be 2,500 ppm or 0.25%, of which 1,500 ppm (0.15%) can be emitted by human organism activities (EVS-ES 15251, 2007). As the standards do not bear legal power, the amounts of carbon dioxide in classrooms are regulated by Resolution no. 109 issued by the Ministry of Social Affairs on August 29, 2003, according to which carbon dioxide concentration in classrooms at the end of the day's last lesson must not be higher than 1,000 ppm (Resolution nr 109, 2003).

The Estonian Health Protection Inspectorate (EHPI) has monitored the internal climate of school classrooms over the years. In 2005–2006, 158 schools took part in a respective survey. The results showed that the situation was rather unsatisfactory: 66% of the classrooms examined did not meet the necessary demands (EHPI, 2006). In

2009, the EHPI undertook a similar survey with 117 kindergartens, which revealed that 62% of rooms had carbon dioxide concentrations over 1,000 ppm. It should be stated here that the results show a positive temporal trend: while in 2004 only 31% of kindergartens met the legislative demands in terms of carbon dioxide amounts, then in 2006 the respective figure was 44%, and in 2007 – 52% (EHPI, 2009). The main reasons for the elevated carbon dioxide amounts were found to be somewhat insufficient room volumes per child, and ventilation – when increased, both resulted in a decrease of CO_2 concentrations.

Besides the EHPI, the Tallinn University of Technology and the University of Tartu have undertaken similar surveys as well. In 2005, Kõiv conducted a survey of carbon dioxide concentrations in 9 schools in Tallinn, publishing the respective data in 2007 (Koiv, 2007). The results showed that due to deficient ventilation, carbon dioxide concentrations could reach as high as 3,300 ppm. In the work of Plangi (2007), a similar survey was undertaken in Tartu schools, showing that in general the CO_2 concentrations measured were between 432 and 2,954 ppm, whereas 89% of classrooms did not meet the demands imposed by the legislation in this issue.

A thorough survey was undertaken lately by Laht (2010) considering the internal climate of four schools in Tartu (December 2009 to March 2010) and a kindergarten in Valga (October 2009). It was shown that in school classrooms the measured CO_2 concentrations ranged from 400–800 ppm at the beginning of the day to 1,300–2,300 ppm during the course of the day, with temporary drops to 400–1,000 ppm upon ventilation. In the kindergarten rooms, carbon dioxide concentrations were shown to increase from 200 to 1,650 ppm during the day.

The experimental part of the present study focuses on monitoring IAQ in offices and school buildings, where the main hazards of the workplace are high air temperatures during the warm season, possible low temperatures in the winter, low relative humidity in centrally-heated rooms in the cold season, and high concentrations of CO_2.

It is possible to calculate the concentration of CO_2 at the end of the lesson or the needed air exchange rate to keep the CO_2 level within the frames of the norms using the equation (Zogla & Blumberga, 2010):

$$n_{av} = \frac{\ln C(t_1) - \ln C(t_2)}{t_2 - t_1},$$

where: n_{av} – air exchange rate, h^{-1}; $C(t_1)$ – CO_2 level in the beginning (with subtracted background CO_2 level), ppm; $C(t_2)$ – CO_2 level in the end (with subtracted background CO_2 level), ppm; t_2–t_1 – time between CO_2 level measurements, h.

The authors of the present paper have been engaged in the measurement of CO_2 in schools since the autumn of 2005. The elevated content of CO_2 in indoor air has been a problem in schools, particularly in computer classes in the years 2005–2008, when there were small numbers of computers available for schoolchildren and they queued in the classes waiting for a free computer. Also, the problem in old school buildings was that the rooms had no mechanical ventilation. A large number of elementary schools, kindergartens and hobby schools were renovated during 2008–2012 and now the conditions are expected to be improved.

The concentrations of CO_2 in schools and kindergartens on Saaremaa Island (in the west of Estonia) in autumn 2005 were measured in the range between 450 ppm and 3,000 ppm (Tint et al., 2011); the measurements of CO_2 concentration (in winter 2010) in a 1984 built school-building in Tallinn gave the following results: 438 to 1,205 ppm. The measurements were carried out in 12 classrooms. The building has been out of use since the end of 2012 (Fig. 5) (Traumann et al., 2012).

The aim of the study was to give recommendations for improvement of indoor air quality and to work out a health risk assessment (HRA) model for office-rooms, including ergonomic principles for work with computers. The HRA model connects the risks in the work environment and medical examinations (ME) according to the risk level in offices.

MATERIAL AND METHODS

Indoor air in schools and offices was investigated. The data from the investigation of indoor climate quality in schools with natural ventilation (based on Laht, 2010) and mechanically ventilated rooms (based on the data of the authors of the current paper) were compared. The measurement equipment and the standard were as follows: EVS-EN-ISO 7726:2003 'Thermal environments – Instruments and methods for measuring physical quantities'; EVS-EN 15251:2007 'Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics', EVS-EN 12464-1:2011 'Light and lighting – Lighting of workplaces – part 1: Indoor work places', EVS 891:2008 'Measurement and evaluation of electrical lighting in working places'. The measurement equipment used for microclimate: TESTO 435. TESTO 435 also enables the measurements of CO_2. The measurement of CO_2 was carried out according to EVS-EN 1231:1999, EVS-EN 15251:2007 and EN 13779:2010.

Workplace lighting and screens were measured using the light-metre TES 1332 (ranges from 1–1,500 lx). Lighting was measured on the desk, on the screen, and on the keyboard. Dust was measured with HazDust EPAM-5000.

Figure 1. Office in an institution 1.

Figure 2. Office in an institution 2.

Figure 3. Office in an institution 3.

Figure 4. Office in an institution 4.

Figure 5. Computer class in an old school building.

Figure 6. Computer class in a renovated school building.

RESULTS

Table 1 shows the results of the measurements in the work environment of the offices shown in Fig. 1–4. In winter, the humidity of the air is too low. By the norms (EVS-EN 15251:2007), relative humidity of 40–60% is required for the worker to feel comfortable. The level of carbon dioxide ~1,000 ppm is felt by the workers as poor microclimate. The lighting of workplaces equipped with computers is usually good, in the frames of the norms (300–500 lx), but sometimes information technologists prefer working in the dark (without electrical lighting). However, this situation must be avoided.

Table 1. Results of the measurements indoors in offices (2012–2013)

Room type	T, °C Cold/warm season U = 0.6°C	R, % Cold/warm season U = 2.0%	L, lx U = 10.4%	CO_2, ppm U = 10%	Dust, mg m^{-3} U = 10%
Office 1, Fig. 1	20–22/28–30	22–23/35–65	495–890	537–998	0.030
Office 2, Fig. 2	20–22/24–28	15–25/35–75	200–250	500–750	0.020
Office 3, Fig. 3	18–22/20–24	20–30/40–74	350–600	350–1,200	0.015
Office 4, Fig. 4	17–20/22–28	15–30/40–70	690–1209	478–1,152	0.011

U – uncertainty of measurements; T – temperature of the air; R – relative humidity; L – lighting; CO_2 – concentration of carbon dioxide in the air; Dust – dust concentration in the air

The ventilation rate and concentration of CO_2 in a new school-building (Fig. 6) in Tallinn in January 2013 are given in Table 2.

Table 2. Concentration of CO_2 and ventilation efficiency in a renovated school building in Tallinn (Fig. 6)

Room description	Concentration of CO_2 corresponding to time, ppm; U = 10%									Mechanical ventilation rate, $m^3 h^{-1}$
	8.00	9.00	9.30	10.15	10.50	12.00	13.35	14.00	14.20	
Computer class 1 (45 m^2)	575	635	600	650	591	730	621	710	673	20
Computer class 2 (40 m^2)	502	560	540	671	580	682	610	720	653	22
Computer class 3 (45 m^2)	543	653	632	733	640	730	621	699	580	21
Laboratory equipped with computers (40 m^2)	501	729	680	1,067	699	854	730	850	630	18
Ordinary classroom (20 m^2), without windows	480	523	520	521	522	632	520	658	533	20
Ordinary classroom (35 m^2)	487	727	601	721	540	663	540	680	533	20
Ordinary classroom (45 m^2)	508	650	520	673	523	688	533	698	512	20

When no ventilation of a class during breaks by opening the windows was undertaken, the CO_2 content increased from 700 to 1,500 ppm during the lessons (Fig. 7), decreasing due to natural ventilation only when a low enough number of students was in the room. However, when ventilation by opening the windows during the breaks is applied, the accumulation of CO_2 is kept under control with a slightly varied CO_2 build-up in classes almost independent of the number of students (Fig. 7, curve 1). However, CO_2 concentrations of 1,200–1,800 ppm were still obtained by the end of the lesson. The duration of the lesson is 45 min. and the break 10 min. (the lunch-break between the 3rd and 4th lesson is 15 min (Fig. 7).

The measurements in the new building (Table 2; Fig. 7, curve 2) equipped with mechanical ventilation (natural ventilation through the windows is not possible) were 550–750 ppm and higher concentrations were measured in an overcrowded classroom (30 people; CO_2 concentration 1,067 ppm). It only takes 15 minutes to balance the CO_2 concentration to the level of 550 ppm.

The health risk assessment (HRA) model worked out by the authors of the current paper is presented in Fig. 8. Concentration of carbon dioxide is one of the indicators of the impurity of indoor air. Other important indicators (shown in Fig. 8) are: lighting of the workrooms, temperature, and air humidity. Dust concentration in office air by comfort classes is determined considering the Estonian regulations (Resolution, 2011), measurements of dust, and the feeling of dust in the air by workers. Comfort at workplaces is also determined with ergonomic indicators, like workplace design, the time spent at the computer per workday. The frequency of medical examinations (ME) is determined by the investigation results of computer-equipped workplaces (Tint et al., 2014).

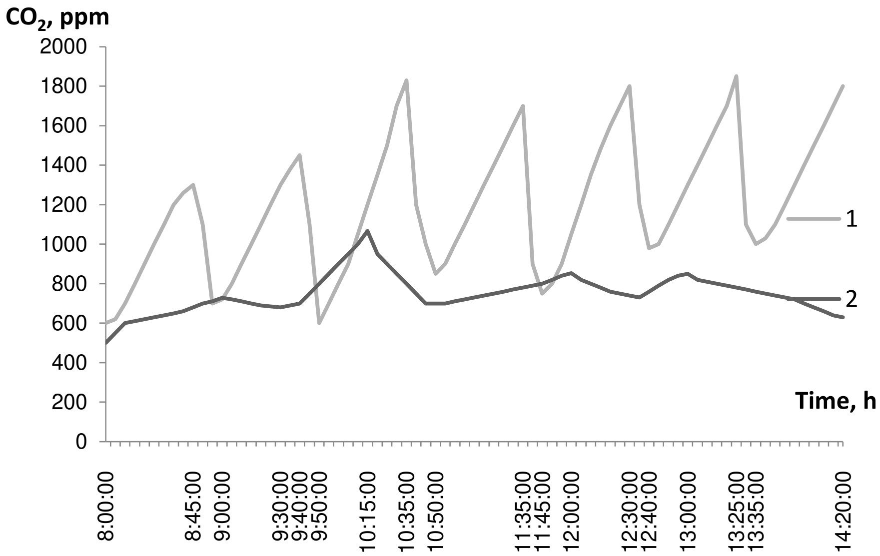

Figure 7. Change of CO_2 concentrations during the lessons and breaks at schools: 1 – School 5 (based on Laht, 2010); 2 – School in Tallinn (new data of the authors of the current paper).

< 100 RH< 20 or RH >70 More	< 300 20<RH<70 19–27	300–500 25<RH<60 20–26	500–600 30<RH<50 21–23.5	Lighting, lx Humidity (RH), % Operative temperature, °C
v < 4	4 ≤ v <7	7≤ v ≤10	v > 10	Ventilation, (v) $l\ s^{-1}$ per person
> 800	**< 800**	**≥ 500**	**350–500**	**CO_2, ppm (over the outdoor level)**
0.09–0.1 Over 8 hours/day	**0.06–0.09** 8 hours/day	**≥ 0.05** 6 hours/day	**0.01–0.05** 4 hours/day	**Dust, mg m^{-3}** Work with computers
Old chairs, static posture, no natural lighting	Standard workplace for everybody, static posture	The desires of workers have been taken into account in some points (the chair)	The workers have designed the workplace themselves	Workplace ergonomics
		Norm		
4th health risk level **ME** twice a year**	3rd health risk level **ME** once a year**	2nd health risk level **ME**once in 3 years**	1st health risk level **ME** once in 3 years**	Variables

Medical examinations (*ME***)

Figure 8. Health risk assessment model for computer-workers in office rooms.

DISCUSSION

Based on the literature review, the air in the classrooms and offices in Europe and North America is often polluted and the ventilation systems are not working correctly. In practice, application of a mechanical ventilation system or improvement of the existing natural ventilation is not always feasible. As an alternative, the ventilation behaviour of the occupants in schools and offices can be improved by the combination of a CO_2 warning device and teaching package for specific ventilation advice, while giving the ventilation advice alone is usually not effective (Geelen et al., 2008).

A CO_2 warning device is a measuring instrument with a display and red light-emitting diode (LED) which turns on when the CO_2 concentration exceeds 1,200 ppm (Geelen et al., 2008). This informs the workers, teacher and pupils of the CO_2 concentration being too high. Along with use of the warning device, a ventilation teaching package was specifically developed for 7–10-year-old pupils by Geelen et al. (2008) as specific behavioural instructions for the teachers and their pupils. The teaching package consisted of three lessons and in each lesson a different theme was discussed with the help of a cartoon character called ‘Outdoor air’. The first theme, ‘Moisture in the air & Ventilation’, described a regular school situation with the occurrence of moisture in the air, emitted from the skin and the lungs. It explained that continuous ventilation was needed to remove the moisture from the classroom. Although other pollutants in the classroom are of importance, moisture was used to simplify the situation for the pupils. The second theme, ‘Dirt in the air & Airing of the classroom’, described that more pollutants, like glues or paints, were emitted into the air during handicraft lessons. Furthermore, it explained that extra ventilation of short duration, like airing, was needed to remove these extra pollutants from the classroom and offices. The third theme, ‘Dust mite & Cleaning’, described the need for a clean environment, for example to avoid the growth of dust mites (Geelen et al., 2008).

CONCLUSIONS

Indoor air and other problems in the same workroom could be defined individually in quite different ways. Therefore, an individual approach has to be implemented for every workplace considering the anthropological and other features of the worker who will work in the certain workplace. Information technology workers often work in under-lighted working conditions although there is a possibility to raise the (artificial) lighting to the normal limits (400–500 lx).

The carbon dioxide measurements showed that there is the 4^{th} level health risk in educational institutons and office-rooms in cities near intensive transport roads in particularly, if the windows cannot be opened and the mechanical ventilation is not working. The all-wall glass windows make the conditions even worse if the temperature outdoors is high (> 25°C) and in this case nearly 30°C inside the office-room.

The concentration of carbon dioxide outside the buildings in towns has increased. In a hot season (May, June), the measurements showed that the content of CO_2 in the street (in towns) was 492 ppm. Considering this, the concentration of CO_2 in office-rooms without mechanical ventilation close to the street was 866…1,986 ppm. The complaints from the side of the workers were enormous. The situation in countryside is better.

The 1st (the best) category of comfort is gained when the workers themselves can design the workplace and work with computers alternates with other work activities. Medical examinations are obligatory in this case once in 3 years. If computer workers do not follow the legislation on computer work as it often happens (work is taken home), then the risk for developing the MSDs is high in the young age already.

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IX ENGINEERING DESIGNS AND MODELLING

AUTOMATION TECHNOLOGY

ENVIRONMENTAL IMPACT

Agronomy Research **12**(3), 937–948, 2014

Theory of motion of a material point along a plane curve with a constant pressure and velocity

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Abstract. The theory of motion of a material point has been developed, as a result of which plane curves as orthogonal sections of cylindrical surfaces with horizontal generators that provide a constant force of pressure during motion of a particle along a curve at a constant velocity have been found. New differential equations of motion of a material point along a plane trajectory on the surface of the cylinder have been made. Visualisation of the obtained results has been performed. Individual cases of motion where the force of pressure on the surface was bigger, smaller or equal to the weight of the particles, and where reaction of the surface equalled zero have been found. The given theory can be successfully used for design of mouldboard surfaces of cultivator machines.
Keywords: engineering design, plane curve, arc length, natural parameter, pressure, velocity.

INTRODUCTION

The cultivator tools used today have a significant shortcoming – uneven wear during operation. This leads to additional untimely technological expenses on repair or even replacement of the tool. Uneven wear is caused by the variable force of pressure of the soil as a combination of material particles along the surface of the tool. The given problem can be solved by finding such surfaces during velocity on which the constant force of pressure of the soil on the surface of the tool will be ensured.

At the same time, cylindrical surfaces will be analysed, as they are widely used in agricultural machines as tools that interact with different technological materials.

Analysis of latest publications. Research of motion of material particles along a surface, including along a cylindrical one, has been performed by the academicians V.P. Goryachkin (1968), P.M. Vasilenko (1960) and P.M. Zaika (1992). Motion of a particle along an inner surface of an inclined stationary cylinder under the influence of the force of own weight was analysed in the paper (Linnik, 2006). Motion of particles along gravitational surfaces was studied in the papers (Pilipaka, 2003a; 2003b; 2003c; 2002). The paper (Pilipaka, 2009) focused on analysis of motion of a particle along an inner surface of a horizontal cylinder revolving round its axis, and in the paper (Pilipaka, 2010) – along an inner surface of an inclined cylinder. Similar cases of a refined theory of motion of a material point (particle) were presented in the papers (Adamchuk et al., 2008; Pilipaka et al.; 2009; Bulgakov, 2009).

Purpose of the paper. Finding surfaces of even wear by using study of plane curves of orthogonal sections of horizontal cylinders, along which the particle moves at a constant velocity and has a constant force of pressure on the surface.

MATERIALS AND METHODS

Results of the research

Motion of a particle along a plane curve – the orthogonal section of a cylindrical surface with horizontal generators, will now be analysed.

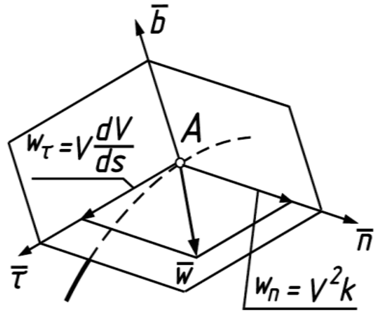


Figure 1. Tangential w_τ and centripetal w_n acceleration of the vertex *A* of a natural trihedral in projections on its unit vectors.

Motion of a point along a curve will always lead to emergence of acceleration *w*, even if the velocity *V* is constant. It consists of two components (Fig. 1): one component characterises speed of change of the value of the vector of velocity, projected on the unit vector of the tangent $\bar{\tau}$ and is called tangential acceleration. Its value is defined by differentiating the velocity *V* with respect to time *t:* $w_\tau = dV/dt$. The other component – normal or centripetal acceleration, characterises speed of change of the direction of the vector of velocity and it is projected on the unit vector of the main normal $\bar{n}$. Its value is designated by the product of the curvature by the velocity squared *V*: $w_n = V^2k$. Respectively, the following can be written in a vector form: $\bar{w} = \bar{\tau}\, dV/dt + \bar{n}V^2k$. In case the velocity *V* is the function of the length of arc *s* (of the path), i.e. $V = V(s)$, then the tangential acceleration will be: $w_\tau = dV/dt = dV/ds \cdot ds/dt = V \cdot dV/ds$. Respectively, the vector of acceleration in projection on unit vectors of a natural trihedral will be written as follows:

$$\bar{w} \quad \left\{ V\frac{dV}{ds};\; V^2k; \quad 0 \right\}. \tag{1}$$

According to resolution of the vector of acceleration into unit vectors of the natural trihedral (1) the differential equations of motion of the particle projected on unit vectors will be written as follows:

$$mV\frac{dV}{ds} = F_\tau; \qquad mV^2k = F_n, \tag{2}$$

where F_τ and F_n – are the projections of forces applied to the particle.

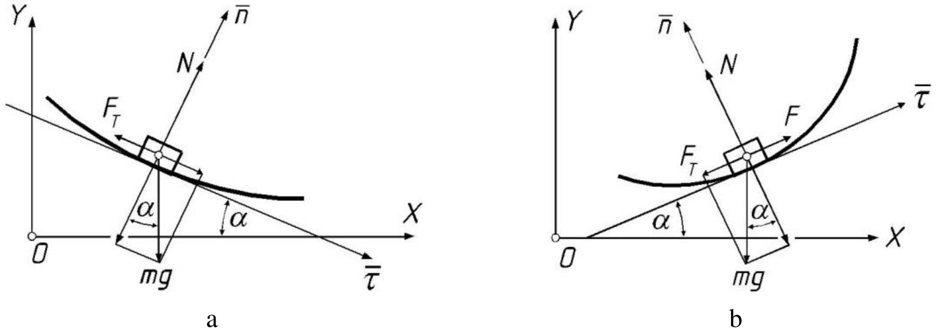


Figure 2. Resolution of the forces having influence on the particle into unit vectors of the natural trihedral: a) the particle travels under the influence of the force of own weight; b) the particle travels under the influence of the applied force *F*.

It will now be assumed that the particle is moving along the curve under the influence of the force of its own weight *mg* (Fig. 2 a). In this case it will be resolved into unit vectors of the trihedral according to the angle α, which is a variable angle and which is the angle between two systems: the system of a moving trihedral and the fixed Cartesian system *OXY*. The particle is still under the influence of the force of reaction *N*, directed along the normal, and the force of friction $F_т$, directed along the unit vector of the tangent in the direction opposite to the direction of motion (Fig. 2 a). Given these forces the equations (2) will look as follows:

$$mV\frac{dV}{ds} = mg\sin\alpha - F_\tau; \qquad mV^2k = N - mg\cos\alpha. \tag{3}$$

As it is known, the force of friction $F_т$ is numerically equal to the product of the force of normal reaction *N* by the coefficient of friction *f*: $F_т = fN$. It follows from the second equation (3) that: $N = mV^2k + mg\cos\alpha$. Given these expressions the first equation (3) will look as follows:

$$mV\frac{dV}{ds} = mg\sin\alpha - f\left(mV^2k + mg\cos\alpha\right). \tag{4}$$

The differential equation (4) can be reduced by the mass *m* of the particle. In order to solve the equation, it is necessary to specify the curve using the natural equation $k = k(s)$ and to search for the law of motion looking as $V = V(s)$, or to set the law of motion $V = V(s)$ and to search for the respective curve.

For example, the speed of motion of the particle will be constant (V = const). The respective line that will ensure such speed will now be found. According to (4) the following will be obtained:

$$g\sin\alpha - f\left(V^2k + g\cos\alpha\right) = 0\,. \tag{5}$$

The equation (5) has two solutions. The first one is the straight line $k = 0$. By solving (5) with $k = 0$, the following will be obtained: $f = \mathrm{tg}\alpha$, which means that the straight line must be inclined at an angle of friction to the horizon. According to the second solution $k \neq 0$, which means that the line will be a curved one. This solution will be analysed later.

It will now be assumed that the particle moves along the curve under the influence of the applied force F (Fig. 2 b). The equations (2) will look as follows:

$$mV\frac{dV}{ds} = -mg\sin\alpha - F_{\text{т}} + F; \qquad mV^2k = N - mg\cos\alpha\,. \tag{6}$$

The condition will now be set for the particle to travel upwards at a constant velocity $V = const$, while the force of reaction N (force of pressure) also remains constant. In practice the surface with the target section will wear equally, and in case of cultivator machines it will possibly be less prone to sticking. The second equation will now be transformed (6):

$$\frac{V^2}{g}k + \cos\alpha = \frac{N}{mg}\,. \tag{7}$$

The relation $N\,mg^{-1}$ has a constant value and it shows what part of the weight of the particle is represented by the force of pressure on the surface. It will now be designated using a_N and the equation (7) will be solved with respect to $k = d\alpha/ds$:

$$\frac{d\alpha}{ds} = \frac{g}{V^2}(a_{\text{N}} - \cos\alpha)\,. \tag{8}$$

After division of the variables integration of the equation (8) is possible for two cases: $a_N > 1$ (meaning that the force of pressure on the surface is bigger than the weight of the particle) and $a_N < 1$ (the force of pressure is smaller than the weight of the particle). These integrals will now be written down (the constant of integration will be left out):

$$\begin{aligned} s &= \frac{V^2}{g}\int\frac{d\alpha}{a_{\text{N}} - \cos\alpha} = \frac{2V^2}{g\sqrt{a_{\text{N}}^2 - 1}}\operatorname{arctg}\sqrt{\frac{a_{\text{N}}+1}{a_{\text{N}}-1}}\operatorname{tg}\frac{\alpha}{2}, \qquad (a_{\text{N}} > 1) \\ s &= \frac{V^2}{g}\int\frac{d\alpha}{a_{\text{N}} - \cos\alpha} = \frac{V^2}{g\sqrt{1 - a_{\text{N}}^2}}\ln\frac{(1+a_{\text{N}})\operatorname{tg}\frac{\alpha}{2} - \sqrt{1-a_{\text{N}}^2}}{(1+a_{\text{N}})\operatorname{tg}\frac{\alpha}{2} + \sqrt{1-a_{\text{N}}^2}}. \qquad (a_{\text{N}} < 1) \end{aligned} \tag{9}$$

In the equations (9) next step is transition from the relation $s = s(\alpha)$ to the natural equation $k = k(s)$. This can be done using two methods: either by changing in the equations (9) to the relations $\alpha = \alpha(s)$ and differentiating with respect to s, or by solving (9) jointly with (8), excluding the common parameter *α*. The natural equations for the first case look as follows:

$$k = \frac{g(a_N^2 - 1)}{V^2\left[a_N + \cos\left(\frac{gs}{V^2}\sqrt{a_N^2 - 1}\right)\right]}. \tag{10}$$

For the second case ($a_N < 1$):

$$k = \frac{g(1 - a_N^2)}{V^2\left(-a_N + \cosh\frac{g\sqrt{1 - a_N^2}}{V^2}s\right)}. \tag{11}$$

The natural relations (10) and (11) set curves irrespective of their position and turn on the plane. In order to build them it is necessary to change to the coordinate form of writing, for example to parametric equations. The required position of the curves on the plane according to the acting forces is chosen when the change is performed, by setting initial conditions (by assigning the required values to the constants of integration). In order to perform the change, the known relations (Pilipaka, 2002b) will be used, and change to the independent variable *α* will be performed:

$$\frac{dx}{d\alpha}\frac{d\alpha}{ds} = \cos\alpha, \qquad \text{and} \qquad \frac{dx}{d\alpha} = \cos\alpha \div \frac{d\alpha}{ds}. \tag{12}$$

Similarly:

$$\frac{dy}{d\alpha} = \sin\alpha \div \frac{d\alpha}{ds}. \tag{13}$$

Having inserted into (12) and (13) the expression *dα/ds* from (8), the relations for finding *x* and *y* of the curve will be obtained:

$$\begin{aligned} x &= \frac{V^2}{g}\int\frac{\cos\alpha d\alpha}{a_N - \cos\alpha} = \frac{a_N V^2}{g}\int\frac{d\alpha}{a_N - \cos\alpha} - \frac{V^2}{g}\alpha; \\ y &= \frac{V^2}{g}\int\frac{\sin\alpha d\alpha}{a_N - \cos\alpha} = \frac{V^2}{g}\ln(a_N - \cos\alpha). \end{aligned} \tag{14}$$

It is evident from (14) that after integration the relation $y = y(\alpha)$ has a simple form, and the expression for the coordinate $x = x(\alpha)$ reduces to the integrals (9), and that's why it is split into two relations for $a_N > 1$ and $a_N < 1$:

$$x = \frac{2a_N V^2}{g\sqrt{a_N^2 - 1}}\operatorname{arctg}\sqrt{\frac{a_N + 1}{a_N - 1}}\operatorname{tg}\frac{\alpha}{2} - \frac{V^2}{g}\alpha; \qquad (a_N > 1) \tag{15}$$

$$x = \frac{a_N V^2}{g\sqrt{1-a_N^2}} \ln \frac{(1+a_N)\mathrm{tg}\dfrac{\alpha}{2} - \sqrt{1-a_N^2}}{(1+a_N)\mathrm{tg}\dfrac{\alpha}{2} + \sqrt{1-a_N^2}} - \frac{V^2}{g}\alpha. \qquad (a_N < 1) \tag{16}$$

Respectively, it is possible to write the parametric equations of the curve, along which the particle travels at a constant velocity and has a constant force of pressure on the surface, for two cases. In the first case the constant $a_N > 1$, meaning that the force of pressure is bigger than the force of own weight of the particle:

$$\begin{aligned} x &= \frac{2a_N V^2}{g\sqrt{a_N^2-1}} \mathrm{arctg}\sqrt{\frac{a_N+1}{a_N-1}}\mathrm{tg}\frac{\alpha}{2} - \frac{V^2}{g}\alpha; \\ y &= \frac{V^2}{g}\ln(a_N - \cos\alpha). \qquad (a_N > 1) \end{aligned} \tag{17}$$

In the second case the constant $a_N < 1$, meaning that the force of pressure is smaller than the force of own weight of the particle:

$$\begin{aligned} x &= \frac{a_N V^2}{g\sqrt{1-a_N^2}} \ln\left[\frac{(1+a_N)\mathrm{tg}\dfrac{\alpha}{2} - \sqrt{1-a_N^2}}{(1+a_N)\mathrm{tg}\dfrac{\alpha}{2} + \sqrt{1-a_N^2}}\right] - \frac{V^2}{g}\alpha; \\ y &= \frac{V^2}{g}\ln(a_N - \cos\alpha). \qquad (a_N < 1) \end{aligned} \tag{18}$$

By using the expression of the length of the arc (9), it is possible to change to the parametric equations in the function of the natural parameter s, at the same time excluding the angle α. For example, by jointly solving (17) and the first equation (9), after exclusion of α the following will be obtained:

$$\begin{aligned} x &= a_N s - \frac{2V^2}{g}\mathrm{arctg}\left[\sqrt{\frac{a_N-1}{a_N+1}}\mathrm{tg}\left(\frac{gs}{2V^2}\sqrt{a_N^2-1}\right)\right]; \\ y &= \frac{V^2}{g}\ln\left[\frac{a_N^2-1}{a_N+\cos\left(\dfrac{gs}{V^2}\sqrt{a_N^2-1}\right)}\right]. \qquad (a_N > 1) \end{aligned} \tag{19}$$

Using the same approach the parametric equations for the curve in case of $a_N < 1$, will be obtained, by jointly solving (18) and the second equation (9):

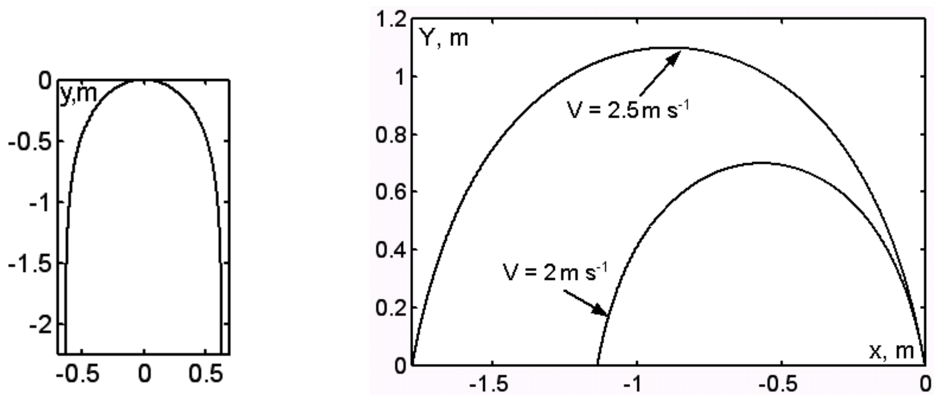
$$x = -a_N s + \frac{2V^2}{g}\operatorname{arctg}\left[\sqrt{\frac{1+a_N}{1-a_N}}\tanh\left(\frac{gs}{2V^2}\sqrt{1-a_N^2}\right)\right];$$

$$y = \frac{V^2}{g}\ln\left[\frac{1-a_N^2}{-a_N+\cosh\left(\frac{gs}{V^2}\sqrt{1-a_N^2}\right)}\right]. \qquad (a_N < 1) \qquad (20)$$

In order to understand the essence of separation of curves by cases of $a_N > 1$ and $a_N < 1$, the analysis will start with the second case where $a_N = 0$ (this value corresponds to the second case and in a certain way divides the respective set of curves into two subsets). In case of $a_N = 0$ the natural equation (11) is significantly simplified and looks as follows:

$$k = \frac{g}{V^2}\operatorname{sech}\left(\frac{g}{V^2}s\right). \qquad (21)$$

In a scientific literature the curve described with the natural equation (21), is known under the name of centenary line of equal resistance. The relation $g\,V^{-2}$ serves as the constant value in the equation (21) of this line. In order to construct it the parametric equations (18) will be used, that are also significantly simplified in case of $a_N = 0$. The curves are presented in Fig. 3.



a b

Figure 3. The curve having the natural equation (21) and described by the parametric equations (18) and (20) in case of $a_N = 0$: a) $V = 2$ m s^{-1}, $\alpha = -90^0 \ldots 90°$; б) $\alpha = -80° \ldots 80°$.

The equation $a_N = 0$ means that the reaction of the surface equals zero, which means that such curve is a trajectory of flight of the particle (point) at a constant velocity of motion without taking the air resistance into account. For example, the lower areas of the trajectory of motion (Fig. 3 a) almost constitute vertical lines, that's why the particle will not exert any pressure on the respective surface. On the other part of the curve the component of the force of weight is balanced by the component of the centrifugal force.

From the course of theoretical mechanics it is known that a body thrown at an angle to the horizon travels along a parabolic curve, however in such case the velocity of motion is a variable. Fig. 3 b demonstrates the built trajectories of the particle with different constant velocity of motion with the initial angle of ascent of 80° (that's why in order to build a curve in this case it is more convenient to use the equations (18), and not (20), as the limits of change of the variable α are known at once). The curves look like a parabola, and their insignificant differences from it are caused by the fact that the particle travels at a constant velocity V. In order to ensure such flight it is necessary to maintain a constant velocity, which is ensured by the force F, acting tangentially (Fig. 2 b). If necessary, it can be found from the first equation (6). Due to the fact that the velocity of motion is constant and the force of friction is absent, the equation will look as follows:

$$F = mg \sin \alpha . \tag{22}$$

Respectively, in the lower part of the trajectory, when the angle α is almost equal to 90° (Fig. 3a), the force F is equal to the weight of the particle, which means that it almost overcomes the force of gravity during ascent. As the particle ascends, the force is reduced and becomes equal to zero at the top point of the trajectory (with $\alpha = 0$), and then, according to the same law it is increased, having changed the sign, i.e. slowing down the fall. That's why the centenary line of equal resistance can be considered as a prototype of a parabola with respect to the trajectory of free flight of a body in the field of gravity of the Earth, with the only difference being that the body travels along a parabolic curve only under an influence of the force of own weight, and along a centenary line of equal resistance it travels with an additional force that ensures constant speed of velocity.

If a goal is set to make the particle having a constant velocity of motion of 2.5 m s^{-1} travelling not along the upper trajectory (Fig. 3 b), but along the lower one, it is necessary to make a limiting cover in a shape of a cylindrical surface with the section corresponding to the lower curve. In this case the force of reaction N of the surface emerges, which in case of a respective selection of the curve can also be constant. At the same time it can be bigger than the weight of the particle (body), or smaller. The equations of the respective curves have been found. The following question arises: what line corresponds to the coefficient $a_N = 1$, i.e. to the case where the force of reaction is equal to the force of weight of the particle? Obviously this will be a horizontal straight line. The same result can be obtained from the natural equation (11) where $a_N = 1$, respectively obtaining: $k = 0$.

The group of curves for which the force of reaction is smaller than the weight of the particle will now be analysed. Obviously, in such case $0 < a_N < 1$. The curves for various values of a_N from this interval are built in Fig. 4.

All three curves have a loop. During motion of the particle along the curve within the range of the loop it is located inside of it. Such motion will be called the motion along the inner side of the surface. As the force of reaction of the surface increases from zero to the value close to one, the curve is transformed, but the loop does not disappear. The branches of the curve going into infinity approach the straight line. In particular, in case of $a_N = 0.5$ (Fig. 4 b) the branch is inclined to horizon at an angle equal approximately to 60^0, which corresponds to position of the particle on the plane inclined at the same angle. In case of a_N close to one (Fig. 4 c), in infinity the branches approach the horizontal line.

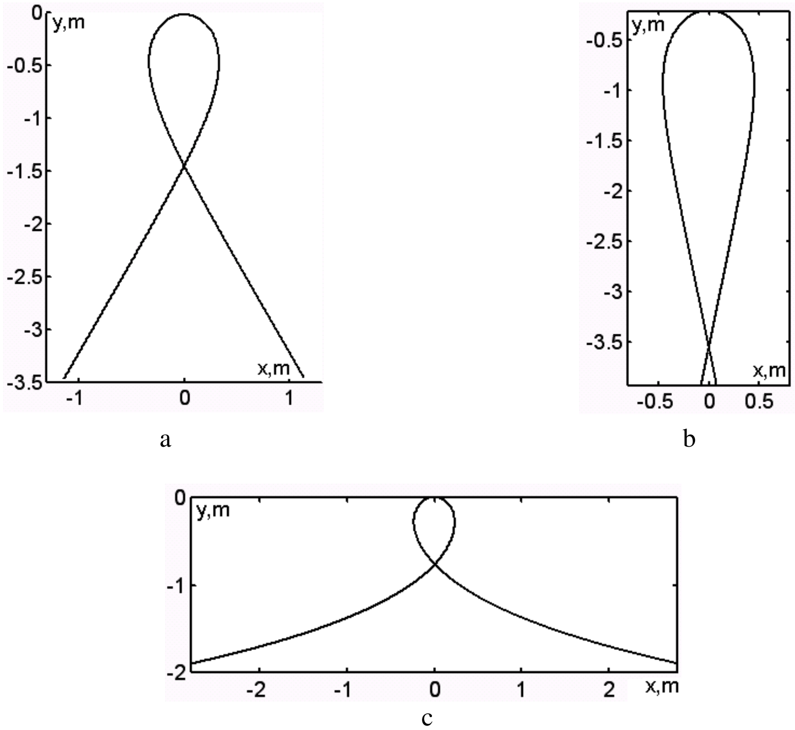
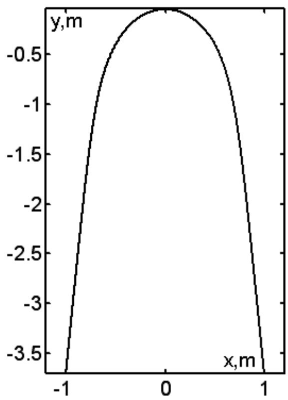


Figure 4. Curves built according to the parametric equations (20) in case of $V = 2$ m s^{-1} and various values of a_N: a) $a_N = 0.2$; b) $a_N = 0.5$; c) $a_N = 0.995$.

The analysed curves constitute the first subset, as there is also another subgroup of curves built with the same values of the coefficient a_N, but with the ‘minus’ sign. At the same time the condition $a_N < 1$ is not breached, and that’s why these two subsets are united into a group of curves, in case of motion of the particle along which at a constant velocity the emerging force of reaction is smaller than the force of weight of the particle. These curves are presented in Fig. 5.

The given curves don’t have loops. During motion along the curve the particle is located above it at all time. Such motion will be called the motion along the outer side of the plane. It must be noted that if the values of a_N are equal in absolute magnitude (i.e. in case of equal force of pressure) the curves of the first and the second subsets have branches going into infinity and having the same inclination (Figs 4 b and 5 b). In case of motion of the particle along the inner side of the surface in the first case, or along the outer side of the surface in the second case, the particle on the branch going into infinity has the same position – above the curve. As the force of reaction of the surface increases from zero to the value equal to one, the curve of this subset is transformed, smoothly approaching the horizontal plane.



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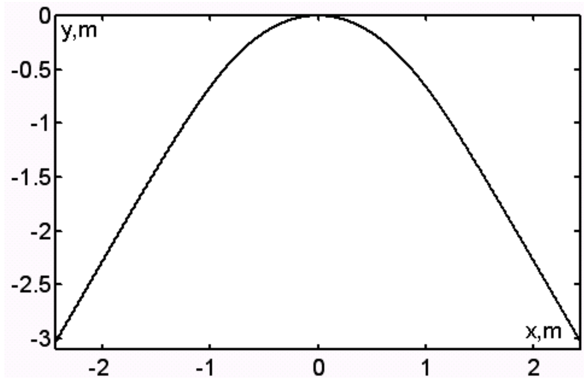

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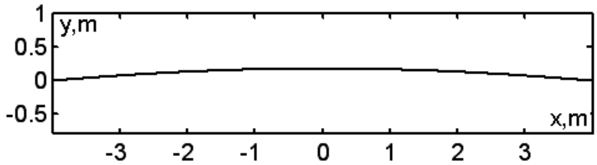
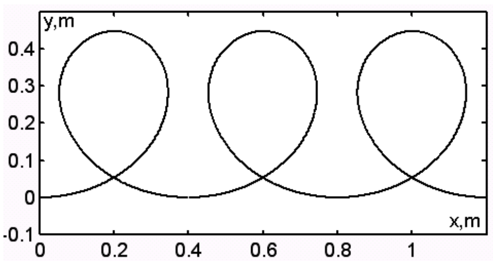


c

Figure 5. Curves built according to the parametric equations (20) in case of $V = 2$ m s^{-1} and various values of a_N: a) $a_N = -0.1$; b) $a_N = -0.5$; c) $a_N = -0.99$.

Now, the second group of the curves corresponding to the value $a_N > 1$ will be analysed. These curves, built according to the equations (14) or (19), are presented in Fig. 6.



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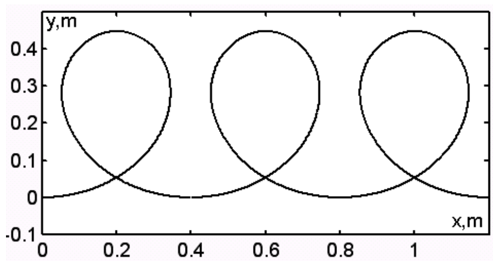

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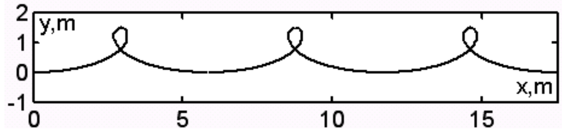

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Figure 6. Curves built according to the parametric equations (17) in case of $V = 2$ m s^{-1} and various values of a_{N}: a) $a_N = 2$; b) $a_N = 1.5$; c) $a_N = 1.05$.

For the presented curves only one-way motion of the particle, which, according to the accepted definition, corresponds to the motion along the inner side, is typical. The curves are periodical ones and have loops. In Fig. they are presented in different scales. Given this circumstance, it is quite apparent that as the coefficient a_N approaches one, the sizes of the curve increase and its shape changes: the period is significantly increased compared to the size of the loop. Smooth transition to the straight line when a_N approaches one is absent. Respectively, when the coefficient a_N approaches one, for two groups of curves only in one of the three cases smooth transition to the straight line is possible.

Influence of the velocity V of the motion of the particle on the shape of the curve is the same in all cases. Analysis of the parametric equations of the curves (17), (19) leads to a conclusion that V^2 plays a role of a scale coefficient. In case of the given value of the coefficient a_N, increase of the velocity of motion by two times leads to increase of the sizes of the curve by four times.

The following example will now be analysed. It will be assumed that a stunt motorcyclist has to make a loop in shape of a curve, presented in Fig. 6. Taking the mass of the motorcyclist with the motorcycle as the material particle, the task is to calculate the difference in height between the highest and lowest points of the curve at the velocity V = 100 km h^{-1} = 27.8 m s^{-1} and overload of 20% (a_N = 1.2).

The lowest point will be at $\alpha=0^0$, and the highest point – at $\alpha = 180^0$. According to the equation $y = y(\alpha)$ (14) the following will be obtained:

$$\Delta y = y_{\alpha=180} - y_{\alpha=0} = \frac{v^2}{g}\ln\frac{\alpha_N+1}{\alpha_N-1} = \frac{27.8^2}{9.81}\ln\frac{1.2+1}{1.2-1} = 189\,\text{m}. \qquad (23)$$

CONCLUSIONS

The new theory of motion of a material point has been developed, and flat curves as orthogonal sections of cylindrical surfaces with horizontal generators that can provide a constant force of pressure (force of reaction) during motion of a particle along a curve at a constant velocity have been found. Such surface will wear evenly and in case of cultivator machines it will be not only less prone to sticking, but also to wear.

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Agronomy Research **12**(3), 949–954, 2014

Reliability of detection of sources of infrared radiation in security alarm and distress signal systems

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Abstract. The problem of detecting sources of infrared radiation affects a large proportion of security alarm and distress signal systems. In a time of increasing property crime, it is highly important for passive infrared detectors (PIR) to be able to detect motion within the guarded area reliably and free of error. In the case of installation of passive infrared detectors (PIR) it is naturally important not only to ensure correct installation, to gauge the external influences impacting upon the detector and ensure proper maintenance, but also to guarantee their capability of detection under more arduous conditions. The tests which have been conducted examine both the normal operation of the PIR detectors and the operation of these detectors under extreme conditions (temperature, soiling, screens etc.). These tests are important both from an informative perspective and due to the possibilities of development of potential counter-measures which could lead to their improvement and an enhancement of their level of security.

Key words: security risks, sabotage, intrusion and hold-up alarm systems, passive infrared detector.

INTRODUCTION

Intrusion and hold-up alarm systems serve primarily for protecting buildings against unlawful conduct of third parties, and can be used as monitoring and control systems. They are therefore primarily a tool for ensuring a state of security. They operate in the material realm (physical protection of property, life and health) and in the emotional realm (providing a feeling of peace, safety and a certain security). As a result it is important for them not to malfunction and for them to be sufficiently resistant to attack. The critical point of every security alarm and distress signal system is predominantly elements of spatial protection. These elements are highly susceptible to poor installation, and as a result it is very important to pay attention to this problem. One of the most widely used types of detector is the PIR detector (passive infrared), which ranks amongst passive detectors. On average, of all the types of detectors used, the largest number of false alarms occur on these detectors. This high error rate is primarily caused by incorrect installation.

MATERIALS AND METHODS

Several security risks may arise during the installation of intrusion and hold-up alarm systems, which impair the security of the entire building. The risks which occur due to poor installation or various sabotage techniques are always a serious danger for the guarded premises. They may jeopardise the guarded property or even the lives of the people who the intrusion and hold-up alarm systems are intended to protect. Above all, however, they have an influence on determining the security risks of buildings.

Upon installation of PIR detectors it is necessary to take into account a number of fundamental prerequisites. The first prerequisite is for the detector not to detect the source of interfering of infrared radiation and to be installed so that the envisaged movement of the attacker is tangentially to the detector (Kic, 2013). The second prerequisite is for the cabling not to be visibly installed. In addition the relevant norms must be adhered to upon implementation of the cable distribution mechanisms (Staff & Honey, 1999; Магауенов, 2007; Capel, 1999). If the cable distribution mechanisms are installed in such a manner that enables access to them, it is possible to sabotage these systems and thus attack the entire installation of the security alarm and distress signal system.

If no end of line (EOL) resistor is connected to the switchboard loop upon installation of the detector, the system is more vulnerable and can easily be bypassed (Fig. 1a). If a resistor is connected, bypassing is far more difficult than in the case of a simple loop (it is not possible to use short-circuiting). Upon sabotage it is necessary to create a dual bypass and use it to replace the original loop at a single moment (Fig. 1b).

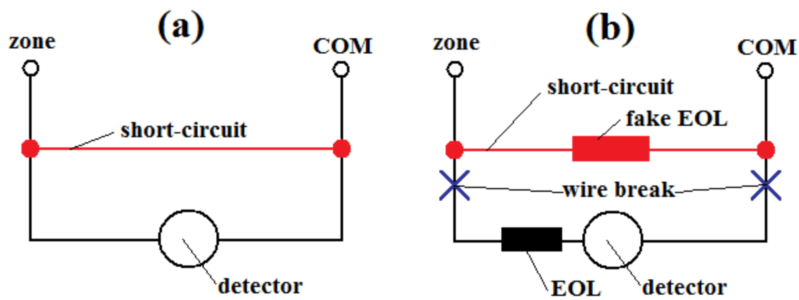

Figure 1. Short-circuit systems.

Upon use of a bus bar (as wiring), sabotage is far more difficult than in the case of loop wiring. Successful sabotage would require for example the use of scanning communication (or decoding) across the bus bar, with subsequent replacement of this communication with false reports which correspond to the communication of the existing system.

Wireless systems for communication most frequently use two unlicensed bands which comply with the Federal Commission for Communication (FCC) and the European Telecommunications Standards Institute (ETSI) (Powel & Shim, 2012). These are the frequencies on bands 433 MHz and 868 MHz. These wireless transmissions should be protected by detecting disturbance of the frequency band, which monitors the load on the communication frequency. In the case of overloading of the frequency, the switchboard evaluates this fact and responds according to the setting (malfunction, alarm etc.). The detectors are also mostly protected, namely by ‘wireless detector surveillance’, which monitors the presence of the detector within the range of the switchboard (Petruzzellis, 1993; Cumming, 1994).

The greatest risk upon use of wireless communication (between detectors and the switchboard) is a signal frequency jammer. This can overload the communication frequency by rendering the switchboard incapable of receiving the signal transmitted from the detector. This signal frequency jammer is dangerous above all because it can attack the system before the saboteur enters the guarded area, where he or she could be detected by one of the detectors.

Upon testing of wireless transmissions, deficiencies have been determined in certain systems, and as a result it is necessary to take these deficiencies into account.

Measurement of PIR detectors should be focused primarily on tests which examine the capability of the PIR detector upon use of a shielding screen.

The PIR detector detects IR (infrared) radiation from the guarded area, and the alarm state of the detector is then evaluated on the basis of the difference in electrical charge which ensues upon the flow of IR radiation through the optics. With regard to the fact that IR radiation is emitted by every element with a higher temperature than absolute zero, the pyro-cell is adjusted in order to be most sensitive within the temperature range of approximately 25°C to 40°C. If this temperature can be reduced on the element by whatever method, this will severely affect the capability of the PIR detector.

The detectors PARADOOR (460), PRO plus (476) and DG 55 were used for measurement. These are frequently used detectors, which are installed in both small buildings and large firms.

All the tested PIR detectors are loop detectors with a simple type of sending of alarm information, which are cheap in comparison with other types of PIR detectors (using a different type of data transmission).

All the above PIR detectors were tested for covering in close proximity, covering in intermittent motion and covering with a screen.Covering in close proximity is testing of testing of a PIR detector, which begins outside the detection boundary of the guarded area at a distance of 2 m ± 0.2 m or at a distance of 0.5 m ± 0.05 m from the reference line (assembly surface) of the detector. Distance is selected according to the degree of security into which the tested detector falls.

Covering upon interrupted motion is testing of a PIR detector beginning outside the boundary of the detection area from the opposite side of the detector and the intersecting centre of the axis of the detector in half the maximum range beneath an angle of 45° to this axis. The standard detection target begins intermittent motion in such a manner that it stands with feet together and then takes two steps 0.5 long at a speed of 0.2 – 0.1 m s^{-1} and stops with feet together. After 5 seconds the cycles are repeated until leaving the detected area.

The tests conducted on the above detectors were performed at two different distances from the detector, namely at a distance of 0.5 m from the detector and at a distance of 50% of the stated range of the detector.

In the tests motion was used at a speed of 0.1 m s^{-1}, 0.2 m s^{-1}, 0.5 m s^{-1}, 1 m s^{-1} and 2 m s^{-1} in the direction designated by the manufacturer (tangentially in the direction of the PIR detector). Ten measurements were taken from each test, and the materials used as a screen were cloth, polystyrene, carton and glass (at approximately the same temperature as the room).

RESULTS AND DISCUSSION

The measured results and the overall comparison of digital and analogue detectors (Fig. 2) do not differ greatly, with the exception of the better elimination of false alarms in the case of digital processing of the output from the pyro-cell. This is caused by the large demands on spatial detector, which leads a thorough checking during certification.

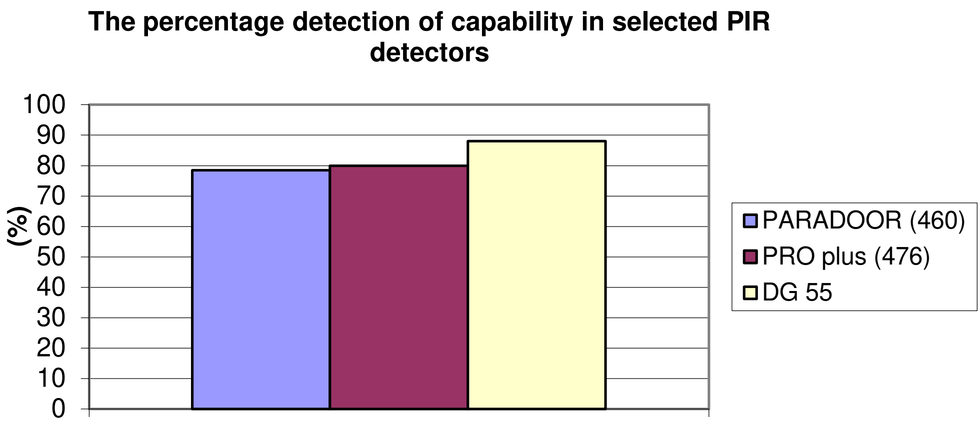

Figure 2. Comparison of analog and digital PIR detector.

One of the greatest potential hazards in the case of a PIR detector is that the offender uses a screen which absorbs IR radiation and thus prevents the PIR detector from detecting movement within the guarded area. Tests conducted in individual types of screens and the detection capability of PIR detectors clearly showed that cloth and carton screens are 30% detectable. By contrast, polystyrene and glass screens present a serious risk, because they were detectable only in values around 5% of the total number of measurements – see Fig. 3.

The tests we conducted pointed to deficiencies in heat detection by a PIR detector upon the use of a screen. The risks which most affect the security risks of PIR detectors were evaluated on the basis of standard and experimental measurement.

Until all the systems are tested, it is possible only to ask how many detectors and systems are at all secure. A further question is whether any system exists which could provide reliable protection for a reasonable price.

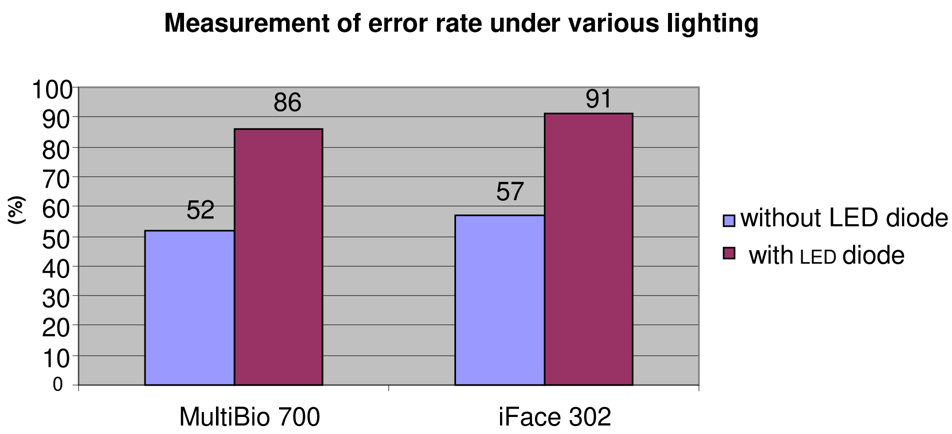

Figure 3. Detection capability of PIR detectors for movement with screen.

Thanks to many years of testing security risks of I&HAS and also thanks to the cooperation with several manufacture of I&HAS we found that the present state of the development of security systems at the point of stagnation.. Although manufacturers are constantly attempting to develop systems, the majority copy old errors in the technical design into new products of a higher class, even despite the endeavours of customers to ensure manufacture is modified. Without innovative approaches and user feedback, this array will career into a blind alley.

CONCLUSIONS

The technical design of security systems is unique for the majority of manufacturers. In the case of every manufacturer it is possible to find some poor technical designs which require modification. This deficiency can be resolved by technical development of the given product and adaptation to customer requirements.

The practical tests conducted on PIR detectors brought an insight into their functionality and usability in practice. If a saboteur is instructed about the operation of these detectors, then they can be overcome. At the same time the saboteur can also bypass the individual loops, and if skilled, can also bypass loops with an EOL resistor.

The only protection which would be usable against current sabotage techniques is the development of new technologies. It is very important not to cast doubt on this development and to apply a constant endeavour to advance towards new technologies and greater security.

ACKNOWLEDGEMENTS. It is a project supported by the IGA 2014 'The Internal Grant Agency TF' (31170/1312/3124).

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Agronomy Research **12**(3), 955–966, 2014

Experimental research of proximity sensors for application in mobile robotics in greenhouse environment

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Abstract. Mobile robots for greenhouse automation are not yet used commercially, but scientific research are being performed in various aspects of using robots in greenhouses. For now, plant examination for diseases and insects, spraying and watering tasks are mostly considered. In all cases, a robot should be able to orient itself globally in the environment and locally relative to the working objects e.g. plants, obstacles and other robots if a multi robot system is assumed. In greenhouses, proximity sensors are used for simple object detection and distance measurement with both metallic and non-metallic materials as well as plants. Consequently, capacitive, ultrasound and optical type sensors can be used. It is known that they are affected by varying temperature, humidity and moisture conditions. In this research, we have used a specialized microclimate chamber to perform experiments in a modeled greenhouse environment with controlled temperature, relative humidity. The controlled environmental parameters were combined to represent real world greenhouse conditions. Three types of materials were used for detection (WxHxD): 1 mm steel plate 255 x 380 mm, 1 mm ABS 245 x 330 mm plastic plate, and 118 x 180 x 60 mm plastic container with water. The environment and the type of the detectable object were used as independent variables. The examined parameters, i.e. the dependent variables of the digital type sensors, were the maximum and minimum detection limits and hysteresis. A statistical analysis was performed to find the factors which may affect the reliability of proximity sensors measurements in greenhouse environment.

Keywords: greenhouse automation, mobile robots, proximity sensors, greenhouse environment.

INTRODUCTION

Mobile robots are growing in popularity in different applications. The primary challenge for these robots is navigation in different locations. This process is usually referenced as localization. Mobile robots for greenhouse automation are not yet used commercially, but scientific research are being performed in various aspects of using robots in greenhouses. Some greenhouse prototypes were already made in 1996, where the *Aurora* mobile robot (Mandow et al., 1996) performs simple greenhouse tasks autonomously and the teleoperator acts as a supervisor taking control, if needed. In more recent studies, researchers are mainly using already available base models such as the *Fitorobot* (González et al., 2009), which have been designed to operate in greenhouses for plant inspection, spraying and other purposes.

A greenhouse can be defined as a construction of polycarbonate, fiberglass or glass design used to multiply, grow and care for plants, fruit and vegetable. The mission of a greenhouse is to create suitable growing conditions for the full life of the plants (Badgery-Parker, 1999). The environmental conditions in greenhouses are characterized by high temperature and humidity levels and are not suitable for robot operation (Van Hentena et al., 2009). Also, humidity is one of the key factors in the greenhouse climate that influences robot's proximity sensors (Sethi et al., 2013). The dynamic of temperature and humidity should also be taken into consideration as humidity and temperature change rates in greenhouses can reach more than 30 percentage points and 10ºC in two hours during sunrise and sunset (Andrade et al., 2011).

Sensors are mostly used for automatic fruit harvesting systems or robots navigation (Harper & McKerrow 2001; Li et al., 2011). For localization tasks in agricultural robotics, mostly complex systems of infrared light based sensors or hybrid sensors with e.g. laser, camera or other types of sensors are used (Mehtaa, 2008). Non-contact proximity sensors are used to measure distance or for detection of objects and are well-suited for contactless recognition of plants and/or specific parts of a plant as well as for detection of special markers positioned relative to plant, so that the robot manipulator can be precisely positioned using limit switches or metallic detection type inductive sensors. Contactless operation is essential because of the necessity to minimize potential diseases spreading between plants.

The main types of proximity sensors used in the industry are ultrasound, infrared, inductive and capacitive.

Inductive sensor (Passeraub et al., 1997; Kej´ık et al., 2004) detects metallic objects and is suitable for industrial applications. This type of sensors produces a magnetic field in the vicinity of an oscillation coil. When a conductive object gets near to the coil, the eddy current on the object induced by the magnetic field reacts with the coil to change the oscillation frequency. Although the inductive sensor is simple, sensitive and suitable for industrial applications, it is unable to detect nonmetallic objects.

Capacitive sensor (Chen & Luo, 1998; Buck & Aherin, 1991) detects metals, objects with high humidity and other types of obstacles that change dielectric permeability of the space around the active area of the sensor. The sensor measures the capacitance between two electrodes and the capacitance changes when a detectable object is approaching.

There are three types of optical sensors (Lee & Allen, 1997; Stoyanov, 2000): reflective, diffusion and interrupt. Reflective type sensor is used for detecting objects and for distance measuring. The sensor uses a light emitter to emit light of specific wavelength at a certain carrier frequency and the receiver senses the light reflected from an object. The phase shift or time of flight will show the distance between the sensor and the object.

Ultrasound sensor (Li et al., 2003) uses the same principle as the bat echolocation. There are two types of ultrasound sensors: with two probes, one emitter and one receiver and with one probe, which is the emitter and receiver the same time. It has a large detecting distance and area. The drawback of ultrasound sensors lies in fact that they are affected by secondary echoes when detecting a closed hard-surface object.

If a robot is used in a controlled domestic environment (Mitka et al., 2012), its proximity sensors will work with a suitable precision and the robot operation, including the localization task, has been well studied in such environments, but the topic of how exactly the real conditions of a greenhouse-specific microclimate affect the performance of proximity sensors has not yet been thoroughly studied.

In recent researches, in order to evaluate the ability of robot parts to resist the environmental effects of a greenhouse, the analytical hierarchy process method has been used. A comparison was made of construction materials, mechanics, contacts, electronics, and inductive, optical and ultrasonic sensors, depending on the effects of the factors: the greenhouse microclimate, plant protection solutions (various pesticides, fungicides etc.), and plant fertilizers. In further research, sensitivity to environmental factors should be evaluated for the parts and sensors of horticultural robots (Lojans & Kakitis, 2012). The abovementioned fertilizer and plant protection solutions are mostly used as sprays increasing air humidity locally around the robot and in most cases also around the sprayer and hull positioning sensors. The humidity is condensing and can hypothetically affect the reliability of various contactless positioning sensors.

This paper covers experiments with inductive, capacitive, optical, and ultrasound sensors carried out in a special microclimate chamber for greenhouse environment simulation. The aim of the research is to find out if and how temperature and relative humidity affect the performance of different types of proximity sensors when detecting various obstacles.

MATERIALS AND METHODS

The sensors used in this experimental research are summarized in Table 1 and Fig. 1.

Table 1. Experimental proximity sensors description

Model	Type	Sensor interface	Dist. (mm) Min.Nom.Max.	Hysteresis, %	Response time, ms	Manu-facturer	Ref.
170710*	ultrasound	4-20 mA	150 – 500	–	25	Festo Didactic	RS1
CR30-15DN*	capacitive	NPN	0 – 10.5	20	20	Autonics	RS2
GP2Y0D 340K	optical	NPN	320 400 480	6	8	SHARP	RS3
165342*	optical	PNP	0 – 430	–	2	Festo	RS4
177464	inductive	PNP	– 4 –	10	2	Festo Didactic	RS5
184118*	ultrasound	PNP	100 – 200	5	166	Festo Didactic	RS6

*Actual configured distances can be seen in Fig. 5.

The sensors were selected to cover long-range and short-range detection as well as the most often used contactless proximity detection mechanisms: capacitive, inductive, optical-infrared, and ultrasound. Inductive type sensors should not be affected by the specific greenhouse microclimate and were included in the study for comparison purposes.

An ultrasound sensor with analog current output referenced as RS1 was modified to operate as a bipolar junction transistor NPN type digital output using a voltage divider and transistor and adjusted to operate at a 120–130 mm distance. The other adjustable sensors were also set to operate at certain distances. The operation of all sensors in control conditions is covered in detail in the results and discussion section. In addition, PNP type sensors were also modified to operate in reverse polarity.

Two models of infrared sensors of different scopes of application and pricing were used: intended for consumer electronics (RS3) and for industrial applications (RS4).

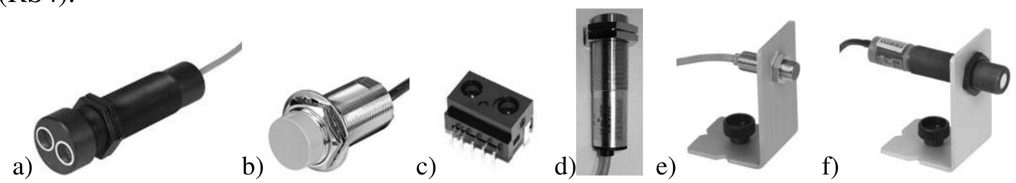

Figure 1. Experimental proximity sensors: a) – 170710; b) – CR30-15DN; c) –GP2Y0D340K; d) – 165342; e) – 177464; f) – 184118.

The performance of the selected proximity sensors was evaluated in a specialized microclimate chamber (see Fig. 2). The chamber allows to create conditions that are observed in a greenhouse during a typical daily cycle (Abdelfatah et al., 2013).

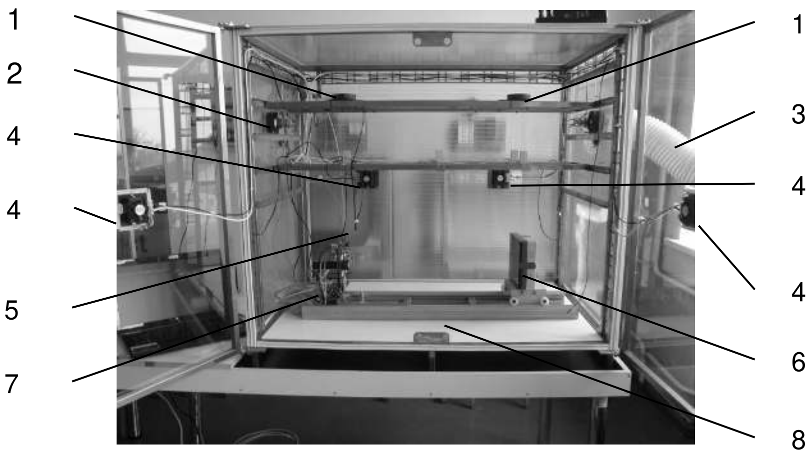

Figure 2. Microclimate chamber for simulation of greenhouse temperature and relative humidity: 1 – air recirculation fans; 2 – ventilation intake fan; 3 – ventilation outtake fan and tube; 4 – heating elements; 5 – temperature and humidity sensors; 6 – moving platform with target (container with water); 7 – senor plate; 8 – rail for target moving.

The microclimate chamber was equipped with heating and cooling elements, recirculation and ventilation fans. The controlled microclimate parameters were temperature (using a Tsic506 digital output sensor with ±0.1°C error) and relative humidity (using a Linpicco Basic A420-G 4–20 mA analog output sensor with ±3% error).

The proximity sensors were installed stationary in a test bench, but the target – the detectable object – was placed on a moving platform (see Fig. 3). The sensors were installed taking into account the manufacturer's installation instructions concerning to the minimum spacing between the sensors and so that the further edges of the hulls were the same distance away from the target. The target was moved by means of a threaded rod driven by a geared DC motor. A metric thread was used; consequently, the platform could move 1 mm per revolution of the DC motor. This step was used as the basic resolution for the platform positioning. The platform with the target was moved at a constant speed of 10 $mm \cdot s^{-1}$.

The evaluation of the sensors was performed in a number of test cycles. Each test cycle was started at the leftmost (null) position of the platform when it was at the minimum distance from the sensors (<1 mm). Then, the target was moved away until all sensors ceased target detection or up to the rightmost position (570 mm) if the environmental conditions forced at least one sensor to malfunction (i.e. it does not stop to detecting the target). Then the target was moved back to the null position.

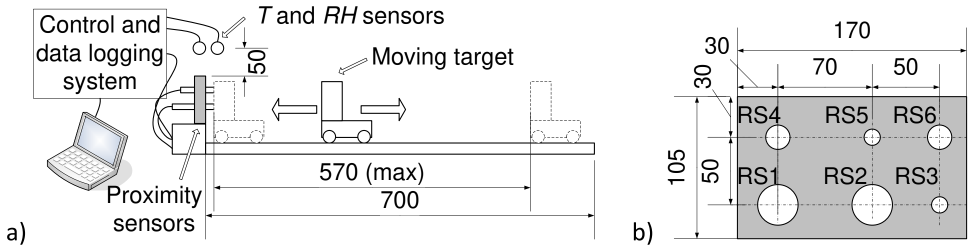

Figure 3. Sensor test bench (a) and positioning of sensors – right side view (b).

The test cycles were grouped by various environmental conditions and detectable objects. Three environmental conditions were used – control conditions, high temperature and dry air, high temperature and humid air; and three types of detectable objects: steel sheet, ABS (Acrylonitrile Butadiene Styrene) plastic sheet, and ABS plastic container with water.

The control conditions with the average temperature T = 27.8 ± 0.5°C and the relative humidity RH = 23 ± 3% were used to obtain the normal sensor detection distances for comparison. High temperature and dry air conditions were used to evaluate sensor performance in T = 24…39ºC and RH <20% and high temperature and humidity conditions in T = 24…39ºC and RH 30…100%. Temperature and relative humidity were not kept constant during the experiments (except control conditions), instead, they were increased up to their maximum values, then decreased by ventilating the microclimate chamber. This allowed to evaluate the influence of transition process on the operation of the proximity sensors. The sensors' detection limits are floating and affected by temperature and humidity. The typical profiles for both types of conditions are given in Fig. 4. The heating and ventilation process typically took approximately

40 min during which the test cycles were performed. Temperature was increased using a 1.5 kW electric heater, but humidity with a 1 kW steam generator. The water volume in the steam generator's tank was kept between 2 and 2.5 l. A steel sheet of 255 x 380 x1 mm was chosen as a detectable object to cover the situations where sensors need to detect metallic structures like greenhouse frames, racks and other robots. The steel sheet can be effectively detected by all types of proximity sensors used in the research. The ABS plastic sheet of 245 x 330 x 1 mm was used to find how sensors will operate with objects like empty plant pots, crates, plastic racks etc. The plastic sheet cannot be detected by the inductive and, due to its 1 mm thickness, also by the capacitive sensors. The 118 x 180 x 60 mm ABS plastic container composed of two parts – a non-transparent base and a transparent lid–, was filled with water and positioned to with the transparent side facing the sensors, which allowed to evaluate the infrared proximity sensor performance with various liquid containers. The capacitive sensor in turn acts with the water-filled container as a model of a vegetable or fruit (Li et al., 2012, Kviesis & Osadcuks, 2013). The water container cannot be detected with an inductive sensor.

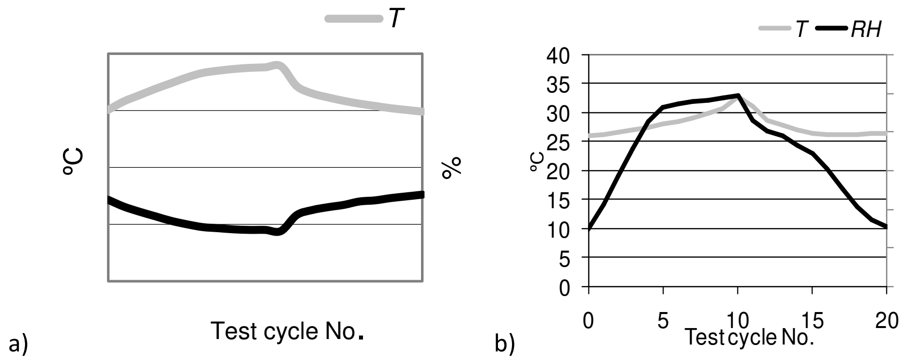

Figure 4. Typical temperature and relative humidity profiles during experiments with high temperature and low humidity conditions (a) and high temperature and high humidity (b).

Three repetitions were performed for all environmental conditions and detectable object combinations. Each repetition consisted of at least 10 test cycles for control conditions and at least 20 cycles for other conditions, thereby 546 test cycles were performed in total. The on and off state of each sensor, temperature and relative humidity were logged at each change in the target position or sensor state. Air recirculation was performed by 4 fans during all tests to ensure homogenous environmental conditions for all sensors and for the whole target moving distance.

The operation of sensors was analyzed graphically and using statistical methods: analysis of variances (ANOVA) to find whether the detectable object, various operating conditions or the operation mode (increase or decrease in T and RH) affect the switching distances of sensors; Spearman's non-parametric test was used to find whether there was a correlation between sensor operation distances and operating conditions for each type of detectable object.

RESULTS AND DISCUSSION

The typical target detection characteristics in control conditions for each sensor are given in Fig. 5. The sensing distances are the longest in the case of the consumer electronic infrared sensor RS3, but it has uncertain detection at long ranges. The industrial infrared sensor switching is more reliable, but has increased hysteresis (80 mm or 28% of maximum sensing distance).

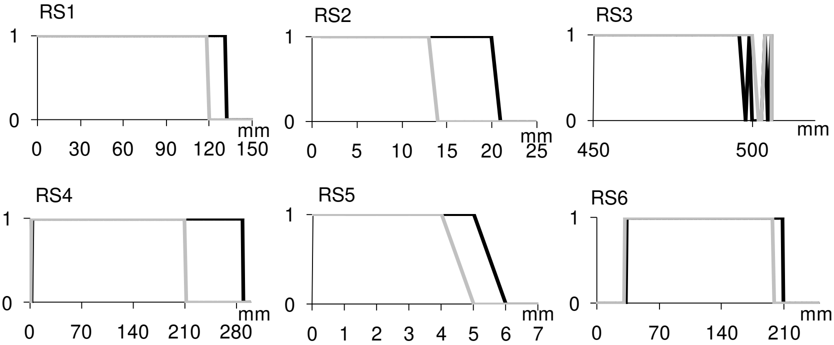

Figure 5. Typical detection distances of a 1 mm steel sheet for each type of sensor; the vertical axis shows the sensor state (1 – object detected, 0 – no detection), the black line shows the sensors' turn off point when the target is moving away, but the gray line shows the sensors' turn on point when the target is approaching: RS1 – analogous output ultrasound; RS2 – capacitive; RS3 – infrared for consumer electronics; RS4 – infrared for industrial applications; RS5 – inductive; RS6 – ultrasound with digital output.

Table 2. Average operation distances of sensors, in mm, by environmental conditions and detectable object

Sensor operation	Steel sheet			ABS sheet			ABS container with water		
	Control	High T, low RH	High T, high RH	Control	High T, low RH	High T, high RH	Control	High T, low RH	High T, high RH
RS1 off	130	127	–	128	127	–	126	124	124
RS1 on	118	120	–	120	121	–	119	119	118
RS2 off	19	15	16	–	–	–	12	12	12
RS2 on	13	13	14	–	–	–	10	10	10
RS3 off	513	460	468	460	468	485	273	265	291
RS3 on	513	459	469	459	468	485	272	265	290
RS4 off	288	304	292	312	306	315	192	191	181
RS4 on	209	227	221	235	234	239	146	144	136
RS5 off	6	7	7	–	–	–	–	–	–
RS5 on	5	6	6	–	–	–	–	–	–
RS6 off	208	207	207	207	206	203	205	204	205
RS6 on	197	199	199	199	199	196	198	197	197
RS6 min off	31	79	62	32	37	26	21	22	21
RS6 min on	34	83	63	32	41	27	23	23	24

Ultrasound sensors have moderate sensing distances and relatively small hysteresis (13 mm or 6% of the maximum sensing distance). Due to the ultrasound range sensing technology, there is a limit for the minimum sensing distance, which can be observed in the RS6 operation. This effect is not observed with the 4…20 mA analog output ultrasound sensor RS1, because of the minimum loop current and transistor switch added at the output for the experiments. The average operation distances for all test cycles in three repetitions grouped by environmental conditions and detectable objects are summarized in Table 2. The table shows both the sensor turn-off distance when the target is moving away and the turn-on distance when the target is approaching. It also shows the minimum detecting distance for the digital output ultrasound sensor RS6.

During the experiments in high temperature and humidity, the ultrasound sensor RS1 malfunctioned with the steel and plastic sheet targets. It took the form of doubling the detection distance in comparison to the tests in control conditions. Most likely, it was internal sensor failure and therefore its measurements were included in further analysis only for comparison purposes.

A statistical analysis was performed for the turn off and on distances, target detection hysteresis and the RS6 minimum detecting distance and its hysteresis. As was expected, the analysis of variances for all parameters shows that the type of detectable material significantly affects the sensor operation. The only exception is the hysteresis of RS3, because, as it was mentioned before, its operation at long distances is uncertain.

An analysis of variances was also performed to find out whether heating and ventilation transient processes have any effect on the detecting distances of sensors. The results show that for almost all of the environmental conditions and detectable objects (with the exception of the 3rd repetition for the ABS sheet in high T and RH) there is statistically significant difference ($P < 0.05$) in the turn-off distance for the ultrasound sensor RS6 and also with all conditions and objects (with the exception of 2 repetitions with steel and 1 repetition with the ABS sheet in the same environmental conditions) for the RS6 turn-on distances. Despite the statistical significance, these changes are only within 3 mm, which is 1.5% of the detection distance. Both the turn on and off distances for the ultrasound sensor are consequently higher by this value when T and RH are increasing. It was stated that the temperature and humidity transients had no effect on the hysteresis of RS6. It is also to be mentioned that the ultrasound sensor RS1, which failed in a number of tests, has also strong dependency on transients. In approximately 40% of the cases, transients also affect the switching distances of both infrared sensors, but again there are no significant differences in hysteresis.

The results of the analysis of variances (P-values) on the effect of the environmental conditions factors are summarized in Table 3. The analysis included test cycles for high T, low RH and high T and high RH conditions, i.e. it shows whether significant differences were observed in the object detection parameters between these two conditions. The results show that environmental conditions have no impact on the inductive type sensor RS5 and it was excluded from this analysis. The most significant changes in the results for all sensor parameters between the environmental conditions are for steel and ABS sheets. The only exception is for the RS3, as in the previous analysis.

The explanation could be that changing environment has effect not only on the physical phenomena used by a sensor for object detection (e.g. dielectric constant or IR ray absorption ability of air), the sensor body, the electronics it is housing, but also on the detectable object. The surrounding air heated steel and ABS sheets due to their small volume, but the temperature of the ABS container with water remained nearly constant throughout the experiments, thus the sensors that relay on the non-optical detection principle were less affected by changing environment.

Table 3. Results of the analysis of variances on the effect of environmental conditions (P-values)

Sensor operation parameter	Steel sheet	ABS sheet	ABS container with water	Sensor operation parameter	Steel sheet	ABS sheet	ABS container with water
RS1 hyst.*	0.000	0.103	0.000	RS4 hyst.	0.000	0.000	0.013
RS1 on*	0.000	0.126	0.000	RS4 on	0.000	0.000	0.000
RS1 off*	0.000	0.385	0.000	RS4 off	0.000	0.000	0.000
RS2 hyst.	0.000	–	0.155	RS6 hyst.	0.000	0.000	0.423
RS2 on	0.000	–	0.064	RS6 on	0.000	0.000	0.816
RS2 off	0.000	–	0.000	RS6 off	0.000	0.000	0.162
RS3 hyst.	0.003	0.743	0.134	RS6 min hyst.	0.020	0.000	0.215
RS3 on	0.000	0.000	0.000	RS6 min on	0.000	0.000	0.626
RS3 off	0.000	0.000	0.000	RS6 min off	0.000	0.000	0.372

* Only for comparison; – not tested

In the tests with the ABS plastic container there are, in turn, no significant differences between environmental conditions for the RS2 capacitive sensor's hysteresis and turn-on as well as for all parameters of the sensor RS6. This can be explained with moisture condensation on the detectable objects during microclimate parameters transients.

Table 4. Spearman's correlation coefficients grouped by environmental conditions and the material of detectable object

Condition	High T, high RH						High T, low RH		
Detectable object	Steel sheet		ABS sheet		ABS container with water		Steel sheet	ABS sheet	ABS container with water
Correlation with	RH	T	RH	T	RH	T	T	T	T
RS3 off	0.61	0.68	0.20	0.28	0.02	-0.39	0.16	0.29	-0.52
RS3 on	0.63	0.70	0.20	0.32	0.04	-0.37	0.18	0.30	-0.54
RS4 off	-0.86	-0.74	-0.05	0.06	-0.66	-0.87	0.08	-0.03	-0.29
RS4 on	-0.90	-0.81	-0.13	0.12	-0.69	-0.89	-0.24	-0.49	-0.23
RS6 min on	0.75	0.73	0.41	0.47	0.21	0.39	0.76	0.74	0.44
RS6 min off	0.66	0.65	0.44	0.43	0.42	0.48	0.75	0.70	0.40

Spearman's correlation coefficient was calculated to find whether there were any correlations between sensor switching parameters, temperature and relative humidity. A statistically significant $P < 0.05$ moderate to strong relationship (the absolute value of Spearman's correlation coefficient greater than 0.6) was observed for both the infrared type sensor on and off parameters in high temperature and humidity conditions and for the RS6 digital output ultrasound sensor's minimum on and off distances both in humid and dry air, but only when detecting the steel sheet. No correlation with any of the sensors hysteresis was observed. The summary of significant Spearman's correlation coefficients is given in Table 4. Note that in high T and low RH conditions, the correlations with humidity are not included as the changes in RH were no higher than 7 percentage points (see Fig. 4).

Although there is strong correlation with temperature and humidity for both infrared sensors, the coefficients are negative, i.e. while the detection distance of industrial-type sensor RS4 decreases with increase in both environmental parameters, the distance of the consumer electronics sensor RS3 increases (see Fig. 6).

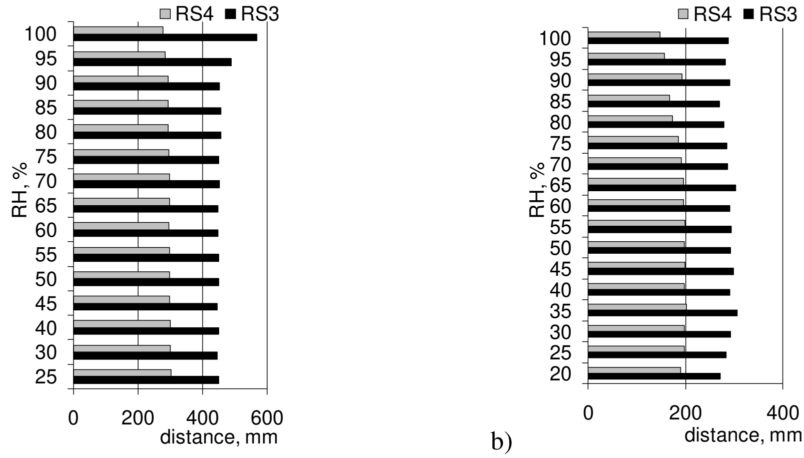

Figure 6. Switch-off distances for infrared sensors RS3 and RS4 with a steel sheet (a) and ABS plastic container filled with water (b) in high T and high RH conditions.

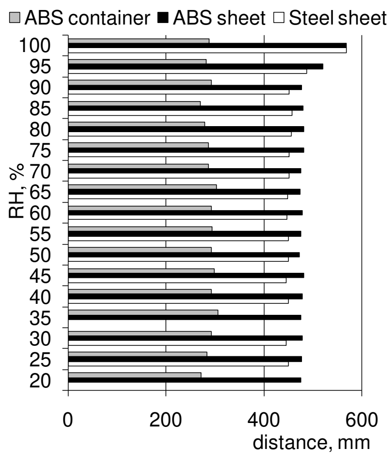

Figure 7. Switch-off distances for the infrared sensor RS3 with three types of objects in high T and high RH conditions.

It should also be pointed out that the sensor RS3 failed to detect objects at long ranges when humidity increased over 95%, as its infrared beam reflected from vapor. This reflection can be observed at a certain distance between 300 and 450 mm. This can be concluded from the fact that the RS3 sensor's detection distance for the water-filled ABS container with a transparent lid because the IR beam diffusion is smaller than for other objects and the sensor switches off properly, but with the objects that can be detected at longer ranges, the sensor does not turn off up to the maximum target distance (570 mm), which is greater than the RS3 detection distance at the control test cycles (see Fig. 7). Therefore, this type of sensors cannot be effectively used in a vaporous environment. This fact was not observed for industrial type sensor.

CONCLUSIONS

1. Infrared devices are most affected by greenhouse environment of the long-range proximity sensor types. The switching distance is strongly dependent on air relative humidity: a change in relative humidity from 30% to 100% results in a 25 mm or 8% decrease of the maximum detection distance for an industrial and a 12 mm or 3% for a consumer electronic infrared sensor. However, the infrared beam can reflect back from aerosols e.g. water vapors, and result in sensor distance detection failure.

2. Ultrasound sensors are the most reliable for long-range obstacle detection in greenhouse environment. Although statistically significant influence of environmental conditions can be observed, changes in maximum detection distances do not exceed 5 mm or 2.5% and there is no correlation with temperature and humidity. It should also be noted that there is a moderately strong correlation (Spearman's correlation coefficient > 0.7) between the minimum detection distance and temperature.

3. If the temperature of obstacles changes when heated by direct sunlight and other heat sources, it can increase the minimum detection distance of ultrasound sensors.

4. Short-range capacitive and inductive type sensors are not significantly affected by greenhouse environment, however, the obstacle detection range of a capacitive can decrease if moisture condensing occurs during temperature and humidity transients.

5. The changes in sensor detection distances should be taken into consideration when designing positioning control systems for a robot and its working units (sprayers, inspection probes, manipulators etc.).

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Agronomy Research **12**(3), 967–976, 2014

A multi-factor approach to evaluate environmental impact statements

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Abstract. The goal of this study is to develop a method for assessing Environmental Impact Statement (EIS) according to various criteria, and to develop recommendations to improve statements and the EIA procedure. To develop a method to assess report quality, the most significant current methods were examined. Their advantages and disadvantages were analyzed and, as a result, the most appropriate method structure was defined – a control list with quality criteria. To determine the quality criteria of an EIA, the effective basic principles of the EIA were formulated based on sources in the literature. During the study, the three most significant elements of a quality EIA were defined. These have been incorporated into the method developed in this project as the most significant criteria. As a result, a systematic method to assess an individual EIS was developed. The method includes quality criteria, which have been determined to be the most significant as a result of an analysis of the efficiency of the EIA procedure. The method has been adapted to the planned amendments in the EIA directive, incorporating these criteria. The structure of the method adheres to another fundamental goal of the directive's amendments – to decrease the administrative load of the EIA procedure. It is anticipated that with the aid of this method, by assessing only the most important report elements in depth, that the time necessary for a competent institution to evaluate a report will be reduced.

Key words: environmental impact assessment, sustainability, evaluation methodology, environmental impact statement.

QUALITY OF THE EIS

EIA is a systematic, technical tool of environmental policy which is currently in use in more than one hundred countries around the world, including Latvia. Until now, no studies have been conducted in Latvia on the quality of the final EIA report – the Environmental Impact Statement (EIS), and the efficiency of the process as a whole. Latvian legislation will be obliged to apply the planned amendments to the European Union EIA directive in the near future. Before applying these amendments, it is practical to assess the current EIA procedure. As an EIS reflects the assessment process, one method to assess the EIA as a policy tool is to assess the quality of the EIS. A report assessment is essential during the EIA process to confirm the quality of the information provided, and following the end of the assessment, to assess the efficiency of the EIA system as a whole. For report assessments to have a valid basis, and for them to be comparable, they must be evaluated systematically by using a specific algorithm or method.

A report evaluation is essential both during the EIA process, to confirm the quality of information provided, and after the assessment has been completed, to evaluate the efficiency of the EIA system as a whole. For the report evaluation to be supported and comparable, it must be conducted systematically by applying a specific algorithm or method. The first definition of the evaluation methods for an EIS is generally considered to be a Canadian study from 1987 which is based on a literature review and interviews with organizations and individual experts in order to determine how to evaluate an EIA. It was also used to formulate some basic principles for an evaluation (Sadler, 1996; Canter & Sadler, 1997).

Criteria for an efficient EIA

EIA efficiency has several definitions and formulations. To evaluate measure and compare EIA efficiency, various factors or criteria describing their efficiency must be proposed. As basic characteristic quantities, the efficiency of implementing the report or procedure can be selected. EIA efficiency can be split into four aspects:

1) Report quality;
2) Influence of EIA in decision-making;
3) Efficiency of predicting impact and of preventative actions;
4) Monitoring and audits following project implementation.

Within the literature, many authors define EIA efficiency as a level at which the EIA has reached its defined goals, results, and reasons for implementation. A basic goal of the EIA procedure is usually defined specifically as the identification and prevention of environmental damage, and in this case EIA efficiency can be defined as the level at which it identifies, assesses, and seeks out methods to prevent or reduce the negative impact of the planned activity (Glasson, 2005; Peterson, 2010).

By defining the criteria of EIA efficiency, they must, firstly, adhere to procedural goals and, secondly, include the most important elements of the process. To evaluate the total efficiency of an EIA, it is necessary to include environmental monitoring within the procedure before beginning the project, as well as once it has been implemented. This is done so that it can be determined how valid the predictions of the project's environmental impact were and how efficient the activities selected to reduce this impact were. This will allow for the reasonable assessment of the efficiency of these parts (Munn, 1970).

The theoretical efficiency of the EIA is much higher than in practice, especially when emphasizing an alternative evaluation, and activites following the approval of a decision – monitoring and auditing.

The basic elements of an efficient EIA can be divided into five groups:

1) EIA goals;
2) Public participation;
3) Quality of reports and other documents;
4) Efficiency of EIA expenses;
5) Influence of the procedure's conclusions on the decision-making process.

EIA efficiency is dependent on public participation in the process, in EIA documentation, in the initial transformation of the project at the EIA level, as well as in the evaluation of the influence of the assessment in the decision-making process. EIA goals must be reached efficiently, with respect to time and money, and EIA efficiency must be verified following project implementation with the aid of monitoring and auditing.

Based on the literature review conducted on the elements and criteria characterising the efficiency of an effective EIS and the process involved, the following criteria were determined to be the most important:

1) The trust placed in the objectivity and quality of the EIA by the public and other parties involved – the process is understood by all parties involved, information is clear and available, the goal of the procedure is clearly defined, all parties involved trust that the process is not influenced by its strongest proponents;

2) It is integrative (incorporates planning documents, legislative standard, etc.) and is connected to decision-making – that is, the results of the EIA process correspond to legislative standards and other corresponding documents, and all are taken into account during the decision-making process;

3) Long-term benefits of environmental quality are encouraged, as well as improvements in the planned activities of the project, including monitoring, to ensure adherence to environmental demands to ascertain the efficiency of predictions and preventive actions made during the process;

4) The report is comprehensible – the report includes information that is easily understood by readers without specific knowledge in the specific field, the significance of various aspects is explained, the reader is able to compare them;

5) The participation of the public and other interested parties is included in the consideration segments, information about the opportunity for interested parties to participate is easily available. The goal of public participation is to improve procedural quality, public consideration does not limit the participation of other interested parties (the location and time of consideration is acceptable to most parties involved), the public view and how it will be incorporated is explained during the decision-making process;

6) It is legal – corresponds to legislative standards;

7) It is all-encompassing – it includes all significant information related to environmental, social, cultural and biophysical aspects, if there is enough reason to consider an aspect insignificant, it is not widely analyzed; an evaluation of valid alternatives is included, cumulative and indirect influences are evaluated;

8) Appropriate human resources and innovations – the EIA administrative process is performed by competent specialists, modern technology and forms of communication are used for accessibility, and during other EIA segments;

9) Assumptions, predictions, evaluations, and decisions are based on true (provable) information, decisions are based on information acquired, information sources are indicated. Undefined information and assumptions are explained.

Appropriate, modern alternatives are analyzed, this is to be completed in the early stages of the project in order to make improvements in the planned activities of the project (Lee & Colley, 1990; Canelas et al., 2005; Androulidakis & Karakassis, 2006; Polonen, 2006; Polonen et al., 2011).

This study has selected three EIS elements as the most essential – an evaluation of alternatives, public participation, and monitoring. Each of these three elements ensures the basic functions of the EIA, and the realization of its goals – firstly, a selection of alternatives guarantees the selection of the best project locations, technology, solutions. Secondly, a basic function of the EIA is performed through public participation – to ensure information for all parties involved. Also, public consideration guarantees a more complete evaluation and identification of the environmental issues. Thirdly, monitoring is an important EIA component to verify the validity of predictions, the project's actual impact and project implementation with respect to the permit received. In addition, monitoring data guarantees a binding database for all parties involved in the EIA (Morrison-Saunders & Arts, 2006).

Methodology

The EIA procedure incorporates the evaluation of the report's quality, and in Latvia this is currently conducted before a decision is made on issuing a permit for project implementation by the competent institution – the State Bureau of Environmental Inspection. In addition, reports may be evaluated following acceptance, to evaluate the overall quality of reports, and, correspondingly, the quality of the EIA procedure, the advantages of the corresponding legislation, weaknesses, and EIA tendencies as a whole. The evaluation of EISs has an important role in the quality control of an EIA, in the development of guidelines and sample practices, and it is also binding for the preparation of further EIA developed reports as well as for the project implementer, who may use information on the EIA process for the further development of planned activities.

A systematic method for evaluating individual reports has been developed in this project. The method includes quality criteria, which have been proposed as the most significant in the analysis as well as other methods of the EIA procedure. The method has been adapted to the proposed amendments in the EIA directive, including such criteria to ensure that reports adhere to the updated requirements of the directive. This approach has been selected due to the fact that the fundamental goal of the directive's amendments is to increase EIA efficiency and quality.

RESULTS

The criteria of the method have been arranged into four groups (see Fig. 1). The significance of criteria in each group increases, and, analogously, the subjectivity of the possible evaluator increases.

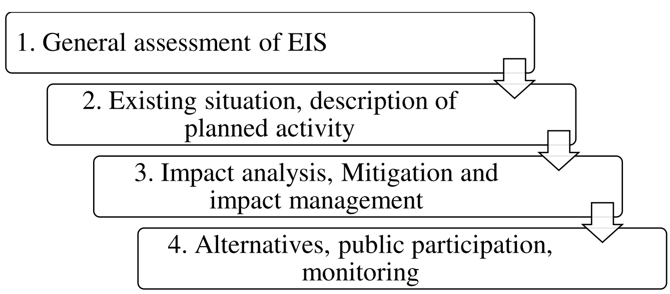

Figure 1. Structure of the method developed.

The first group summarizes criteria which guarantee the correspondence of the EIS to minimal requirements, that is, legislative standards. As several authors have indicated, the correspondence of the report to legislative demands does not always signify that it has been prepared qualitatively. The EIA procedure can be completed so as to reach one of two goals:

1) Adherence of all planned activity to all legislative standards;
2) With the goal to have the smallest environmental impact possible in a rational, valid fashion.

By evaluating the report only by the adherence to legislative standards, it is impossible to determine if it is inclined towards the most efficient and rational solution in environmental issues. The criteria characterising report quality have been summarized in the following chapters of the method.

The second part of the method includes criteria that characterise the description of the current situation and planned activities. Thus, an analysis of the selected location of the project, its environmental condition and dynamics, pre-project implementation and the characteristic quantity of the planned activities. The information of the second part in the report aids in the identification of the criteria of the third part – identification of impacts, their prevention, reduction or compensation. The fourth part of the evaluation must assess the most essential identified elements – alternatives selected, public participation and monitoring.

If the report is consistent with the requirements of the method's first part, that is to the directive and legislation, then it meets minimal requirements. If the criteria of this section have been evaluated as unsatisfactory, then it cannot be considered to be consistent because it does not correspond to standard requirements, but consistency with the first section of the method does not indicate the quality of the EIS. This structure to the method has been selected because the following section derives from the previous – accordingly, if the report contains qualitative and all-encompassing information about the location of the planned activities, project scope, and its specifications (Part 2 of the method), then it is easier to identify potential impacts and their respective actions (Part 3). At the close of the evaluation, the correspondence of alternatives and monitoring to all previous conclusions, as well as the quality of public participation to evaluate report quality and efficiency, or the degree to which it has reached the goals of the EIA procedure. A full method chart can be viewed in Appendix 1, and each of the four sections, their criteria and the basis for criteria selection are elaborated upon in the following sub-chapters.

Methodological criteria, the basis of selection

The evaluator of the first section should, firstly, evaluate the criteria dichotomously as either ‘yes’ or ‘no’. If any of these section points is missing, then the report does not adhere to legislation and the minimal requirements, and cannot be accepted (see Table 1).

Table 1. Criteria of the method's first section

Correspondence to legislation (minimal requirements)		Evaluation
1.1.	Description of project location	
1.2.	Description of planned activities	
1.3.	Description of potential impact(s)	
1.4.	Activities to reduce of prevent significant impact	
1.5.	Summary	
1.6.	Adheres to the program issued by the responsible institution	
	Final evaluation	

The criteria of the method's second section (Table 2) are proposed in a manner that allows for the verification of the completeness and quality of the information used, to determine the project's impact on the environment. In addition to the information on the direct influences in the report, information on indirect activities related to the project must be included, for example, infrastructural expansion.

Table 2. Criteria of the method's second section

Description of the current situation and planned activities		Evaluation
2.1.	Project goal and its necessity have been explained and supported	
2.2.	Specifications, size, location of the planned project	
2.3.	Description of construction process, materials used, amount	
2.4.	Life cycle of project construction, operation, dismantling time	
2.5.	Description of operational process (incl. Raw materials, if such are used)	
2.6.	Transportation of raw materials, products, labour, etc.	
2.7.	Type of waste, amount	
2.8.	Characterisation of environmental factors and processes of selected location, their dynamics	
2.9.	Description of the project's socio-economic environment	
2.10.	Description of indirectly affected territories	
2.11.	Data sources, their quality, age, correspondence	
	Final evaluation	

Criteria in Table 3 describe the prediction of impact, its assessment and preventive measures. In this section, it is important to identify whether all significant impacts have been described in detail, whether they each have appropriate, modern reduction activities recommended. In adherence to the criteria in this section, the report should not describe in detail those effects with insignificant consequences. The methods and/or programs according to which the potential amount of influence are modelled and predicted must be evaluated. Impact reduction activities must adhere to the principles of preventive measures, wherever possible, in order to reduce the source of pollution, and not the consequences created (that is, end-of-the-line activities are not used).

The fourth section of the method (criteria in Table 4) is the most significant of the assessment system because the most important EIA efficiency indicators are evaluated according to the criteria in this section – assessment of alternatives, public participation, and monitoring. These criteria define the fundamental principles of assessment efficiency, also incorporating those basic functions of the report which often contain vital inconsistencies in the evaluation of both reports from European countries, and the EIA system as a whole. Alternatives are evaluated in a way that the best solution of the planned activity can be applied, corresponding to the best possible technology, and to select the most appropriate location for project implementation. Alternatives can be consciously selected so that the project initiator's first option is the most appropriate, by evaluating the quality of these criteria, the appropriateness of alternatives must be weighed.

Table 3. Criteria of the method's third section

Identifying impact, assessment, risk analysis		Evaluation
3.1.	Potential environmental impact of the project	
3.2.	Impact has been defined clearly, comparably, measurably, prediction methods and models are used	
3.3.	Most significant effects have been described in detail	
3.4.	Environmental impact has been assessed over the entire life cycle of the project	
3.5.	Selection of impact prevention/reduction/compensation activities are adequate, corresponding to best practice and available technology, the principle of caution is observed	
3.6.	Impact reduction activities include improvements to the project	
3.7.	The effect of impacts to be reduced following reduction activities is described	
3.8.	Risk analysis	
	Final evaluation	

Table 4. Criteria of the method's forth section

Description of the current situation and planned activities		Evaluation
4.1.	A basis for selected alternatives (their type – location and/or technologies), consistent with most significant impact. Alternative selection begun in the initial stages of the EIA process.	
4.2.	Selected alternatives include the principle of best possible technology, in accordance with project goals, if the selected alternative is the selection of a different territory, the selection is valid, adequate, comparable	
4.3.	Participants of public consideration, submitted proposals	
4.4.	Availability and conformity of publicly available information	
4.5.	A monitoring plan is including, corresponding to the most significant potential effects	
	Final evaluation	

The terms of correspondence of the method criteria developed in the project may change, through the application to specific types of projects, and due to the most significant current environmental issues. The criteria of the method are such that they can be applied to all types of projects (for example, wind turbines, roadwork, etc.). The method can be adapted to different types of projects by specifying the kind of information to be included in the report, to make it consistent with each criterion, through the use of information in the respective guidelines and practical examples. This type of modification of the method could increase its ease of use, and would facilitate its use by evaluators with a low level of competence in the field of the respective project.

CALCULATION OF THE ASSESSMENT RESULT

When evaluating a report using the method developed in this project, the evaluator must first evaluate the criteria of each section by applying a number of points on a scale of 0 to 5; explanations of these rankings are summarized in Table 5.

Table 5. Explanation of rankings of the method developed

Ranking	Explanation
5	Excellent, information is clear, understandable, complete, and of good quality
4	Good, overall satisfactory, with insignificant shortcomings
3	Satisfactory, with shortcomings and inconsistencies
2	Unsatisfactory, significant inconsistencies
1	Poor, significant shortcomings and inconsistencies
0	Very poor or information corresponding to criteria non-existent

Once each criterion has been evaluated with its corresponding ranking, each of the four sections is evaluated. The final evaluation of the section can be expressed mathematically, as the average arithmetic value of the criteria values using equation (1). The method may also be used where the evaluator selects the final evaluation of each section subjectively, by selecting the most significant project criteria of the specific report. These are then given a greater weight in the section's final evaluation

$$x = \frac{a_1 + a_2 + \cdots + a_n}{n} \quad (1)$$

The EIA is a cyclic process, its sections are interconnected, and the EIS itself reflects the process. This means that the information contained in the first chapters of the report is also analysed in all further chapters. As a result, key conclusions are reached. While all report information is significant, the most essential for guaranteeing the functions of the EIA process are qualitative conclusions. For this reason, when developing a calculation diagram for method evaluation, specific sections in the final evaluation have been given a perceptibly larger weight. The sections of method criteria have been arranged in increasing order by significance in the evaluation of the report quality, and their significance is expressed as a percentage; this hierarchy can be seen in Fig. 2.

The final evaluation of the report is calculated using equation (2), by multiplying each section's final evaluation with its respective perceptual value according to Fig. 2:

1) Adherence to legislation – 10%;
2) Description of current situation and planned activities – 20%;
3) Identification of impact, assessment, risk analysis – 30%;
4) Monitoring, alternatives, public participation – 40%.

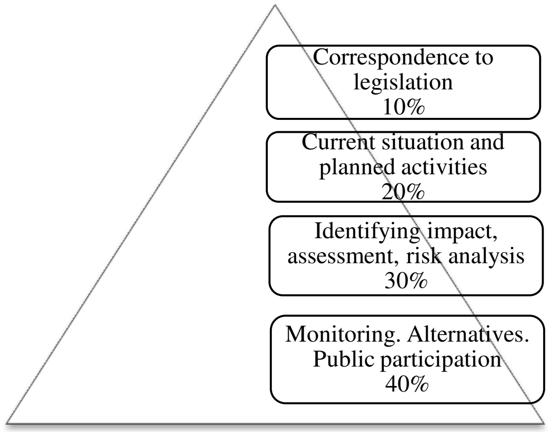

Figure 2. Division of section impact in the final evaluation.

Formula to calculate final evaluation of the report:

$$y = x_1 \cdot 10\% + x_2 \cdot 20\% + x_3 \cdot 30\% + x_4 \cdot 40\% \quad (2)$$

where: y – report assessment; x_1, x_2, x_3, x_4 – final evaluation of respective section.

As a result, the evaluator acquires the report evaluation on a scale from 1 to 5, and the result gained is an indicator. To achieve a comparable evaluation, the evaluation of each section must also be presented, and the evaluator should prepare a short summary discussing the main deficiencies in the quality, and other significant factors of the report.

CONCLUSIONS

1) This study has developed a method for EISs which can be used for the evaluation of the quality of reports. The goal of the method is to assess report quality with the least amount of criteria, but with those that encompass the most significant sections of the report. The method is binding to the initiator of the anticipated activity, and to the report's authors, in order to avert deficiencies during the development of the report, as well as for the competent institution, in order to be able to evaluate EISs systematically to obtain a comparable result, and to decrease the amount of time used in the evaluation of reports. The method can be applied to EISs already evaluated, to evaluate the overall quality and efficiency in the country of the EIA procedure.

2) In Latvia, the deficiencies in EISs are similar to those found in studies of other European countries. The most significant deficiencies are an incomplete assessment of alternatives, a lack of validity of selected alternatives, the degree of detail in measures to prevent, decrease and compensate for impact.

3) In comparing the evaluation of EISs by using the method developed in the project, and its evaluation according to the guidelines of the European Commission, it can be concluded that:

- In order to determine the most significant deficiencies of the report, a method with multiple questions need not be used;
- By using the method developed in the project, the report may be evaluated in a comparatively shorter period of time;
- The method developed in the project does not include all report elements that need to be corrected or supplemented, which means that it is not beneficial to the report author. However, the method indicates the most significant deficiencies in the report's quality.

ACKNOWLEDGEMENTS. This work has been supported by the European Social Fund project 'Involvement of Human Resources for Development of Integrated Renewable Energy Resources Energy Production System' (project No. 2013/0014/1DP/1.1.1.2.0/13/APIA/VIAA/026).

EIROPAS SOCIĀLAIS FONDS

EIROPAS SAVIENĪBA

IEGULDĪJUMS TAVĀ NĀKOTNĒ

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X REVIEWS

Agronomy Research **12**(3), 979–988, 2014

Overview of the waste-to-energy sector in Latvia: driving forces for a cluster creation

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Abstract. Waste to energy (WTE) sector includes collecting and pre-treatment of various types of organic and recyclable waste that is used as feedstock for conversion technologies generating valuable outputs (i.e. power, heat, biomethane, syngas etc.). Consequentially, the WTE value chain includes stakeholders from waste management and energy production markets.
The development of Latvian WTE is governed by advancements and availability of technology and innovation, the national legislation and binding regulations, and cooperation between the involved stakeholders. To promote more efficient waste management techniques, increase the use of alternative energy sources and improve cooperation between different target groups within the WTE sector (i.e. policy makers, investors and researchers) the establishment of a WTE cluster in Latvia is proposed. The initial information about the state-of-the-art of the WTE sector in Latvia is vital for development of such cluster.
The aim of this paper is to characterize the WTE sector in Latvia and analyse its driving forces (technology push versus demand pull) in order to determine a strategy for WTE cluster development. To reach this objective an analytical framework based on the technology push and demand pull methodological approach is applied. To reach the aim of this study, an inventory of WTE related stakeholders in Latvia is developed and the push and pull factors driving the development of WTE field are defined. Various factors and their interactions are analysed to determine which are the most influential for Latvian WTE sector development, finally we provide our conclusions and discussion.

Key words: waste to energy (WTE), push factors, pull factors, industrial clusters.

INTRODUCTION

Waste-to-energy (WTE) is an interdisciplinary sector; it includes collecting and pre-treatment of various types of organic and recyclable waste that is used as feedstock for conversion technologies generating valuable outputs (i.e. power, heat, biomethane, syngas etc.). Energy can be recovered from various types of waste, e.g. municipal solid waste (MSW), industrial and agricultural biomass waste etc. For each type of waste different energy recovery technologies are available. Energy recovery from solid waste is typically performed using incineration, pyrolysis, gasification or co-incineration technologies. After reviewing previous comparisons of WTE technologies Rentizelas et al. (2014) conclude that incineration is currently most dominant type of thermal treatment. On the other hand Münster & Lund (2010) stress the opportunity to produce transport fuels from waste for which case thermal gasification or anaerobic digestion technologies are more appropriate. Anaerobic digestion, e.g. in biogas reactors or landfill gas recovery, is another widespread waste to energy transformation strategy. Anaerobic digestion in comparison with thermal treatment enables the processing waste with high water content (Appels et al. 2011).

Given the diversity of the input wastes and the desirable outputs the development of WTE sector is also strongly related to the development of new technologies and market innovations. Currently research on the new WTE technologies is widespread: Münster & Meibom (2011) have evaluated the feasibility of different WTE technologies, Di Gregorio & Zaccariello (2012) proposed an effective WTE system configuration for fluidized bed gasification. Research on gasification of packaging scrap in fluidized bed reactor (Di Gregorio & Zaccariello, 2012) reveals that environmental load reduction can be achieved by cleaning syngas prior to combustion. Rentizelas et al. (2014) suggest that developing countries could benefit from implementing alternative MSW management technologies that have already been approbated in developed countries. On the other hand, direct technology transfer is typically unfeasible for countries where total amounts of generated waste are lower and the capacity of these technologies is too high to be used without adjustments.

WTE is both a waste management strategy and a means of energy production. Therefore WTE sector is governed by the policy and regulations of both waste management and energy production sectors. Waste management is regulated by requirements on waste collection, storage, treatment and disposal operations. The energy production sector is regulated by requirements on allowed technologies, production safety, allowed emission limits, feed-in quotas etc. This dualism complicates the constitutional and organisational subjection of WTE sector. The development of the WTE sector is therefore dependent on government's ability to coordinate the management of these spheres in order to provide the nurturing and interrelated framework for WTE related fields.

Overall, the development WTE sector is driven by various aspects, most important being amounts and types of generated waste that needs to be managed, availability of appropriate technologies, capacities and innovation, the regulation framework for waste handling and energy production. Given the broad extension of involved operations, the development of this sector is strongly affected by cooperation and communication possibilities between various actors along the WTE value chain.

Regarding the business perspectives and market analysis there are two different approaches that typically are used to characterize the dual drivers of economic and innovation development: technology push and demand pull (Di Stefano et al., 2012, Peters et al., 2012). Technology push strategy emphasizes that science, e.g., in the form of research and development of new technologies and innovation, stimulates market development, whereas, demand pull strategy is based on the notion that market features, particularly user demand, drives the innovation and market development. (Di Stefano et al., 2012). The discussion over which of the two strategies is predominant has been on-going for decades. Nowadays it has been widely recognized that both these perspectives and, most importantly, their interaction is the driver of innovation.

To characterize WTE sector in Latvia we adopt the two way oriented – technology push and demand pull - research methodology. In specific the aim of this paper is to characterize the waste to energy sector in Latvia and analyse its driving forces (technology push versus demand pull) in order to determine a strategy for WTE cluster development.

In order to reach this objective the article is organized in following way: in next chapter the applied methodology is described, then the generated initial inventory of WTE related stakeholders in Latvia is described, the push and pull factors driving the development of WTE field in Latvia are defined and the various factors and their interactions are analysed to determine which have the largest influence on WTE sector development in Latvia, finally we provide our conclusions and discussion.

MATERIALS AND METHODS

Activities in waste-to-energy are typically perceived as cooperation and interaction between waste management and energy sectors. Though both these sectors have been analysed independently, there have been no previous researches in Latvia describing the whole waste-to-energy sector. One way to promote more efficient waste management techniques, increased use of alternative energy sources and cooperation between different target groups within the WTE sector (i.e. policy makers, investors and researchers, technology providers) is to develop a WTE cluster in Latvia. Clusters are cooperation networks between companies in the same or similar industrial field or related to products chain of value. The aim of the cluster development is to improve the skill and knowledge exchange between the cluster participants and to promote innovation and smart specialization. Detailed analysis of WTE sector in Latvia allows identifying the main stakeholders involved in waste related activities and proposing various ways of cooperation between waste-to-energy stakeholders and potential cluster participants.

To establish cluster development strategy, firstly, the WTE stakeholders have to be identified. An inventory of main combustible and fermentable wastes and their treatment was generated to determine the stakeholders in WTE sector in Latvia. Data for 2008–2012 was collected. All stakeholders were grouped into related categories. Waste to energy sector is characterized by different crucial aspects and economic indicators such as: number of involved companies, number of employees, and characteristics of the value chain, as amounts of waste generation and energy recovery from wastes.

To evaluate the influence of 'technology push' and 'demand pull' further analysis of waste-to-energy sector in Latvia was done. The main driving forces were grouped into push and pull factors (see Table 1). The push factors are mainly identified as those internal trends of the industrial sector development that enhance the WTE sector development. The push factors incorporate information about the actual situation in Latvia and various aspects that facilitate introduction of WTE technologies and innovation that can stimulate the market development. The pull factors represent the national side attractiveness that facilitates the implementation of WTE technology and installations. These groups of factors include national regulations of waste management and energy supply utilities, as well as, public procurement initiatives and novel business model incorporation can facilitate further development of WTE field.

Table 1. Considered push and pull factors that influence WTE sector in Latvia

Push factors	Pull factors
Available amounts of waste	Governmental regulations
Availability of WTE education	Taxes and subsidies
Availability of appropriate technologies	National infrastructure for technology development
Availability of capital	Cooperation of research institutions and private business
Promotion of entrepreneurship at national level	

RESULTS AND DISCUSSION

Statistical data form Central Statistics Bureau of Latvia (2013) was used to identify the structure of waste management sector. Within waste management sector 50% of 166 companies related to management of non-hazardous wastes are providing waste collection services, with a smaller part of companies performing recovery of sorted materials (39%) and waste treatment and disposal (11%) (see Table 2). Regarding economic performance of the waste management industry (including hazardous and non-hazardous waste management) – 61% of total added value in the sector is generated by waste collection, 20% by recovery and 19% by waste disposal. Sequentially, waste recovery and treatment subsector that has high potential of resource and energy recovery is underdeveloped. Only overall data can be provided for energy supply industry (see Table 2). A detailed distribution of energy suppliers by used resources or technology is not available due to structure of statistical database.

Table 2. Characterization of WTE related industry branches in 2011

Industry	Number of companies	Turnover (thsd €)	Value added at factor cost (thsd €)	Number of employees
Energy supply	383	2566,455	609,121	10,667
Production of electricity	222	n.d.	n.d.	1,944
Steam and heat supply	121	n.d.	n.d.	4,191
Waste management	178	204,528	56,023	3,609
Collection, treatment and disposal and recovery of non-hazardous waste	166	n.d.	n.d.	3,499
Collection of non-hazardous waste	83	71,188	32,254	2,564
Treatment and disposal of non-hazardous waste	19	n.d.	n.d.	300
Materials recovery	64	102,077	11,235	635

n.d. – no data available

Historical data on waste generation was gathered to analyse WTE development tendencies in Latvia. Table 3 presents data on the amount of generated waste for various European Waste Catalogue waste classification chapters which include wastes that could be used for energy recovery. A reduction tendency can be seen for municipal wastes, whereas the amount of wastes from waste treatment plants has increased in recent years. This is due to increased sorting and recovery of wastes at treatment plants and management facilities.

Table 3. Amounts of generated waste in Latvia from 2008 to 2012

	Amount of waste, tonnes				
Waste chapter, description	2008	2009	2010	2011	2012
02.Wastes from agriculture, forestry	140,231	185,668	247,400	265,456	288,201
03.Wastes from wood processing, pulp, paper and cardboard	72,586	75,588	86,067	97,993	43,573
15.Waste packaging (specifically wooden packaging 150103)	19,141	1,437	1,060	7,785	807
16.Wastes not otherwise specified in the list (specifically end-of-life tires 160103)	648	467	837	1102	484
17.Construction and demolition wastes (specifically wood 170201))	35	15	24	855	8417
19.Wastes from waste management facilities, waste water treatment plants	60,781	58,913	111,853	163,437	327,854
20.Municipal wastes including separately collected fractions (municipal solid waste)	260,741	189,629	179,593	229,940	171,731

A summary of data about amounts of waste treated for energy recovery for period from 2008 to 2012 is given in Table 4.

Table 4. Amounts of waste treated for energy recovery in Latvia from 2008 to 2012

	Amount of waste, tonnes				
Waste chapter, description	2008	2009	2010	2011	2012
02.Wastes from agriculture, forestry	0	0	0	27,226	96,598
03.Wastes from wood processing, pulp, paper and cardboard	840	862	1,290	2,235	3,397
15.Waste packaging (specifically wooden packaging 150103)	291	521	2,318	1,420	1,124
16.Wastes not otherwise specified in the list (specifically end-of-life tires 160103)	3,077	782	4077	16,171	10,825
17.Construction and demolition wastes (specifically wood 170201))	0	0	12	216	18
19.Wastes from waste management facilities, waste water treatment plants	7,215	3,035	52,254	102,540	129,378
20.Municipal wastes including separately collected fractions (municipal solid waste)	171	5,549	36	36	376

The total number of companies performing energy recovery for described waste chapters varies annually. As can be seen from Table 4, largest amounts of treated waste in 2012 were agricultural wastes, wastes from waste management facilities, and end of life tyres. The rapid increase in treatment of agricultural wastes was due to favourable regulation initiated in 2009 (Cabinet of Ministers, 2009a) which introduced guaranteed feed-in tariff policy for biogas plants. The noticeable increase in energy recovery from waste tires and wastes from waste treatment plants (mainly refuse derived fuels (RDF)) is due to increased use as fuel in cement industry. Since production of RDF in Latvia is still developing, 95% of wastes within waste chapter 19 are the imported RDF. Similarly the import of waste tires s twice larger than is annually collected state-wide.

The identified WTE stakeholders include organisations within waste management, waste-to-energy conversion and technology providers, public stakeholders as the government and research facilities and universities.

Most commonly used WTE technologies in Latvia are anaerobic digestion and thermal treatment, mostly combustion. Combustion of wood and wood wastes is common energy recovery technology in Latvia. Therefore most local WTE technology providers are specialized in this area. There are local technology providers for technologies of small (12–500 kW) and large (1–10 MW) capacity. Pyrolysis or gasification technology is gradually being introduced in Latvia. Few plants have been installed for waste tire pyrolysis and waste wood gasification.

Apart from waste generation, collection, treatment and energy production another important part of WTE value chain is research and innovation. WTE research in Latvia is a small but developing sector. It is mainly driven by research at universities, e.g. research on organisation of waste management and the potential of organic wastes to be used as energy resource (Bendere & Āriņa, 2011) and research on the potential of alternative feedstock for biogas production and combustion (Beloborodko et al., 2013; Ruģele et al., 2013). The main shortcoming is the lack of research oriented towards the WTE companies.

Driving forces of waste-to-energy sector: Push factors

The identified push factors characterize the capital and technology availability, availability of WTE specialists, entrepreneurship opportunities and introduction of new innovation that advance the development of WTE sector. Push factors incorporate information about the actual situation in Latvia and various aspects that facilitate introduction of waste-to-energy technologies and innovation. These aspects include the data on waste generation; possibilities for investments in WTE, related research and transfer of knowledge to industry, as well as WTE related education programs.

Analysis of statistical data on available amounts of waste suggests large potential for energy production of municipal solid wastes (MSW), wastes form waste management facilities and agriculture wastes. The use of agricultural wastes for energy recovery has been advanced by installation of more than 30 new biogas plants in recent years, still in 2012 only 33% of agricultural wastes were treated for energy recovery. Regarding data for wastes from waste treatment plants (chapter 19) 95% of the amount of wastes used for energy production is imported wastes. Therefore regarding nationally generated wastes from treatment plants (excluding RDF import) in 2012 only 2.35% were recovered as fuel or other means for energy production.

Installation of new waste treatment technologies provide new jobs, but also requires qualified specialists. Therefore coherent development of sector also requires availability of WTE education. As waste-to-energy field is related to various areas of knowledge, including among others waste management, energy production, environmental impact, different programs were explored that provide waste-to-energy related education. There are six higher education institutions that provide bachelor and master level programmes in fields related to energy production, waste management and environmental engineering. There are also two colleges providing professional education and several vocational education institutions that provide training in WTE related programs.

WTE sector strongly depends on the availability of appropriate technologies. The main technology related issue in Latvia is that the capacity of existing technologies, typically adopted from other countries, is too high in regard to the amount of produced waste. Therefore technology is not used at its optimal capacity, which leads to various limitations regarding use of equipment, emissions, quality of source waste and economic considerations. Although such limitations influence the development of WTE sector in Latvia, they also provide good opportunities for research and technological improvements. In Latvia research and development of innovative WTE technologies that are adjusted to local conditions has been underdeveloped. One of indicators of innovation situation is the patent activity. Four national patents directly related to waste to energy have been applied for by Latvian authors from 2008 till 2013; six national patents have been granted for biomass incineration related technologies, two of which are in the process of being granted as worldwide patents. Three patents have been granted for anaerobic fermentation, biomass fermentation and biogas related technologies from 2010 till 2014. Overall a good tendency of increased patent activity can be seen in past five year period showing the increasing national interest in innovation related to waste-to-energy sector. Strengthening of Technology availability, research and innovation should be one of the main objectives of WTE cluster and further development of WTE sector in Latvia.

The recent rapid development of WTE sector in Latvia has been promoted by availability of capital though national funding schemes as Climate Change Financial Instrument and European Union and European Economic area funding schemes.

The development of new technologies can also be promoted by business incubators and sector associations. Although there are several business incubators in Latvia, they are mostly directed towards creation and aiding new small and medium size businesses, most of them producing consumer goods. Only few of companies involved in business incubators in Latvia are related to engineering sector. As WTE sector has not been fully established as a separate sector in Latvia, the sector associations are mostly related to either waste or energy sector. As there is no unifying WTE association in Latvia yet, the development of WTE cluster would provide better communication of all stakeholders and would also allow to address the interdisciplinary issues of WTE sector.

Driving forces of waste-to-energy sector: Pull factors

Pull factors represent national side attractiveness that facilitates the implementation of waste-to-energy technology and installations. National regulations of waste management and energy supply utilities, as well as, public procurement initiatives and novel business model incorporation can facilitate further development of waste-to-energy field.

Governmental regulations, taxes and subsidies are important pull factors that drive the demand for new technologies and sector development. As WTE sector in Latvia is connected to both waste management and energy production sectors, an important restrictions for WTE sector development in Latvia is the division of policy and regulation of these sectors. Main limitations are related to complicated organisation of WTE sector and communication of WTE stakeholders. Nevertheless WTE regulations have promoted sector development. Regulations regarding the production of electricity using renewable energy sources (Cabinet of Ministers, 2010) and regarding electricity production and price determination upon production of electricity in cogeneration (Cabinet of Ministers, 2009b) have been instrumental to ensure increase of use of renewable energy resources and energy recovery form biomass.

From demand pull point of view the production of RDF should be stressed in Latvia. Yearly around 100,000 tonnes RDF is imported, therefore, the use and local production of RDF is currently a topic of interest in Latvia. Many industries are using natural gas as energy resource due to its advantage of higher combustion temperatures in comparison with wood biofuels. In 2008 a cement producer started to import and use RDF as additional energy source for production process. In response to such demand, there have been attempts to introduce RDF sorting plants in Latvia. Since 2012 RDF is being produced and sold to the cement producer by close located waste management organisation, in 2013 the another producer started to sell RDF produced in their waste sorting and treatment station to the cement producer (Waste statistical database, 2014)

Another pull factor is the national infrastructure for technology development and research. A nationwide long-term cooperation platform has been implemented in Latvia using public and European Union funding (Ministry of Education and Science). With the aim of aiding cooperation between research institutions, technology providers and users this platform is a good example of consolidated approach to innovation and technology development. The cooperation of research institutions and private business is currently intensively promoted in Latvia. Several research institute spin-offs have been developed, though there are few information sources about the actual firms as they are typically only start-ups. There are no significant spin-offs directly related to waste-to-energy.

Overall the main demand pull factors for WTE sector in Latvia as national regulation, innovation infrastructure, and technology demand from infrastructure are favouring the development of this sector.

CONCLUSIONS

The analysis of historic data on energy recovery from different types of wastes shows a growing demand of RDF, waste tyres and agricultural wastes in previous years. As the national production of such high calorific wastes has been hindering, this demand has been covered by imported materials. Improved communication between involved stakeholders and awareness of national potential, e.g. through cluster collaborations, could promote efficient use of locally available energetic wastes.

Current development of WTE sector in Latvia has been mostly guided by push factors as capital availability and pull factors as governmental regulations, taxes and available subsidies. This is clearly demonstrated by the rapid development of agricultural biogas stations and utilization of agricultural wastes for energy production due to guaranteed feed-in tariff policy. An influential push factor for installation of these plants has been the availability of capital and appropriate technology. The development of WTE for other wastes (as mixed municipal wastes) in Latvia is limited by availability of appropriate technology. Specifically the capacity of existing technologies is too high in regard to the amount of produced waste. Although such limitations provide large opportunities for research and technological improvements, in Latvia there is a lack of research and development of innovative WTE technologies that are adjusted to local conditions. This restriction may be offset by improving the cooperation of stakeholders in this sector through development of efficient WTE cluster.

Although many of push and pull factors in Latvia are well developed, currently the main shortcoming is lack of coordination and cooperation between stakeholders in the WTE sector. Therefore creation of a cluster that connects WTE stakeholders would be a significant driving force for strengthening of WTE sector. The main objective of WTE cluster should include ensuring the cooperation between researchers and technology provider and technology users in order to develop innovative and locally appropriate WTE technologies.

ACKNOWLEDGEMENTS. The work was supported by European Union 7th Framework Programme project 'Coordinating and Leveraging regional knowledge for initiating a Sustainable and optimised EU Waste to Energy Programme (COOLSWEEP)' Grant agreement no: 319893.

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The feasibility of phase change materials in building structures for saving heating energy in the Nordic climate

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Abstract. The study is based on a nearly two-decade research at the Department of Civil Engineering at the Tampere University of Technology (Finland). The purpose of the current study is to find out the structural solutions for the thermal storage of solar radiation in buildings. A significant effect of solar gains was noticed in massive external walls as well as roof structures in sunny days from March until September. However, modern lightweight materials lack the thermal inertia to store energy. An idea to utilize the latent heat of phase change materials (PCMs) inside the insulation of a light-weight roof structure enables to overcome this problem. The idea is supported with a principal example of the diurnal performance of a metal sheet roof structure as well as comparative calculation of the energies consumed and gained. The results of the current study show that PCMs have potential in the future application of light-weight roof structures. In general, efficient solar solutions still need to be developed in order to store energy in summer and to release it in winter.

Key words: 10-year data, temperature distribution within a structure, calculation of heat losses and gains, phase change materials (PCMs).

INTRODUCTION

Nowadays, the construction industry is constantly evolving. An increasing amount of modern lightweight materials and glass surfaces are applied in the facades of buildings. Still, these materials lack thermal inertia i.e. their thermal capacity is insufficient to store energy. Thermal storage is an efficient way of energy conservation possible by incorporation of latent heat (concealed heat) storage in building materials and structures. A hot-air floor system has been designed to accumulate the excessive heat from the fireplace (Kic, 2013). Energy storage in the walls, ceiling and floors of buildings may be enhanced by applying suitable phase change materials (PCMs) within these surfaces to capture solar energy directly and increase human comfort by maintaining the temperature in the desired interval for a longer period of time.

Latent heat storage such as using a phase change material (PCM) has gained growing attention recently due to its ability of storing significant thermal energy within a small volume, making it one of the most promising technologies for developing energy efficient buildings. PCMs absorb and release heat when the material changes from one phase to another. Solid-liquid phase change is the main phase change of interest since other types, such as the liquid-gas phase change materials, are generally not practicable for most energy storage applications. As a matter of fact, the liquid-gas phase changes involve large changes in volume or pressure when going from the liquid to the gas phase, which prevent effective implementation. Some materials exhibit solid/solid phase changes, in which the crystalline structure is changed at a certain temperature. These are available in limited temperature ranges (Tekes 2010).

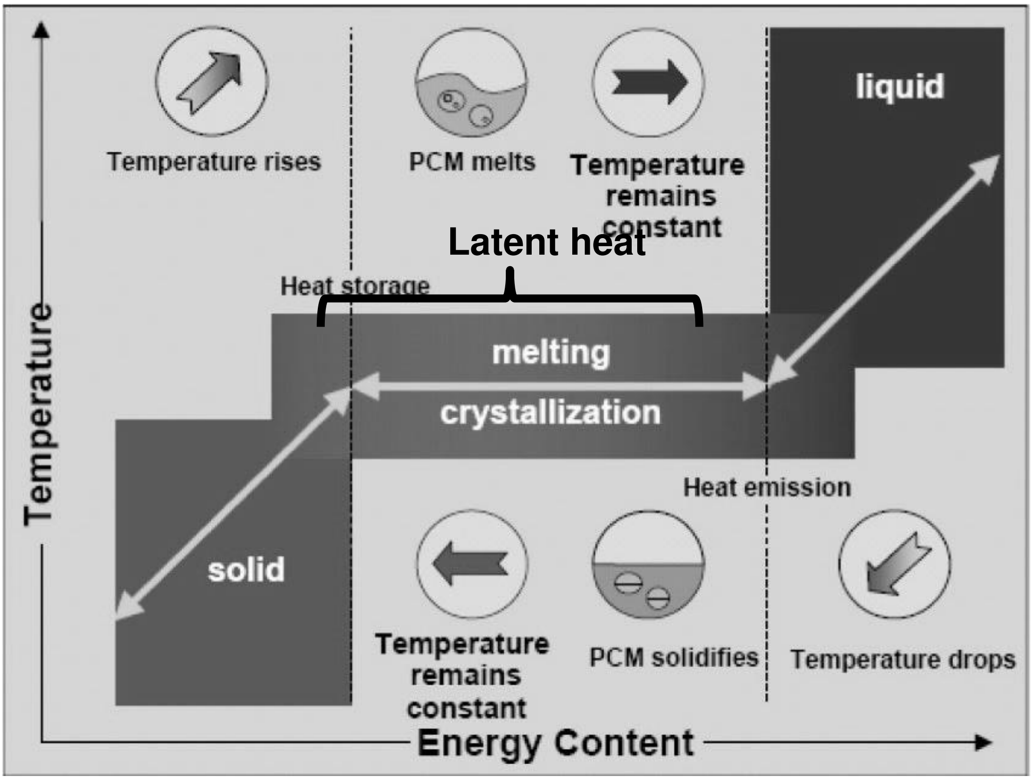

Figure 1. Material phase change (Tekes 2010; Minux 2012).

Initially, unlike conventional energy storage materials, when solid-liquid PCMs reach the temperature at which they change phase (their melting point), they absorb large amounts of heat without a significant rise in temperature. Despite the heat input, the temperature of the material stays relatively constant while the phase change is taking place (Fig. 1). Storage of latent heat means storing heat in a material which undergoes a phase change. When the temperature around a liquid material falls, the PCM solidifies and releases its stored latent heat (Tekes 2010). As no temperature increase can be observed over a long period of time, despite the application of heat, the heat stored during the phase transition is called ‘latent heat’. For a solid-liquid phase transition, the latent heat is equal to the heat of melting or crystallization of the storage material.

Phase change materials can be divided into different subcategories based on their chemical composition. Three groups are commonly formed: (i) organic compounds, (ii) inorganic compounds, and (iii) inorganic eutectics or eutectic mixtures. The group of organics can be divided into paraffins and non-paraffins. Each group has its typical range of melting temperatures and its range of melting enthalpies.

Commercial paraffin waxes (i) or $CH_3(CH_2)_nCH_3$ are inexpensive and have a reasonable thermal storage density of 120 kJ kg^{-1} up to 210 kJ kg^{-1}. Paraffins are available in a wide range of melting temperatures from approximately 20°C to up to about 70°C. However, paraffins have a low thermal conductivity of about 0.2 W (m K)$^{-1}$ which limits their application (Farid et al., 2004), and have a large volume change during the phase transition (Hasnain, 1998). The non-paraffin organics (ii) include a wide selection of organic materials such as fatty acids, esters, alcohols, and glycols. Generally, they have excellent melting and freezing properties, but are about three times more expensive than paraffins (Hasnain, 1998). The most commonly used fatty acids are divided into 6 groups: caprylic, capric, lauric, myristic, palmitic, and stearic.

Inorganic PCMs in general have a rather high heat of fusion, good thermal conductivity, are cheap, and non-flammable. However, most of them are corrosive to most metals, undergo supercoiling, and undergo phase decomposition. Most common inorganic PCMs are hydrated salts (EPIC-HUB 2014).

Eutetic mixtures or eutetics have, in general, sharp melting points and their volumetric storage density is slightly higher than that of organic compounds. However, limited data are available on their thermal and physical properties. Eutetics may be divided into 3 groups according to the materials of which they consist: (i) organic-organic, (ii) inorganic – inorganic, and (iii) inorganic – organic eutetics (EPIC-HUB 2014).

Since the late 19th century, PCMs have been used as a medium for thermal storage applications. Kuznik et al. (2011) reviewed the history of PCMs in buildings based on the published journal articles. The first studies were dated from the 1980s. These dealt with methods for impregnating gypsum wallboard, concrete, and other architectural materials with phase change materials (Salyer et al., 1985; Shapiro et al. 1987; Banu et al., 1998). Then, during the period between 1980 and 1990, only very few articles were published. From 1990 to 2000, the number of publications increases to about 1 publication per year. After 2003, an increase in the number of publications occurred (reaching up to 14 articles). Almost 80% of the studies have been carried out over the past 10 years which have seen the development of new encapsulation technologies and new energy standards.

Baetens et al. (2010) have performed a review of phase change materials for building applications. The principle of latent heat storage can be applied to any porous building material, but research so far has primarily concerned on gypsum wallboards and boards, concrete and insulation materials. For example, Zhang et al. (2012) have studied the thermal performance of gypsum boards incorporated with microencapsulated PCMs for thermal regulation. Gypsum boards incorporated with 50 wt% micro-PCMs were found to have a good potential for thermal energy storage purpose in buildings (Zhang et al., 2012). Ling & Poon (2013) reviewed the use of phase change materials for thermal energy storage in concrete. PCM-concrete has some useful characteristics, such as better latent heat storage and thermal performance. PCM-concrete also has some undesirable properties, such as lower strength, uncertain long-term stability, and low fire resistance. These undesirable properties, however, can be minimized if appropriate PCM types and means of incorporation are employed.

Tyagi et al. (2011) have performed a review of phase change materials based on microencapsulation technology for buildings. Microencapsulation was found to be one of the well-known and advanced technologies for better utilization of PCMs with building parts, such as walls, roofs and floors, and within building materials.

Sharma et al. (2013) also dealt with development of phase change materials for building applications. Specifically, eutectics based on commercial grade fatty acids i.e. capric acid (CA), lauric acid (LA), myristic acid (MA), palmitic acid (PA), and stearic acid (SA) were developed with different weight percentages. The melting temperature and latent heat of fusion of these developed eutectics were measured by using the differential scanning calorimetry (DSC) technique. The DSC showed that the melting temperatures and latent heat values of the developed PCMs were in the range of about 20–30°C and 100–160 J g^{-1}. It was concluded that if CA mixed with any other lower melting temperature PCM, a desired eutectic can be developed for building applications.

Also, the practical application and development of PCMs in the construction industry is gaining interest. An overview of industrial research projects on Energy-efficient Buildings (EeB) can be found on the European Commission/CORDIS/FP7 web page. EeB consists of a financial envelope of € 1 billion to boost the construction sector. For example, important developments were achieved within the project: New Advanced iNsulatiOn Phase Change Materials (NANOPCM; from 2010-06-01 to 2013-05-31). The objective of NANOPCM was the development, implementation, production, and demonstration of low cost and improved Phase Change Materials for new high performance insulation components in existing buildings. The project aimed to reduce the cost of nanotechnology-based insulation systems and make their wide scale commercial application feasible.

MATERIALS AND METHODS

The Department of Civil Engineering at the Tampere University of Technology (RTEK/TUT) has been studying the energy consumption and thermal performance of building structures. Ten years (Sept. 1997–Aug. 2007) of measuring data from six test buildings have been gathered. Also, six years (Apr. 2001 – Aug. 2007) of data from additional two test buildings is also available at the RTEK/TUT. The test buildings were identical-sized, having different external wall structures. Detailed description of test buildings, their structures and data collection can be found in Lindberg et al. (2004) and Kiviste et al. (2013). The temperatures at various depths of external wall structures were monitored in order to determine the temperature distribution. The temperatures were measured with calibrated semiconductor sensors and copper–constantan thermocouples. Multiplexers were used to collect the data from the sensors so that readings from each channel were recorded in a computer after every 20 s. Analogue-to-Digital and Digital-to-Analogue (ADDA) cards were used for data collection and conversion. The minimum, maximum, and average values from the values measured in every 20 seconds were saved to a computer hard disc in every 30 min. The level of detail (200 sensors in each building), the huge amount (after each 20 seconds), long-term (measuring period of six and ten years), and coherency (measured at the same time in the same conditions) makes that data unique in Finland as well as in Europe.

RESULTS AND DISCUSSION

Through the analysed period from September 1998 to May 1999, the heat losses through the external walls of the test buildings were up to 50% smaller than calculated (Lindberg et al., 1998). Three main reasons for the difference were found: (1) the material properties from which the U-values are calculated, (2) the areas of the walls, and (3) the solar radiation energy stored in the external part of the exterior walls (Lindberg et al., 2008).

The influence of solar gains was found to be significant to the thermal performance of some massive external wall structures during sunny days from (late February) March until September. The heat storage capacity of Autoclaved Aerated Concrete (AAC) (Lindberg & Leivo, 2005) and insulated brick external walls (Lindberg et al., 2012) was remarkable.

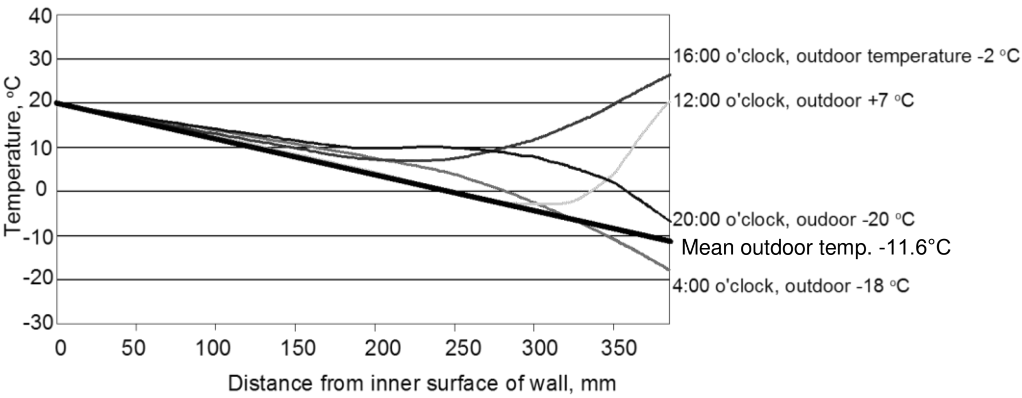

Figure 2. Temperature distribution in the Autoclaved Aerated Concrete (AAC) south wall on 11.3.1998 (Lindberg & Leivo 2005).

Fig. 2 shows the influence of solar radiation to the outer parts and surface of a AAC south wall. The thick line is showing the well-known stationary temperature distribution, based on average indoor and outdoor temperatures. In the morning, the sun starts to heat up the outer parts of the AAC wall. At noon, the temperature of the outer surface has increased to 20°C, while the outdoor air temperature was 7°C. In the afternoon (16:00 o'clock), the outer surface temperature has reached 27°C, while the outdoor air temperature has decreased to -2°C. In the evening, it is freezing cold outside (-20°C), but the outer half of the AAC wall still stays relatively warm (from -7°C at the outer surface up to 10°C in the mid-part), due to its heat storage capacity. Only at night (4:00 o'clock), the outdoor temperature is about the same as the surface temperature (both about -18°C), being rather similar to stationary temperature distribution.

The effect of solar gains was found to be greater in the massive roof structures. During the winter of 2002–2003 the temperatures in the Autoclaved Aerated Concrete (AAC) roof structure of a Finnish factory were constantly measured. A rough summary of the measurement results is shown in Fig. 3. The thickness of the reinforced AAC elements was 300 mm, and it had roofing felt glued on top.

The average daily temperature at the moment of examination was 0°C and the indoor air temperature +20°C. Fig. 3 has a curve representing the stationary temperature distribution. Fig. 3 shows how the solar radiation striking a dark felt roof affects the temperature of the structure below it. It is known that the effect can be substantial, even tens of degrees. At night, the felt cools, but the heat storage capacity of AAC keeps the elements warm. The end result is that the external surface of the AAC roof remained above the mean outdoor air temperature even during the night.

The diurnal temperature distributions of massive and lightweight wall structures of the test buildings have been carefully compared at the RTEK/TUT. It has been found that due to the lack of thermal storage capacity, the effect of solar radiation is almost lost in conventional light-weight wall and roof structures.

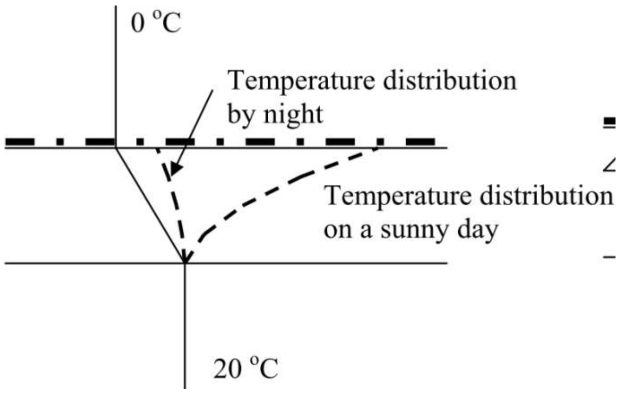

Figure 3. Rough summary of the typical diurnal thermal performance of an AAC roof structure (Lindberg et al., 2008).

The situation could be improved considerably if PCMs could be effectively applied inside insulation, thus enabling energy storage and release in light-weight structures as well. Fig. 4 shows the principal idea of applying PCM inside an insulation of a light-weight flat roof structure. Metal sheet roof cover is applied in Fig. 4, however, the principle would be similar in case of dark bituminous roof cover.

The width of the air gap or use of an attic in Fig. 4 could be optimized to achieve the maximum efficiency of thermal storage of solar radiation. As mentioned before, the thermal storage principle in Fig. 4 is fully effective only in a sunny day and from early spring to autumn. A small but still noticeable effect of thermal storage could be found even on the days with less sun radiation (cloudy days); therefore, a considerable amount of daylight is necessary.

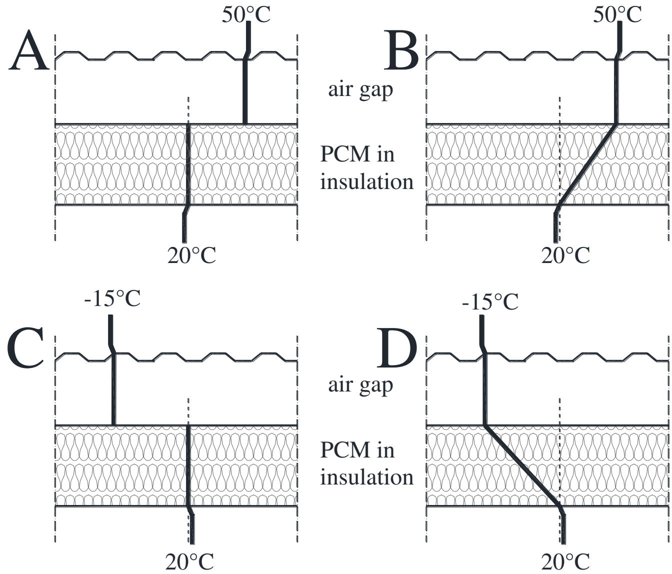

Figure 4. Principal idea of the daily temperature distribution of a metal sheet roof structure, where PCM is applied inside insulation. A. In the morning and at noon (e.g. 7 a.m. – 12 noon) the sun heats up the metal sheet and air-gap, therefore the PCM starts to store latent heat while changing phase (melting). The temperature of the PCM does not change. B. In the afternoon (e.g. 12 noon – 19 p.m.), the air-gap is very hot and, after phase change, the temperature inside insulation becomes stationary. C. In the evening and at night, the air-gap cools down and freezes. During that phase, the PCM solidifies and releases its stored latent heat, thus saving heating energy of the building. D. At night, the air-gap is cold and the PCM has given away its latent heat (become solid).

The conduction heat losses (Q) of a building could be calculated with the following formula:

$$Q = \sum A \cdot U \cdot \sum \Delta t \cdot t\,, \tag{1}$$

where: A is the area of enclosing structures, m^2; U is thermal conductivity (U-value) of a structure, W $(m^2K)^{-1}$; Δt is temperature difference between indoor and outdoor air, K; t is duration, hours.

In case of a typical one-family (15 × 10 m) dwelling, the area of the enclosing structures would be around 460 m^2 (roof 160 m^2, floor 150 m^2, walls including windows and doors 150 m^2). If a U-value of 0.2 W $(m^2K)^{-1}$ and a temperature difference of 18° K (average indoor air temperature 20°C, average outdoor temperature 2°C). According to the FMI (Finnish Meteorological Institute), the annual average temperature in Finland varies from +5.9°C (Southern coastal area) to -0.4°C (Lapland). Generally, +2.0°C is recommended, which is suitable for large areas in Southern Finland. Therefore, the conduction heat losses could be calculated as follows: $Q = 460 \cdot 0.2 \cdot 18 \cdot 24 = 39{,}744 Wh \approx 39.7 kWh$.

Sharma et al. (2013) recommended that capric acic (CA) mixed with any other lower melting temperature PCM could be developed for the building applications. For example, eutectic capric-myristic acid (CA-MA) PCM has a melting temperature 21.7°C and a heat of fusion 155 kJ kg^{-1} (Karaipekli & Sari, 2008). 3,600 kJ equals to 1 kWh. Therefore, 8 kg m^{-2} of CA-MA inside insulation could store/release energy $\frac{155}{3{,}600} \cdot 8 = 0.34$ kWh $(m^2)^{-1}$. Based on the previous example of a one-family building, CA-MA applied in roof structures would absorb/release 0.34·160 = 54.4 *kWh*. Therefore, the amount of energy stored by PCM would cover the average heat losses of 39.7 *kWh*. Previous calculations serve the purpose of explaining the principle. Due to the high variability of factors, a rather conservative approach was taken by the authors in conductive heat calculations. The comparisons of heat losses and gains show that PCMs have a potential in the future application of light-weight roof structures. Although, for example, Estonia is a relatively solar-poor country, the solar radiation to the horizontal surface is still 990 kWh $(m^2\ year)^{-1}$. 63.5% of it could be stored in summer, 30% in spring and autumn together, and only 6.5% of the annual solar radiation is available at winter (Masso, 2012).

In future studies at the RTEK/TUT, dynamic calculations and simulations are needed to further understand and describe the process. Additional proof in still necessary before initiating extensive and expensive tests with PCMs inside building structures at the RTEK/TUT.

Mankind still needs solar energy storage solutions to store energy in summer and release it in winter. Although solar panels are becoming cheaper and thus more affordable, solar cells are still too expensive for wide-spread solar energy storage in buildings structures.

CONCLUSIONS

The current paper is presenting an idea of storing and utilizing the latent heat of phase change materials (PCM) in building structures. Some examples of nearly two decades of research results at the Department of Civil Engineering at the Tampere University of Technology (RTEK/TUT) are presented in that sense. The effect of solar gains was found to be significant to the thermal performance of massive (AAC and insulated brick) external wall structures during sunny days from March until September. That effect was found to be greater in massive (AAC) roof structures. However, even modern lightweight wall and roof structures lack the thermal inertia to store energy. Effective application of PCMs inside the insulation of a light-weight roof structure enables to overcome this problem. A principal example of the daily temperature distribution of a metal sheet roof structure as well as the comparative calculation of energies is demonstrated. These findings show that PCMs have potential in the future application of light-weight roof structures. As energy accessibility (from early spring until September) and demand (heating season, especially in winter) do not match, long-term thermal energy storage and release plays a crucial role in taking full advantage of solar radiation in buildings.

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Life cycle assessment of bio-methane supply system based on natural gas infrastructure

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Abstract. Many sites for biogas production in Latvia currently do not have sufficient heat load to provide power production in co-generation mode. The alternative to relatively inefficient power production could be production of bio-methane which is known as one of the most important renewable option for gas supplies. After removal of contaminants bio-methane is of quality of natural gas and can be delivered to power plants and industry using the natural gas supply infrastructure. For analysis of environmental benefit of using bio-methane the environmental impact of the proposed solution has to be assessed. The aim of the study is to make life cycle assessment of the system for bio-methane supply to industrial plant via the natural gas grid. The analysed system includes bio-methane production and transport to the natural gas pipeline including the infrastructure. Functional unit was 1 MWh of bio-methane energy injected into the natural gas transmission pipeline. Life-cycle model was created and analysed with software '*SimaPro*'. *ReCiPe* and *Eco-Indicator'99* were used as characterization methods to analyse the life-cycle environmental impacts. Results show the influence and contribution level expressed in mid-point categories as well as in a single-score indicator. The largest impact is created by use of fossil energy sources in production of bio-methane. The results can be used to design renewable energy supply systems and for the comparison of alternatives.

Key words: bio-methane, life cycle assessment, natural gas, renewable energy.

INTRODUCTION

Many sites for biogas production in Latvia currently do not have sufficient heat load to provide power production in combined heat and power generation mode. The alternative to relatively inefficient power-only production could be production of bio-methane which is known as one of the most important renewable option for gas supplies. After removal of contaminants bio-methane is of quality of natural gas and can be delivered to combined heat and power plants in energy utilities and industry via the natural gas infrastructure. Thus, bio-methane could serve as one of the most feasible replacement of fossil fuel for firing industrial furnaces.

The focus of the study is to find a substitute of natural gas for brick manufacturing industry which is important economic branch in Latvia. As it is known from previous studies, brick firing is the most energy intensive of the brick manufacturing processes (Rose et al., 1978; Moedinger, 2005; Koroneos & Dompros, 2007; Machado et al., 2011; Skele et al., 2011; Oti & Kinuthia, 2012, Repele et al.,

2013) and natural gas is used as a firing fuel in Latvia. Also propane, oil, sawdust, coal or combinations of these fuels can be used for this purpose (Venta, 1998; Moedinger, 2005). Nonetheless, due to innovative development these traditional sources can be successfully replaced by renewable alternatives (Moedinger, 2005) and will result in significant reductions in greenhouse gas emission (Gomes & Hossain, 2003; Repele et al., 2012). One of the most viable renewable substitute of natural gas is bio-methane (Adelt et al., 2011) which can substitute natural gas after quality upgrading (EBTP, 2014). Thus, advantages of the well-developed natural gas infrastructure can be utilised. Due to sufficiently high average heating value (21 MJ $(m^3)^{-1}$ with 60% methane) biogas can also be directly used as fuel in burning processes (Ellersdorfer & Weiβ, 2014). However, use of bio-methane as a substitute of natural gas allows introducing renewable energy sources in industry to much larger extent.

Therefore, research to ascertain environmental impact caused by bio-methane production and injection in natural gas grid is necessary. The aim of this study is to make life cycle assessment of the system for bio-methane production and supply to industrial plant via the natural gas grid. The results can be used to compare alternative energy solutions for the industry.

MATERIALS AND METHODS

The aim of the study was to make LCA of the system for bio-methane supply to industrial plant via the existing natural gas grid. Geographic information system program '*ArcGis*' with *ArcMap* and *ArcCatalog* (ArcGis, 2010) was used to map the bio-methane production plants and transmission natural gas pipelines in order to estimate length of pipelines for connection of the facilities to the existing natural gas transmission grid. 42 point and line object files were created to represent bio-methane stations and to calculate distances for connections, respectively. The map was created on grounds of the data reported in different sources and previous studies (Ministry of Economics I & II, 2013; Cinis, 2013; Dzene et al., 2013). Seven biogas plants were chosen for this study – the nearest to the brick factory located in Ozolnieki district, Latvia and having relatively large annual production volume of biogas relative to the length of connection to the natural gas grid. The study was based on the data reported in the polluting activities permits issued to the bio-methane production plants in Latvia ('A' category permits No1–No7, 2011–2013). Since the database for country specific processes is not available, LCA software (SimaPro, 2013) with *EcoInvent* (v2.2) database was used to model and analyse environmental impacts caused by bio-methane production and transportation from the bio-methane production facility to the natural gas transmission pipeline via the connecting pipe. For this study only system processes that are most relevant to Latvian conditions were selected from the database:

- For bio-methane production process 'Methane, 96%, from biogas, at purification' was used. Included electricity consumption and emissions represent the raw gas compression, H2S removal, gas conditioning and methane enrichment of biogas. Infrastructure expenditures are included employing generic data for facilities of a chemical plant as a first approximation. Bio-waste production is not included. A plant using the described technology is in operation in Switzerland.
- For bio-methane transportation 'Transport, natural gas, pipeline, long distance' process was chosen. This dataset des'cribes the energy consumption and the emissions

linked to the transport of 1 ton-km average natural gas in Europe. The data for emissions and for energy requirements is based on German data.

- 'Pipeline, natural gas, low pressure distribution network' process was selected to describe the infrastructure needed for bio-methane transportation. This dataset describes the Swiss low (< 0.1 bar) pressure distribution network: life time 40 years and annual transport is 30 TJ km^{-1} a. Data is based on Swiss data.

The analysed system includes bio-waste collection and transport to the plant, bio-methane production and transport to the natural gas pipeline including the infrastructure (Fig. 1). Based on the information about the considered biogas production facilities and connection pipelines, life cycle assessment (LCA) is done for the functional unit of 1 MWh of bio-methane energy.

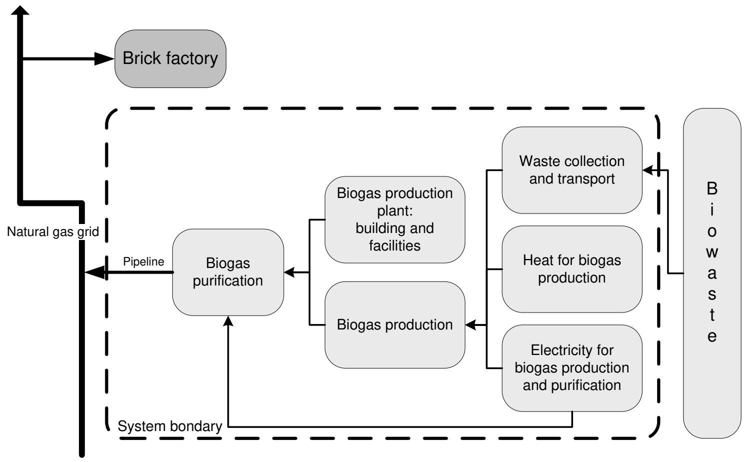


Figure 1. Processes considered within the system boundary.

Environmental characterization was done at midpoint impact category level and by calculating the single score impact indicator. To make the study results comparable with previous studies and make the results applicable for ecodesign purpose the following two impact assessment methodologies were used:

- *ReCiPe* which is the most recent and harmonised indicator approach available in life cycle impact assessment and comprises harmonised category indicators at the midpoint and the endpoint level (SimaPro Database Manual, 2013);
- *Eco-indicator'99* which is one of the most widely used impact assessment methods in LCA, which also allows the environmental load of a product to be expressed in a single score (SimaPro Database Manual, 2013).

For the study *ReCiPe* Endpoint (Europe ReCiPe HA) (Goedkoop et al., 2013) and *Eco-indicator'99* (Europe EI 99 HA) methodologies (Goedkoop & Spriensma, 2001) were selected. 'H' refers to the weighting set belonging to the 'hierarchist perspective'. 'A' refers to the average weighting set and is recommended by the developers of both methods. 'Hierarchist perspective' was chosen because it is often considered to be the default model (SimaPro Database Manual, 2013) and described (Marceau & Vangeem, 2002; De Schryver, 2010) as the one which takes a long-term look at all substances if there is consensus regarding their effect.

Only those impact categories which had at least 3% of the total environmental impact were chosen for further analysis. Hence, the five impact categories of the *ReCiPe* and *EcoIndicator'99* methods were considered.

Tables 1, 2 summarises characteristics of the selected bio-methane plants. Bio-methane plants which were chosen for analysis are marked with numbers '1' to '7'. The plants use combination of different bio-waste to produce bio-methane (Table 1). Amount of produced biogas and upgraded bio-methane varies throughout plants due to the different sizes of the plants, i.e. installed electrical capacities, amounts and contents of input and other factors (Table 2).

Table 1. Type of bio-waste used at the selected bio-methane plants

Plant	No1	No2	No3	No4	No5	No6	No7
Manure	√	√	√	√	√	√	√
Silage, plants and/or residues	√	√	√	√	√	√	√
Corn	√	√	√	√	–	√	√
Grain and/or grain flour	√	√	√	√	√	–	√
Whey	√	–	–	√	–	√	√
Animal by-products	√	–	–	√	–	√	√

Table 2. Data for the selected bio-methane plants

Plant	No1	No2	No3	No4	No5	No6	No7
Bio-waste input $[10^3 \text{ t y}^{-1}]$	54.50	54.50	13.07	16.50	21.40	40.00	24.90
Installed electrical capacity [MW]	1.95	2.00	0.50	0.50	0.60	1.00	1.00
Potential bio-methane yield $[\text{GWh y}^{-1}]$	45.26	41.23	42.46	14.67	12.32	70.58	20.66
Distance to the natural gas grid [km]	0.8	4.6	6.5	6.6	12.1	12.7	18.9

Data required for the study were obtained from the biogas station pollution permits ('A' category permits No1–No7, 2011–2013), previous studies (Cinis, 2013). Further calculations of the best scenario for injecting upgraded biogas into the natural gas pipeline were carried out by taking into account the bio-methane production capacity of the plants and distances from the plants to the natural gas transmission grid estimated with the program *ArcGis* (ArcGis, 2010).

RESULTS AND DISCUSSION

According to the calculations using *EcoInvent* (v2.2) database (SimaPro, 2013) results of environmental impact of 1 MWh energy from the biomethane plant No1 including infrastructure varies from 9.92 Pt MWh^{-1} when assessed using *ReCiPe* method (and 6.29 Pt MWh^{-1} when using the *EcoIndicator'99* method) to 10.38 Pt MWh^{-1} (6.86 Pt MWh^{-1}) for the plant No 7 respectively (Table 3). For comparison, environmental impact of 1 MWh of natural gas energy is 15.3 Pt MWh^{-1} when *ReCiPe* method is used for analysis (and 17.6 Pt MWh^{-1} obtained with *EcoIndicator'99* method).

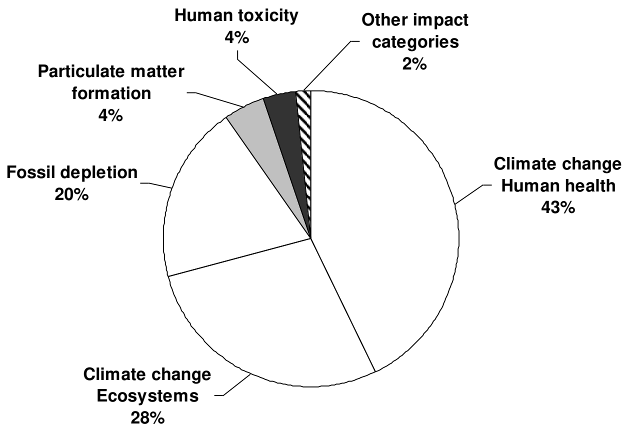
Table 3. The results of the environmental impacts per one megawatt-hour of energy produced at the selected bio-methane plants in Latvia

Plant		No1	No2	No3	No4	No5	No6	No7
Environmental impact, Pt MWh^{-1}								
ReCiPe	9.92	10.02	10.07	10.07	10.21	10.22	10.38	
EcoIndicator'99		6.29	6.41	6.47	6.47	6.64	6.66	6.86

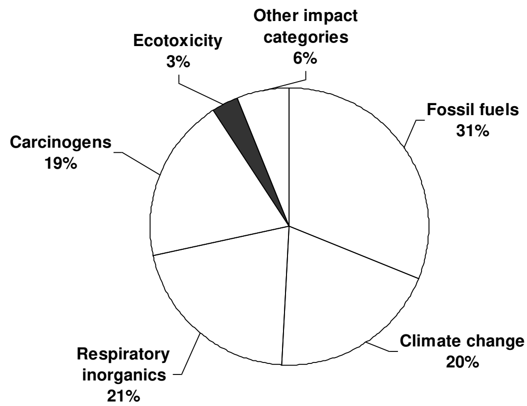
The share of the environmental impact of the infrastructure and transport of the gas, which includes energy consumption and the emissions linked to the transport, in the total impact is rather insignificant in the case when bio-methane plant is located close to the natural gas grid and increases with the distance from it. For example, in the case of the plant No1 which is the closest to the natural gas pipeline the share of the infrastructure and transport is 0.21% (0.4%) of the total environmental impact. But for the most distant plant, i.e. No7, the share is 4.63% (8.73%). It was found in the study, that infrastructure and transport can represent more than 10% (or even more than 15% depending on the evaluation method) of the total environmental impact for the complete bio-methane generation and injection if the distance between the bio-methane production plant and the natural gas grid is increased up to 30–40 km. Even if this percentage could be lower or higher depending on the distance from the natural gas grid, our opinion is that the gas supply infrastructure is still rather important element and should be taken into account if new energy supply systems are designed and considered, which seems to contradict with the opinion in Patterson et al (2011). Whereby, in order to reduce the potential environmental impact, efforts should be made to find the best location for a new bio-methane plant, also taking into account the distance to the existing gas transmission network as well as the location of resources for biogas production.

When using the *ReCiPe* method the greatest environmental impact occurs in the following impact categories (Fig. 2): climate change (human health and ecosystem), fossil depletion, particulate matter formation and human toxicity. Analysis with the *EcoIndicator'99* method shows that the largest impact is caused in the categories fossil fuels, climate change, respiratory inorganics, carcinogens and ecotoxicity. It may mean that the energy use for production and transportation of bio-methane is the largest impact factor.

With the increasing distance of the bio-methane production plant from the grid, impact increases most in the category 'human toxicity' (by ~ 16%), 'particulate matter formation' (~9%) and 'fossil depletion' (~8%), but slightly (~ 2%) in the categories 'climate change (human health and ecosystem)' when analysis is carried out with the *ReCiPe* method. If the *EcoIndicator'99* method is used, environmental impact mostly increases in such categories as 'carcinogens' (~ 16%), 'respiratory inorganics' and 'ecotoxicity' (both by ~ 11%) and 'fossil fuels' (~ 8%), but slightly increases (~ 3%) in the category 'climate change'. Whichever method is used, the environmental impact increases remarkably in the categories that do not have a large overall impact. These categories are related to the land use: *ReCiPe* categories 'natural land transformation' (~ 40%) and 'agricultural and urban land occupation' (~ 34–39%) and *EcoIndicator'99* category 'land use' (~ 28%).



(a)



(b)

Figure 2. Environmental impact by impact category of 1 MWh of bio-methane produced at the plant No7 (*ReCiPe* method (a); *EcoIndicator'99* method (b)).

CONCLUSIONS

Results of this study show that although the share of the environmental impact from the infrastructure which connects distributed bio-methane production facilities to the natural gas pipeline infrastructure is rather insignificant in the case when the plant is located in close proximity to the natural gas grid, nevertheless the impact increases with the distance and in overall can represent more than 10% of the total environmental impact. It can be concluded, that even if the percentage of environmental impact of bio-methane injection infrastructure is lower in case of smaller distance from the grid, it is still rather important element and should be taken into account when new energy supply systems are considered.

Results also indicate that even though the environmental impact of the gas injection infrastructure increases with distance of the bio-methane plant from the natural gas grid, the bio-methane still could be considered as environmentally better alternative than the natural gas.

Further studies are necessary to evaluate also economic aspects of the development of bio-methane system as a renewable energy substitute for the natural gas supply system.

ACKNOWLEDGMENTS. We are grateful to Esri (Envirotech Ltd – distributor in Latvia) for the permission to use 'ArcGis' software and to PRé Consultants bv for allowance to use Faculty version of the 'SimaPro' software.

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