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ENERGY MANAGEMENT FOR BETTER INDOOR ENVIRONMENT

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INDOOR CLIMATE OF BUILDINGS

10th International conference

ENERGY MANAGEMENT FOR BETTER INDOOR ENVIRONMENT

Nový Smokovec, 30th December – 30rd December 2019

Plenary Session

30 years of ICB conference

Sessions

INDOOR AIR QUALITY AND HEALTH

INDOOR CLIMATE AND COMFORT OF BUILDINGS

INDOOR BUILT ENVIRONMENT AND EVALUATION

ENERGY EFFICIENCY AND MANAGEMENT OF BUILDINGS

OUTDOOR ENVIRONMENT AND RENEWABLE ENERGY

ENERGY PERFORMANCE OF HVAC-R SYSTEMS

Dear Madam, Dear Sir,

It is my pleasure to invite you to ICB 2019 Conference.

ICB 2019 Conference is celebrating the 30th Annual and 10th International anniversary this year. It is organized by Slovak Society of Environmental Technology (SSTP), held in Slovakia – Nový Smokovec. This year the conference is mainly focused on the topic "Energy Management for better Indoor Environment"

The conference will examine indoor environmental quality related to health, comfort and productivity and associated with building design, construction, retrofit and operation of HVAC-R Systems, e.g. environmentally friendly and energy efficient nZEB.

It is a forum mainly for PhD. students and young researchers to exchange of their knowledge and ideas especially during the Young Scientists Workshop. There is a great opportunity to gain contacts for future cooperation.

The conference program will include international speakers; original peer reviewed conference papers and extended abstract presentations. The topics of conference will cover following areas:

- Indoor air quality and health
- Indoor climate and comfort of buildings
- Indoor built environment evaluation
- Energy efficiency and management of buildings
- Energy performance of HVAC-R systems
- Outdoor environment and renewable energy

prof. Ing. Dušan Petráš, PhD., EUR ING
president ICB 2019

PLENARY SESSION I

PLENARY SESSION II

CAN WE GET FUNGAL INFECTION IN THE INDOOR ENVIRONMENT?

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Abstract

Fungi have developed the ability to colonize or even to penetrate into the warm-blooded organisms during their evolutionary cycluses. The fungi that are true pathogens, i. e. dependent onto the living hosts, are grouped in just few taxonomic units. The spectrum of clinically relevant fungi is growing constantly, esp. in long-term hospitalized patients with impaired immune system. In the medical practice, the fungal infections – mycoses are divided according to their localization: superficial (colonization without tissue invasion), (muco)-cutaneous (skin and mucoses), subcutaneous infections and deep mycoses. Superficial mycoses may develop on skin or hair due to mostly lipophilic fungi, and never provoke inflammatory reaction. Cutaneous mycoses are infections of the upper layers of the skin, mucoses, hair or nails accompanied by inflammation. The causative agents are mostly keratinophilic dermatophytes, but also yeasts, airborne moulds, or black yeasts. Subcutaneous mycoses have usually chronic, not life threatening course, as a consequence of traumatic infection. Typically, they provoke white blood cell reaction. Deep mycoses may develop after inhalation or internal invasion (surgery) of fungal propagules. Localized disease affect either the particular tissue of organs (systemic mycosis) or may disseminate via blood (fungaemia). Once complex fungal dissemination appears, it always points to the dramatic immune system impairment. The majority of their causative agents belong to primary dimorphic fungal pathoges endemic in sub- and tropics. These kinds of infections are mostly fatal. Other deep mycoses are commonly due to yeasts, naturally airborne, phytopathogenic etc. moulds. Antimycotics of limited spectrum are utilized in fungal infection therapy.

Keywords – fungal pathogen; tinea; airborne fungi; inhalation; immunity

1. INTRODUCTION

Fungi have developed the ability to colonize or even to penetrate into the warm-blooded organisms during their evolutionary cycluses. The fungi that are true pathogens, i. e.

dependent onto the living hosts, are grouped in just few taxonomic units. The spectrum of clinically relevant fungi is growing constantly, esp. in long-term hospitalized patients with impaired immune system (oncological, metabolic, infectious disorders, or pharmacotherapy, or intravenous drug abused). Practically, any fungus can cause the fungal infection under certain conditions.

In the medical practice, the fungal infections – mycoses are divided according to their localization: superficial (colonization without tissue invasion), (muco)-cutaneous (skin and mucoses), subcutaneous infections and deep mycoses. The last three groups of infections always provoke immune response of the body [1, 2].

2. SUPERFICIAL MYCOSES

Fungi able to utilize components present on the surface of human body (keratin, lipids) may start to growth actively and lead to development of superficial fungal infections. The disease is never accompanied by inflammation of the affected tissue. E. g. piedra (colonization of hair with typical white or black nodes at their surface), tinea nigra (hypercoloured spots on palm or soles), pityriasis versicolor (skin lipid assosiated discoloration of the skin due to the activity of *Malassezia* sp. yeasts). Pityriasis is highly contagious illness, called also a wrestler disease, but might be caught in gyms, fitness centers, saunas, from shared sheets of towels. After massive colonization of outer ear tunnel (after primary bacterial infection, or local broadspectral antibiotic overuse) with usually airborne (*Aspergillus niger, A. fumigatus*) or lipophilic fungi (*Malassezia* spp., *Pseudallescheria boydii*), so called otitis externa may occur. The one may be related to stay of a patient in very dusty indoor places with high concentration of fungal particles in the air [1].

3. CUTANEOUS MYCOSES

During the course of the disease, superficial layers of skin, mucouse or nails are damaged in the presence of typical local inflammation. Also hair might be disintegrated by the fungi growing inside. The most typical representatives are dermatophytoses caused by keratinolytic dermatophytes: different forms of ringworm – circular skin lesions, highly irritative, with elevated reddish margines. Under the UV Wood´s lamp they show yellow-green fluorescence.

<u>Tinea pedis</u> – lesions on the soles (extensive scaling) and/or between all the toes (wet deep ridges in the macerated skin).

<u>Tinea manuum</u> – very irritative red lesions between the fingers, progreeding to the palms, hand backs or even forearms.

Tinea corporis – circular extremely itching lesions on the non-hairy skin (face, arm and shoulders, chest), esp. in children after contact with animals (zoonoses).
Tinea capitis – can appear on the scalp or eyebrow, the fungus infects tha hair roots. Commonly caused by zoophilic fungal strains (pets, cattle, horses etc.).
Tinea cruris – very often the endogenous infection by dermatophytes present on the feet and manifesting on the hairy genital skin.
Tinea barbae – inflammate ringworm lesions in the barb.
Onychomycoses – chronic infections of nail beds or nail plates, leading to extreme thickness, fragility, disintegration, deformation or even lost of nails. The adjacent skin might be inflammed or sometimes leaking as well.
Yeast infections of any mucous (mouth, urogenital tract, skin folders etc.) usually remark immune system impairments (application of broad spectral antibiotics, diabetes, several basic diseases – polymorbidity ...). The eye mucocutanous infection (keratitis), on the other hand, commonly follows some injury and invasion of airborne fungi (predominantly aspergilli, fusaria or *Paecilomyces (Purpureocillium)* sp.). there are known eye infections obtained in swimming pools or spas [3].

4. SUBCUTANEOUS MYCOSES

They have mostly chronic course, they are not life threatening, well encapsulated, post-traumatic with adequate immune respond. Cysts or granulomas are formed, the structures filled with fungal matrix of hyaline (e. g. *Acremonium* sp.) or melanized (*Exophiala* sp.) moulds. Majority of their agents are of tropical or subtropical origin. In our climate, zygomycotic rhinitis (esp. due to *Rhizopus* sp.) and mycotic sinusitis (*Mucorales*, aspergilli and so on) occur as complication of nasal polyps and hay fever with a posiblity of an extreme cerebral dissemination in immunocompromised patients. These infections migt be required in the indoor environment (e. g. hospitals) as well [2].

5. DEEP MYCOSES

The infections usually develop in patients with debilitated immune system after inhalation or internal invasion (surgery) of fungal propagules (Figure 1). The disease can remain localized in tissues or organs (systemic mycosis) or can disseminate via the blood (fungaemia) or via lympha (into the skin as secondary cutaneous mycosis). Generalized fungal infection is always a symptom of dramatic decrease of immune system capacity. It might belong to hospital required (nosocomialň infections.

Fungi belonging to *Onygenales*, dimorphic primary fungal pathoges (able to infect in principle healthy people) endemic in tropics and subtropics, are causing mostly fatal infections:

- blastomycosis (*Blastomyces dermatitidis* – respiratory tract infection, later spreading to bones and skin, nerval system, viscera, gastro-intestinal tract as the last, fatal stage of the disease),
- paracoccidioidomycosis (*Paracoccidioides brasiliensis* – chronic infection from airways into mouth with tooth erosion and loss of teeth, into the nasal mucous, lymphatic nodes and organs, leaking ulcers in the terminal stage),
- coccidioidomycosis (*Coccidioides immitis* – unspecific fever, respiratory infection, rush, eye inflammation, blood spread into all skin layers, bones, joints and internal organs),
- adiaspiromycosis (*Emmonsia parva* – cysts in the lungs, zoonosis from rodents) – might be a professional health damage in e. g. guano cleaners in buildings,
- histoplasmosis (*Histoplasma capsulatum,* endemic in tropic areas of North America - – the fungus is hidden in white blood cells, spreads via blood and lymph into the organs, granulomatous inflammations leading to the death. Types of infection: asymptomatic – over 99 % of the exposed patients, positive skin test and immune response; accute pneumonia – epidemic or after endogenous reactivaton, typical for AIDS patients; chronic pneumonia – typical for smokers in Florida, calcificates in the lungs resembling carcinoma; disseminated form – in immunocompromised patients, from respiratory tract into the bone marrow, liver, spleen, rarely gastro-intestinal tract, sometimes ulcerative mouth mucous, in AIDS patients into CNS; primary cutaneous form – localized ulcers, enlargement of local lymphatic nodes – is possible also after professional exposition in the lab) [2].

Deep mycoses caused by other fungi:

- penicilliosis (*Talaromyces (Penicillium) marneffei* – endemic in East-South Asia, from respiratory tract invading into withe blood cells and proliferating there),
- aspergillosis (mostly due to *Aspergillus fumigatus, A. flavus, A. niger, A. terreus*)
- cryptococcosis (*Cryptococcus neoformans* – pneumoniaa, 5 – 10 % AIDS pacienta in Western countries, 30 % in Africa, hematogenic dissemination into nervous system. Types of infection: pulmonary; disseminated into NS, eventually with skin ulcerations;, cerebral in health people - *C. gatii* symbiotic in eucalyptus; primary cutaneous after wounding),
- systemic yeast infections,
- zygomycoses (zygomycetes, esp. *Rhizopus* sp., *Absidia corymbifera (Mycocladus corymbifer*), *Mucor/Rhizomucor* spp. – accute inflammation, swelling, necrosis in the

site of entrance, fast growth of the fungus liading to thrombosis and infarct, bleeding, death; risky patients with diabetes, corticoid therapy etc. Types of infection: rhinocerebral – lesions in nose and mouth, progreeding into the brain, possible complication after invasive stomatologic procedures; pulmonary; gastro-intestinal - in patients with malnutrition or immunocompromised; primary cutaneous – local gangrene with swelling in polytraumatic patients, usually with burnings

- phaeohypomycoses (caused by melanized neurotropic fungi – brain lesions ,fatal, from upper airways into CNS),
- *Pseudallescheria boydii*/*Scedosporium apiospermum* – lung colonization esp. in cystic fibrosis patients, in patients with blood circulation failure, leukemia, in coma or chronic CNS absceses might occur; in otherwise healthy patients the disease migh develop after traumatic inoculation (after neardrawing in standing waers, severely wounded in muds etc.) with the fatal course,
- hyalohyphomycoses (very often fusarioses after extensive surgery in liver and spleen, endocarditis), almost always fatal [1, 3].

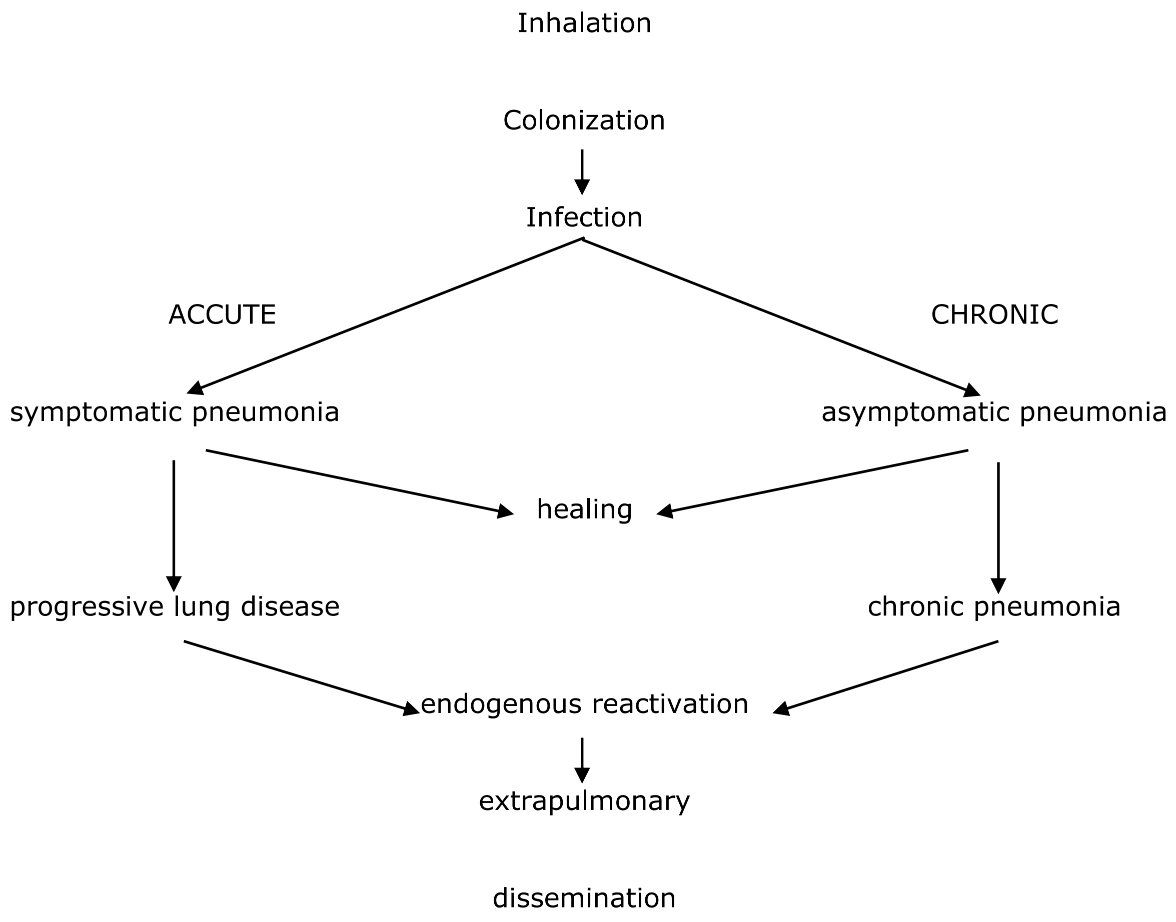

Fig. 1 *Scenario of development of deep mycosis [2]*

6. THERAPY

Recently, the number of medicaments applicable in topic or systemic therapy of mycoses is growing. Despite of it, there is no universal therapeutic spectrum of effective preparations and dosage regimens.

Topic antimycotics are effective in therapy of superficial and cutaneous mycoses. They are susually being applied once or twice a day onto affected area, sometimes for even 8 weeks [1].

Systemic antimycotics

Representatives of antibiotics (griseofulvin), polyenes (amphothericin B), allylamines (terbinafine), azoles (imid- and triazoles), antimetabolites (fluorocytosine) and the newest echinocandins are used in clinical practise.

Resistence to antifungal therapy develops in relation to extension of clinical use of antimycotics. Treatment of severe systemic mycoses can reach the positive goal mosty more difficult, when compared to antibacterial therapy, not only due to limited spectrum of applicable medicaments, but also due to the fact the fungal infections attack mostly the pacients with severe/life threatening basic diseases [2, 3].

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I. SESSION

INDOOR AIR QUALITY AND HEALTH

OVERVIEW OF ORGANIC COMPOUNDS OCCURRENCE IN INDOOR ENVIRONMENT

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Abstract

Volatile organic compounds (VOCs) belong to a category of chemical substances commonly found in indoor environments. They enter the interior of the building mainly from internal sources in the form of consumer products. Most of them have carcinogenic and mutagenic effects. The following study provides a brief overview of the occurrence and sources of VOCs in the indoor environment of buildings, focusing predominantly on residential buildings, schools and office buildings. BTEX, α-pinene, D-limonene and formaldehyde are the most frequently monitored substances in indoor buildings. Their concentrations in different indoor environments are variable and depend on various factors such as emission characteristics of the source, seasonal changes and ventilation conditions. Benzene enters the indoor environment of buildings from external sources, especially from transport or industrial areas. Formaldehyde is released into the atmosphere in the form of emissions from building materials and furniture. Limonene and α-pinene are contained in cleaning products.

Keywords - indoor air quality, volatile organic compounds (VOCs), sources and occurrence of VOCs, indoor environment

1. INTRODUCTION

Nowadays, people spend most of their time indoors. The indoor air is often more polluted than the outside air due to emissions from internal sources and low air exchange rates. Poor indoor air quality can have a negative impact on human health and lead to sick building syndrome [1, 2].

Volatile organic substances are considered to be ubiquitous pollutants, which enter the indoor environment of buildings from external sources in the form of industrial by-products, incomplete combustion of organic matter and exhaust gases. Most of the volatile organic compounds enter the interior of buildings from internal sources in the form of emissions from building materials, floors, composite wood products, adhesives and other consumer products [3]. By their presence, these substances contribute to poor indoor air quality and by their effect are able to influence a person´s everyday life. Short-term exposure to high VOC levels may cause eye, nose or throat irritation, headache, nausea or vomiting, dizziness, allergies and asthma. Long-term exposure to high VOC levels may lead to an increased cancer risk, liver, kidney and central nervous system damage [4]. For this reason, the monitoring of VOCs focuses on those buildings that are considered critical and where users spend most of their time. These buildings include mainly schools, public buildings and households.

The main objective of this article is to review current literature on the occurrence and sources of VOCs in the indoor environment of buildings.

2. DEFINITION OF VOLATILE ORGANIC COUMPOUNDS

In general, all chemical compounds with a boiling point between 50-100 ° C and 240-260 ° C are considered as volatile organic compounds. There are several classifications of volatile organic compounds. The most commonly used classification is the World Health Organization (WHO), which distinguishes VOCs on the basis of their volatility (boiling point), namely very volatile, volatile and semi-volatile organic compounds (Table 1). This classification also involves the molecular length of the carbon structure i.e., the number of carbon atoms in the chemical formula. The summation of all VOCs is called the Total Volatile Organic Compounds [5].

Tab. 1 *Classifications of Volatile Organic Compound*

Class	Name	Typical boiling point [°C]	Typical number of Carbon Molecules
VVOC	*Very Volatile Organic Compound*	< 0 to (50 - 100)	$< C_6$
VOC	*Volatile Organic Compound*	(50 - 100) to (240 - 260)	C_6 to C_{16}
SVOC	*Semi-volatile Organic Compound*	(240 - 260) to (380 - 400)	$> C_{16}$
TVOC	*Total Volatile Organic Compound*	*Sum of all coumpounds listed above*	

3. VOLATILE ORGANIC COMPOUNDS OCCURRENCE IN DIFFERENT TYPES OF BUILDINGS

3.1 Residential buildings

Kaunelienė et al. monitored the quality of the indoor environment in 11 new low-energy residential buildings. TVOC concentrations were monitored at various stages of completion. The results showed that despite low air exchange, TVOC concentrations remained at acceptable levels, while formaldehyde concentrations (3.3-52.3 μg/m^3) exceeded permitted limits. In the second stage of completion, TVOC concentrations increased rapidly after the installation of the home furnishings. Due to constant ventilation, an exponential decrease in BTEX concentrations to an acceptable level was again observed within one month. The authors also pointed out that one of the goals in the construction of low-energy new buildings should be the selection of suitable low-emission building and surface materials that, together with efficient mechanical ventilation, are able to guarantee good indoor quality [6]. According to Stamatelopoulou et al., the average daily TVOC concentrations were above the required limit of 500 μg/m^3 in several cases. Increased concentrations of TVOC in the monitored residences were shown to be mainly related to the activities of participants involved in the presented study. These activities included smoking, cooking and cleaning [7]. Cahna et al. investigated the effect of natural ventilation on the quality of the indoor environment in the bedroom during the sleep of the occupant. The highest average TVOC concentration of 820 μg/m^3 was achieved under conditions where both the window and the door were simultaneously closed. In contrast, the highest average formaldehyde concentration of 205 μg/m^3 was observed when the window and door were simultaneously open. It has been shown that although natural ventilation can achieve a higher air exchange rate in the room, it can also contaminate indoor air due to the infiltration of undesirable pollutants from the outside [8]. Monitoring of the indoor environment in homes, according to Sun et al., was performed in rooms where their occupants spend most of their time. The results showed that the most common TVOCs include toluene, nonanal, α-pinene and p-xylene with respective average concentrations of 21.45 μg/m^3, 16.13 μg/m^3, 12.91 μg/m^3 and 12.23 μg/m^3. The average concentrations of TVOC and formaldehyde were 586.95 μg/m^3 and 100 μg/m^3. The highest concentration of formaldehyde was observed during the summer period. Research also showed that higher air exchange rates (≥ 30 h^{-} 1) resulted in decreased VOC and formaldehyde concentrations. A significant decrease was recorded for toluene and benzene [1]. Huang et al. monitored formaldehyde concentrations in 21 households over four seasons under airtight and natural ventilation conditions. Under airtight conditions, the highest average concentrations of formaldehyde in selected rooms were recorded during summer and the lowest average concentrations during winter period. The highest average concentration of 94 μg/m^3 was reached in the living room in the autumn. In the case of natural ventilation, the lowest average concentration in selected rooms was recorded during summer. The highest average concentration was reached during autumn and subsequently in winter, since in winter the ventilation infiltration rate is higher than in other seasons. The second phase of the research involved monitoring VOC and formaldehyde concentrations using suitable sensors. For this long-term monitoring, the highest average formaldehyde concentration was recorded during the winter. It has been shown that as the outside temperature increases, the concentration of formaldehyde in the interior decreases due to natural ventilation. The highest average TVOC concentration was recorded under airtight conditions in the transitional period (1243 μg/m^3), followed by winter (978 μg/m^3) and summer (573 μg/m^3). In the case of long-term monitoring, the highest average TVOC concentration in summer was 924 μg/m^3. Of all VOCs detected, toluene reached the highest concentrations in all periods. The study pointed out that there was a negative correlation between the formaldehyde concentration, window opening time, indoor temperature and relative humidity. The results also indicated that even the furniture surface area per unit volume is positively related to the HCHO concentration. In contrast, a positive correlation was observed between concentrations of TVOC and temperature, indoor relative humidity and furniture surface area per unit volume [9]. Li et al. investigated VOC concentrations in Canadian apartment buildings. Of all measured VOCs, limonene (43.3 μg/m^3), decamethylcyclopentasiloxane (37.7 μg/m^3), α-pinene (18.5 μg/m^3), toluene (16.6 μg/m^3), hexanal (14.1 μg/m^3) and nonanal (10.5 μg/m^3) reached the highest average concentrations. Limonene and α-pinene are considered to be naturally occurring VOCs. Limonene is present in detergents and α-pinene in many perfumes and deodorants. Toluene is present in fuels, is a component of paints and diluents, or is used as a solvent. Decamethylcyclopentasiloxane is manufactured artificially and is part of cosmetic products. Hexanal and nonanal are fruit-flavored aldehydes found in building materials. The study also noted that aliphatic and aromatic hydrocarbon concentrations were higher in winter and summer months. On the other hand, oxygenated hydrocarbon derivatives (alcohols, aldehydes and ketones) reached higher concentrations in the warmer months and reached their maximum during the summer [10].

3.2 Schools

Compared to adults, children are generally more vulnerable to the negative effects of air pollutants. They breathe more air per unit of body weight and their immune system is less resistant to hazardous chemicals. As schools are a place where children spend much of their time, several studies have focused on monitoring of indoor air in schools.

Kalimeri et al. evaluated the quality of the internal environment in two primary schools and one kindergarten. The study focused primarily on the monitoring of formaldehyde and benzene, which are considered to be known human carcinogens. Formaldehyde was detected in all three schools. Furniture and wood products (particle board, fibreboard and plywood) containing formaldehyde resins are expected to be placed in all classes. The highest concentration of formaldehyde was recorded in kindergartens, where carpets were also placed and consumer products were used more widely. The average concentration of formaldehyde was higher in summer (14.2 $\mu g/m^3$) than in winter (4 $\mu g/m^3$) and the average concentration of benzene in winter was higher (6.2 $\mu g/m^3$) than in summer (3.1 $\mu g/m^3$). Based on the ratio of indoor and outdoor concentrations, it was confirmed that the presence of formaldehyde and benzene in selected classes is due to emissions from internal sources. Trichlorethylene, α-pinene and D-limonene were detected only in the indoor environment of buildings, with only D-limonene reaching the highest concentrations in winter. A more detailed analysis of building materials has shown that the share of building material emissions in VOC concentrations detected in school settings can be as high as 30%, while the contribution of other sources may be higher than 90%. These additional resources may include furniture, cleaning products, office equipment, personal care products, handicrafts, toys and user activities [11]. The most common air pollutants in schools in Spain were aldehydes - formaldehyde and hexanal. In this study, Villanueva et al. focused primarily on schools located in rural, urban and industrial areas. The results showed that there was no significant difference in TVOC concentrations between the three regions. The impact of transport and the petrochemical plant was significantly reflected in the increased concentrations of benzene in the internal environment of schools located in the industrial area. These concentrations were significantly higher compared to urban or rural areas. An evaluation of the indoor and outdoor concentrations (I/O) ratios has shown that most VOCs come predominantly from internal sources. Benzene and n-pentane come from external sources. VOCs, such as aldehydes, terpenes, alkanes and most aromatic hydrocarbons, come from internal sources and ethylbenzene and toluene come from both internal and external sources [12]. Jovanovic et al. monitored formaldehyde concentrations and five individual VOCs in three primary school classes. The total mean VOC concentration reached 48.67 $\mu g/m^3$. The highest mean concentration was observed for trichlorethylene (29.15 $\mu g/m^3$). The average concentration of formaldehyde in the indoor environment was 63.74 $\mu g/m^3$ and in the outdoor environment 5.07 $\mu g/m^3$. Increased concentrations of formaldehyde in the air of the monitored classes are due to the presence of internal sources such as old furniture and carpets, shelves and flooring [4]. Goodman et al. monitored internal VOC concentrations in selected areas of the university campus. The analysis revealed that the indoor VOC concentrations are higher compared to the outdoor concentrations. Hazardous substances such as formaldehyde, benzene, toluene and xylenes were one level higher in the interior than in the exterior. The concentration of these compounds was 51.6 μg/m^3 for classrooms, 42.8 μg/m^3 for renovated offices and 23 μg/m^3 for green buildings. Limonene, ethanol, hexanal, α-pinene and isobutane were two levels higher in the interior than in the exterior. This means that internal contamination came mainly from internal sources. Of all the buildings involved in the research, the highest I/O ratios of formaldehyde, toluene and xylenes were observed in the building, which is considered to be so-called green building. Building materials and fragrant consumer products have been identified as possible major sources of VOCs [13]. Based on the results of Beccer et al., it has been shown that the overall quality of the internal environment is also influenced by the location of the school. Placing the school in an environment with high traffic density or near industrial zones can significantly affect the internal concentrations of TVOC, benzene and toluene. The authors also noted that the levels of TVOC and aldehydes in the classroom may be affected by a wide range of building and housing materials, detergents or specific products that are associated with classroom activities. Exceeding the concentration limits of ethylbenzene, m + p-xylene and o-xylene in some classrooms is directly related to internal resources. Similar exceedances were observed in several classes for toluene, tetrachlorethylene and α-pinene and were related to external sources [14].

3.3 Administrative and public buildings

The main sources of VOCs in offices include copiers, printers, furniture, cleaning products, wall and floor coverings. The use of printers has been found to lead to increased concentrations of toluene, xylene and ethylbenzene, while other electronics, such as computers, may also contribute to toluene and xylene emissions [15]. Research results from Nunes et al. states that the incidence of VOCs is related to their potential sources and seasonal changes. VOC concentrations were lower and showed less variation in winter and summer compared to spring and autumn seasons. From October to April (winter period), when temperatures are lower, most compounds were detected at lower concentrations. The opposite was observed from May to June (spring period). Increased D-limonene concentrations were observed in autumn and increased α-pinene concentrations during spring, autumn and winter. The highest average annual concentrations were found for toluene, limonene and heptane with respective values of 5,10 μg/m^3, 3,48 μg/m^3, 8,46 μg/m^3 [16]. In another large study, according to Mandin et al., the effect of seasonal changes on VOC concentrations in modern mechanically ventilated office buildings in 8 European countries was studied. The indoor VOC concentrations measured in summer differed significantly from those measured in winter, with the exception of xylenes. Formaldehyde reached higher concentrations in summer than in winter (16 μg/m^3 and 8.1 μg/m^3) and compounds such as benzene and terpenes (ɑ-pinene and D-limonene) reached higher concentrations in winter than in summer [17]. Increased BTEX concentrations in offices during the summer and winter seasons, according to studies by Campagnola et al., were attributed to external sources. Other major resources have been linked to building materials such as flooring materials (especially carpets), wood-based products and various types of paint. Increased ozone concentrations, which react with the VOCs present in the atmosphere to form further intermediates, also contributed to the deterioration of the indoor environment during the summer months. Office air quality was also affected by emissions from printers and cleaning products, especially in winter [15].

Baurès et al. monitored concentrations of selected VOCs in two hospitals. The highest concentrations in both hospitals were measured for ethanol and isopropanol in winter. The reason was the presence of ethanol in the hand cleaning solution used in the hospital. Its concentration depends on the rate of air exchange. BTEX concentrations reached very low values in all areas of both hospitals. Limonene concentrations were relatively low, higher concentrations were found in only one hospital, which was related to cleaning activities. Higher toluene concentrations were observed in the laboratory premises of one of the hospitals where it was used as a solvent. Average concentrations of formaldehyde in both hospitals reached higher values in the summer months. This study points to low pollution in two hospital buildings compared to the indoor dwelling environment, probably related to ventilation and central air conditioning [18]. Cincinelli et al. found that the most abundant VOC group in the internal environment of libraries and archives was BTEX, followed by cyclic volatile methylsiloxanes, aldehydes, terpenes, and organic acids. The obtained results showed that BTEX in the indoor air of libraries and archives situated in urban areas and in some cases also in city centers do not come only from emissions of internal sources, but also from the external environment. Acetic acid, a substance that can oxidize books and other exposed objects, was detected at concentrations ranging from 1.04 μg/m^3 to 18.9 μg/m^3, while furfural, a known marker of paper degradation, was still present at concentrations between 5.26 μg/m^3 and 32.6 μg/m^3. The average concentration of TVOC was 161 μg/m^3, with the highest concentrations were found in academic libraries and the lowest in historical libraries [19].

4. CONCLUSION

In general, the amount and composition of undesirable volatile organic compounds in the indoor environment depends on several factors. The most important ones include the number of people in indoors, interior and technical equipment, relative humidity, the age of the building and its location within the urban unit, degree of air pollution, intensity and quality of ventilation, season and type of heat source.

Most VOCs in the indoor air of buildings come mainly from internal sources, predominantly from building materials and consumer products. The most common sources of formaldehyde include furniture and building materials. Limonene and α-pinene penetrate to the indoor air from detergents. Benzene is most often the product of external sources, which include emissions from transport and industrial activity. Long-term exposure to these compounds has adverse effects on human health and can lead to sick building syndrome.

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ANALYSIS OF INDOOR AIR QUALITY AND THERMAL ENVIRONMENT IN CLASSROOMS WITH DIFFERENT VENTILATION SYSTEMS

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Abstract

In this paper, the effect of the different ventilation systems, both on indoor air quality and thermal comfort in classrooms at the VSB-Technical university of Ostrava, was analysed. Indoor air temperature and carbon dioxide (CO_2) concentration, as well as opening of windows, were continuously monitored in several classrooms with different ventilation systems. Ventilation was achieved by manually operable windows (almost classrooms) or by mechanical ventilation system and air conditioning unit. The result of measurements were compared with simulation computing models.

Keywords – infiltration, carbon dioxide, classrooms, ventilation

1. INTRODUCTION

The Czech Republic is characterized by mild climate, which is caused by the infiltration and mixing of oceanic and continental influences. Most of the Czech Republic territory lies at an altitude of up to 500 m above sea level. The mild climate is specific by the fact that temperatures change sometimes by more than 50°C during the year. For designers, it is more difficult to find a balance that ensures thermal comfort in both, winter and summer seasons. Compliance with hygienic and operational ventilation requirements should be prioritized before achieving energy savings according to the standard ČSN 730540 - 2, which sets the requirements for thermal protection of buildings [1]. Ventilation ensures the discharge of exhaust air, fresh air supply into the indoor environment, and in the summer season, it helps to remove the thermal load. The air is deteriorated in classrooms by carbon dioxide produced by breathing, and by other pollutants that may come off the furniture or enter this environment with the air supplied from outside. These harmful substances can be, for example, volatile organic substances, water vapour, dust, radon, pollen, etc. The indoor air quality is assessed under Regulation No. 268/2009 Coll., as amended, based on the concentration of carbon dioxide [2].

2. CO_2 CONCENTRATION

Why to measure the concentration of CO_2 at all? It is a good indicator of stuffy air indoors. It responds to the number of people staying in the specific confined space. The air of the Earth's atmosphere consists of the following components: 78 % of nitrogen, 21 % of oxygen, 0.4 % of water vapours, 0.04% of carbon dioxide, and the rest is formed by noble gases. Carbon dioxide is thus a normal component of the Earth's atmosphere. The outdoor concentration of CO_2 is approximately 0.04%, i.e. 400 ppm. CO_2 concentration is more frequently stated in ppm unit, which demonstrates the number of volume units of CO_2 in a million of volume units of air.

When breathing, a person changes inhaled oxygen to carbon dioxide, while the air exhaled by adult contains on average 40,000 ppm of CO_2. If no adequate ventilation is provided, the concentration of logically increases CO_2.

Carbon dioxide is a colourless gas, tasteless and odourless. At higher concentrations, it may have a slightly acidic taste in the mouth. Its increased concentration in the room shows in most cases noticeably at the persons present. CO_2 concentration up to 5,000 ppm does not represent serious health hazard for healthy individual. However, it is proven that drowsiness, lethargy, fatigue, and decreased concentration ability occur from a certain level of carbon dioxide concentration. Some studies even show a connection with the decline in productivity and performance [3].

CO_2 concentration [ppm]	Specification and impact on humans
360 - 400	Fresh air in the open
800 – 1,000	Suggested CO_2 level indoors
> 1,000	Fatigue symptoms and reduced concentration occur
1,200 – 15,00	Maximum acceptable concentration indoors
> 2,500	Drowsiness, lethargy, headache
5,000	Maximum safe concentration without health hazards
> 5,000	Increased pulse, the stay is not recommended
> 40,000	Dangerous to life
35,000-50,000	Air exhaled by adult

Tab. 1 *CO_2 concentration in the air and its impacts on humans*

What measures should therefore be taken against the increased concentration of CO_2 in the indoor environment? At present, the technology allows us to measure the CO_2 concentration in the air easily and relatively inexpensively and, based on the results measured, to control ventilation systems which would ensure the required air quality and to optimize the energy demand.

3. DESCRIPTION OF MEASUREMENT

ALMEMO 2690-8A - Combined universal measuring instrument with 5 inputs and 2 outputs was used for measurement in all rooms. Two sensors were connected to ALMEMO. The first combined temperature and humidity sensor for ALMEMO instruments, which has 4 measuring devices - temperature, relative humidity, dew point and atmospheric pressure. The typical sensor was a digital sensor of CO_2 concentration in the air type FYAD600CO2B10 with a measuring range of 0 - 10,000 ppm.

Room LPOA 204

The room is located in an old school building that has been renovated. The room area is 60 m^2, the exterior wall contains windows along its entire length of 8.5 m. The windows are located 1.1 m above the floor and are 2.0 m high. The windows are oriented to the south and are equipped with outdoor blinds. The classroom is equipped with 24 desktop computers and 12 students and teachers were present at the time of measurement. If the classroom was fully occupied, the measurement results would be even less favorable. During the measurement there was only minimal exchange of air by infiltration. The sensor was placed on the desk of the teacher's desk located at a height of 0.8 m above the floor. The first graph shows the measured CO_2 concentration values. The graph shows that the recommended limit values are exceeded after 20 minutes and rise to 1 980 ppm. The second graph shows the temperature and humidity in the classroom.

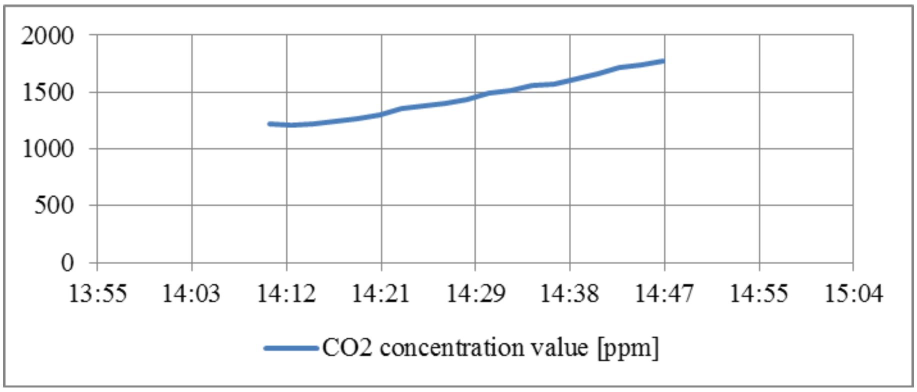

Fig. 1 *chart of CO_2 contcentration value in room LPOA 204*

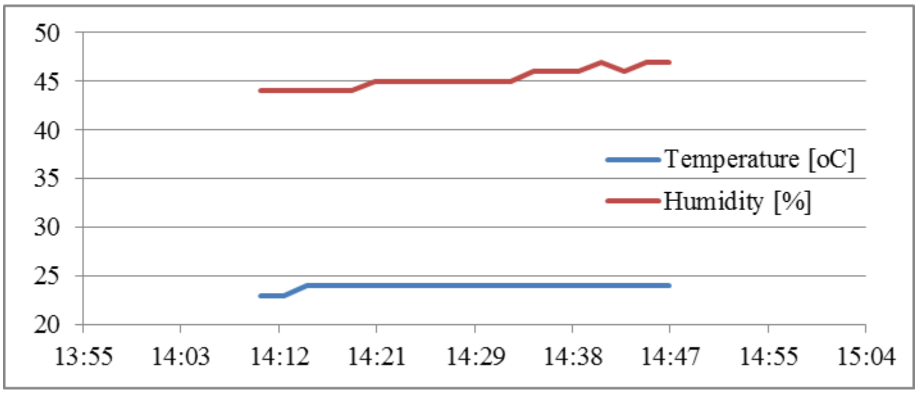

Fig. 2 *graph of temperature and humidity in room LPOA 204*

Room LPOB 301

The room is located in an old school building that has been renovated. The room area is 82 m^2, the exterior wall contains windows along its entire length of 11.5 m. The windows are located 1.1 m above the floor and are 2.0 m high. The windows are oriented to the west and are equipped with internal blinds. The classroom is for 47 students, but at the time of measurement 22 students and teachers were present. If the classroom was fully occupied, the measurement results would be even less favorable. The room was not ventilated before the measurement, so the initial CO_2 concentration was high and increased during the class. During the measurement there was only minimal exchange of air by infiltration. The sensor was placed on the desk of the teacher's desk located 0.8 m above the floor. The first graph (fig.3) shows the measured CO_2 concentration values. It is clear from the graph that the recommended limit values have been exceeded since the beginning of the course and are increasing up to 3680 ppm. The second graph (fig.4) shows the temperature and humidity in the classroom. For this room a model was created in the software Design Builder and the values were set according to the classroom schedule and the expected number of people. The results from the software that we can compare are mainly temperature and humidity and are shown in graphs 3-6 (fig.5). The results will be further examined and compared with the actual measured values.

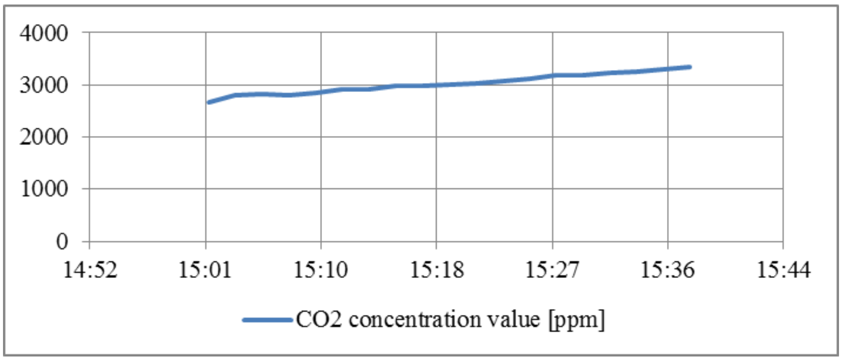

Fig. 3 *chart of CO_2 contcentration value in room LPOB 301*

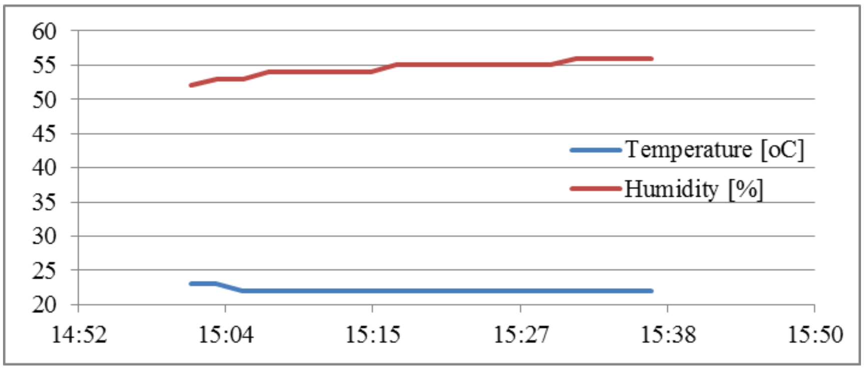

Fig. 4 *graph of temperature and humidity in room LPOB 301*

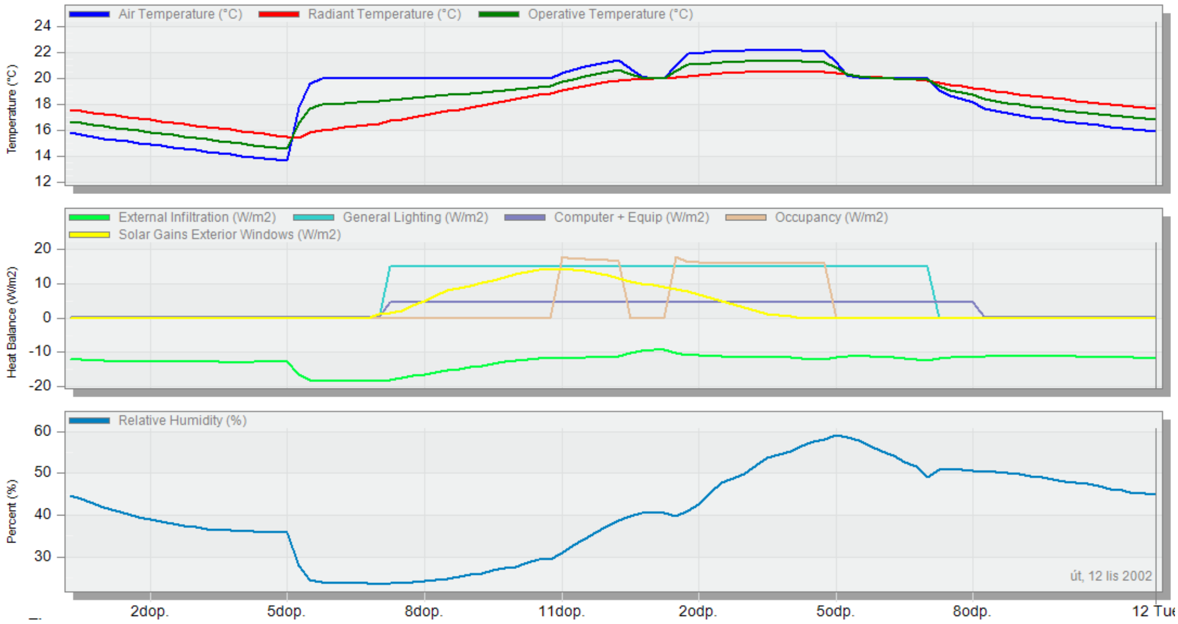

Fig. 5 *temperature and humidity graph from software Design Builder*

Room 204

The room is located in a passive house on the attic of the Faculty of Civil Engineering. Room area is 20 m^2. There are two south-facing windows with a total area of 3.5 m^2 and one east-facing window with an area of 1.2 m^2. All windows are equipped with outdoor blinds. At the time of measurement, 10 students and a teacher were present in the room. During the measurement there was only minimal exchange of air by infiltration. The sensor was placed on the desk of the teacher's desk located at a height of 0.8 m above the floor. The first graph shows the measured CO_2 concentration values. It is clear from the graph that the recommended limit values are exceeded after 20 minutes and rise to 3500 ppm. The second graph shows the temperature and humidity in the classroom.

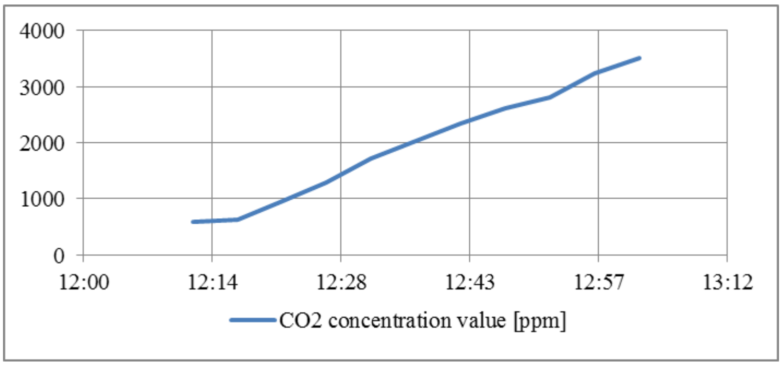

Fig. 6 *chart of CO_2 contcentration value in room 204*

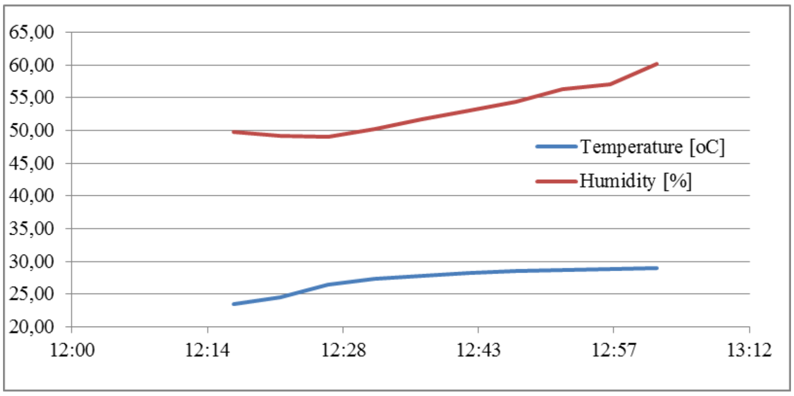

Fig. 7 *graph of temperature and humidity in room 204*

Room LPOH 109

The room is located in the new school building. The room area is 180 m^2, the exterior wall does not contain windows. The classroom is equipped with forced ventilation and at the time of measurement, 29 students and a teacher were present. The sensor was placed on the desk of the teacher's desk located at a height of 0.8 m above the floor. The first graph shows the measured CO_2 concentration values. It is clear from the graph that the values of the recommended limit are not exceeded because forced ventilation is used and air exchange is ensured. The second graph shows the temperature and humidity in the classroom.

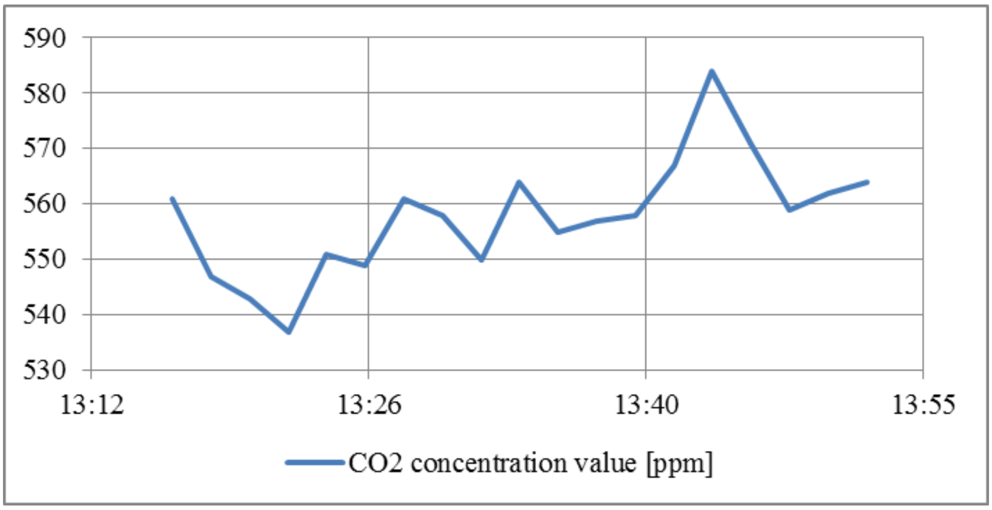

Fig. 8 *chart of CO_2 contcentration value in room LPOH 109*

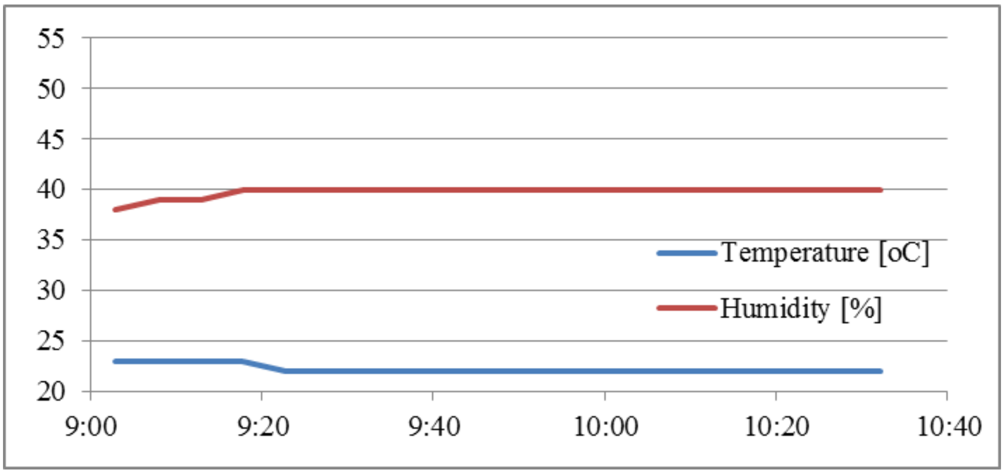

Fig. 9 *graph of temperature and humidity in room LPOH 109*

4. CONCLUSION

There are no binding regulations for university classrooms in the sense of the amount of air per student, as in primary and secondary schools. Only the limit value of CO_2 concentration is intended for the classrooms at the university. However, the quality of the internal environment should also be ensured for university students, as they often spend much more time in classrooms than primary and secondary school students. Carbon dioxide is not the only pollutant of the indoor environment, it is only considered to be a meaningful measure of indoor air quality. The deterioration of the indoor air quality has been observed especially since the structures are insulated by the contact system and the opening fillings are replaced and in a passive house without a functional ventilation system. In case of forced ventilation it is possible to control both the amount of supply and exhaust air and the ventilation time. The ideal solution to ensure the recommended CO_2 concentration is to connect the ventilation system to a sensor that measures the concentration of carbon dioxide. Forced ventilation brings with it an investment problem, however, it is necessary to realize that ventilation is necessary and it is not possible to save money to the detriment of people's health and thus also of buildings.

Acknowledgment
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THERMAL COMFORT AND INDOOR AIR QUALITY IN THE LIBRARY OF THE FACULTY OF CIVIL ENGINEERING STU

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Abstract

During designing and operating buildings, it is necessary to pay attention to the requirements for ensuring a healthy and comfortable indoor environment in terms of the thermal-humidity microclimate and air quality. The high quality of the indoor environment, expressed by indicators such as air temperature, relative humidity, carbon dioxide concentration, lighting and alike, has a great impact on human health, comfort, and performance. A quality indoor environment is especially important in areas where there is a high concentration of people. The environment directly and indirectly affects the mental and physical aspects of man, so it is important to ensure the best possible conditions of indoor air. This work evaluates the space of the University Library and Information Center at the Faculty of Civil Engineering of the Slovak University of Technology in Bratislava. The criteria to be considered are temperature, humidity and carbon dioxide. The main monitored variable was carbon dioxide, which accumulates in the visors through the influence of man during insufficient air exchange. In the library, long-term measurements of all assessed quantities were carried out. The work is divided into theoretical and experimental part. All experimental measurements are all focused on office space with sedentary or very low activity, where easy access to openable windows and where users can freely adjust their clothes according to the thermal conditions of the indoor or outdoor environment.

Keywords – indoor environment, thermal comfort, air quality, library

1. INTRODUCTION

This research deals with evaluation of the indoor climate in the Library and Information Center at the Faculty of Civil Engineering of the Slovak University of Technology in

Bratislava. The criteria to be considered are temperature, humidity and carbon dioxide. All quantities were measured in the library during the cold period of the year (29.1.-13.2.2019). Four sensors were used to detect temperature, humidity and CO2 concentration at 10-minute intervals. Based on the measured data, the space was evaluated according to STN.

2. THERMAL COMFORT

Thermal comfort expresses the state of mind when a person is satisfied with the thermal environment. It can be evaluated using the PMV and PPD indices which express the thermal sensation of a large group of people. STN EN 15251 specifies categories I, II, III, and IV of the indoor environments. Category I represents the criteria of the highest standard of thermal comfort and category, category II is a normal level of expectation, and category III non-ideal although still acceptable values. Category IV can only be acceptable for a very short period of time. Optimum and permissible thermal comfort conditions are determined by people's clothing, the overall heat production of their organism and the activity performed
[2].

3. LOCATIONS OF SENSORS

Four sensors were used to record the parameters of the indoor environment, during the two weeks (January 29 - February 13, 2019) in the winter period and during one week (April 6 - April 12, 2019) in the spring period. The internal temperature, humidity and carbon dioxide concentration were recorded in ten-minute intervals. One device was placed on the window sill from outside to measure outdoor temperature, humidity, and carbon dioxide levels.

The first sensor was placed at the entrance at a height of 1.2 m above the floor, the second on the first window from the entrance at a height of 1.2 m above the floor, the third at the rear of the library at a height of 1.9 m above the floor. The last one was on the second floor at a height of 1.9 m above the floor. Figure 1 and 2 show the exact location of the sensors in the Library [1].

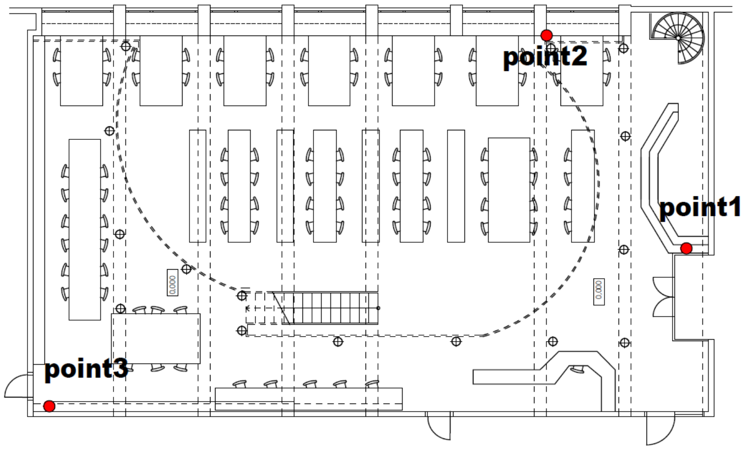

Fig. 1 *Placement of portable sensors on the 1st floor in Library and Information Center* [1]

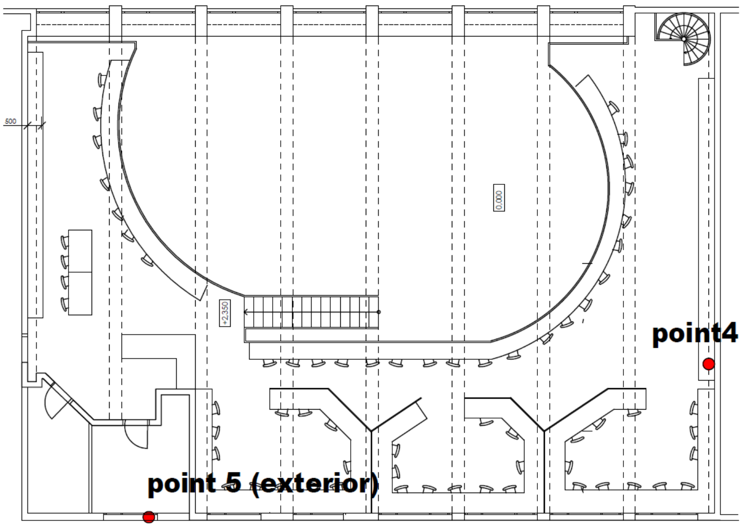

Fig. 2 *Placement of portable sensors on the 2nd floor in Library and Information Center* [1]

3. RESULTS

We classified the Library and Information Center into categories according to STN EN 15251 based on the measured values of the level of CO_2 concentration in space, room temperature and relative humidity. According to the results over the period from 29.1. to 13.2. it is possible to determine how many percent of time from the monitored period the room corresponded to the requirements of individual categories of environment. Data was also recorded also during off-hours and weekends.

Depending on the temperature, the room is classified into Category I with a temperature range of 21-23 ° C, where temperatures were up to 38,39% of the monitored time. With regard to the humidity values of the indoor air, we can classify the space into category I with values ranging mostly in the range of 30-50% for 74,94% of the monitored time. Figure 3 and 4 show the exact progress of temperature and relative hummidity in the Library [1].

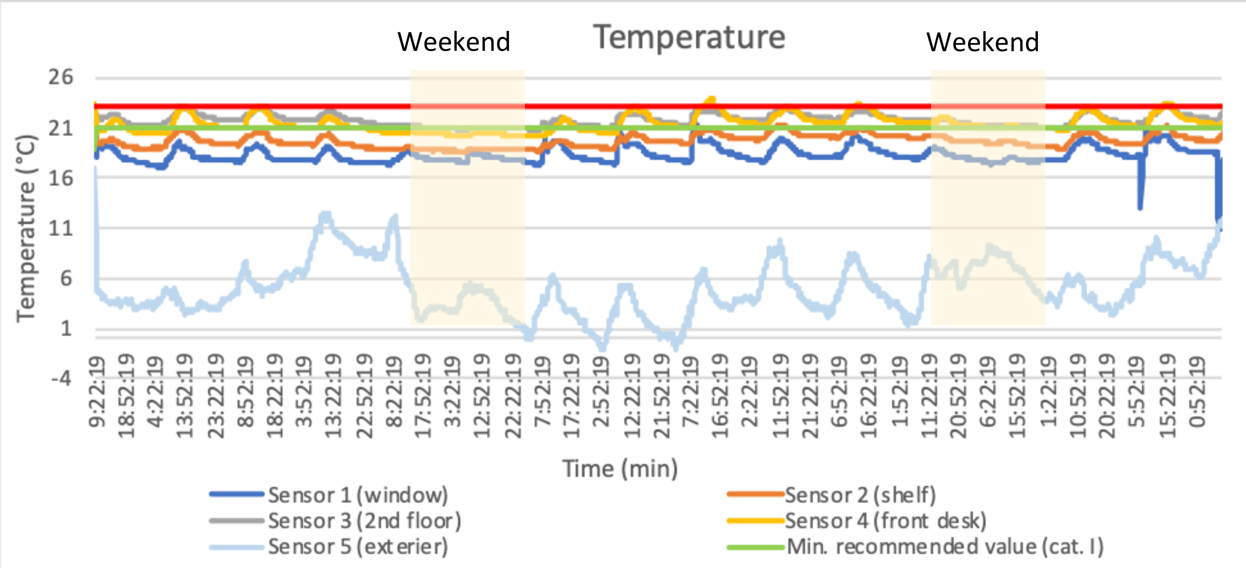

Fig. 3 A *graph showing the progress of temperature* [1]

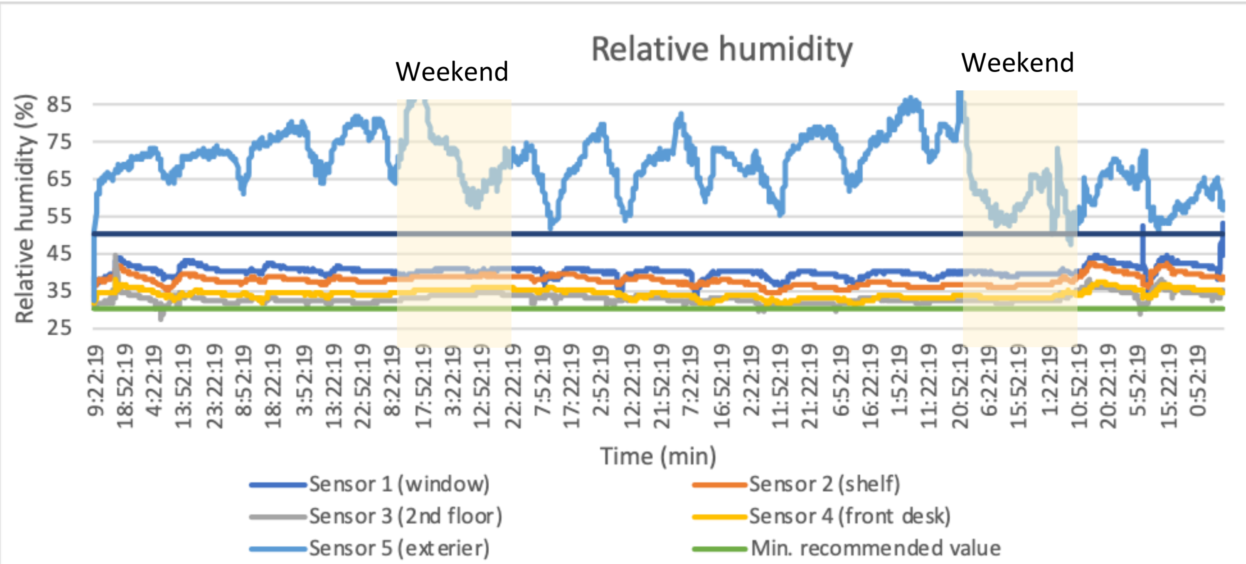

Fig. 4 *A graph showing the progress of relative humidity* [1]

The graph in Figure 5 shows the course of the measured concentration over the whole period considered from 29 January to 13 February 2019. The maximum allowable concentration in the room that should not be exceeded is shown in red. The recommended CO_2 concentration value is displayed in green. The library was occupied at the time from 7:45 to 17:15. At that time, the persons in the room were only performing light sedentary activities. At this time, the concentration level rises from morning to afternoon, in the afternoon the values stabilize and do not change significantly. Significant reduction in occupancy occurs when people leave the room. When the library is closed, no one is in the room and the windows are closed. The concentration is reduced by infiltrating through leaks in the window. The values gradually decrease until 7:00 am when people start coming to the library. Growth of concentration in the room is gradual and irregular, but its course resembles the theoretical course of concentration with a steady amount of pollutant production [1].

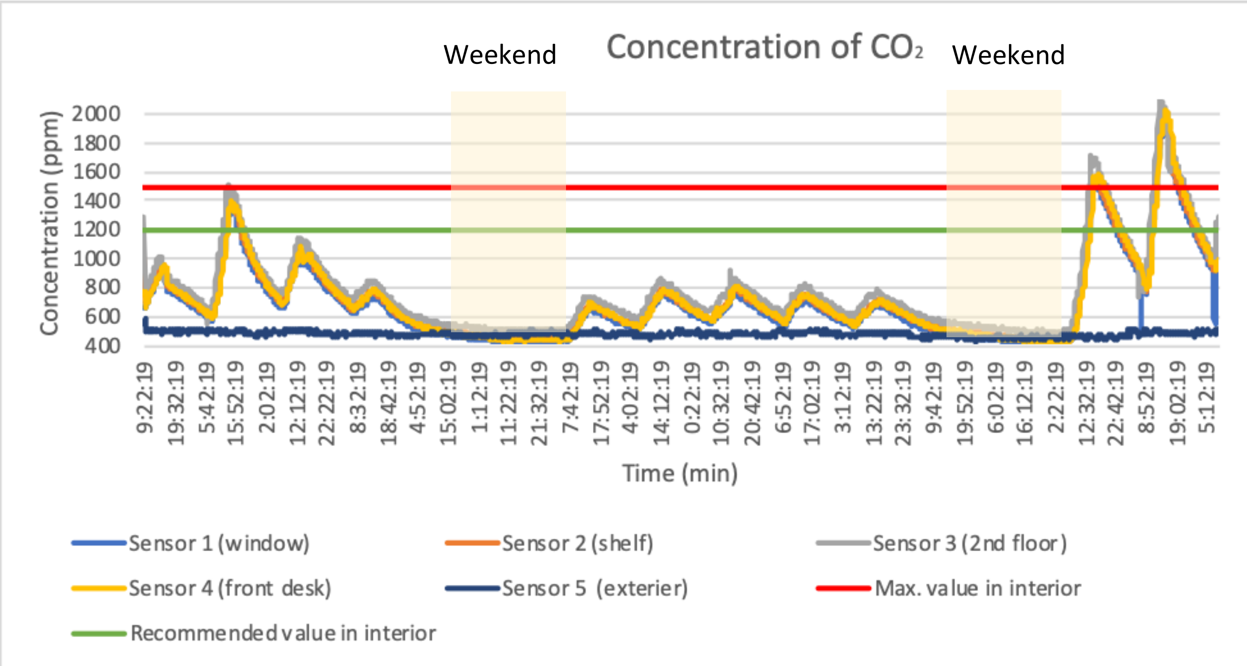

Fig. 4 *A graph showing the progress of concertation of carbon dioxide* [1]

4. CONCLUSION

The aim of this work was to evaluate the indoor climate in the Library and Information Center with the focus on the indoor temperature, relative humidity and carbon dioxide concentration. The values were measured during winter period. The space according to the temperature falls to cat. I during 38.39% of time and to cat. II during 19.43% of time. According to the relative humidity the values fall within cat. I during 74,94% of time. The concentration of CO_2 was relatively low because the measurements were performed during the exam period and therefore the occupancy rate was lower. Therefore, the CO_2 concentration fell into the cat. II for 33,69% of time as defined in STN EN 15251.

Acknowledgement

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INDOOR ENVIRONMENTAL QUALITY EVALUATION IN A NZEB WITH HEAT RECOVERY AND WARM AIR HEATING SYSTEM

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Abstract

The European Commission in 2010 accepted Energy Performance of Buildings Directive (EPBD) and the 2012 Energy Efficiency Directive (EED) are the main energy conservation legislative instruments for to reduce the energy consumption of new built and renovated buildings in Europe. The national regulation based on EPBD states that after the year 2016 only so called ultra-low energy buildings can be built. The next tightening in energy saving will come after 2021 (for commercial buildings after 2019), when only nearly zero energy buildings (NZEB) would be allowed to build. It means that these buildings must fulfil A0 category requirements by energy labelling. But what about the indoor environmental quality in objects like this? This article shows results of indoor environmental quality measurement in NZEB building. Indoor air temperature, relative humidity, carbon dioxide concentration and air exchange rate had been measured. Except these parameters energy consumption from the grid and from the photovoltaic panel had been evaluated.

Keywords - Indoor air quality, indoor environmental quality, nearly zero energy building

1. INTRODUCTION

Most of the residential buildings in Slovakia that were built in the 20th century do not satisfy the current requirements for energy efficiency presented in the national building code. [1]

Nationwide remedial measures have been taken to improve the energy efficiency of these buildings and reduce their energy use [2].

From the year 2021, all the newly built buildings will have to comply the most stricter building energy criteria so far in Slovakia. It means that the houses will have to fit into energy class A0 according to the global indicator. Simplistically the primary energy consumption of the buildings mentioned above need to be lower than 54 kWh/(m2.a) regarding to family houses, 32 kWh/(m2.a) regarding to apartment buildings and 60 kWh/(m2.a) regarding to office buildings. provides These buildings are called as nearly zero energy buildings (nZEB).

These requirements can be achieved by perfect application and increased thickness of thermal insulation systems on to building envelope (for example 350 mm of mineral wool to the roof, 200 mm of EPS polystyrene to the external walls and 150 mm of XPS polystyrene to the floor). Of course, the terms for the transparent constructions are as much strict as for the thermal insulation requirements mentioned above.

Indoor environmental quality (IEQ) refers to all aspects of the indoor environment that affect the health and well-being of occupants. This must include not only air quality but also light, thermal, acoustic, vibration, and other aspects of the indoor environment. With respect to the indoor environment, a healthy building is one that does not adversely affect the occupants. Some authors suggest that it should even enhance the occupants' productivity and sense of well-being to be considered healthy. Thus, it is not only the absence of harmful environmental characteristics but also the presence of beneficial ones that defines a healthy building. Thus, designers should begin by avoiding harmful elements and attempt to incorporate supportive, beneficial ones

The aim of the study was to evaluate the indoor environmental quality in a nearly zero energy building.

2. BUILDING DESCRIPTION

The investigated single-family house (Figure 1.) is located in Bad Tatzmannsdorf, Austria. It was built after 2010 from modern materials with good thermal insulation parameters.

Four permanent occupants lived in the house, when the measurements were carried out.

Fig. 1: *The evaluated building*

Mechanical ventilation system with heat recovery is installed in the building (Figure 2.) An air-source reversible heat pump is used as heating source, which is connected to the ventilation system – warm air heating by compact heat pump and ventilation unit.

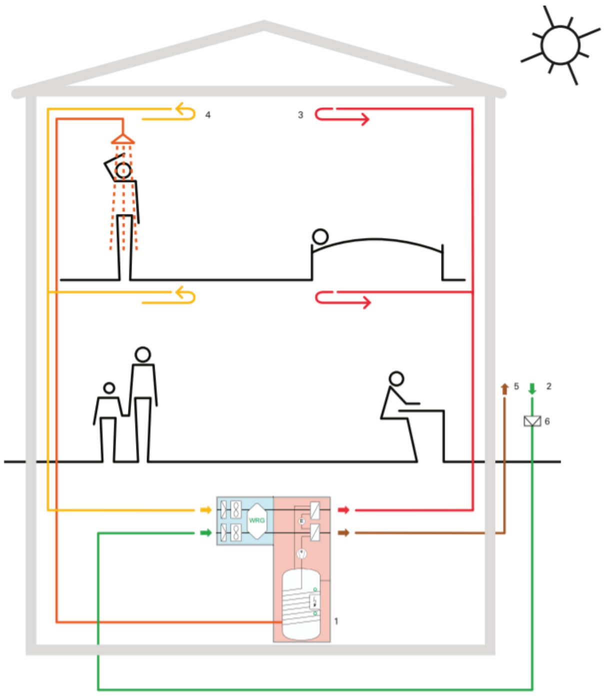

Fig. 2: *Compact heat pump, unit scheme – DHW, heating, ventilation [drexel-weiss]*

The heat is transferred from outgoing to incoming air using the heat recovery system. This type of heating is used in passive houses with very low energy demand.

Fig. 3: *Compact heat pump, unit photos*

3. METHODOLOGY

Two rounds of measurements had been completed. The first round of the indoor air quality and thermal environment measurements was performed in summer 2018 when the building was set up to cool the indoor environment. The second round had been performed in January and February 2018 in winter season. This study is presenting the winter season indoor environmental quality measurements.

Three rooms had been selected across the building, where measuring devices were installed:

- Livingroom
- Master bedroom
- Children's room

The same rooms were investigated in both winter and summer seasons over a period of 16 days where temperature, relative humidity and CO2 concentration, were measured with the following device.

Lutron MCH-383SD

Range:	CO2 concentration	from 0 ppm to 4000 ppm
	Temperature	from 0 °C to 50 °C
	Relative humidity	from 10 % to 95%
Resolution	CO2 concentration	1 ppm
	Temperature	0,1 °C
	Relative humidity	0,1 %
Accuracy	CO2 concentration	+/- 40 ppm
	Temperature	+/- 0,8 °C
	Relative humidity	+/- 0,1%

Fig. 4: *Measuring device Lutron MCH-383SD*

This device saved the measured values every 5 minute in all the evaluated rooms. Except full time measurements three time periods were defined for the analysis:

- Full time measurements
- Work time
- Free time
- Night time

The data evaluation was carried out according to standards EN 15 251 and EN 7730 (the evaluation categories can be observed in Tab. 1).

Fig. 5*: Measuring devices in children's room (left) and in livingroom (right)*

Categories I. and II. can be accepted according to the thermal environment standard, when the indoor air temperature is between 20-24 °C, while the relative humidity should be between 30 and 70 %.

In case of the indoor air quality the category I, II, and III can be acceptable. category IV can be not acceptable because of there is CO2 concertation higher than the limit, 1000 ppm.

Table 1: Categories of evaluation

	Temperature (°C)	**CO2 concentration (ppm)**
I.	**21-23**	**<600**
II.	**20-24 (except cat. I)**	**600-800**
III.	19-25 (except cat. I. and II.)	**800-1000**
IV.	<19 - >25	>1000

4. RESULTS

In this section the indoor air quality analysis and the thermal environment evaluation results are presented room by room only from winter measurements.

4.1 Livingroom

The average CO2 concentration in the room was 623 ppm. The measured maximum was 1817 ppm. Only 4 % of the measured time was spent in category IV. Average indoor air temperature was 23,4°C and relative humidity 25,4 %.

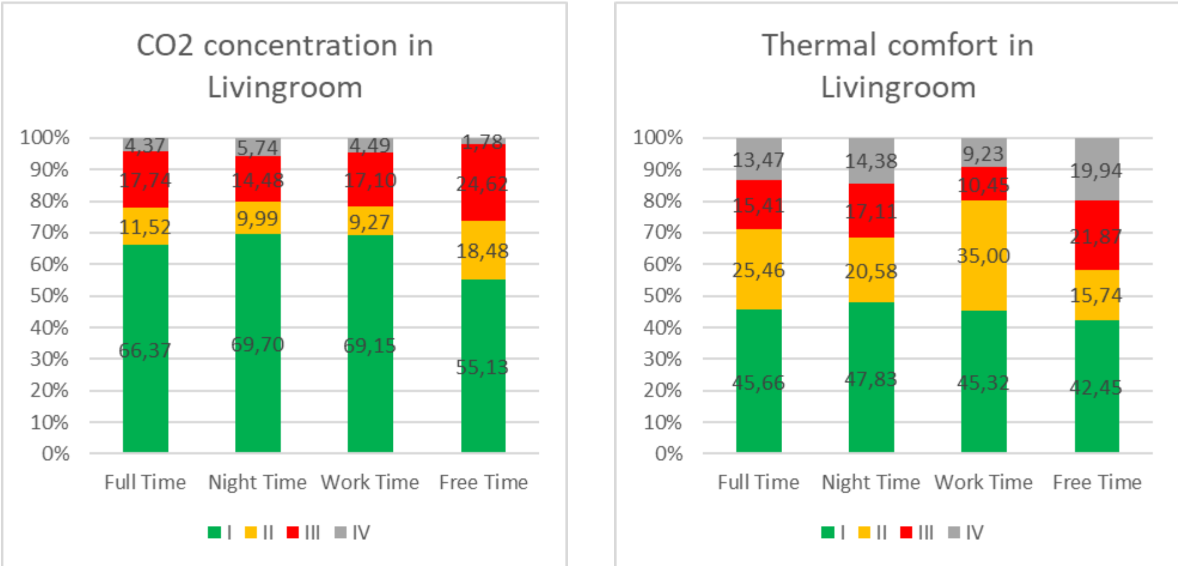

Fig. 6: *CO2 concentration (left) and thermal comfort (right) in the Livingroom*

Tab. 2: *Table data – full time measurements (left), free time measurements (right) - Livingroom*

Full time	Livingroom		
	CO2 (ppm)	T (°C)	RH (%)
AVERAGE	623.1	23.4	25.4
MEDIAN	516	23.2	25.1
MIN	465	21.2	20.4
MAX	1817	26.7	32.4

Free Time	Livingroom		
	CO2 (ppm)	T (°C)	RH (%)
AVERAGE	648.4	23.6	25.4
MEDIAN	552	23.5	25
MIN	469	21.4	20.4
MAX	1274	26.6	32.4

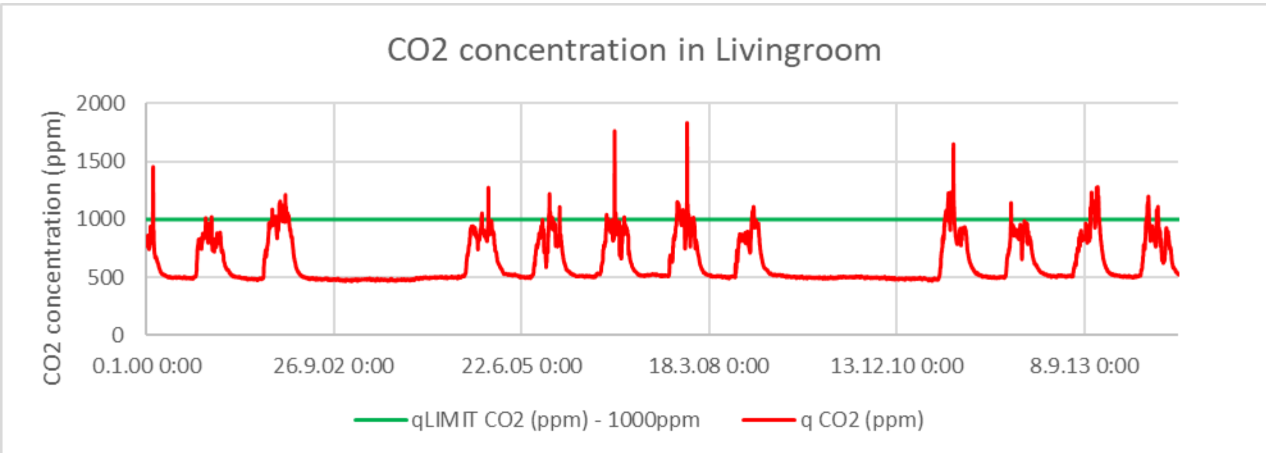

Fig. 7: *CO2 concentration behaviour during the winter season measurements in Livingroom*

4.2 Master bedroom

The average concentration in the room was 575 ppm, at night time 787 ppm. The maximum measured value 1154 ppm at worktime. Thermal comfort parameters are: average temperature 22,7°C and average relative humidity 32,8 %

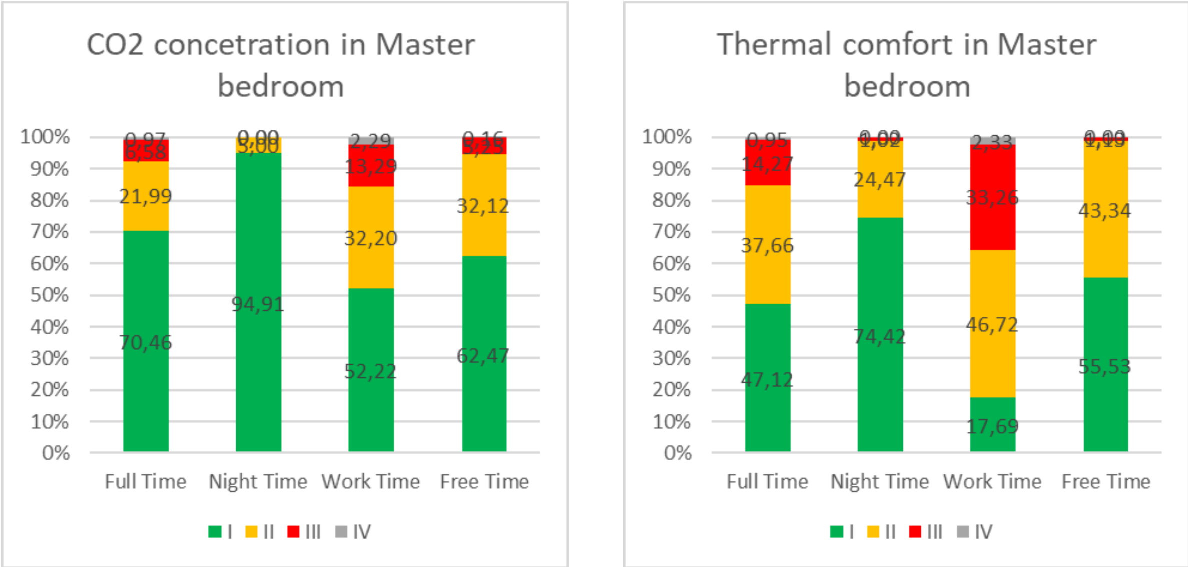

Fig. 8: *CO2 concentration (left) and thermal comfort (right) in the Livingroom*

Tab. 3: *Table data–full time measurements (left), night time measurements (right)–Master bedroom*

Full time	Master bedroom		
	CO2 (ppm)	T (°C)	RH (%)
AVERAGE	574.8	23.2	32.8
MEDIAN	509	23.1	32.7
MIN	444	21	24.1
MAX	1154	25.8	44.1

Night Time	Master bedroom		
	CO2 (ppm)	T (°C)	RH (%)
AVERAGE	505.5	22.7	32.8
MEDIAN	495	22.6	33.3
MIN	446	21	26.9
MAX	787	24.1	40.1

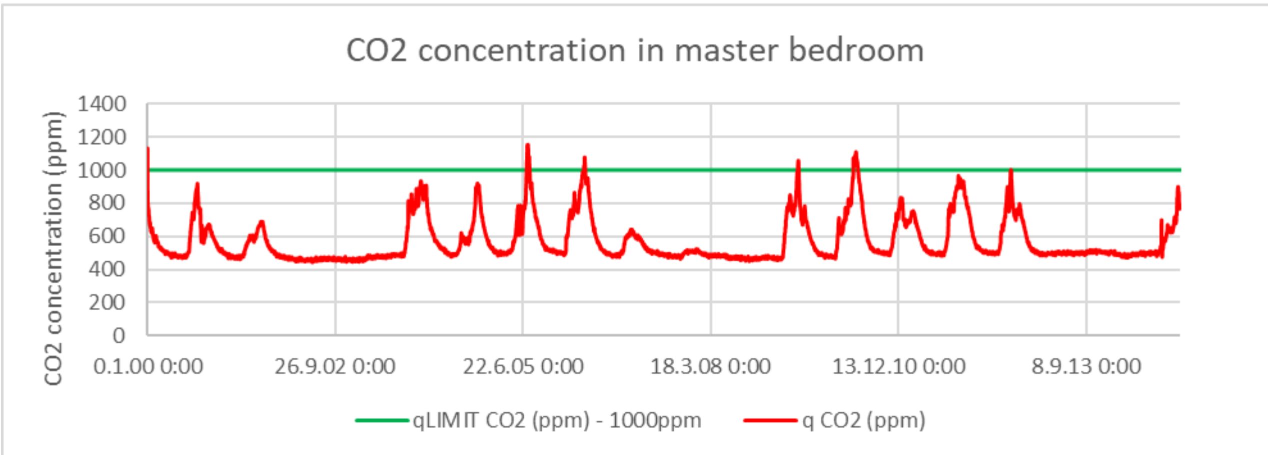

Fig. 9: *CO2 concentration behaviour during the winter season measurements in Master bedroom*

4.3 Children's room

CO2 concentration in average was 587 ppm, maximum measured value was 1241 at worktime. The average room temperature was 22,6 °C and the average relative humidity was 34,8 %

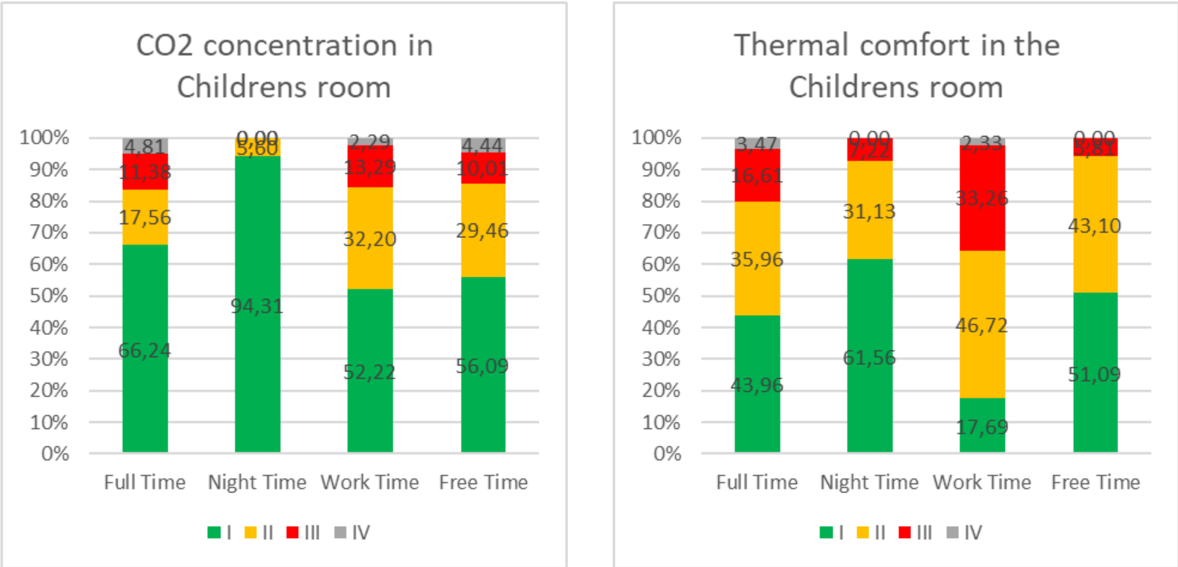

Fig. 10: *CO2 concentration (left) and thermal comfort (right) in the Livingroom*

Tab. 4: *Table data–full time measurements (left), night time measurements (right) – Childrens room*

Full time	Childrens room		
	CO2 (ppm)	T (°C)	RH (%)
AVERAGE	587.1	23.2	34.5
MEDIAN	489.5	23.2	34.4
MIN	411.0	20.8	28.8
MAX	1241.0	26.5	43.2

Night Time	Childrens room		
	CO2 (ppm)	T (°C)	RH (%)
AVERAGE	477.8	22.6	34.8
MEDIAN	463.0	22.6	34.7
MIN	416.0	20.8	31.2
MAX	683.0	24.2	38.4

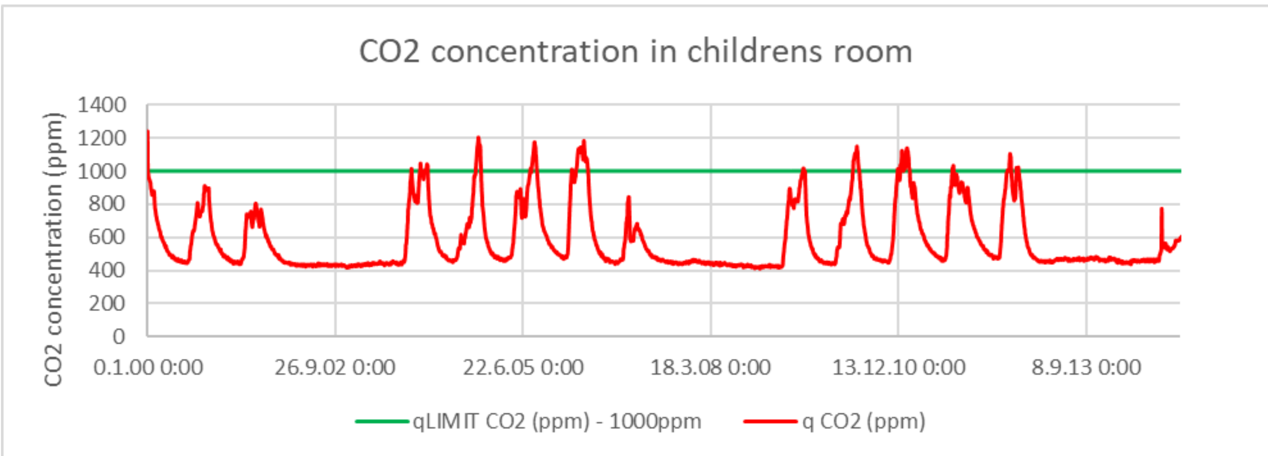

Fig. 11: *CO2 concentration behaviour during the winter season measurements in Childrens room*

5. DISCUSSION

Summarized results of indoor environment quality in the single-family house with three occupants, evaluated in four rooms in winter season showed the following.

Thermal comfort in the evaluated rooms in full time measurements mainly ranged between categories I and II. In the bedroom some peeks had been measured during daytime, which can be explained by the solar radiation through the transparent construction. Only 16% of the measured time was categorized to unacceptable categories (15,43% in c. III. And 4,47% in c. IV.) The average temperature was 23,4 °C for evaluated rooms in winter season, which is acceptable.

Relative humidity was very low, the average from the measured values was 30,9 %.

The CO2 concentration crossed the 1000 PPM limit only: 5,96 % in full time measurements.

The average indoor air quality for the evaluated rooms is the following:

Tab. 5: *Indoor air Quality in the evaluated rooms perceptually categorized based on the spent time in time in the category*

categorized IAQ (qCO2)	Livingroom				Master bedroom				Childrens room			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
Full Time	66.37	11.52	17.74	4.37	70.46	21.99	6.58	0.97	66.24	17.56	11.38	4.81
Night Time	69.70	9.99	14.48	5.74	94.91	5.00	0.00	0.00	94.31	5.60	0.00	0.00
Work Time	69.15	9.27	17.10	4.49	52.22	32.20	13.29	2.29	52.22	32.20	13.29	2.29
Free Time	55.13	18.48	24.62	1.78	62.47	32.12	5.25	0.16	56.09	29.46	10.01	4.44

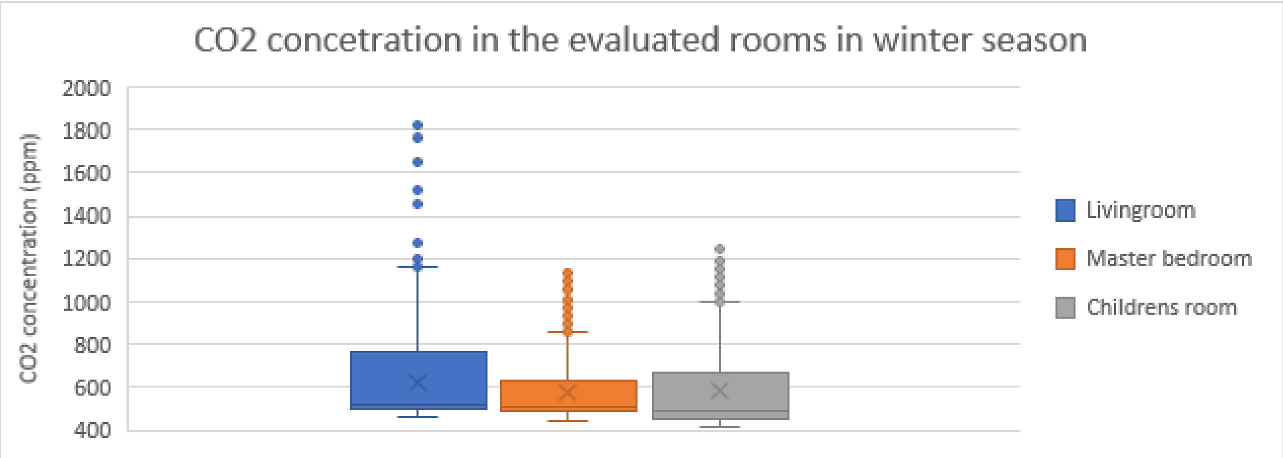

Fig. 12: *Summarization of CO2 concentrations in the evaluated rooms in winter season expressed in boxplots*

6. COCLUSION

Indoor air quality is a dominant contributor to total personal exposure because most people spend a majority of their time indoors [7]. The findings presented in this measurement campaign further support the conclusions of previous studies [2][3][4] that mechanical ventilation helps set up a healthier and more comfortable indoor environment.

The study showed that to the building (full time measurements) provided fresh air (average CO2 concertation below 600ppm) and thermal comfort parameters shows 23,5°C in the whole building

Lots of studies have also attributed this phenomenon that the new built buildings are very tight. This can cause indoor environment quality problems, which primary lead to sick building syndrome. Mechanical ventilation system and modern environmental technology can insure the proper indoor environmental quality. The validation of the results on a larger sample size is warranted. The study is ongoing, and additional results will be available in the near future.

Acknowledgment

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PRODUCTION OF POLLUTANTS FROM ORGANIC LITTER FOR DAIRY COW

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Abstract

The aim of the experiment was to analyse the production of ammonia, greenhouse gases and dust concentration in dairy farms depending on the type of litter used. Two stables A and B – with the same structure situated next to each other - were used for the analysis. Straw litter was utilized in the deepened cubicles in building A; the bedding based on recycled manure solids (RMS) was used in building B. A significant difference in concentration of all gases were observed in stable A and B ($P < 0.01$). Production of ammonia and methane was significantly lower in stable A ($NH_{3,(straw,AVG)}$ = 0.86 mg.m-3±0.53 and $CH_{4,(straw,AVG)}$ = 8.36±2.93 mg.m-3) than in stable B ($NH_{3,(RMS,AVG)}$ =2.35 mg.m-3±0.69 and $CH_{4,(RMS,AVG)}$ = 20.61±12.26 mg.m-3), while other microclimatic conditions in both were not statistically different. However, the average and maximum values of ammonia and other monitored gases in stable A, as well as in stable B with RMS, did not exceed permitted limit values. Dust concentrations in object A were highest during the deposition, but by calculation for workers, they did not exceed the limit values. Dust concentrations in the object B ranged from 0.05 to 0.23 mg.m-3, while in the summer period there were no statistically significant increased dust concentrations when activating motor ventilation.

Keywords - dairy cattle; organic bedding; harmful gases concentration; dust concentrations key words

1. INTRODUCTION

Livestock farming systems are a major source of trace gases contributing to atmospheric pollution locally and globally. Emissions from dairy cow production systems need to be reduced to limit the environmental problems associated with livestock (Saha et al., 2014).

Currently, great attention is paid to usage of livestock manure so that it can be re-evaluated in the further agricultural activity. Dairy farms are under gradual pressure to improve their management of manure. Bedding is a very costly component of dairy farming that has significant implications for animal health, as well as environment. The cost and availability of bedding fluctuates, and good bedding materials can be expensive and difficult to obtain. Farmers using RMS report greater cow comfort than with other bedding materials they have used (Harrison, et al., 2008). Recent technological advancements in the dairy sector have enabled the dairy farms with liquid manure to use mechanical solid-liquid separation systems equipped with active composting of the separated solids. Farmers consider this desirable, because liquid manure storage requirements are reduced, and composted solids are used as bedding material, avoiding thus an increase in cost of purchased bedding (Husfeldt et al., 2012). Selection of bedding materials by farms is related to the manure system used, availability and cost of materials. Increased promotion of high-performance slurry separation machinery that can produce separated manure solids with dry matter (DM) exceeding 30% has provoked interest in this practice in European farms, in which there are very different climatic conditions. Scientists also try to address the issue of bacteriology and hygiene risks of organic litter. With increasing temperature, the production of specific harmful gases also increases (Zhang et al., 2005, Rong et al., 2014). The aim of the experiment was to analyze the production of ammonia, greenhouse gases and dust concentration in dairy farms depending on the type of litter used.

2. MATHODS

INNOVA Air Tech Instruments Photoacoustic Multi-Gas Monitor with a 1309 multichannel sampling system was used to measure NH_3, CO_2, CH_4, N_2O concentrations. This equipment was installed in two buildings A and B with the same ground plan dimensions and roof height. Dairy cows are housed in comfortable lying cubicles with a length of 2.5 m and a width of 1.2 m, which are located at the external walls in two rows. Manure corridor is between them. The feeding passes are in the middle of the stall. During the experiment, 170 dairy cows were housed in each stable, the Holstein-Friesian breed with an average weight of 580 kg. The experiment was conducted in the summer months of June, July and August on selected days when the indoor air temperature ranged from 14 to 34 °C. Temperature and relative air humidity were recorded using a Comet datalogger. Straw is used as bedding in cow cubicles in the stable A; and the identical cubicles with the same location are filled with litter of separated slurry (RMS) in the stable B. The produced liquid manure and urine are continuously removed by a hydraulic blade scraper into the cross-channel and from there to the two-chamber pumping sump and then to a slurry separator where the liquid is separated from the solid part. The liquid part – slurry is pumped into above-ground storage tanks and the solid part is sprinkled from the separator into the transport mechanism and is used as litter for the cubicle lying in the cowshed.

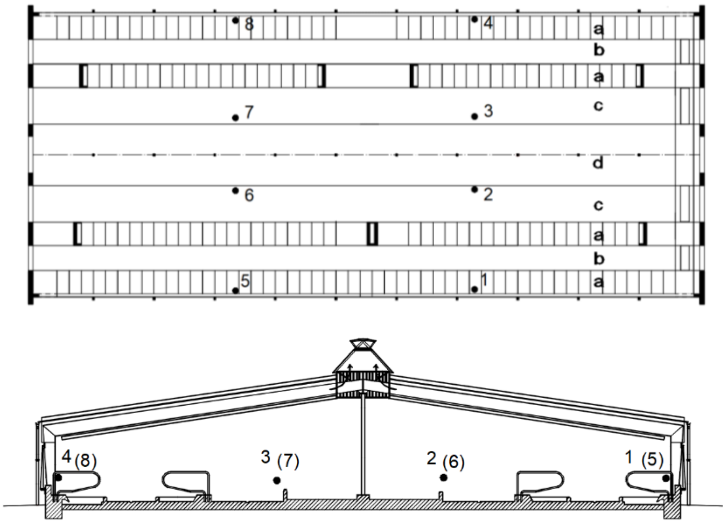

Fig. 1 *Ground plan and cross-section of the stable (A and B) with air sampling locations Legend: a - cubicles; b - manure corridor; c – feeding area; d - feeding passage; 1, 4, 5, 8 - measuring points in the cubicles; 2, 3, 6, 7 - measuring point in the feeding area (with liquid manure)*

Both stables have longitudinally opened walls protected by a net with hexagonal openings that can be covered with a controllable flow system from a height of 600 mm above ground. Natural ventilation is ensured by roof ridge that is 56 m long. The measuring points of livestock gases production were at eight locations in both buildings (Fig. 1).

3. RESULTS AND DISCUSSIONS

Indoor and outdoor temperatures, relative humidity of air and gas concentrations recorded during the measurement periods are presented in Tab. 1. The Statistica 10 software, one-factor ANOVA, the Tukey HSD test at the significance level α = 0.05 was used to evaluate and compare the gas production in the monitored stables in terms of used litter material in the lying cubicles. Test results show that the average values of the gas concentrations observed in measurements at stables A and B were significantly different (Tab. 2). Ammonia production was statistically significantly lower in building A (0.86 mg.m-3$\pm$0.53), in which the straw was used for litter than in building B (2.35 mg.m-3$\pm$0.69), in which the separated slurry was used. However, microclimatic conditions in both housings were not statistically different. The average and maximum values of ammonia and other monitored gases in stable A, as well as in stable B with litter of separated slurry did not exceeded permitted limit values.

Similar results in terms of ammonia concentrations in free dairy housing utilizing deep straw litter were reported by Herbut and Angrecka (2014), who recorded average values of ammonia as follows: 0.98 mg.m-3 in June; 0.79 mg.m-3 in July; and 0.86 mg.m-3 in August. Straw is frequently used bedding material, and it is characteristic with an ability to absorb the water and gases, as well as with high content of dry mass (approx. 85%). For many years, these two factors determined the popularity of its application (Adamski et al., 2011). One kilogram of straw absorbs approx. 2-5 g of ammonia. In absorption is increased in modified straw, (treated by i. e. cutting or gridding). This experiment also included investigation of the physical properties of materials used in the cubicles, namely the dry matter content under operating conditions. Results are reported in Lendelova et al. (2016), who found an average dry matter content value of 27.18 ± 0.96% by measuring the dry matter content of the RMS prior to its supplying to the cubicle without significant differences at each sampling site (P <0.01). After four days, the average RMS dry matter content in the selected samples taken from the cubicle was 51.61% and 65% after another 4 days. The average dry matter content of straw was 90.88 ± 0.79% prior to its spreading to the cubicles, dropping to 88.12% after supplying with litter, and continued to drop to 68.38% before being removed from the storage.

Results showed that after spreading the separated sludge slurry into cubicles in the stable with free stalls filled with separated raw manure solids, there was a significant increase in dry matter during 2–8 days from starting dry matter content of 27% to 65%, which is positive in terms of hygiene and comfort. Situation is quite the opposite in wet and cold environments, where RMS farmers are skeptical (Leach et al., 2015) and the research was subsequently devoted to the chemical and bacteriological characteristics of RMS and their impact on milk quality and welfare (Gooch et al., 2005, Bradley et al., 2018). Efficiency of DM removal is greatly variable depending on the type of used separators: 16-78% for screw pressers, 14-40% for roller presses, and 25-77% for decanter centrifuges (Godbout et al., 2002, Gooch et al., 2005). According to Rumburg et al. (2004) and Rogge et al. (2006), the quality of beddings and their moisture influence the emissions of organic compounds, and odour and dust into the air and are assessed on the basis of animal behaviour standards that are an important determinant of welfare in addition to other things (Adamski et al., 2011). According to Misselbrook and Powell (2005), there is a number of ways, influencing the emissions from different bedding materials. These include physical structure, chemical composition of bedding and different capacity to absorb deposited urine.

Tab. 1 *Evaluated gas concentrations, indoor and outdoor temperature and relative humidity during measurement in housing stable A (straw litter) and stable B (litter from RMS), P<0.01*

	unit of measur.	stable	N valid	average	stand. dev.	var. coefic.
NH_3	$mg.m^{-3}$	A	3328	0.9	0.5	61.4
		B	3328	2.4	0.7	29.2
CO_2	$mg.m^{-3}$	A	3328	1032.2	120.9	11.7
		B	3328	1370.7	384.8	28.1
CH_4	$mg.m^{-3}$	A	3328	8.4	2.9	35.0
		B	3328	20.6	12.3	59.5
N_2O	$mg.m^{-3}$	A	3328	1.0	0.1	8.2
		B	3328	1.2	0.2	16.2
indoor air temperature	°C	A	3328	24.6	4.2	17.2
		B	3328	24.3	4.1	16.9
relative humidity of indoor air	%	A	3328	60.2	13.7	22.7
		B	3328	61.1	14.0	22.8
outdoor air temperature,	°C		3328	23.8	5.0	21.1
relative humidity of outdoor air	%		3328	58.6	18.7	31.8

Tab. 2 *Statistical analysis of gas concentrations, indoor temperature and relative humidity during measurement in stable A (litter from straw) and stable B (litter from RMS), Tukey´s HSD, P<0.05*

		unit of meas.	stable	average value	p-value
1	NH_3	$mg.m^{-3}$	A	0.9	0.000009
2			B	2.4	
1	CO_2	$mg.m^{-3}$	A	1032.2	0.000008
2			B	1370.7	
1	CH_4	$mg.m^{-3}$	A	8.4	0.000009
2			B	20.6	
1	N_2O	$mg.m^{-3}$	A	1.0	0.000007
2			B	1.2	

Absorption may reduce emissions by increasing the resistance to gaseous transport. For example, mixture of peat and chopped straw reduced emissions from young cattle in bedded pens by approximately 50% compared to long straw, chopped straw, or wood shavings; this reduction was attributed to high ammonia absorbing capacity of this bedding (Jeppsson, 1999). Considering the recycled manure solids with the much greater absorbance capacity presented by Misselbrook and Powell (2005), it was suggested that the majority of the urine was retained in the upper layers of bedding with a lower resistance to transport, resulting in higher emissions in comparison to sand bedding. Generally, the presence of bedding material can reduce NH_3 emissions from cattle housing. Chambers et al. (2003) reported emissions lower from a deep straw litter in cattle housing system to be lower by 30% in contrast to a slurry-based system. Our possibilities at experimental farm did not allow us to compare the absorption capacity of RMS with sand or non-bedded system. However, a partial analysis of concentration of ammonia and other gasses over the cow beds in stable A and stable B did not show any significant difference in stable utilizing the RMS in contrast stable using the straw litter. Nevertheless, this claim will be subject to detailed analysis of litter exposed to different litter cycles and with a different rate of excrement removal from the manure corridors, both of which may have a significant impact on the overall result for cubicles filled with straw and cubicles filled with bedding from recycle manure solids.

We found, that dust concentrations in object A were highest during the deposition, but by calculation for workers, they did not exceed the limit values. Dust concentrations in the object B ranged from 0.05 to 0.23 mg.m-3, while in the summer period there were no statistically significant increased dust concentrations when activating motor ventilation.

4. CONCLUSIONS

Straw is well formable litter, flexible and usually thermally insulated, but problem lies in its availability, labour demands and cost. The issue of their influence on the internal and subsequently external environment, which is dependent on changes in physical properties in relation to changes in air chemistry, is also essential. The recycled sludge bedding gives the impression of non-hygiene, unpleasant odour and undesirable production of emissions. The work is based on the assumption that ammonia and methane productions increase with increasing ambient temperature. Therefore, the first experiments were focused on monitoring of production of pollutants in the building with litter made of separated sludge slurry in the summer and opportunity of simultaneous measurements in the same neighbouring building utilizing straw as litter had allowed us to compare the obtained data. The experiment was conducted in two phases, the first phase included observation of litter physical properties, the second phase included measurement of differences in the concentrations of produced gases. On the basis of the results of our measurements, we have determined the following conclusions. Considering the two neighbouring buildings (each with 170 cow cubicles), the average concentrations of NH3, CO2, CH4, resp. N2O were significantly higher in the building with recycled sludge slurry bedding (2.35 mg.m-3, 1370 mg.m-3, 20.61 mg.m-3, 1.19 mg.m-3, respectively) than in building with the straw bedding (0.86 mg.m-3, 1032.24 mg.m-3, 36 mg.m-3, 0.98 mg.m-3 respectively). Increased concentrations of NH3, CO2, CH4 and N2O did not show that

RMS litter absorbs produced pollutants, however, observed concentrations did not exceed permitted limits for dairy farming.

Acknowledgment

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II. SESSION

INDOOR CLIMATE AND COMFORT OF BUILDINGS

ANALYSIS OF THERMAL COMFORT IN MODERN LARGE UNIVERSITY LECTURE HALL

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Abstract

The paper is oriented on the analysis of the thermal comfort in the modern large lecture hall. Providing the optimal parameters of the thermal comfort in the interiors of a university is immensely important for the students. Meeting these parameters is inevitable not only from physiological point of view but also to achieve the desirable students' performance. Parameters of the thermal comfort are also influenced by air distribution system in large university lecture hall. Correct position of supply air and extract air is very important. Experimental measurements of thermal comfort were carried out in the winter season in the large lecture hall of Vienna University of Economics and Business. The device Testo 480 was used for the measurements. Obtained values of air temperature, air relative humidity, air velocity, globe temperature, indexes PMV and PPD are presented in the charts. Modern air distribution system and air conditioning system of the large university lecture hall were evaluated on the basis of thermal comfort parameters. Conclusion of this paper states the principles of how to design modern air distribution systems and air conditioning systems in the new large university lecture halls.

Keywords - thermal comfort, design of large university lecture hall and air distribution systems

1. INTRODUCTION

Architectural design of a large university lecture halls with big amount of students is impacted by air distribution system of air conditioning system or mechanical ventilation system. Apart from architectural design, it has significant impact on multiple parameters of the thermal comfort [1]. Position of supply air and extract air, direction of airflow and air velocity in large university lecture halls influence selected parameters of the thermal comfort [2]. Incorrectly designed position of supply air and extract air, and excessive air velocity may cause disruption of the thermal comfort and formation of local thermal discomfort [3].

Providing the thermal comfort in the large university lecture hall is very important because students spend the majority of their time in school in the schoolrooms. Thermal comfort in the small university lecture hall is defined as the state of mind that expresses satisfaction with the surrounding environment. The fundamental quantities for the evaluation of the thermal comfort are internal air temperature, operative temperature, globe temperature, air relative humidity and air velocity [4]. Then the thermal comfort is evaluated with index PMV (Predicted mean vote) and index PPD (Predicted percentage dissatisfied) [5], [6]. Not fulfilling the parameters of the thermal comfort in the large university lecture hall contributes to the high sickness rate of students, especially in the winter [7], [8].

The local thermal discomfort might arise when the parameters and air elements of air conditioning system or mechanical ventilation system are incorrectly designed. The incorrect operation of ventilation system might also contribute to its creation. Local thermal discomfort (the thermal dissatisfaction) can also be caused by unwanted cooling or heating of one particular part of the body [9]. The most common cause of the local thermal discomfort is the draught but local discomfort can also be caused by an abnormally high vertical temperature difference between head and ankles, by too warm or too cool floor, or by too high radiant temperature asymmetry. People are most sensitive to radiant asymmetry caused by a warm ceiling, a cool wall (windows, glazed facade), a cool ceiling or by a warm wall. The major problem in the large university lecture hall is the draught that is caused by incorrect position, distance of supply air and extract air from the floor, and the incorrect velocity of the air flow.

2. ANALYSIS OF DESIGN OF LARGE UNIVERSITY LECTURE HALLS

Design of a large university lecture hall must enable correct air distribution system of air conditioning system or mechanical ventilation system. Students have to feel pleasantly warm without the feeling of draught. Therefore, besides the air temperature and air velocity in air vents the position of supply air and extract air in large university lecture hall is very important [10]. The most suitable solution is the air distribution from the bottom towards the top, which must be considered in architectural design of the interior of large university lecture hall. During this air distribution, air velocity in vents for supply air can be very low and thus a sitting student does not have a feeling of draught. It is not suitable to install inversely oriented air distribution from the top towards the bottom inside of modern university lecture halls. Also, the air distribution from the front to the back wall is not suitable. In both unsuitably distributed directions of air, a high air velocity is created in the place of students' seating which causes the feeling of draught, dissatisfaction and worse concentration during the lecture. Therefore, the mutual interaction between architectural design and placement of vents for supply air in university lecture hall was closely analysed. The air distribution from the bottom to the top was analysed. Most often, the vents for supply air in university lecture hall are located in the stepped floor which is built because of stepped seating.

The main hall of Vienna University of Economics and Business was chosen for the research purposes, Fig. 1.

Fig. 1 *Main large lecture hall of Vienna University of Economics and Business*

Fig. 2 depicts the position of rectangular continuous vents for supply air in the stepped floor in the large lecture hall of Vienna University of Economics and Business. It is main large lecture hall which has interior significantly segmented. The interior is harmonized with the continuous vents for supply air in the stepped floor. Shape of the hall is significantly segmented which is harmonized with vents for supply air in stepped floor. Modern look of large lecture hall is harmonized with unobtrusive and modern vents for supply air, which does not disturb architectonic appearance of the interior. Suppressed design of vents for supply air contrasts interestingly with bright red armrests and seats. Vents for extract air are placed under the wooden slotted ceiling. In the back glassed wall, window sill fan coil units are placed creating continuous strip.

Fig. 2 *Rectangular continuous vents for supply air in the stepped floor*

3. METHODOLOGY OF EXPERIMENTAL MEASUREMENTS

Experimental measurements were carried out in the large university lecture hall – Fig. 1 at the Vienna University of Economics and Business in the end of March. The aim of the measurements was to record the parameters of the thermal comfort: air temperature, air relative humidity, air velocity, index PMV and index PPD.

The measurements were carried out in the large university lecture hall in eight standpoints in the height of 1.1 m above the floor level, Fig. 3. Standpoint A was in the right segment of the seating, in the third row from above on the left side near aisle. Standpoint B was in the middle of the back door which leads to the exterior. Standpoint C was in the middle of the back glazing. Standpoint D was in the right segment of the seating in standpoint B the last row on the right side near aisle. Standpoint E was in the right segment of seating in the seventh row (centre) on the right side near aisle. Standpoint F was in the right segment of seating in the seventh row (centre) on the left side near aisle. Standpoint G was in the central segment of seating in the last row on the left side near aisle. Standpoint H was in the left segment of seating in the eighth row (centre) on the right side near aisle.

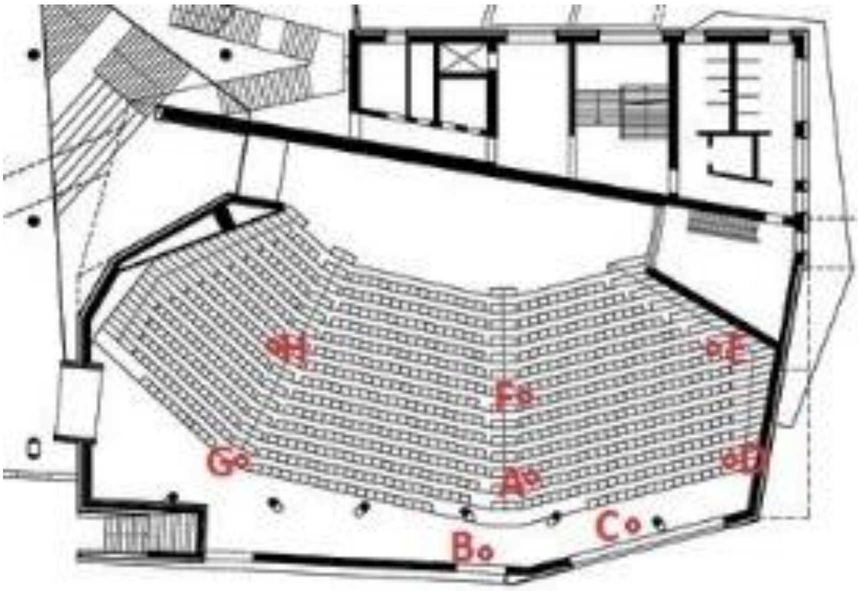

Fig. 3 *Ground-plan of large university lecture hall with standpoints*

The parameters of the thermal comfort were recorded with the device Testo 480. Input data in measurements were: metabolic rate 1,0 met, clothing insulate 1,0 clo. Twenty measurements with time delay (one by one) were carried out in each standpoint. Statistical mean was calculated from measured values. Measurements were carried out one by one in individual standpoints. Outdoor air temperature and air relative humidity were measured and recorded by the separate device. Outdoor air temperature increased from value 20.1 °C to value 21.8 °C. Outdoor air relative humidity decreased from the value 48.1 % to the value 45.2 %.

4. RESULTS AND ANALYSIS OF MEASUREMENTS

Fig. 4 shows the values of air temperature in the height of 1.1 m above the floor level in all standpoints. In standpoints A and B, the air temperature was increased which was caused by insulation through glazing in the back part of large university lecture hall. Air temperature in standpoint C was the highest and in standpoint D, it was very high meaning that the values in both standpoints were inadmissibly high. Standpoint D was the most critical since it is the place of students' seating. The architectural act to open part of the back wall of the lecture hall and place there glazing is questionable. The intention of the architect to create visual contact between students passing by and the action in the lecture hall is evident but it is questionable in terms of ensuring thermal comfort. Technically, it would be needed to create independent regulated air-conditioned zone for the last four rows of seating on the right side. This zone would be regulated depending on insulation. It is obvious from this example that mutual cooperation of specialists of these two professions has not brought desired effect. The HVAC (heating, ventilating, air conditioning) designer would be needed who is able to perceive modern architectural challenges and is also able to react on them with technology. On the other hand, there should be an architect who is significantly more educated in technology. In standpoints E, F, G, H, the values of air temperature were slightly increased but the values among themselves were relatively equal. This balance of values shows that this modern air conditioning system of large university lecture hall is suitable and the design of big part of the interior was technically well designed.

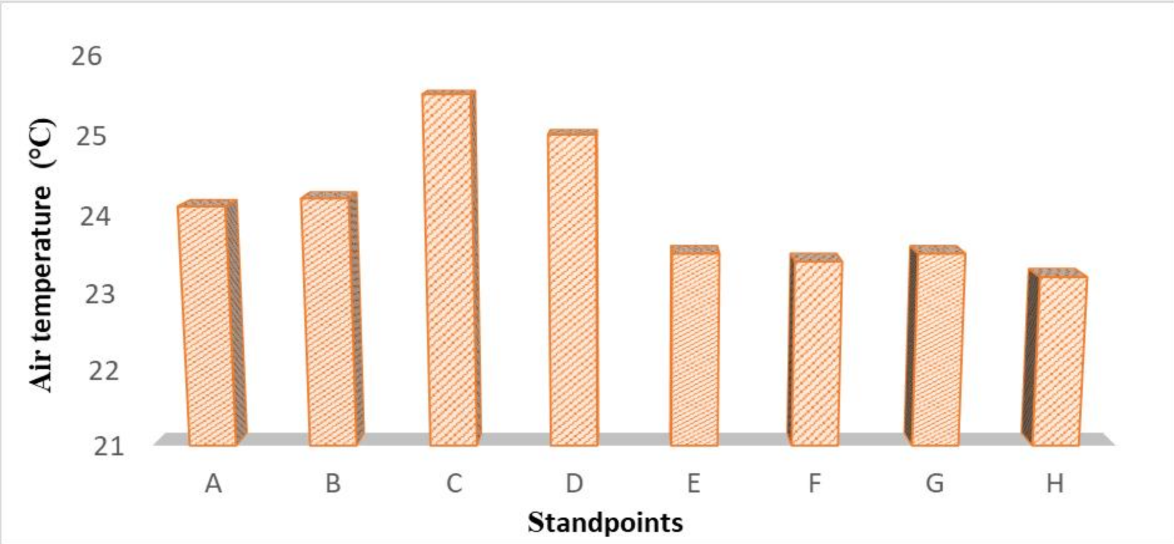

Fig. 4 *Values of air temperature in all standpoints*

Fig. 5 shows the values of index PMV in the height of 1.1 m above the floor level in all standpoints. The highest value of index PMV was in standpoint C; it was caused by insolation through glazed surface – students do not sit here so it is not a problem. The second highest value was in standpoint D where students sit; it was also caused by insulation. This value is considered as bearable; it can be improved by creating independently regulated air-conditioned zone for last four rows of seating on the right side. This solution would also help in standpoint A. In standpoints E, F, G, H where students were sitting, the values were in range of optimal values what confirms the quality of air conditioning system.

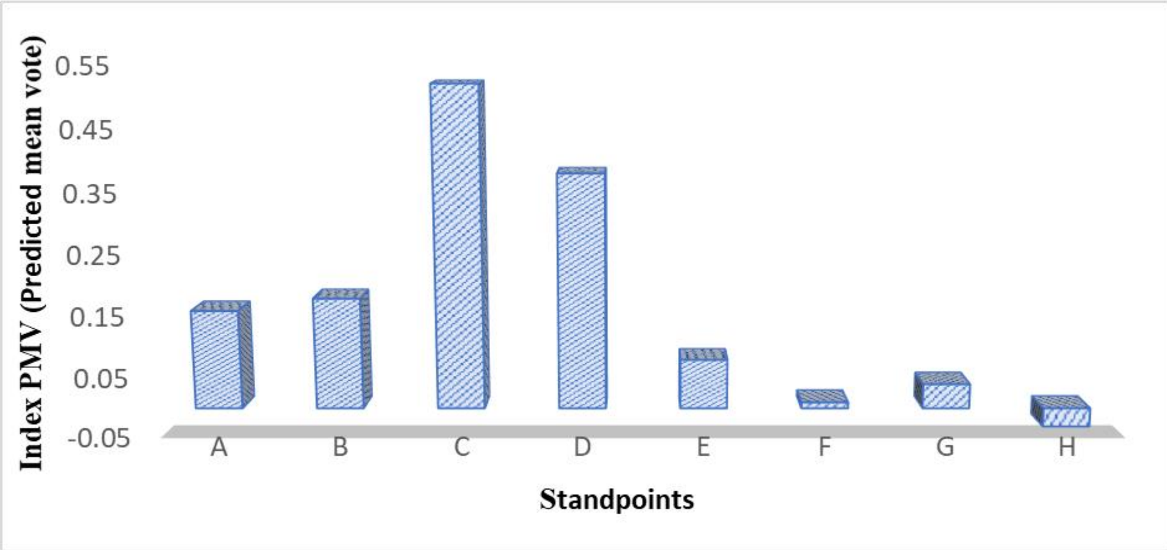

Fig. 5 *Values of index PMV in all standpoints*

5. CONCLUSION

To sustain concentration and required performance of students, it is inevitable to ensure optimal values of the thermal comfort parameters in large university lecture hall. The most modern large university lecture halls use vents for supply air in the stepped floor. Experimental measurements showed suitability of this air conditioning system for large university lecture halls. Parameters of thermal comfort in large part of university lecture hall were satisfactory. The problem arose by modern, atypical, architectural touch in the back part of the lecture hall where the large glazed surface was built. Insolation on this glazed surface significantly influenced parameters of thermal comfort in the last rows of students' seating which are in front of the glazing. This modern, architectural intention created visual contact between students passing by and the action in the lecture hall but it was not thought-out in terms of thermal comfort. In this case, the solution would be to create independently air-conditioned zone for the last four rows of seating on the right side which would be regulated depending also on the insolation. In general, it can be stated that an HVAC designer should undergo more education to tackle modern architectural challenges.

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ANALYSIS OF THERMAL COMFORT EXPERIENCED IN RESEARCH LABORATORIES

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Abstract
Research laboratories are often designed as cleanrooms to satisfy the requirements for low levels of airborne and microbial contamination. Indoor environmental conditions of each lab vary not only in the class of cleanliness but also in other parameters such as indoor temperature or relative humidity, therefore, the design and operation of each laboratory are unique. Generally, the thermal conditions are maintained at levels required by technologies installed and ongoing processes. Frequently, a suitable thermal environment for researchers is not achieved.
The study investigated the thermal environment of research laboratories. A comparison of conditions experienced in laboratories with different classes of cleanliness and air distribution system was presented. The evaluation of differences enabled to determine a possible link between the class of cleanliness and the thermal comfort of researchers. Besides the major factors of discomfort such as high air velocities or inconvenient temperatures, the selection of cleanroom garments was assessed as the fundamental source of dissatisfaction. Higher classes of cleanliness require different sets of cleanroom clothing with various impacts on user's thermal satisfaction, however, this factor is very often not taken into account when designing and operating a cleanroom.

Keywords - cleanroom; thermal comfort; indoor environment;

1. INTRODUCTION

Nowadays, a clean environment is often required in many laboratories focused on various fields of research due to the negative effect of airborne particles and microbes on sensitive technologies and processes. Not only the contamination level but also other variables such as the air temperature or relative humidity are controlled. According to the

European standard EN ISO 14644-5 [1], not only the barrier properties against dispersed contamination but also the thermal comfort whenever is possible should be considered when choosing cleanroom garments and clothing materials. Since the diversity in applications, there are no general requirements for specific design values of these variables. According to the Good Manufacturing Practice Annex 1, the temperature and relative humidity are dependent on the product and the type of ongoing operations [2]. Nevertheless, the cleanliness should not be affected by these variables.

Moreover, some of the cleanroom applications require tight control of these variables without further considerations of the thermal comfort of users. The unsuitable thermal conditions are a frequently occurred phenomenon even in cleanroom facilities without strictly determined temperatures due to the primary focus on achieving the required class of cleanliness both during the design process and operation. One of the main reasons for the lower thermal satisfaction of users is the fact that the indoor environment is not tied to the type of activity performed and the clothing requirements for a particular class of cleanliness. It is believed that the low thermal comfort of users may affect their productivity and additionally, they may present a threat to the desired class of cleanliness.

Among cleanroom applications, the most discussed are the indoor environmental conditions in the operating theatre to enhance the success of surgery. Rarely, all participants are fully satisfied with the current conditions. A study performed by Mazzacane et al. [3] pointed out difficulties in ensuring suitable thermal conditions for all occupants because of different activity levels as well as cleanroom clothing. Similar situation with low thermal comfort could occur in other cleanrooms such as research laboratories where the appropriate thermal environment for researchers is not achieved. This study analysed the thermal environment of research laboratories by conducting both the measuring and subjective evaluation. A comparison of results between various classes of cleanliness and air distribution systems together with responses from questionnaire can help with a determination of fundamental problems and applicable subsequent actions.

2. METHODOLOGY

The assessment of thermal comfort in cleanrooms is a complex task due to uncertainties such as the determination of clothing insulation and activity level. Unfortunately, the actual activity levels of lab users are difficult to define and very often do not exactly correspond to the values provided in the European standard EN ISO 7730 [4]. A similar problem occurs in determining clothing insulation of a set of cleanroom garments. Experiments and the assessment of thermal comfort were carried out in accordance with the European standard EN ISO 7730. Questionnaires for subjective evaluation were created with the guidance of ASHRAE 55 [5]. In this study, eight research laboratories in three different buildings (A, B and C) designed and operated as cleanrooms ISO 5 or ISO 7 were assessed. Although the laboratories serve various research activities, the similarities in schedule and operation allow the comparison of indoor environmental conditions. Parameters of each laboratory are listed in the Tab. 1. The clothing level was determined as a careful assumption based on EN ISO 7730 and a study conducted by Mora et al [6]. The level of activity was assessed as a light activity of a standing person in a laboratory with a metabolic rate of 1,6 met (= 93 W/m^2) according to EN ISO 7730. The measurement of thermal comfort variables was carried out at least at three different workplaces within one cleanroom at three heights (0,1; 1,1 and 1,7).

Tab. 1 *Parameters of analysed research laboratories*

Cleanroom	Class of cleanliness	Floor area [m^2]	Air change [h^{-1}]	Type of supply outlets	Type and position of exhaust outlets	Clothing insulation [clo]
A5.1	5	35	180	Laminar flow ceiling (70 % coverage)	Perforated wall diffusers, floor height	0,9
A7.1	7	35	25	Swirl diffusers	Perforated wall diffusers, workplace height	1,1
A7.2	7	450	17	Perforated laminar diffusers	Perforated wall diffusers, floor height	1
A7.3	7	550	15	Perforated laminar diffusers	Perforated wall diffusers, floor height	1,1
B5.1	5	30	360	Laminar flow ceiling (90 % coverage)	Perforated wall diffusers, floor height	0,9
B7.1	7	4	20	Swirl diffusers	Perforated ceiling diffusers	1,1
C7.1	7	400	35	Perforated laminar diffusers	Perforated wall diffusers, floor height	1,1
C7.2	7	70	10	Perforated laminar diffusers	Perforated wall diffusers, floor height	1,1

The first part of the analysis was focused on the link between cleanrooms with a different class of cleanliness, type of supply outlets and measured local discomfort. The second part examined the calculated PMV and PPD indexes in comparison with the users' overall perception of the thermal environment. The thermal sensation of respondents was evaluated on a seven-point thermal sensation scale [5]. With a view to both the general thermal satisfaction and local thermal comfort assessment, the turbulence intensity was calculated using the formula below [7]. The widely used estimation of turbulence intensity as 40% is not applicable due to a design of unidirectional airflow.

$$T_u = \frac{SD}{v_a} \cdot 100 \quad [\%]$$

T_u – turbulence intensity

SD – standard deviation of the local air velocity

v_a – local mean air velocity

3. RESULTS AND DISCUSSION

According to the results of average cleanroom conditions listed in Tab. 2, the air temperature increases in all cases upwards and the difference between head and feet meet the recommendations for the maximum difference of 3°C as all values are below 1°C. The lowest average difference found in cleanrooms with swirl diffusers proved the ability of these outlets to provide homogenous conditions. Despite the fact that the air velocity in ISO 5 cleanrooms decreases with height, the velocity change is less predictable in cleanrooms ISO 7. It is believed that the major contributors besides the type of supply outlets and supply velocities are the position of outlets and the layout of installed equipment and technologies.

Tab. 2 *Average cleanroom conditions in relation to the type of supply outlets*

Type of supply outlets	Cleanroom	Air velocity [m/s]			Air temperature [°C]			
		Height of measurement			Height of measurement			Vertical difference
		0,1 m	1,1 m	1,7 m	0,1 m	1,1 m	1,7 m	
		[m/s]	[m/s]	[m/s]	[°C]	[°C]	[°C]	[°C]
Laminar ceiling	A5.1	0,227	0,231	0,127	19,37	19,85	20,04	0,67
	B5.1	0,372	0,245	0,152	23,66	23,68	23,85	0,19
Laminar diffuser	A7.2	0,182	0,418	0,160	20,27	20,58	20,73	0,46
	A7.3	0,238	0,145	0,092	17,95	18,37	18,79	0,84
Swirl diffuser	A7.1	0,248	0,137	0,171	20,51	20,61	20,70	0,20
	B7.1	0,102	0,136	0,147	22,78	22,71	22,81	0,03

Even though there are values of velocities that are clearly high above design recommendations for people's satisfaction, it is not possible to calculate the local discomfort caused by a draught without a further examination of turbulence intensity in each position and height. As can be seen from Fig. 1, the velocity at the neck height in B5.1.1 is very stable compared with the other two cases. This behaviour is simply explained by the difference in the air distribution systems and thus in the turbulence intensity. Unidirectional airflow commonly applied in cleanrooms with higher classes of cleanliness is responsible for low turbulences to minimize the risk of contamination and avoid particle retention. In contrast, the non-unidirectional airflow pattern used in cleanrooms with class ISO 6 and lower enables the supply air to mix with indoor air and reduce the particle concentration in the environment.

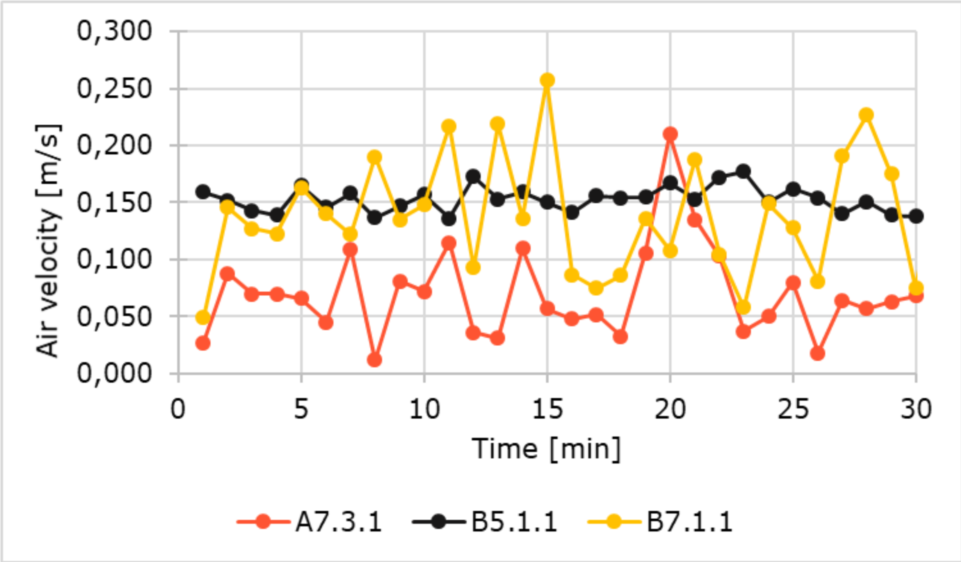

Fig. 1 *Comparison of air velocity fluctuations for different supply outlets (1.7 m height)*

Principally, the higher air velocities cause a higher discomfort, however, the turbulence intensity can create a draught at places even with low velocities. Another important factor affecting the draught rate is the air temperature, as the higher values reduce the impact of high velocities on occupants. In addition, the higher activity of occupants results in a lower draught sensation. These facts were confirmed also by respondents who hardly evaluated the draught as an issue. The turbulence intensities in relation to the type of supply outlets and the airflow patterns are presented in Tab. 3. Regardless the highest velocity, a low draught can be expected in laboratory A5.1 with laminar ceiling due to the lowest turbulence. The similar draught rate was calculated for laminar diffusers and lower velocities but the highest turbulences which in reality may cause a high discomfort.

Tab. 3 *Local conditions in relation to the type of supply outlets*

Workplace	Air velocity [m/s]			Air temperature [°C]			Turbulence int. [%]			Draught [%]		
	Height of measurement			Height of measurement			Height of measurement			Height of measurement		
	0,1 m	**1,1 m**	**1,7 m**	**0,1 m**	**1,1 m**	**1,7 m**	**0,1 m**	**1,1 m**	**1,7 m**	**0,1 m**	**1,1 m**	**1,7 m**
A7.3.1	0,241	0,125	0,070	18,15	18,62	19,14	17,33	33,51	55,74	26,66	14,45	6,05
B5.1.1	0,372	0,245	0,152	23,66	23,68	23,85	2,84	4,42	7,22	18,07	13,28	8,76
B7.1.1	0,120	0,164	0,139	22,81	22,81	22,97	42,59	33,02	37,18	10,86	14,92	12,50

The experiment held in various workplaces enabled to capture differences in indoor conditions across each cleanroom. Especially in large spaces, differences may be noticeable. Homogeneity in thermal conditions is important not only for the comfort of personnel but also for the research held in laboratories. In regard to the standard deviations in Tab. 4, the most stable conditions are maintained by swirl diffusers. In spite of their great impact on thermal environment, there is a conflict with the achievement of desired cleanliness. The air mixing flow pattern caused by these outlets is not suitable enough for a removal of airborne particles and could be installed only in special cases.

In general, the thermal conditions in laboratories were assessed neutral to slightly warm both by objective and subjective evaluation. Based on the results from the questionnaires, the real perception of thermal comfort was warmer than predicted. The main reason for the differences is given by the personal factors which cannot be measured. The apparent divergence in results in cleanroom A5.1 could be caused by a higher activity than the laboratory was designed for and respondents declared. Also, irregular local heat gains may influence the subjective evaluation. Differences between results from the experiments and questionnaires can be also explained by improperly identified clothing and activity levels, which are often unknown in these applications.

Tab. 4 *Thermal comfort in research laboratories*

Cleanroom	**Measured**				**Calculated**		**Questionnaire**	
	Air velocity [m/s]		**Air temperature [°C]**		**PMV**	**PPD**	**PMV**	**PPD**
	Average	**Standard deviation**	**Average**	**Standard deviation**				
[-]	[m/s]	[-]	[°C]	[-]	[-]	[%]	[-]	[%]
A5.1	0,195	0,075	19,76	0,93	0,03	5,73	1,67	60,14
A7.1	0,186	0,030	20,61	0,06	0,38	7,93	N/A	N/A
A7.2	0,253	0,142	20,52	0,43	0,17	6,08	1,00	26,12
A7.3	0,158	0,033	18,37	0,52	0,07	5,30	-0,50	10,23
B5.1	0,256	N/A	23,73	N/A	0,61	12,90	N/A	N/A
B7.1	0,140	0,003	22,77	0,15	0,78	17,70	N/A	N/A
C7.1	0,158	0,043	22,20	0,20	0,64	13,53	0,90	22,10
C7.2	0,046	0,014	22,06	0,12	0,69	15,00	1,00	26,12

The majority of users (90 %) responded that the change in the set of cleanroom garments as the number of layers or types of clothing was needed in order to satisfy their thermal comfort requirements. Unfortunately, their choice of materials rarely corresponds to the clean clothing policy and the cleanrooms might end up with a higher risk of contamination. Higher classes of cleanliness require different sets of cleanroom clothing with various impacts on user’s thermal satisfaction. However, this fact is very often not taken into account when designing and operating a cleanroom and suitable clothing or thermal conditions are not ensured.

4. CONCLUSION

A suitable indoor environment should be provided when people are present regardless the application. Nevertheless, it is clear that in some applications it is more difficult to provide the desired environment than in others. As already mentioned, cleanrooms represent an example of an environment in which the thermal conditions are not designed on behalf of occupants. Clearly, it can be assumed that the higher dissatisfaction with the environment is likely. On the other hand, this does not mean that dissatisfaction should be considered as a standard without any measures.

It is no doubt that thermal comfort in cleanrooms is highly influenced by the air conditioning system and design values of temperature, humidity and air velocity. Designers and cleanroom supervisors are responsible for the actual level of these parameters in accordance with the requirements of the processes or manufactured product. No less important is the type and layout of both supply and exhaust outlets. Especially in cleanrooms ISO 5 and ISO 7, the commonly designed airflow patterns play a significant role in maintaining the thermal conditions. Moreover, the higher the class of cleanliness, the more strict are the requirements for a clothing level. In view of the fact that suitable clothing is rarely considered and optimum temperature not designed, the lab users are often not satisfied with the indoor environment. The easiest option to increase the thermal comfort of users is the guided choice of appropriate clothing in relation to the actual temperatures and classes of cleanliness.

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ASSESSMENT OF DAYLIGHT AND SUNLIGHT IN BUILDINGS ACCORDING NEW CZECH EUROPEAN STANDARD ČSN EN 17037

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Abstract

The new Czech European Standard ČSN EN 17037 Daylight of buildings was published in August 2019, with effect from 1st September. The standard considers, except daylight, several factors such as sunlight, view and glare. But at the same time, it does not include some requirements that were in the original (currently amended) Czech standards. In this paper, the results of the calculation and evaluation of daylight and sunlight in buildings according to the original standards and the new standard, were compared on practical cases. There are some uncertainties that arise from some clauses of the new standard.

Keywords - daylight; sunlight; view; glare;

1. INTRODUCTION OF EN 17037 DAYLIGHT OF BUILDINGS

Daylight is important for the health and well-being of building users, for providing sufficient illumination to carry out tasks and for making a connection with the outdoors. Providing appropriate levels of daylight also helps save energy by not relying on artificial lighting as often [1].

Published at the end of 2018, EN 17037 [2] is the first Europe-wide standard to deal exclusively with the design for, and provision of, daylight in buildings. It replaces a patchwork of standards across different European countries. The exact date of adoption for EN 17037 depends on when it is incorporated into national standard frameworks.

Standards bodies in each country must produce a national annex (NA), detailing local information that helps with applying the recommendations of the standard in the specific country [1].

The Czech version of the European Standard ČSN EN 17037 Daylight of buildings [3] was published in August 2019, with effect from 1st September. It was translated by the Czech Standardization Agency. It has the same status as the official version. This standard has canceled and amended some provisions of the current Czech national standards:

- ČSN 730580-1 Daylighting in Buildings [4],
- ČSN 734301 Residential Buildings [5],
- ČSN 730581 Insolation of Buildings and Outdoor Areas – The Method of Assesment the Values (the whole standard has been canceled) [6].

2. WHAT DOES THE STANDARD ČSN EN 17037 COVER?

To achieve its multiple aims in respect of daylighting and occupant comfort, ČSN EN 17037 covers four different areas:

- **Daylight provision -** Daylight provision, or illuminance levels, allow users to carry out tasks and play a part in determining the likelihood of artificial lighting being switched on. Assessment can be via either climate-based modelling or daylight factor calculations.
- **Assessment of window views** - Building users should have a large, clear view of the outside. ČSN EN 17037 considers the width and outside distance of the view, as well as landscape "layers" (sky, landscape and ground). The view should be perceived to be clear, undistorted and neutrally coloured.
- **Access to sunlight** - Calculating access – or exposure – to sunlight is a comfort and health factor for users of dwellings, nurseries and hospital wards. Daily sunlight exposure can be established through detailed calculation or table values.
- **Prevention of glare** Prevention of glare is concerned with removing the probability of glare for building users, especially those who do not choose where they sit. It uses a detailed calculation of daylight glare probability (DGP), or a standard table of values for sun-screening materials.

EN 17037 sets a minimum level of performance that must be achieved for each of the four areas of daylighting design, to provide flexibility for architects and designers, while also making the standard useable and understandable.

As well as the minimum recommendation, it also gives two further performance levels: medium and high. Users of the standard are free to select the performance level that best relates to the building design and proposed building use.

3. CRITERIA OF DAYLIGHT PROVISION AND ACCESS TO SUNLIGHT

Criteria of daylight provision according ČSN EN 17037 [3] recommended for vertical or oblique lighting apertures: An area with satisfactory daylighting shall be considered to be an area in which a target illuminance value of 50 % of the reference plane (F_{plane}) is reached within at least half the time of daylight. At the same time, it must be fulfilled on the whole, it means 95 %, fraction of the reference plane (F_{plane}), the minimum target illumination value of at least half the time with daylight.

Recommendations for horizontal lighting apertures: An area with adequate daylighting shall be considered to be an area in which a target illuminance value of at least half the time of daylight has been reached within 95 % of the fraction of the reference plane.

The required minimum and target values for the daylight factor are given in the standard for the 33 capitals of the CEN member countries, depending on the different climatic conditions of each country.

The requirements for daylighting in the European standard ČSN EN 17037 [3] for the Czech Republic are designed more strictly in comparison with the Czech standard ČSN 730580 – 1 [4]. Some requirements are not addressed by the new European standard at all (eg the effect of shading of buildings). Therefore, the new criteria of this standard will need to be fitted with limits that will protect building users from inconvenience but at the same time will not conflict with the capabilities and objectives of our construction.

Table 1 provides a comparison of the daylight and sunlight requirements of buildings according to the new European standard and the existing Czech standards.

Tab. 1 *Comparison of daylight and sunlight requirements*

standard	ČSN EN 17037 [3]		ČSN 730580 – 1 [4]		
Daylight requirements	D_T Target daylight factor	2 %	D_{min} Minimum daylight factor D_m Average daylight factor	By visual activity class	canceled
	D_{TM} Minimum target daylight factor	0.7 %	For permanent residence of people D_{min} D_m	1.5 % 3 %	canceled
	-	-	Daylight uniformity	≥ 0.2	remains
	-	-	D_w Daylight factor of the window glazing from the outside	According to the type of space	canceled
Reference plane	height	0.85 m	height	0.85 m	remains
Calculation net of points	distance of end points from walls	0.5 m	distance of end points from walls	1.0 m	changed
Calculation methods	1. Using daylight factor 2. Using daylight illuminance		Evenly overcast sky on dark or light terrain with given sky luminance distribution		canceled
Sunlight requirements	Minimum sunlight exposure for a specified day between 1th February and 21th March	1.5 hours	Minimum sunlight exposure for 1th March and 21th June	1.5 hours	changed
	Sunlit at least one apartment living room		The sum of the floor areas of sunny living rooms must be at least 1/3 of the sum of the floor areas of all living rooms of the apartment		changed
	Minimum height of the sun above the horizont	13°	Minimum height of the sun above the horizont	5°	changed
	Angle of incidence of sunlight	Depending on the window reveal	Ineffective angle of incidence of sunlight	25°	canceled

3. EXAMPLE OF DAYLIGHT EVALUATION

To compare the results of the daylight assessment according to the original national standard and the new European standard, two identical office rooms were chosen. Office room A) was solved according to the original national standard ČSN 730580-1 Daylighting in buildings, office room B) was solved according to the new European standard ČSN EN 17037 Daylight in buildings. The calculation of daylight was performed using the simulation software BuildingDesign [7]. Figure 1 and 2 shows the graphical output of daylight calculation for the both offices. The highlighted isolines indicate the required daylight factor limits as required by both standards.

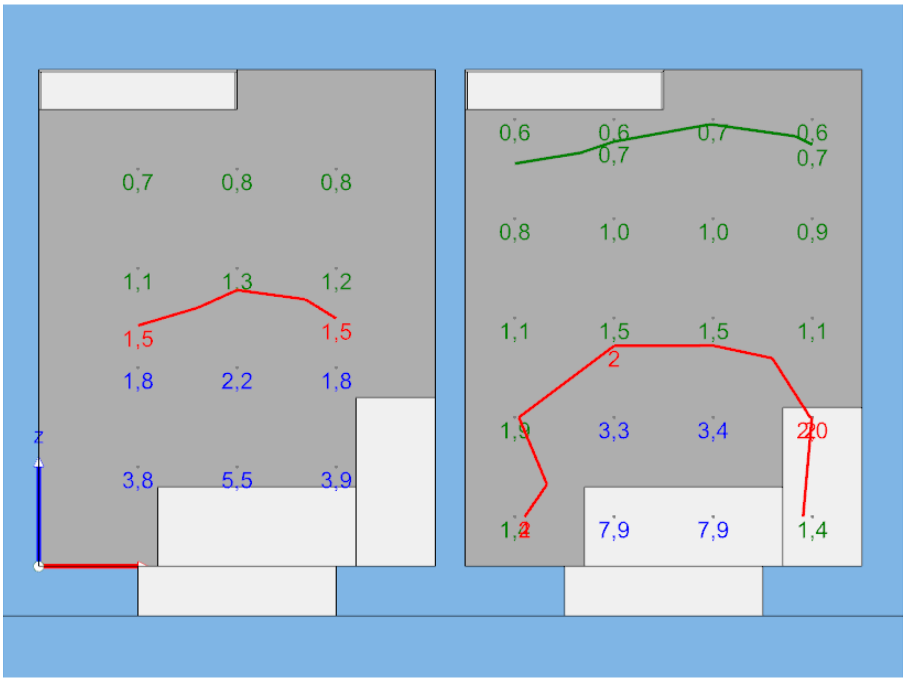

Fig. 1 *Calculation of daylight in the simulation software BuildingDesign [7]*
A) according to ČSN 730580-1 *B) according to ČSN EN 17037*

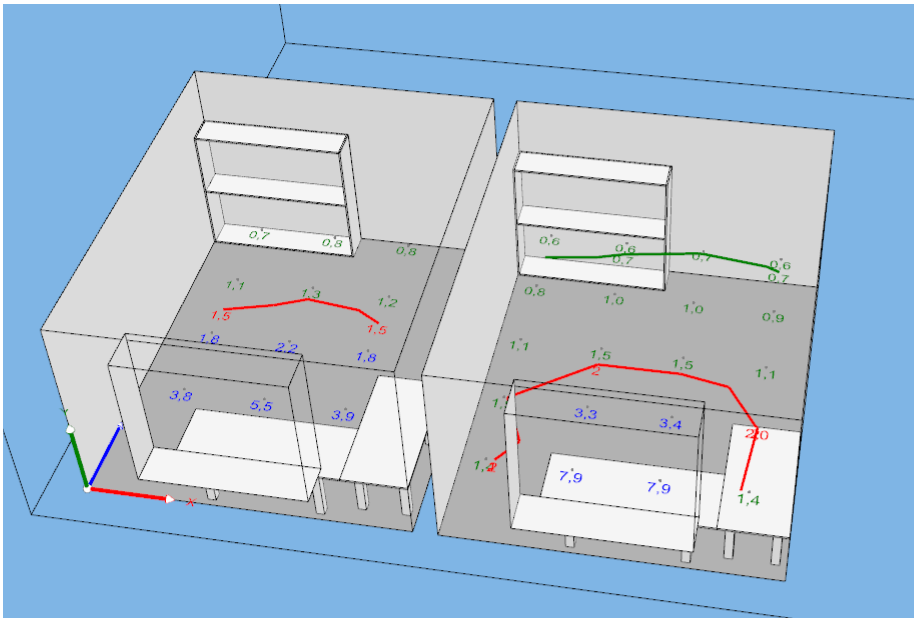

Fig. 2 *3D Graphical output of daylight calculation in the simulation software BuildingDesign* [7]

Tables 2 and 3 show the results of daylight calculation in both offices and compared with the requirements of the standards.

Table 2 *Daylight calculation results (office room A)*

Purpose of the room	Minimum daylight factor calculated D_{min} [%]	Minimum daylight factor required $D_{min, N}$ [%]	Evaluation
Office room A	0.7	1.5	Daylight is satisfactory in a functionally defined part of the room

Table 3 *Daylight calculation results (office room B)*

Purpose of the room	Target daylight factor/Fraction of the reference plane		Minimum target daylight factor/ Fraction of the reference plane		Evaluation
	calculated	recommended	calculated	recommended	
	D_T [%]/F_{plane} [%]		D_{TM} [%]/F_{plane} [%]		
Office room B	2/25	2/50	0.7/85	0.7/95	Daylight is unsatisfactory

4. CONCLUSION

In this paper, the calculation and evaluation of daylight and sunlight in buildings according to the original national standard ČSN 730580-1 Daylighting in buildings [4], and new European standard ČSN EN 17037 Daylight in buildings [3], were compared. There are some uncertainties that arise from some clauses of the new standard. As can be seen from the results of the calculation on the examples given, the new European Standard tightened the assessment of daily lighting of buildings.

Acknowledgment
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TESTING OF PILOT BUILDINGS BY SRI METHOD

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Abstract

The paper deals with issues of Smart Readiness Indicator (SRI), which describes buildings in terms of their intelligent systems. In first part the principles of SRI and process of building assesment are explained. The second part contains a case study of four buildings in Czech Republic with different technical systems and the Smart Readiness Indicator Score is calculated for them.

Keywords – Smart Readiness Indicator; Intelligent Buildings

1. INTRODUCTION

The revised European Energy Performance of Buildings Directive (EPBD) supports smart building technologies, but the question, how to describe the "smartness", have arisen. European Commission assembled the consortium of experts accordingly. This consortium put together so-called Smart Readiness Indicator (SRI), which describes how the building is prepared for smart systems, which can ensure the indoor environmental quality, energy performance, convenience and other parameters of building operation.

The SRI is a percentage of real level of smart systems according to the maximal achievable condition in assessed building. The total SRI score is calculated from impact scores and domain scores by weightings for each impact/domain. The term of Impact score means, how the fields of building use are equipped by smart ready technologies, the domain scores are focused on building technical systems and their "smartness".

2. PROCESS OF BUILDING ASESSMENT

At first the general information of assessed building is defined:

- Building type (residential, non-residential),
- Building usage (for residential building, e.g. Single-family house, large multi-family house etc., for another type, e.g. Educational, office building etc.),
- Location in climate zone (European Union is divided to five zones),
- Net-floor area,

- Year of construction,
- Building state (original, renovated),
- Building domains (technical systems) presence (heating, domestic hot water, cooling system, controlled ventilation, lighting, dynamic envelope, electricity: renewables and storage, electric vehicle charging, Monitoring & Control).

Then for each building domain the type of technical system is defined. For example each heating service has its emission type (TABS, hydronic or non-hydronic system), production type (district, central, decentral heating, heat pump), presence of energy storage and number of heat generators. Thereafter each domain has its services. The maximum number of services is 52 but the real number depends on presence of the domains and their type.

Each service has its own impact and domain weightings according to functionality level, climate zone and building usage. Functionality level is a description of the service and marked by number. Number 0 means the simple system with nothing smart and higher number means smarter service. Some services have maximum at functionality level 2 (for example detecting faults of technical systems and their diagnostics), the maximal functionality level is 4 (for example Heat control on demand side).

The final SRI score is calculated from these parameters and their impacts. The score for single impact parameter is a percentage of the real score to the maximum which can be achieved. The total SRI score is a percentage of sums of scores for each impact to the maximal achievable score.

The impact scores which together make up the total Sri score, are:

- Energy savings on site,
- Flexibility for the grid and storage,
- Comfort,
- Convenience,
- Wellbeing and health,
- Maintenance and fault prediction,
- Information to occupants.

The domain scores are calculated for each domain (technical system) which is installed in the assessed building.

3. CASE STUDY

The case study contains of SRI assessment of four different buildings in Czech Republic. Each building has a different level of smart services.

Building 1 – family house in Všenory

The first case is a small renovated family house located in Central Bohemian region. It is a stone-structure combined with newer extension of aerated concrete. It is a traditional non-smart family house built in early 19th century and equipped only by electrical heating (accumulation stoves) and electrical hot water preparation in a water tank. Lighting is classic as well (on/off switches). The charging of the stoves has a timetable connected with the switching to the cheaper tariff (8 hours per day). The renovation took place in 2000's and 2010's.

Fig. 1 *Building 1 – family house in Všenory (source: www.mapy.cz)*

Building 2 – apartment block in Praha-Suchdol

Another residential building is an apartment block located in the outskirts of Prague. It is a large multi-family house of prefab concrete structure built in 1980's and renovated in 2000's. As in the previous case the building has heating, domestic hot water preparation and lighting. The heat source is a gas boiler, which prepares domestic hot water as well. The heating system is a hydronic with radiators and is controlled by outside temperature (equithermal regulation). DHW has its own schedule of charging of the water tank. Lighting is similar, HVAC system is simple with the indication of detected faults and alarms.

Fig. 2 *Building 2 – apartment block in Praha-Suchdol (source: www.mapy.cz)*

Building 3 – Faculty of Civil Engineering, CTU in Prague, Block A

It is the only non-residential building in this case study. The building is a 15storey building located in Praha-Dejvice, built in 1970's and renovated in 2010's. This building is supplied by district heating as the only heat source for both heating and DHW preparation. Part of the building is equipped by controlled ventilation (air-handling units). The exposed south/west façade has movable motorized shades reacting to the solar irradiation. Each room has its own heat control, distribution of heat is in accordance with the outside temperature. The heating system is hydronic. Some parts (corridors) have an occupancy control for lighting.

Fig. 3 *Building 3 – Building A of Faculty of Civil Engineering (source: cs.wikipedia.org)*

Building 4 – Family house in Rýmařov

Fourth case is a family house located in Moravian-Silesian region in Jeseníky mountains. It is a newly built wooden structure of one storey with currently non-occupied attic. The main heat source is a stove where piece wood is burnt. The stove is connected to the hydronic heating system. There is also an electrical boiler as a backup source, which is connected to the heating system as well. DHW is prepared in a water tank, whose heat source is above-mentioned heating system by heat exchanger inside the tank. There is another heat exchanger connected to a circuit with solar collectors. Third back-up source is an electric heat cartridge. The heat emission is controlled room by room, DHW is controlled in accordance of solar energy supply. All energy flows are measured and the data are collected for indication of changes. So the HVAC system has a central reporting of technical building system performance and energy use.

Fig. 4 *Building 4 – Family house in Rýmařov (source: Kabele, Urban: Grant no: te02000077 Smart Regions – buildings and settlements information modelling, technology and infrastructure for sustainable development)*

Tab. 1 below is describing all the different input parameters of the buildings. All the buildings are in the Czech Republic, so the climate zone for SRI assessment is North-East Europe.

In the field of technical systems any building is equipped by cooling, renewable electricity source, electric vehicle charging.

Tab. 1 *Description of buildings and their technical systems*

	Building	Building 1	Building 2	Building 3	Building 4
GENERAL INFORMATION	Building type	Residential	Residential	Non-Residential	Residential
	Building usage	Single-family house	Large multi-family house	Educational	Single-family house
	Net-floor area (m²)	<200	>25.000	>25.000	<200
	Year of construction	<1960	1960-1990	1960-1990	>2010
HEATING	Emission type	Non-hydronic	Hydronic (radiators)	Hydronic (radiators)	Hydronic (radiators)
	Production type	Decentral	Central	District	Decentral
	Thermal Energy Storage	Yes	No	No	No
	Multiple heat generators	No	No	No	Yes
DOMESTIC HOT WATER	Production type	Electric	Non-electric	Non-electric	Combination
	Storage present	Yes	Yes	Yes	Yes
	Solar Collector	No	No	No	Yes
CONTROLLED VENTILATION	System type	No	No	Controlled natural ventilation (10% of the building)	No
DYNAMIC ENVELOPE	Movable shades	No	No	Yes	No

4. SRI CALCULATION

This chapter includes the results of SRI calculation for all four buildings. The total SRI score and single impact scores are shown in Tab. 2. Tab 3. Describes the domain SRI score.

Tab. 2 *Total SRI score and impact SRI score assessment*

Building	Building 1	Building 2	Building 3	Building 4
Total SRI score	**14%**	**28%**	**35%**	**37%**
Energy saving on site	17%	31%	43%	52%
Flexibility for the grid and storage	31%	35%	36%	12%
Comfort	9%	34%	39%	51%
Convenience	5%	29%	30%	39%
Wellbeing and health	0%	100%	31%	100%
Maintenance & fault prediction	0%	12%	25%	32%
Information to occupants	0%	13%	18%	31%

The results shown in Tab. 2 say that the best total SRI score has Building 4. The worst score has Building 1 as expected, which is equipped only by classic technical system. The number is increased partly thanks to the flexibility of heating system to the grid. Building 2 is common apartment block type. In can be estimated, that many apartment blocks in the Czech Republic can reach similar SRI score. Building 3 is strong in energy savings because of shading control. The shading increases the comport of the building. Building 4 is designed as low-energy house, so the energy savings on site have highest score. But there is low flexibility to the grid.

In the table 2 one peculiarity can be observed: The 100% impact score of Wellbeing and health. The reason is that the only two HVAC services have influence to the Wellbeing and health assessment. The maximal score is reached in case of presence of any functionality, not in case of functionality level.

Tab. 3 *Domain SRI score*

Building	**Building 1**	**Building 2**	**Building 3**	**Building 4**
Heating system	26%	36%	55%	39%
Domestic hot water	29%	12%	34%	57%
Cooling system	-	-	-	-
Controled ventilation	-	-	4%	-
Lighting	0%	0%	10%	0%
Dynamic envelope	-	-	38%	-
Electricity: renewables & storage	-	-	-	-
Electric Vehicle Chasrging	-	-	-	-
Monitoring & Control	0%	25%	27%	32%

The most interesting in terms of domain score is Building 3, which is equipped by more technical systems than the other buildings. As only a part of the building has a controlled ventilation, only 4% score of Controlled Ventilation domain was reached. The dynamic envelope contains only automatic shading system, not the control of window opening or performance information reporting, so the score is "only" 36%. Building 4 has highest DWH score because of renewable energy source presence.

5. CONCLUSION

The Smart readiness indicator provides simplified, but good information about the technical building systems in terms of their smartness. The calculation has some shortcomings. For example it is impossible to define two different heat sources (e.g. hydronic heat systems combined with fireplace). Some impact score calculations are insufficient, so the Wellbeing score can easily reach 100 % because there is small number of services which have impact to this score.

It is difficult to reach 100 % of total SRI score because such buildings would have very sophisticated intelligent systems, which can be expensive and sometimes non user-friendly. On the other side the assessed buildings have big potential to improve their parameters in terms of smart readiness.

Acknowledgment
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THERMAL COMFORT BY OPERATION OF WALL RADIANT COOLING SYSTEM

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Abstract

Radiant systems are being increasingly used for space heating and cooling of buildings. The contemporary research of radiant systems addresses mainly floor and ceiling structures. Research regarding the possibilities of their incorporation in wall structures is lacking, despite their potential advantages. This study addresses a radiant wall system manufactured according to a patent. The patented design involves panels that consist of pipes arranged in milled channels in thermal insulation. The potential advantage of this system is the fact that the thermally active panels can be attached to the facades of existing buildings as a part of their retrofit. Thereby, only minor interventions on the interior side of the retrofitted buildings are needed. To test and improve the design of the wall system, laboratory measurements and computer simulations were performed on a wall fragment for its operation under summer conditions. The results indicate a significant potential for improvement of the patented design by addressing the imperfections in the contact between pipe and wall. Inserting a metal fin between pipe and wall enhanced the cool distribution within the wall fragment considerably. From the three materials of the metal fin considered, using copper led to highest values of the cooling output, followed by aluminium. For these two metals the effect of increasing the thickness of the fin on the cooling output was small. On the contrary, the fin made of steel was the least efficient in terms of cool distribution. In this case the cooling output was most sensitive to the thickness of the fin.

1. INTRODUCTION

Current trends in the design and operation of heating, ventilation and air conditioning include the increasingly frequent use of low-exergy water-based radiant systems. Installation of such systems can be beneficial due to their suitability for combination with low-grade renewable energy sources such as ground-coupled heat pumps and solar collectors [1, 2], the high sensible cooling capacity [3], and the possibility to use the same system both for heating and cooling [4-6]. Although research on radiant surfaces has been mostly focused on structural floors and ceilings, evidence from several research studies suggests that radiant walls also present a potentially feasible solution for space heating and cooling [7-9]. Nevertheless, scientific studies related to radiant wall systems are relatively scarce, and research regarding the potential of their installation in existing buildings as a part of retrofit is lacking. In this study we explore the potential of a wall cooling system constructed according to a patent [10]. The patented design involves pipes arranged in milled channels in thermal insulation, whereby panels are formed. The potential benefit of this system is the possibility to attach the panels to the facades of existing buildings as a part of their retrofit so that only minor interventions on the interior side of the retrofitted buildings are needed. The system can be operated both as

space cooling in summer and as space heating in winter. Moreover, it can potentially serve as a thermal barrier to reduce transmission heat losses in winter and heat gains in summer. This is possible in situations when the water temperature is very close to the room temperature, thus preventing heat losses in winter [11, 12] and absorbing external heat gains in summer [13]. Numerical simulations and experiments were employed to explore details of the heat transfer within a wall fragment manufactured in accordance with the patent [10]. The investigations refer to the operation as space cooling under summer conditions. Subsequently, the possibilities to enhance cool distribution within the wall fragment by inserting a metal fin between pipe and wall were researched by numerical simulations.

2. LABORATORY MEASUREMENTS AND COMPUTER SIMULATIONS OF HEAT TRANSFER THROUGH THE WALL

The results of laboratory measurements and computer simulations are presented for operation of the wall system as space cooling under summer conditions. The laboratory measurements were also used for validation of the computer simulations.

2.1. Measurement of the heat transfer

The laboratory measurements were performed on an experimental wall fragment. The wall fragment consisted of cooling pipes embedded in milled channels in thermal insulation made of polystyrene, attached to the concrete core in the form of panel. The dimensions of the fragment were 1 140 mm x 1360 mm (Fig. 1). The calculated heat transfer coefficient of the wall was 0.35 W/(m^2.K). The temperature of the concrete was monitored by PT100 platinum resistance thermometers with the accuracy variable in the range of ± 0.15 °C, located at selected points along the panel (points A, B, C, D in Fig. 1) at several depths (points 1 to 5 in Fig. 1). Supply and return water temperature was also recorded. The heat flux was monitored by a thermopile sensor for studies of the radiative and convective heat flux with a level of accuracy variable in the range ±5% of the value measured. The sensor was located underneath the surface in the centre of the fragment as recommended by Ref. [14].

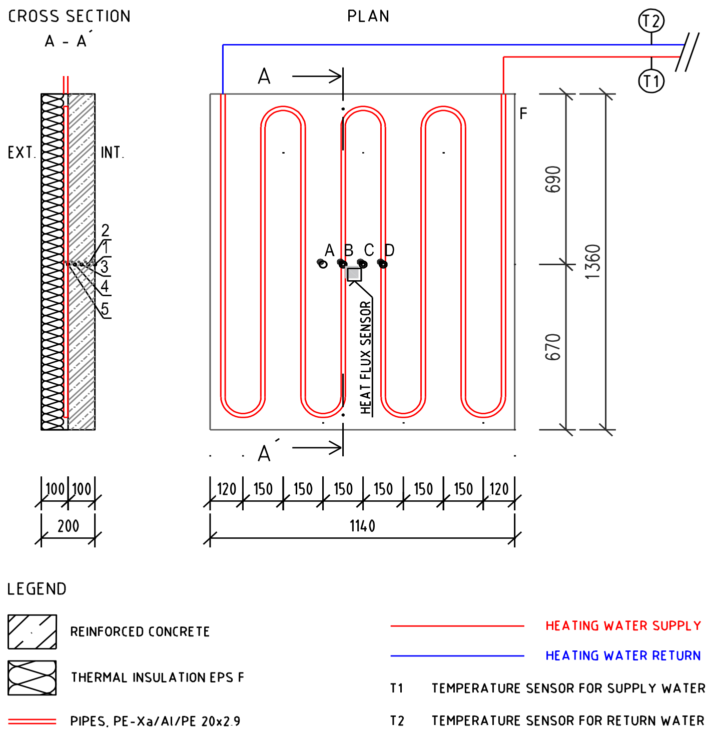

Fig. 1 *Details of experimental wall with position of sensors*

The wall was located between two climate chambers with controlled air temperature and humidity (Fig. 2). The fragment was exposed to the air temperature of 32 °C simulating ambient conditions on one side, and to the air temperature of 26 °C simulating the room conditions on the other side. Direct solar radiation was not considered in this study. The temperature of the supply water was kept constant at about 18 °C. The temperature of the inlet air was adjusted to obtain the desired air temperature in each of the two chambers. The heat transfer coefficients between the surface of the wall and each chamber were calculated by a CFD simulation in ANSYS Fluent.

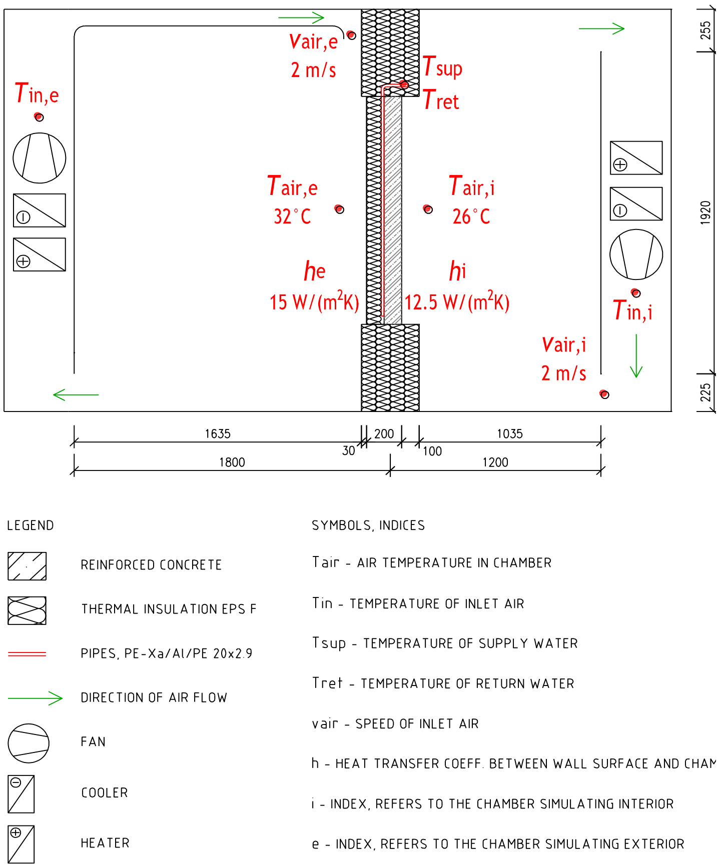

Fig. 2 *Cross section of experimental chambers with position of sensors*

2.2. Heat transfer coefficients between wall and room

We used computer simulations in ANSYS Fluent software to visualize the air temperature and velocity fields and calculate the heat transfer coefficients between wall surface and chamber. Fig. 3 shows the results of CFD simulations for the chamber simulating the interior of a building.

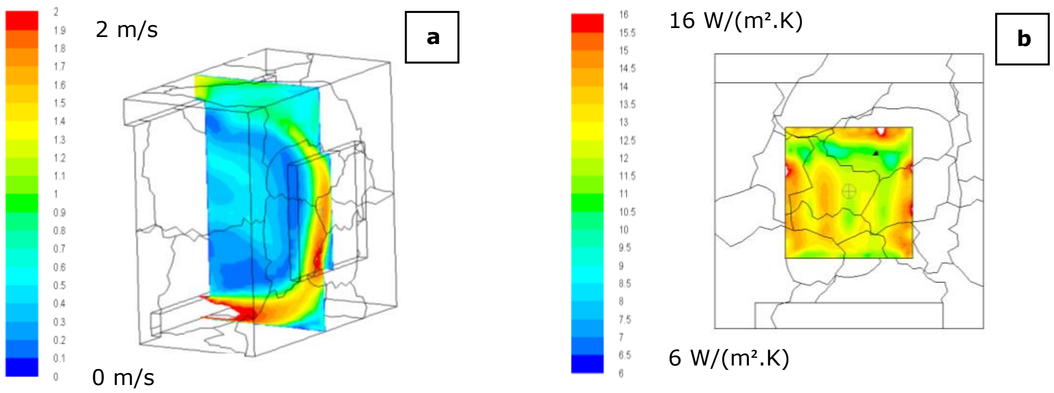

Fig. 3 *Results of CFD simulation in the chamber simulating indoor environment: a) air velocity profile, b) heat transfer coefficient between wall surface and chamber*

The air flow pattern resulted in the air velocity higher at the wall surface than in the rest of the chamber (Fig. 3a). Consequently, the heat transfer coefficient at the inner wall was higher than the 8 W/(m^2.K) recommended for the design of radiant wall systems [15]. Although the heat transfer coefficients fluctuated over time, the value 12.5 W/(m^{2}K) was determined as representative of the area where the measurement sensors were located (Fig. 3b). For the chamber simulating the exterior the heat transfer coefficient was determined to 15 W/(m^2.K).

2.3. Calculation of the heat transfer

The results were obtained by solving a set of equations of two-dimensional heat transfer by conduction, using a dedicated CalA software [16, 17], which has been validated in accordance with [18]. The calculation was based on a detailed numerical solution of two-dimension stationary temperature field by the method of rectangle-shaped control volumes, each representing a single temperature [19]. The distribution of the temperature in the Cartesian coordinate system was described by the Fourier equation of thermal diffusion [20]:

$$\frac{y}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right)+S=\rho.c.\frac{\partial T}{\partial \tau} \tag{1}$$

where T is the temperature (K); S is an internal heat source (W/m^3); τ is time (s); λ is thermal conductivity (W/(m.K)); ρ is bulk density (kg/m^3); and c is the specific heat capacity at a constant pressure (J/(kg.K)).

The heat transfer coefficient for the water and pipe surface α was determined to be 1 218 W/(m^2.K). The boundary conditions defining the specific heat flux on the surface of a computational domain were calculated according to the Newton's law of cooling, assuming adiabatic boundaries of the wall fragment (Fig. 4). The temperature and heat flux distribution over time was calculated using the Robin-Newton´s boundary condition.

The simulated fragment represented a section of radiant wall, symmetrical along the horizontal axis. The pipes in the radiant wall were spaced regularly and the temperature of the water in the pipes and material properties were considered homogeneous along the wall.

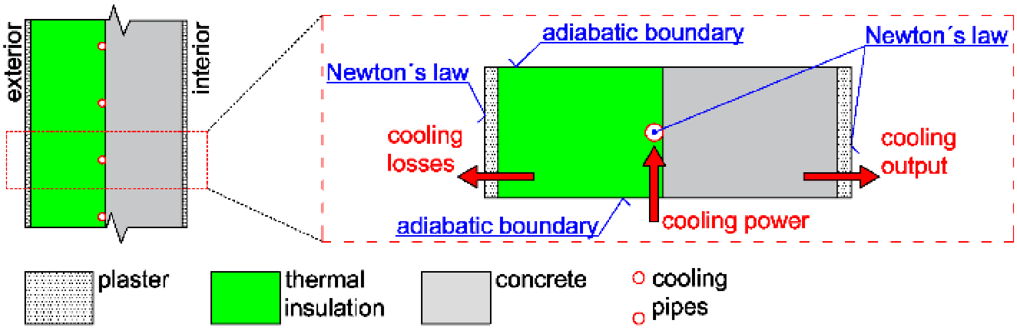

Fig. 4 *Boundary conditions defining specific heat flux on a wall surface.*

2.4 Results

Fig. 5 shows the values of air temperature measured in the chambers simulating the indoor (θ_i) and the outdoor environment (θ_e) and compares the experiments with the results of dynamic simulations in CalA software. In the simulations measured data were used as the input regarding air temperature. The inputs regarding heat transfer coefficients were obtained by CFD simulations in ANSYS Fluent as described in 2.2. The volumetric weight of the reinforced concrete and the heat transfer coefficient between pipe and wall were adjusted to fit the results of simulations on the experimental data. Very good agreement was achieved between simulations and experiments regarding heat flux and surface temperature at the point C1 (see Fig. 1). The cooling output was relatively low, about 7 W/m^2 of wall surface.

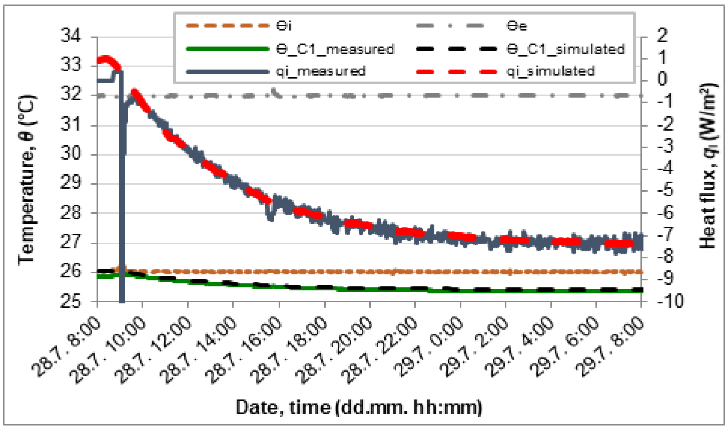

Fig. 5 *Comparison of temperature and heat flux obtained by measurements and simulations*

2.5 Heat transfer between pipe and wall

The low values of heat flux were attributed to imperfections in the contact between pipe and wall. In the computer simulations of heat transfer in CalA software (Fig. 5), these imperfections were approximated by an air gap between pipe and thermal insulation as shown in Fig. 6a. In order to fit the simulations on experimental data, an equivalent heat transfer coefficient between pipe and wall (hequiv) was defined. This coefficient takes into account the heat transfer between water and pipe (hwater), equal to 1 218 W/(m^2.K), and also the hindering effect of the imperfect contact between pipe and wall. The effect of imperfections, simulated by the air gap, can be expressed by an additional heat transfer coefficient between pipe and its surrounding (hgap), calculated from eq. 2 (Fig. 6b).

$$h_{equiv} = 1 / (1/h_{gap} + 1/h_{water}) \qquad (2)$$

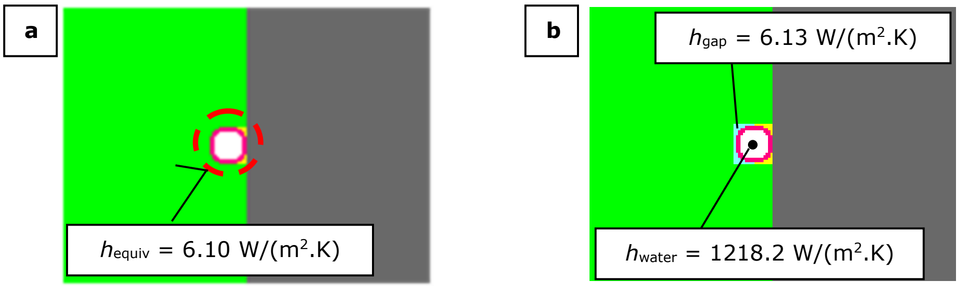

Fig. 6 *Heat transfer between pipe and wall: a) equivalent heat transfer coefficient, b) heat transfer coefficients between water and pipe (h_{water}), and between pipe and its surrounding (h_{gap})*

3. OPTIMIZATION OF THE COOLING OUTPUT

The simulations and experiments proved that imperfections in the contact between pipe and wall can hinder the heat transfer considerably. In the following sections we therefore investigate the possibilities to improve the patented solution [10] with the aim to find feasible designs for enhancement of the cooling output.

3.1 Physical model and boundary conditions

The possible enhancements of the cooling output were researched by stationary simulations performed by CalA software in accordance with the calculation principle as described in 2.3. Fig.7 shows the simulation model as defined in CalA. The thermo-physical properties of the individual material layers are summarized in Table 1.

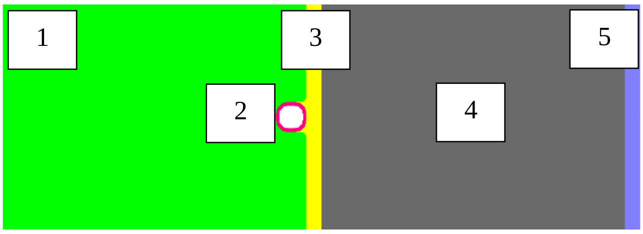

Fig. 7 *Physical model of wall fragment as defined in CalA*

Table 1 *Thermo-physical properties of the material layers*

No.	**Material**	**Thicknes s** m	**Vol. weight** kg/m³	**Thermal conductivit y** W/(m.K)	**Specific heat capacity** J/(kg.K)
(1)	Insulation - EPS F	0.02	17	0.04	1270
(2)	Plastic pipe DN 20	--	1200	0.35	1000
(3)	Plaster between pipe and concrete	0.01	1300	0.8	840
(4)	Reinforced concrete	0.2	2400	1.58	1020
(5)	Inner plaster	0.01	1600	0.88	840

The results presented in this section refer to the room temperature of 26 °C, which is interpreted as the operative temperature [21], and the mean temperature of cooling water of 21 °C, considered as typical for radiant cooling systems operated in temperate climates. The total heat transfer coefficient (h_i) between the radiant surface and the space was 8 W/(m^2.K), and the heat transfer coefficient for the water and pipe surface was 1 218 W/(m^2.K). The combined effect of ambient temperature and solar radiation incident on the wall was approximated by the sol-air temperature ($T_{sol\text{-}air}$) [20]:

$$T_{sol\text{-}air} = T_{amb} + \alpha . I_g / h_e \tag{3}$$

where T_{amb} is the temperature of the ambient air, equal to 30 °C; α is the absorptance of surface for solar radiation, equal to 0.9; I_g is the solar radiation incident on the wall, equal to 450 W/m^2; h_e is the coefficient of heat transfer by long-wave radiation and convection at outer surface, equal to 15 W/(m^2.K). The sol-air temperature, $T_{sol\text{-}air}$, was determined to 57 °C.

3.2 Enhancement of the cooling output

The improvements to enhance the cooling output are represented by inserting a metal fin between pipe and thermally conductive plaster. The purpose of the fin is to efficiently distribute the cool from the pipe to the thermally conductive plaster. Fig. 8 illustrates the difference in the cooling output between a wall fragment without any fin (a) and with a fin with the thickness of 1.56 mm, made of copper (b). Adding the metal fin enhanced the cooling output by about 50%.

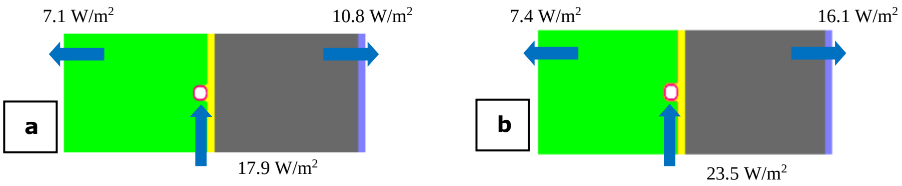

Fig. 8 *Cooling power, output, and losses of wall fragment: a) without metal fin, b) with metal fin made of copper, thickness of 1.56 mm, thermal conductivity λ = 372 W/(m.K)*

The distribution of temperature and cooling output for the wall fragment with and without any metal fin is visualised in Fig. 9. The metal fin between pipe and plaster improved the distribution of cool within the wall. This is illustrated by the larger (dark blue) area with cooler temperature between pipe and interior (Fig. 9a) and by the homogeneous distribution of heat flux in the case with metal fin (Fig. 9b).

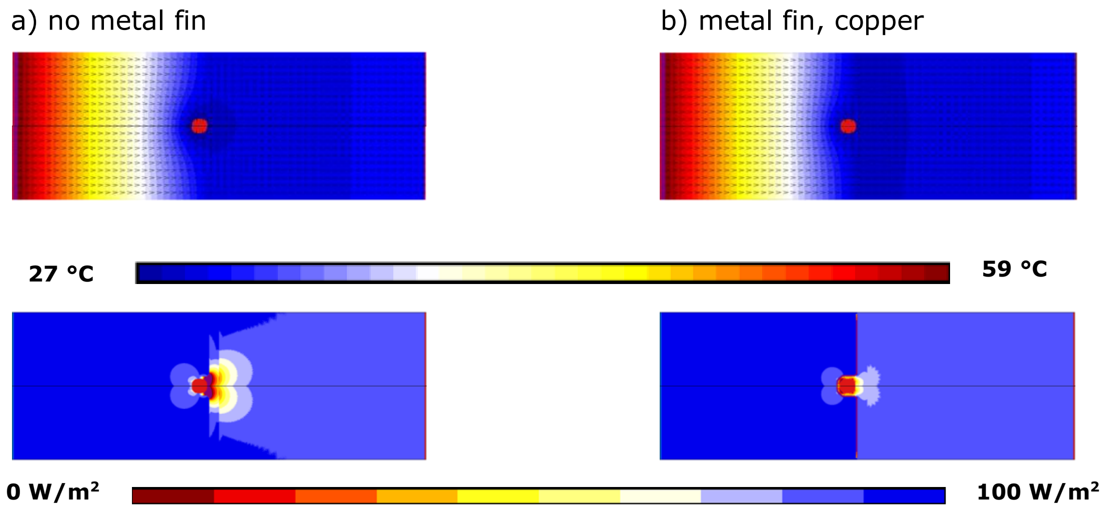

Fig. 9 *Distribution of temperature (°C) and heat flux (W/m2) within the wall fragment: a) without metal fin, b) with metal fin*

To find out the most feasible design, it is crucial to know the effect of material and thickness of the fin on the cooling output.

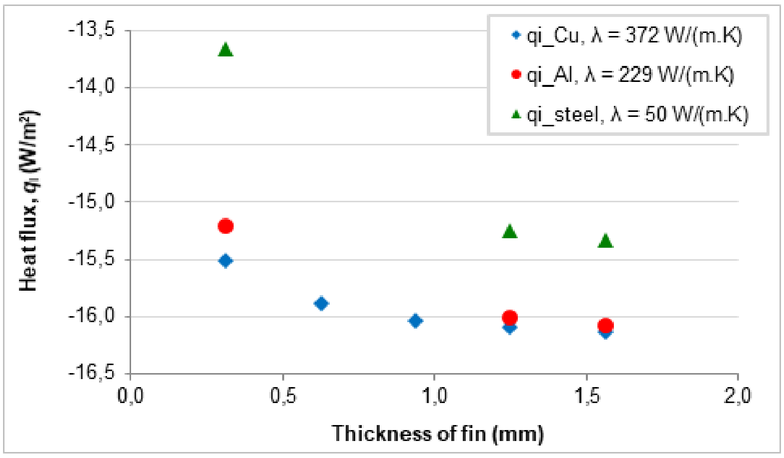

Fig. 10 *Cooling output of wall fragments with variable thickness and materials of the fin*

Fig. 10 shows comparison of the heat flux to the interior, i.e. the cooling output, for the fin made of three different materials – copper (qi_Cu), aluminium (qi_Al), and steel (qi_steel). Five cases were considered for the solution with the fin made of copper which was most efficient in terms of cool distribution. Three cases were considered for both aluminium and steel to allow comparison. The difference between the fins made of aluminium and copper was small regardless of its thickness. Increasing the thickness of the fin had only minor effect on the cooling output. Fin made of steel was the least efficient. In this case the cooling output was most sensitive to the thickness of the fin.

4. Conclusion and recommendations

We explored details of the heat transfer within a wall fragment manufactured in accordance with a patent under summer conditions. Subsequently, we researched the possible improvements of the design to enhance the cooling output. The conclusions that may be drawn from this study are:

- There is a significant potential for improvement of the patented design. It was found that the cooling output can be enhanced by addressing the imperfections in the contact between pipe and wall. Inserting a metal fin between pipe and plaster has improved the cool distribution within the wall fragment considerably.

- From the three materials of metal fin considered, using copper led to highest values of the cooling output, followed closely by aluminium. The cooling output of the fin was increasing with its thickness, however, for copper and aluminium the effect of fin thickness on the cooling output was relatively small. On the other hand, fin made of steel was the least efficient in terms of cool distribution. In this case the cooling output was most sensitive to the thickness of the fin.

- In future research other designs should be considered such as, for example, embedding the pipe in a thermally conductive plaster. This could be a potentially feasible solution because the associated costs might be lower than in the case of metal fin. Moreover, the design of the fin could be potentially improved by using grooved instead of smooth surface.

Acknowledgment

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III. SESSION

INDOOR BUILT ENVIRONMENT AND EVALUATION

INFLUENCE OF SUSTAINABLE ASPECTS ON ASSESSMENT OF INTERNAL BUILDING ENVIRONMENT

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Abstract

Present design of buildings and the way of building assessment focus primary on decreasing of energy consumption, efficient energy management and reduction of greenhouse gas emissions. This emphasis stems from European Union 2020 targets. However, in the issue of comprehensive building assessment are missing headline targets or limits to achieve type-stable level of indoor environment quality. Under the scope of sustainable building assessment can be considered aspect of acoustics, natural and artificial lighting, air quality or thermal behaviour. By means of sustainable development are applied wider targets directly and indirectly influencing overall building performance. This contribution focuses on comparison of different building envelope solutions and impact on internal environment. The paper describes connection between application of specific sustainable aspects applied by BREEAM with final influence on energy efficiency and indoor environment in terms of evaluation of thermal comfort using predicted mean vote and predicted percentage dissatisfied indices. The subject of analysis is office building in Brno certified with BREEAM Excellent certificate.

Keywords – sustainability, thermal comfort, dynamic simulation

1. INTRODUCTION

The current trend in building design is largely mirrored by a need to reduce impact on the environment. Green buildings are getting to the foreground, the demand for using systems of renewable energy is constantly increasing and more and more are used globally recognized or local certification systems to improve overall performance of the building. But is this race for energy reductions and reaching of sustainability through certification on the right place?

Firstly, the purpose of applying certification system is often seen as a marketing move to improve market position but not as a way how to improve quality of the building, to make the building more energy efficient or to reduce the environmental impact of the building. Secondly, previous studies [1] demonstrated, that having a certified facility may not necessarily mean bringing of benefits to the building users. Nevertheless, certification of buildings offers comprehensive approach in assessment of buildings. **Chyba! Nenašiel sa žiaden zdroj odkazov.**One of the most known certification system is British BREEAM assessing and certifying the sustainability of buildings [2]**Chyba! Nenašiel sa žiaden zdroj odkazov.**. Methodology of BREEAM was applied on the office building Office Box II in Brno, Czech Republic.

Effective adaptation of sustainable solutions and measures through BREEAM is undertaken through range of issues that assess energy efficiency, water use, health and wellbeing, materials, waste, ecology, pollution, etc. [3]. In the certification is the possibly highest potential for reaching the most credits signifying higher certification level in energy efficiency and reduction of energy consumption. In Czech republic using of global certification scheme for energy assessment is supported by accepting of local national standards [4,5] and calculation tools. These calculation tools except energy assessment also often provide way how to comprehensively assess buildings in means of daylighting, Life Cycle Cost (LCC), Life Cycle Assessment (LCA), passive design or thermal comfort. One of the results of previous study [6] shown, that high-mass envelope technique in contrast to light-mass techniques helps to maintain better comfort conditions. However, indoor thermal environment is influenced in many ways. The quality of the building envelope is one of the other factor. Different approach in analysis of various low-energy cooling technologies [7] demonstrated the satisfactory measures for keeping optimal thermal comfort without taking into account energy efficiency. Another study [8] presented use of thermal comfort analysis to identify causes of discomfort. Comprehensive assessment of buildings is multidisciplinary approach evaluating different aspects in mutual connection, but significantly in terms of energy efficiency. Assessment of relationship between energy efficiency and thermal comfort can be undertaken in different extent on various case studies with many rare boundary conditions.

This article is dedicated to analysis of thermal behaviour of indoor environment in the office building certified by BREEAM. Within the analysis are compared three variants of building high-mass envelope with the same value of heat transfer coefficient, but different composition. Results of simulations are subsequently evaluated according to standard ISO 7730 [9] using predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) indices.

2. METHODOLOGY

2.1. General approach

The analysis is based on an experimental method using dynamic simulation, the same as has been used formerly in previous study [7]. The analysed alternative variants are high-mass construction compositions based on findings of study [6]. Table 1 summarizes the general aspects observed within the study.

Table 1. *Methods and aims observed within study*

Method	Dynamic simulation, Fanger's model, steady-state conditions
Subject	Office building Office Box II, 3rd floor
Target	Thermal comfort analysis. Comparison of massive external wall variants with equal U-value and observation of influence on thermal comfort
Simulation boundaries	Stable – Construction data, local climatic data, solar gains, shading effects, HVAC data, lighting and equipment data, occupancy and activity data Variable – Building construction layers within variants, see Table 2
Tools	DesignBuilder version 5.0.3.007, EnergyPlus 8.5, Microsoft Excel 2016
Outcomes	PMV, PPD, Surface temperatures,
References	[6-8]
Standards	ISO 7730, ČSN 73 0540-3

The actual building consists of four-storeys of which upper three storeys provide open space office area. The construction system of the building consists of reinforced concrete skeleton with axial ground dimension 48 x 60 m.

The building model used within the analysis accounts with actual building form and orientation, external and internal layout, construction techniques, building services and other input date as is listed in Table 1. Illustration of the building model is shown on Figure 1.

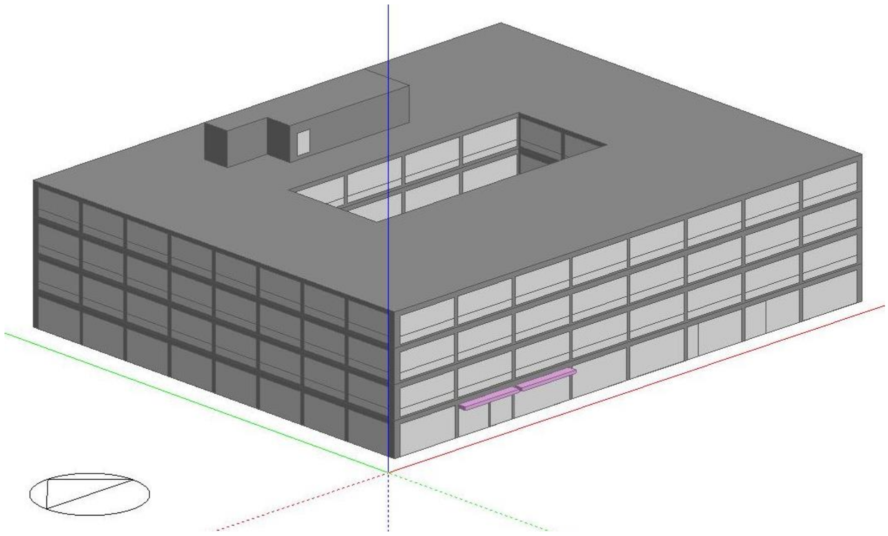

Figure 1. *Model of the Office Box II building*

Using the DesignBuilder software were calculated operative temperatures, PMV values and indoor surface temperatures with a time step detail of one hour during the whole year. For evaluation of thermal comfort are guiding PMV values at the periods of occupancy. The baseline variant outlined in Table 2 represents the actual state of the building evaluated in thermal comfort analysis. Variants 1 and 2 have been composed to provide comparison against baseline. Proposed alternative variants were analyzed within the same model with the same boundary conditions. In the baseline variant and in the both other variants, the envelope of the building is made of heavy construction. The building's skeleton system does not allow the use of lightweight envelope.

Table 2. *Variants and constructional characteristics*

Ref.	Construction layers	t (mm)[a]	λ (W/m K)[a]	c (J/kg K)[a]	ρ (kg/m³)[a]	U (W(m² K)[ab]
Baseline	Plaster (innermost) Reinforced concrete Insulation Ventilated air gap Facing brick (outermost)	15 200 140 40 100	0,870 1,430 0,035	1600 1020 880	840 2300 100	0,23
Variant 1	Plaster (innermost layer) Reinforced concrete Insulation Facade plaster (outermost)	15 200 140 2	0,870 1,430 0,035 0,700	1600 1020 880 1000	840 2300 100 1800	0,23
Variant 2	Plaster (innermost layer) Reinforced concrete Insulation Air gap Facing brick (outermost)	15 200 130 40 100	0,870 1,430 0,035 0,19 0,84	1600 1020 880 800	840 2300 100 1700	0,23

[a] t = thickness; λ = thermal conductivity; c = specific heat; ρ = density; U = heat transfer coefficient
[b] Overall heat transfer coefficient for a variant of construction composition as a whole

2.2. Thermal comfort

For the evaluation of thermal comfort are nowadays used two distinct approaches. The first approach was developed by Fanger in the 1970s [9,10], the second approach [11] uses adaptive model, which considers reaction of people, when change causing discomfort occurs. Using DesignBuilder calculation of PMV was done according to standards [9,12] used in practice. The classic Fanger's approach aims to predict the mean thermal sensation of group of people using PMV index categorized on seven-point sensation scale and their percentage of dissatisfaction through PPD index. Human thermal balance expressed by PMV is affected by environmental parameters as indoor air temperature, indoor mean radiant temperature, indoor air velocity and indoor air humidity and by personal parameters metabolism and clothing. Considering these parameters within the calculation of PMV according to standard ISO 7730 is the boundary of comfort environment recommended for PMV values varying between -0,5 and 0,5. PPD as a function of PMV does not exceed 10%.

3. RESULTS AND DISCUSSION

The PMV and PPD indices shown on Figure 3. demonstrate annual profile of thermal comfort during the occupied periods in the 3rd floor of the building. Presented results show prevailing value of PMV between -0,5 and 0,3. This corresponds to PPD values below 10%. Thermal comfort analysis was in largely influenced by HVAC system, thermal accumulation of building and physical activity of people and their clothing characterized by CLO index [9]. The final profile of PMV, PPD indices is composed of multiple simulations, which considers different clothing resistance in winter, summer and transitional period.

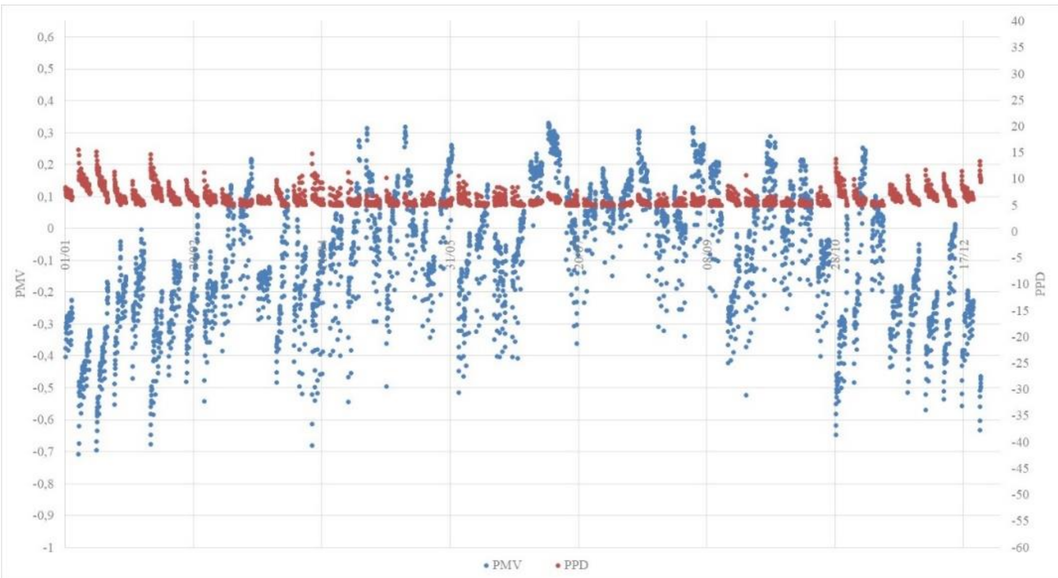

Figure 3. *Annual profile of PMV, PPD indices – baseline variant*

The comparison of variants is done based on surface temperature differences. On the vertical axis the plus values represent warmer temperature of baseline against compared variant. Figure 7 shows comparison of the baseline and the Variant 1. In this comparison the baseline variant composing of ventilated air gap appears to be more beneficial in means of keeping higher and more stable internal surface temperature during the winter. Figure 8 comparing variant composing of closed air gap does not result more significant performance. The possible benefit can be in this case potentially explored in means of LCC.

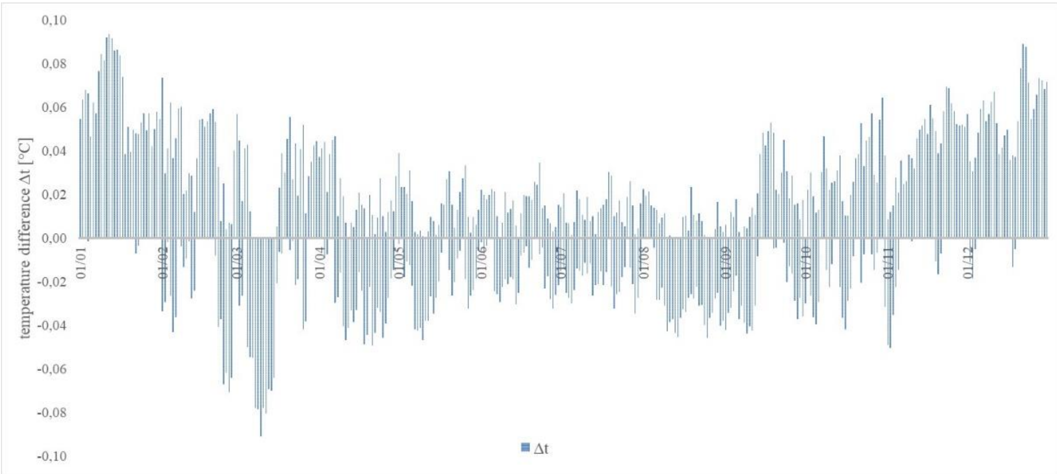

Figure 7. *Temperature difference between baseline and Variant 1, annual period*

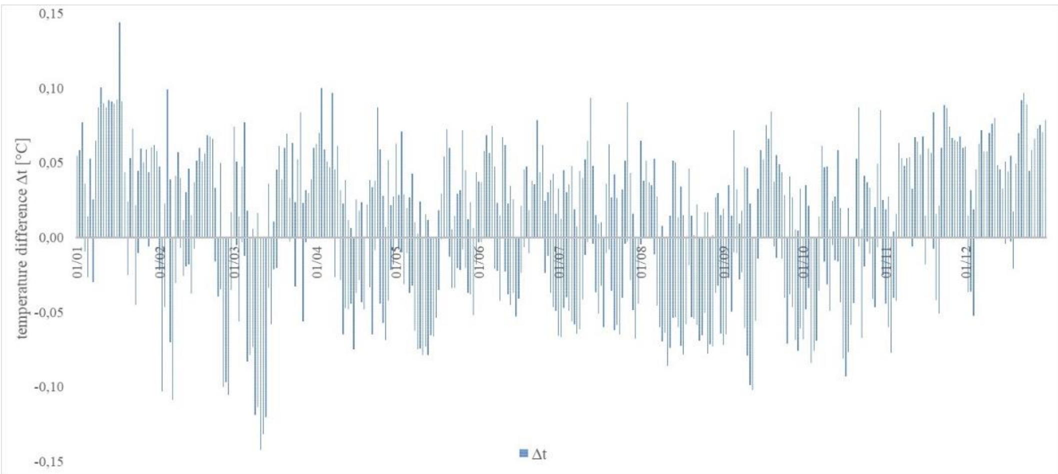

Figure 8. *Temperature difference between baseline and Variant 2, annual period*

4. CONCLUSION

The aim of the study was to point on the direct and indirect connections in application of specific aims of sustainability in terms of regular criteria of methodology of BREEAM assessment. As has been introduced, the terminology of comprehensive assessment of buildings can be undertaken in different ways and extent. The analysis of thermal comfort done on the building influenced with BREEAM proved ability to create optimal indoor environment. Compared to the results from previous study [6], the simulation proved good accumulation features of the high-mass envelope. In the comparison of proposed variants were found just slight deviations in surface temperatures, therefore no further evaluation of thermal comfort was observed. Results were influenced by the type of the building with high percentage of glazing and the fact, that the alternative variants were high-mass construction compositions. The variants were selected with respect on previous findings [6] and also to keep in line with building's skeleton system. Assuming a lower ratio of glazed areas, the results of surface temperatures and PMV/PPD indices would be more significant. The analysis pointed on connection of energy efficiency of building's envelope and thermal comfort.

Acknowledgments

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INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY OF AIR ON DEHUMIDIFICATION CAPACITY OF WATER WALL

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Abstract

Presented paper is a part of the doctoral thesis, which focuses on the influence of the water wall on the physical parameters of indoor air. The aim of the work is effective use of this element, which at present is primarily perceived only as decorative. The contribution is divided into several parts. The introduction is devoted to the theoretical part of the use, then the prototype of the water wall is presented and described its most important parts. In the contribution, the dehumidification ability of the water wall is investigated. In order to verify the dehumidification capacity of the water wall, experimental verification under laboratory conditions (climate chamber) was chosen. The present document describes the system and measurement conditions which were steady state. Plate heat exchanger ensured a water temperature in the system approximately 14 °C cold during all measurements. Air temperature and relative humidity were changed during the measurements. A total of 6 measurements were performed at different temperatures and relative humidity. The results showed that at different temperatures and relative humidity of air, the water wall has a different dehumidification capacity. These results were compared and the dependence between air temperature, relative humidity and dehumidification capacity of the water wall was shown.

Keywords - ***indoor air*** **humidity, water wall, dehumidification**

1. INTRODUCTION

The humidity of the indoor air is an important factor affecting the energy consumption of buildings, the durability of building elements and the perceived air quality. In summer, due to relatively high temperatures, their content in the outside air is significant, the higher the air temperature, the more it is able to absorb water. The air supplied to the interior is then, after cooling to an internal temperature, approximately saturated with water vapor, the relative humidity may be close to its saturation. [1].

Indoor humidity depends on a several factors, such as sources of humidity, air flow, moisture exchange with a material or the state of water vapor in the outdoor environment. The present document describes how the water wall is used for cooling and dehumidifying air in space. The water film is cooled and its temperature is below the dew point, so a condensation process occurs. This condition must be met. Similarly oriented research was realized at FRAUNHOFER Institute for Building Physics. This research presents the dependence of water temperature to the condensation ability of the water wall [2].

2. EXPERIMENTAL PROTOTYPE OF WATER WALL

The goal of this work is verify potential of water wall for dehumidification of indoor air. To achieve this goal, the water wall prototype was developed. The formation and thickness of the water film affects, among other things, the geometry of the upper part of the water wall (fig. 1). The upper part consists of a water collection tank of rectangular shape made from polypropylene material by melt-welded in order to achieve waterproof. A water supply pipe that is perforated is inserted into this tank. The downward perforation allows a steady flow of water into the tank to create a uniform water film across the whole width of the water wall. The effective water film area is $1m^2$. The overflow edge is formed by a glass plate which is connected to a collecting tank with a silicone adhesive. The overflow edge must be in the horizontal position. In order to achieve a united appearance of the water wall and at the same time, to prevent unwanted evaporation of water, the collecting tank is covered by a cover.

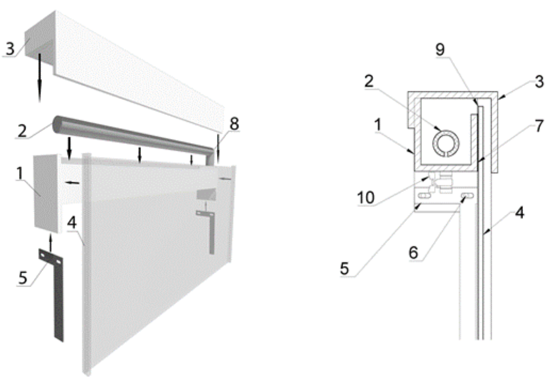

Fig. 1 *Scheme of main components of the upper part of prototype and section: collection tank (1), perforated pipe (2), a cover (3), glass pane (4), supporting metal structure (5), screws (6), silicone adhesive (7), water supply (8), spillway edge (9), ball valve (10)*

3. METHODOLOGY OF MEASUREMENT

Experimental verification of hypotheses take place under laboratory conditions in the climate chamber where steady conditions can be maintained, the temperature range is from - 20°C to +125 °C and the climatic range is from 20% to 95%. The chamber walls are made of stainless steel, so during the experiment there isn't exchange of mass between air and chamber. The set of sensors has been installed for monitoring boundary conditions in the chamber. The temperature and relative humidity sensors are connected via the AHLBORN control unit. The AMR Win Control software was used to obtain and collect measured data. This provided continuous recording of the measured values in a 5 minute time step. Two sensors measured the water temperature in the lower tank and two sensors in the upper tank. From these sensors the average water temperature for the lower and upper part was determined. In front the water film, two sensors were placed to measure the temperature and the relative humidity of the air, and one behind the glass.

For the measurement of influence of water wall to dehumidification and cooling of the indoor air, the system with using a measuring cylinder and weight increment measurement (fig. 2) was proposed using the RADWAG laboratory scale to an accuracy of 0.01g. This system made it possible to accurately and continuously record the increase in the condensate formed on the water film. Also plate exchanger, which is connected to well water, was added to the water wall system which allowed a constant water temperature in the system around 14 °C. After experiment started, parts of water wall are flooded, and water needs to be added to the level of the overflow created in the measuring cylinder. Then, water from the lower collection tank flows into the measuring cylinder. From it water is supply into the upper part of the water wall by the pump and cooled by the plate exchanger. During the experiment the increase water by condensation process overflow to collecting tank which is put on laboratory scale. The shut-off valve is used to control the flow rate velocity and the flow meter are used to monitor accurately flow rate. During experimental measurements the flow rate was 350 l/h what had been found like optimal flow rate during past experiments [2].

Fig. 2 *Measurement system of water wall*

4. RESULTS

During the series of the measurements aimed at determining the amount of condensate on the water film, the climate chamber was used actively, that provided steady boundary conditions during the experiment. Two series were made, water temperature in the lower tank was 14.58 °C, then it was cooled by the plate exchanger to 13.86 °C, the air temperature was different. In the first case it was 25,7°C and was carried out three measurements with relative humidity: 58,2% (RH_1), 73,4% (RH_2) and 83,4% (RH_3). In the second case air temperature was 27,4°C and relative humidity: 59,1% (RH_1), 74,3% (RH_2) and 83,6% (RH_3). The graphs (fig. 3 and 4) represent the courses of condensate weight created on water film in time dependence.

In the first case (Fig. 3), when relative humidity was 58,2%, the hourly gain of condensate was 21,99 g/h, at the relative humidity 73,4%, the hourly increase of condensate was 152,48 g/h and when relative humidity was 83,4% condensation performance was 235,9 g/h. In the second case (Fig. 4), when relative humidity was 59,1%, the hourly gain of condensate was 69,14 g/h, at the relative humidity 74,3%, the hourly increase of condensate was 208,59 g/h and when relative humidity was 83,6% condensation performance was 310,03 g/h.

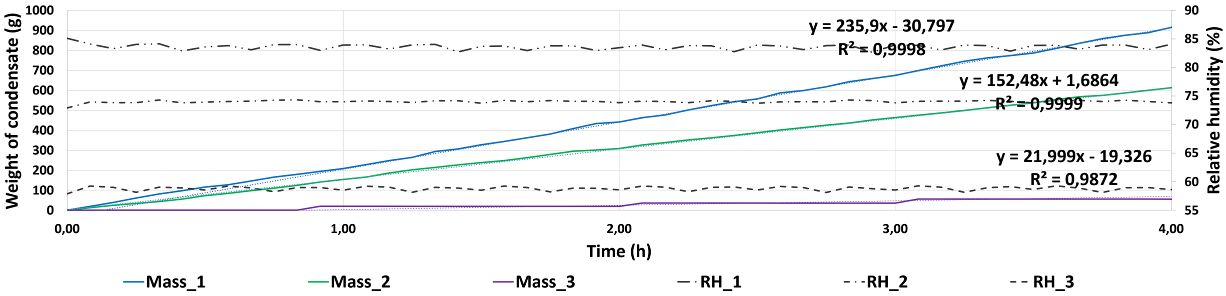

Fig. 3 *Curves of condensate weight when air temperature is 25, 7°C*

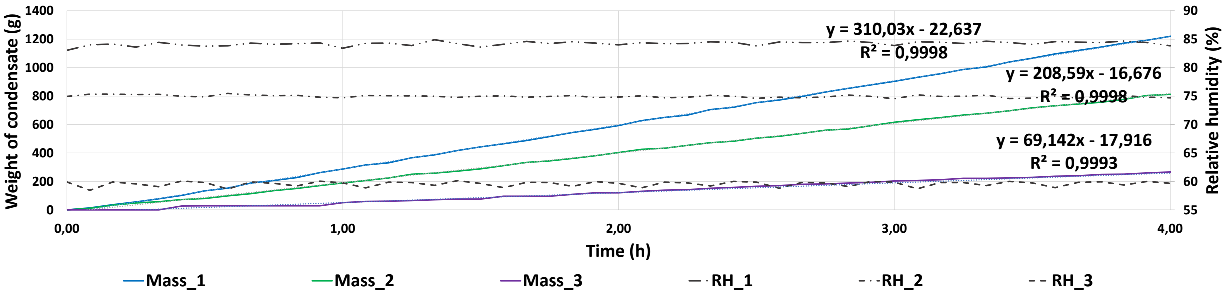

Fig. 4 *Curves of condensate weight when air temperature is 27, 4°C*

5. CONCLUSION

Regulation of air temperature and humidity is a basic priority and a requirement to achieve an optimal environment. In addition to using conventional systems such as air conditioning systems, also water walls may be used for this purpose. Water wall isn't able cover all needs but combination with conventional systems can lead to decreasing of energy consumptions of buildings. Using the climate chamber to measure its impact has proven to be appropriate for laboratory analysis. The ability of the water wall to reduce the relative humidity of the air by the condensation process was presented. During stationary conditions (water temperature, air temperature), the influence of relative humidity on the amount of condensate on the water film was investigated. In the first case when air temperature was 25,7°C and relative humidity 58,2% the condensation performance was 21,99 g/h. Increase of relative humidity by 15,2% represents a rise in condensate weight by 130,49g, what is 7 times more, with increase by 25,2% a condensate weight increases by 213,91g, what is 11 times more compared when relative humidity is 58,2%. When air temperature increase by 1,7°C to 27,4°C dehumidification performance for relative humidity 59,1% was 69,14 g/h. Increase of relative humidity by 15,2% represents a rise in condensate weight by 139,45 g, what is 3 times more, with increase by 24,5% a condensate weight increases by 240,89 g, what is 4,5 times more compared when relative humidity is 59,1%.

The presented contribution is part of the doctoral study. Together was carried out 15 measurements under different boundary conditions from which the general equation was for dehumidification performance of water wall was determined.

Acknowledgment

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INFLUENCE OF THERMAL RESPONSE OF HEATING SYSTEMS ON ENERGY CONSUMPTION AND INDOOR CLIMATE OF THE BUILDING

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Abstract

The paper deals with research of dynamics of thermal behavior of selected heating surfaces. Using energy simulations, the heat consumption during the heating season in a typical room of apartment building is compared. Heating with a radiator, convector and floor heating was compared. Individual models were created in the TRNSYS 18 software. The results of the simulations show, that the convector with a small volume of water in the exchanger shows more savings, while the floor heating consumes the most energy. Lower heat consumption is achieved using heating surfaces with lower thermal capacity of individual construction layers and with lower water volume.

Keywords – thermal response; floor heating, radiator, convector, energy savings

1. INTRODUCTION

In modern buildings, increasing importance is placed on reducing their energy consumption. There are also increasing demands on the regulation of the heating systems. Changes in external climatic conditions are reflected on the state of the indoor environment, during the day there may be rapid changes in the actual required energy for heating. Heating systems with good dynamic properties are able to react quickly enough to these changes, thus avoiding overheating or underheating of the room and thus generate energy savings.

The aim of this research is energy simulation of three variants of heating systems with different thermal response times - heating using radiator, convector or floor heating. The simulation compares energy consumption for heating during one heating season and at the same time the influence of heating on the indoor climate of the building, especially the influence on the heating up of individual heating systems. Simulations were used to compare individual variants of heating systems in terms of energy consumption and their dynamic behavior. The energy consumption for heating of a typical room of a residential building was measured. A separate model has been created for each variant of the heating surface in the TRNSYS 18 program. It is a graphically based simulation software used to simulate the behavior of transient systems

2. CALCULATION MODEL

Three types of heating surfaces were compared - radiator of conventional construction, convector of new construction with very low water volume [1] and floor heating. Fig. 1 shows the designed types of heating surfaces together with their inlet water temperature. All systems were designed to cover the heat loss of the room they are placed in.

Variant	Name	Type	Inlet water temperature [°C]
1	Radiator	Radik VK 22/060/140	50
2	Convector	Tomton R1 Double TH	50
3	Floor heating	l=149,8m, R=150mm,m=102 kg/h	40

Fig. 1 *Overview of simulated variants*

The heating systems were situated in the living room of the apartment building. The heat loss of this room was 744 W, corresponding to outdoor temperature of -12 °C and operative interior temperature of 20 °C. This room is adjacent to the exterior where the calculated temperatures were obtained from real climatic data and the interior where the temperature were assumed to be 20 °C. For room on of this type, a natural air exchange of 0.5 1/h was chosen for this model. During the calculation, the program takes into account the external temperature, solar radiation gains, internal heat gains, thermal-accumulation properties of building constructions and on their basis dynamically determines the interior temperature.
Internal heat gains included gains from people in the room and gains from lighting. Two persons were considered to be in the room, each producing 95 W and lighting producing 6 W/m^2. Each internal gain can be assigned its own schedule, specifying the time period in which the gain is applied in calculation. The schedule showing occupancy of the room by people is shown in Fig.2. Lighting is using the Daylight Control function, which simulates the switching on and off of the lighting within the specified illumination range (300-500 lux).

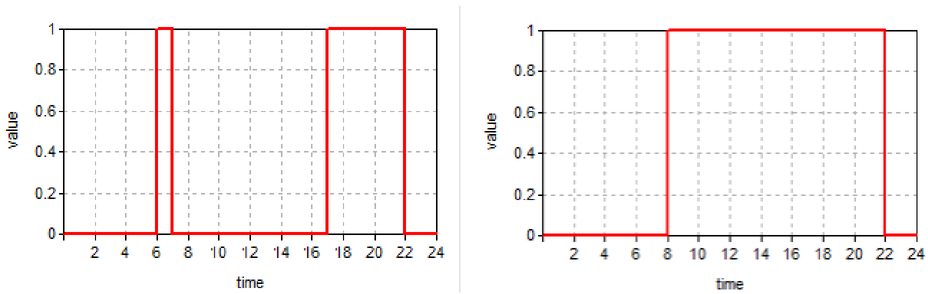


Fig. 2 *Occupancy schedule for week (Left) and weekend (Right)*

One whole heating season was simulated - from 1.9 to 31.5.. The time step of the calculation was chosen to be 10s, a total of 6504 hours were simulated. The interior temperature was maintained at 20 ° C throughout the season.

3. HEATING SURFACE MODEL

Our own simplified calculation model was used for simulating the heating surfaces. The basic idea of this model is to replace the heating surface in the room with a circular pipeline filled with water, which has the equivalent performance and dynamic characteristics as the replaced heating surface. The basic condition for this model to work is that the product of the heat exchange surface and the heat transfer coefficient of the pipe and the heating surface are the same. Considering the same heat transfer coefficient for both surfaces, the problem is reduced to finding an equivalent pipe that has the same area and the equivalent volume of water as a given heating area. Equivalent volume of water expresses what the volume (weight) of water would be if the whole heat surface body was replaced with water, while maintaining the original characteristics. Each heating surface consists of materials with different heat capacities, the replacement pipe has the same heat capacity as the whole body, but is composed only of water. The equation for total thermal capacity C_{Tot} [J/(K)] of heating surface is:

$$C_{Tot} = m_m \cdot c_m + m_w \cdot c_w$$

Where m_m [kg] is the mass of the material from which the heating surface is constructed, c_m [J/(kg.K)] is the thermal capacity of this material, m_w [kg] is the mass of the heat carrier of the heating surface and c_w [J/(kg.K)] is the thermal capacity of heat carrier. The equivalent mass of heating surface $m_{w,eq}$ [kg] is calculated by equation:

$$m_{w,eq} = \frac{m_w}{C_m / \Sigma C_{Tot}}$$

Weight of heat carrier in the body of heat surface m_w and heat exchange surface S [m^2] were obtained from the manufacturer's documents. Heat transfer coefficient α [W/(m^2.K)] was calculated by equation:

$$\alpha = \frac{Q}{S \cdot (t_{sm} - t_i)}$$

Where Q [W] is heat output of heating area, t_{sm} [°C] is mean surface temperature of the heating surface and t_i [°C] is interior temperature. The parameters of the equivalent pipe - its length l [m] and diameter r [m], were determined by iterative calculation, while:

$$\pi \cdot r^2 \cdot l = m_{w,eq}$$
$$2 \cdot \pi \cdot r^2 + 2 \cdot \pi \cdot r \cdot l = S$$

For all variants, quantitative control was simulated using a proportional controller with a 3 K proportionality band. Mass flow rate through the heating surface M_{in} [kg/h] is acquired according to the equation:

$$M_{in} = M \cdot max[1 - exp(-2{,}1 \cdot (t_{set} - t_i)); 0]$$

Where M [kg/h] is the actual mass flow into the heating surface, t_{set}-t_i [K] is the difference between the desired and the actual room temperature.

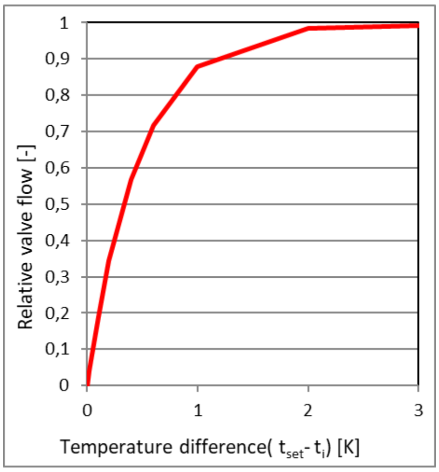


Fig. 5 *Relative flow through valve according to given equation*

Using this equation, a thermostatic valve was simulated, which is able to change the flow of heating water without delay. This uniform equation for all simulated cases was chosen because the real valve characteristics for each variant is unknown. Choosing uniform control eliminates errors that could arise from incorrect equations used for each variant. Only the dynamics of the heating surfaces themselves is compared, the influence of the thermostatic valve is neglected. The initial temperature of the heat carrier (water) as well as the indoor temperature was chosen to be 20 ° C.

7. RESULTS

Fig. 6 shows the start-up of the heating systems when the heating is switched on at 6:00 AM on a winter day after night setback. Initial air temperature in the interior is 20 ° C, the internal temperature decreases due to heat losses. The heating system is triggered and the temperature starts to rise. The time it takes to reach the desired temperature depends on the dynamic properties of the heating surface. The areas marked in green show the period when the room is underheated relative to the desired temperature. With increasing heat capacity and water volume of the heating surface, the time during which the room is underheated increses and the indoor temperature decreases. The red areas indicate the period when the room is overheated, in this case by internal gains from people and lighting. The smaller this area, the faster the heating surface can cool down and energy is saved.

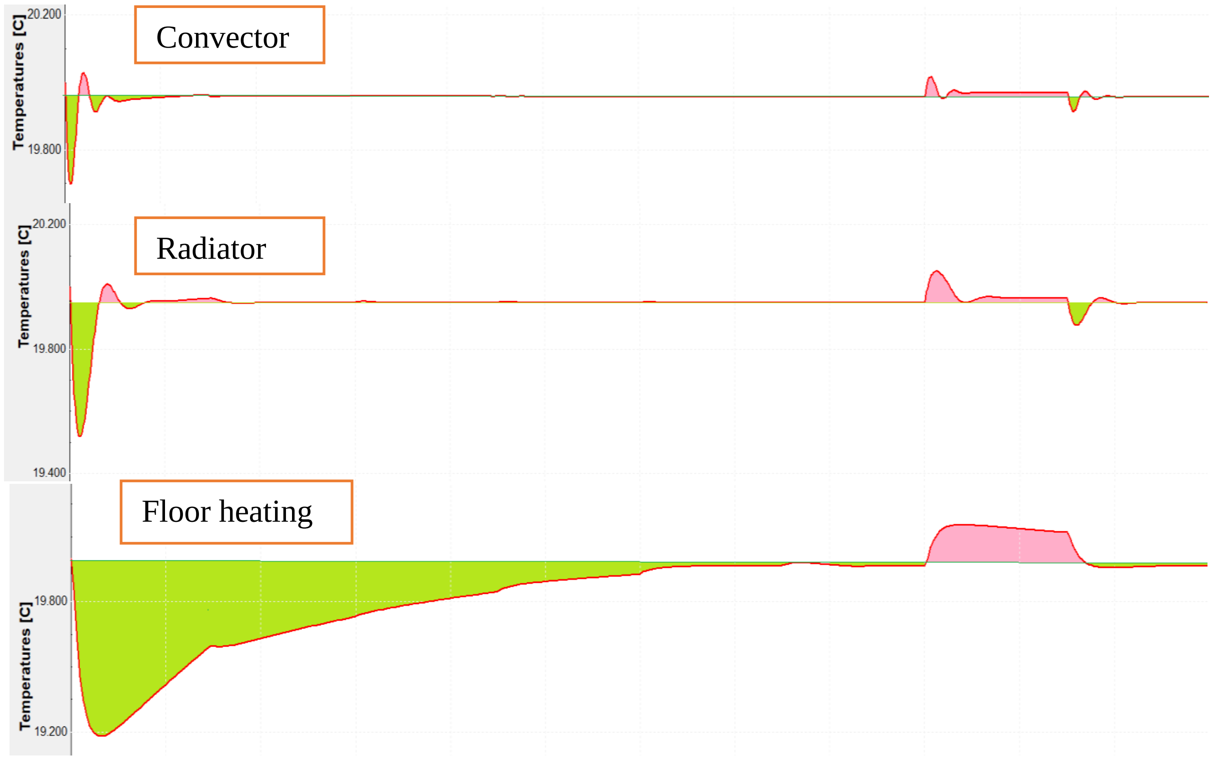


Fig. 6 *Differences in heating up of individual heating surfaces*

A total of nine months were simulated, for each of them the total energy consumption for heating for a given month was calculated. The basic parameter for evaluation of the simulation was the total haet consumption for heating during the heating season. The lowest consumption is achieved by a convector with an annual consumption of 1.26 MWh, which is almost 0.1 MWh less than the consumption of floor heating and 0.05 MWh less than the radiator. In terms of savings, this is 7.1% lower than floor heating and 3.1% lower than radiator. The radiator saves 0.05 MWh per year compared to qfloor heating, which means 4% savings.

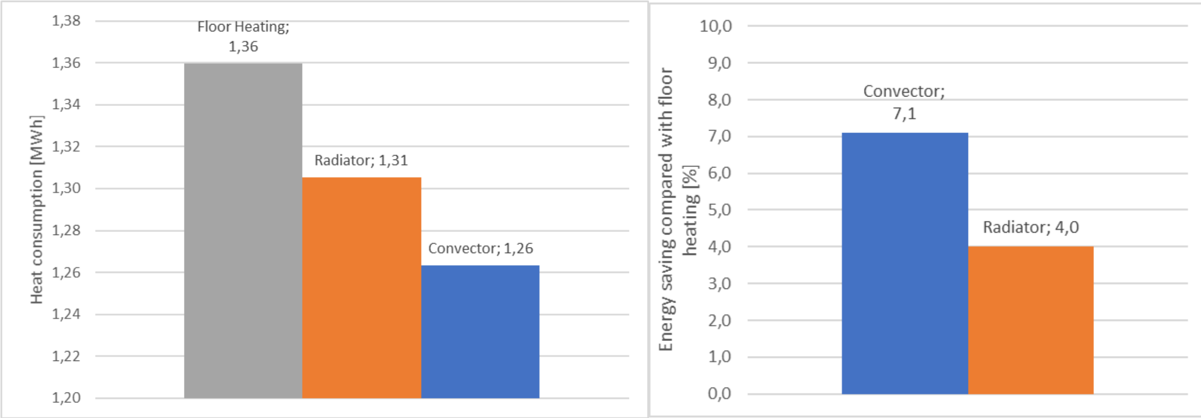
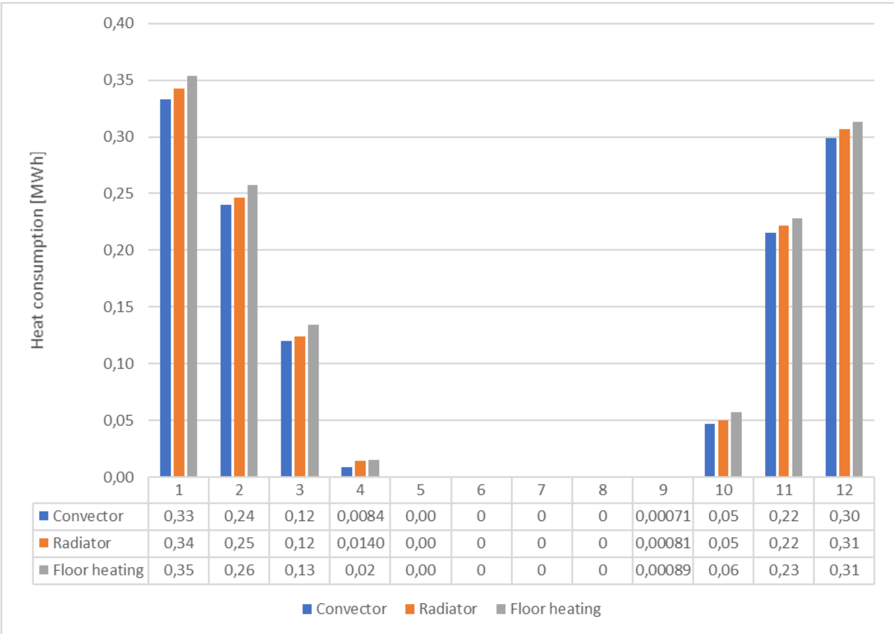


Fig. 7 *Total annual energy consumption for heating (left) and energy saving compared to floor heating (right)*

When we compare monthly consumption we get similar results.



	1	2	3	4	5	6	7	8	9	10	11	12
Convector	0,33	0,24	0,12	0,0084	0,00	0	0	0	0,00071	0,05	0,22	0,30
Radiator	0,34	0,25	0,12	0,0140	0,00	0	0	0	0,00081	0,05	0,22	0,31
Floor heating	0,35	0,26	0,13	0,02	0,00	0	0	0	0,00089	0,06	0,23	0,31

Fig. 8 *Monthly energy consumption for heating*

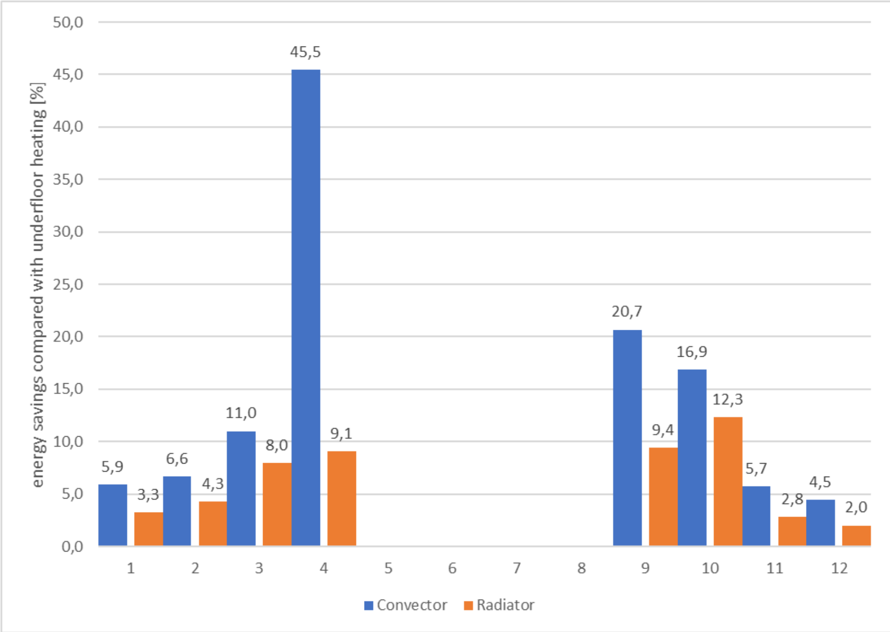


Fig. 9 *Monthly energy saving compared to floor heating*

8. CONCLUSION

The results obtained show the dependence of energy consumption on the dynamics of heating surfaces. Heating systems with high thermal capacity (floor heating) are more suitable for rooms with stable heat demand. Heating systems with fast thermal response (convector, radiator) work optimally even in rooms where frequent fluctuations in heat demand. The greatest differences between energy consumptions are observed in the warmer months, when there are more frequent temperature fluctuations. During this period, there is a frequent change in the heat demand and frequent switching on and off of the heating system, thus the dynamic properties of the individual heating surfaces are more relevant. In colder months, when the temperature is more stable and the heating system operates permanently, the differences in energy consumption diminish.

Overall savings are relatively small, it is important to realize that all three variants have been modeled with a uniform way of regulation. If we take into account the differences in regulation, we can expect a reduction in energy consumption for heating systems using convectors and radiators. On the other hand, the calculation does not take into account the effect of radiant temperature on the thermal comfort. Floor heating can ensure the same thermal comfort even at a lower interior temperature due to the higher proportion of heat transfer by radiation. Floor heating uses a lower inlet water temperature of 40 °C, which reduces heat production costs and is more suitable in combination with low-grade renewable energy sources.

The biggest advantage of heaters, which arises from this article, is their impact on indoor environment of the building. Convector and radiator systems can achieve their maximum

heat output much faster and thus shorten the period while the internal temperature is below the desired temperature or the period while the room is overheated (Fig.6).
The results achieved are similar to those of similar simulations [2]. Inaccuracies were inserted into the calculation using a relatively simple model of the heating surface which immediately regulates the mass flow. In the future research, the different functioning of the regulation for different heating systems should be included into the model.

Acknowledgment
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PRIMARY AND RECYCLED MATERIALS FROM LCA ANALYSIS

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Abstract

Building industry is in long term the biggest energy consumer in the world. Energy for building operation together with energy needed for construction is making 36% of total consumption. Along with energy consumption is linked to 39% of total carbon dioxide (CO_2) emissions. This leads to higher focus on increasing building energy efficiency. This leads to an increased use of thermal insulation materials and consequently to an increase in energy consumption during the production phase. This article deals with the use of recycled materials in construction as alternative to conventional building materials from primary raw materials. Article discusses current production and kind of waste in EU, informs about alternative building materials and compares differences in environmental impacts to conventional materials. As a result, article wants to assess the impact of recycled materials in a building.

Keywords – recycled materials; LCA; EPD

1. INTRODUCTION

Landfill storage is limited not only by reducing the availability of space but also by increasing liquidation costs. Increasing waste production therefore requires new strategies for re-use and recycling. In our neighbourhood Czech republic, they have good experience with crushed bricks in embankments under hall constructions. In some cities, they give a fraction of concrete – brick even under the sidewalks and the quality is good. Also concrete with recycled components is as good as concrete with natural aggregates of lower fraction. Problem occurs with use of polystyrene an PVC from buildings. This components often contain additives an fire retardants, that make recycling impossible, that is why they often ends up on landfills or incinerator. Obtained recycled material could be used for manufacture of plastic window frames, lightweight middle layer of new pipes or middle layer of floors [17]. The last two decades have shown a growing interest in the use of alternative materials in different sectors of the national economy in order to conserve natural resources and reduce storage. For example, government regulations and methods have been issued in several countries to support the development of road construction using recycled materials [1]. This study examined alternative materials, such as ash from the incineration of municipal solid waste, ground recycled asphalt waste from roads and pavements, and foundry sand, intended for different road layers. Potential contamination was detected by leaching on road sections during traffic, creating special LCI data that was implemented into LCA tools.

Life Cycle Analysis (LCA) is a method for quantitative assessing the use of materials, energy flow and environmental impacts of the examined products. It is used for systematic assessment of each material and process. LCA is a process of evaluating various aspects related to product / building development and its potential life-cycle impact from raw material acquisition, transport, processing, transport to construction, installation, use, maintenance to demolition or possibly recycling [2].

Different materials, which are possible to use in the same type of structures in building, have different environmental impact not just during manufacture process, but also during their whole life cycle. Through the LCA analysis it is possible to evaluate an environmentally more suitable alternative. For example, when evaluating primary polypropylene, CO_2 emissions increased 10 times and a more than energy consumption increased more than 15 times over recycled polypropylene. This suggests a significant positive difference in the use of recycled materials as compared to conventional primary raw materials. Given the current increase in production in the construction industry, which, according to Eurostat, was on average 2.9% higher in the 28 European Union countries in 2017 and 2018, compared to 2015 [3], this hypothesis needs to be broadly examined.

Increased use of recycled materials could improve the deteriorating waste generation situation. In 2016 alone, 2 312 million tonnes of waste were treated in the 28 EU Member States. Of this amount, up to 36.4% was construction waste. 53.6% of the total waste was reused, recycled or incinerated to recover energy. Landfills and incinerated without energy use accounted for 46.7% of the total waste. Total waste is growing not only in Europe but also worldwide. Figure 1 shows the percentage of waste generation from individual economic activities and households in the EU countries in 2016**.**

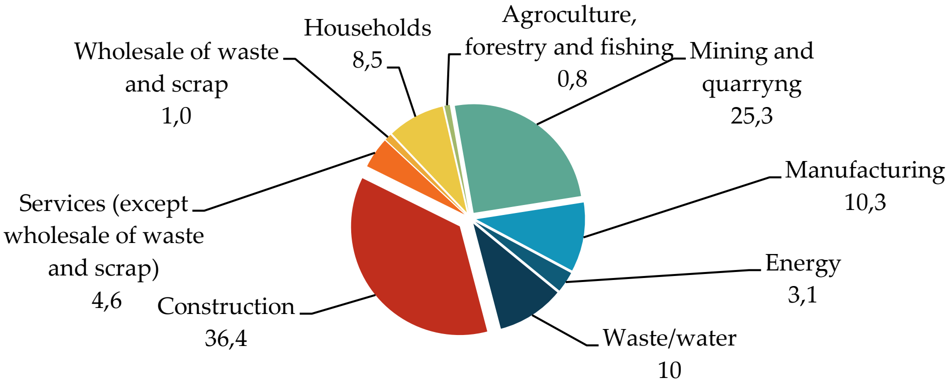

Fig. 1 *Waste production from individual economic activities and households, EU-28, 2016 (%)*

2. METHODOLOGY AND AIMS

The aim of this article is evaluation of environmental impacts of recycled materials and comparation with conventional materials with help of LCA method. Methodology is based on life cycle analysis (LCA) and it follows STN EN ISO 14040 norm [4]. The eToolLCD software, which uses the available BRE IMPACT version 4, was used to develop the life cycle analysis of each material. System boundaries were unified and narrowed to product phase (A1-A3) to make the results transparent and simplified. In the analysis used, the processed data is declared by the manufacturers. The environmental impact data is processed in the Environmental Product Declaration (EPD). EPD is an independently verified and registered document that provides transparent information on the environmental impacts of a product during its life cycle. As a voluntary declaration of environmental impacts, EPD does not serve to demonstrate environmental superiority over other alternatives. According to STN EN ISO 14025, this document belongs to type III environmental labelling, which quantifies and verifies the life cycle of products.

3. INVENTORY ANALYSIS: MATERIALS OVERVIEW

Materials are divided depending on application to: load-bearing, non-load-bearing, protective, operational, installation and insulating materials. They are further divided into recycled and conventional primary raw materials.

In building industry, waste materials are increasingly being used. Either in the form of partially recycled materials where the primary raw materials are combined with waste materials, or fully recycled where the waste material becomes the primary raw material source for production of a new material. The emphasis in this study is on materials with more than 50% recycled content.

As load-bearin material it is possible to use recycled plastic lumber Recycled plastic lumber is a wood-like recycled plastic material designed to reduce pollution caused by plastic [5]. The recycled content of this material is 96%. Its treatment is similar to traditional timber, but is more resistant to external climatic conditions [6]. It is still used predominantly for the production of low-stress or non-critical structures, for example as exterior furniture or fences. The structural elements of this lumber are non-homogeneous in cross-section and the non-linear nature of the material causes different compressive and tensile behavior. It is also difficult to determine some mechanical properties. Therefore, it is not yet classified as a structural element, but it is being worked on [5].


Fig. 2 *Recyclated plastic lumber*

The thermoplastic composite is based on high-density polyethylene. The approximate recycled content of this material is 96%. The first bridge using this composite was built in Fort Leonard Wood, Missouri in 1998. The damaged bridge deck was replaced with a thermoplastic composite, while the existing steel beams remained as support. In 2002 in New Jersey, the first bridge was build, using thermoplastic I beams as main beams. [7] [7] The first such bridge in Europe was built in Scotland. [8]


Fig. 3 *Bridge made of thermoplastic, Scotland*

Significant use potential could have concrete with building debris, it consists of recycled concrete or recycled brick, ceramic or a mixture of all with the addition of Nano Filler for special stability properties. Available sources indicate that 100% recycled material is used as filler component. However, the total share is unknown. It can be used both for prefabricated elements and for transport concrete, spray mixture, manual processing, special decoration products or monolithic concrete [9].

Fig. 4 *Concrete sample with building debris*

Plastic blocks can be included among non-load-bearing materials. It is similar material to wood, but with ability to be specifically formed for easy folding into wall systems. The recycled content is same to plastic lumber due to similar material, up to 96%. This solution is suitable for the construction of low-cost houses. Therefore, the highest appearance of references on this building material is associated with projects for poor communities, communities affected by natural disasters or conflicts. One such example is houses in Bogota, Columbia [10]. The study examining the construction of houses made of such plastics, came with the hypothesis of the suitability of such houses in places with high seismic activity, mainly because of the low bulk density, which could pose less risk to people in the event of collapse [11].

Fig. 5 *Plastic block, Recycled House in Columbia*

Laminated tetrapack boards are another equivalent to the more traditional lightweight wall material, with 95% recycled content. They are lightweight, water resistant, with the addition of a small amount of additives.

Glass foam granulate is recycled material from glass waste. It has almost 100% recycled content. It transmits 280kN / m2 load in 1,6:1 ratio of compacting. It is frost-resistant, and has a conductivity of 0.080 W / mK when compacted to 1.3: 1ratio when dry. It is an ideal material for use as a bed under the base plate and as a fill material [12].

Recycled brick, by this term is meant the original brick product sorted during the demolition of an old building, cleaned and sorted. This material was used, for example, by

Danish architects to create the facade of a residential building. Since the same material is used, only in the new construction, the recycled content is therefore 100%.

As protective material it is possible to use also recycled porcelain façade tiles made from spray-dried clays from regenerated solid ceramic waste produced during the manufacturing process (green particles and clay particles from air filter systems). Recycled content is around 95% [13].

Glass mineral wool is made by combining sand and recycled glass. The recycled content is 80%. The use of recycled glass reduces the melting temperature, thereby reducing energy consumption and emissions. It has good heat-insulating and sound-insulating properties and is non-flammable [14].

Textile fiber insulating boards are insulations with a high proportion of textile recycled material, up to 90%. Their manufacturing process varies according to the material used. Textiles are collected, sorted, cut and divided into fibers. These are further classified according to characteristics such as length, strength and number. For synthetic fibers, a process may be required to recover the polymer from the recycled material. Depending on the desired properties, the different fibers may be mixed. In some cases, high temperature and pressure are used to form a composite material [15].

Blown cellulose insulation is made of 90% recycled newsprint and mineral additives and boric acid to enhance fire resistance. The paper is graded, divided into smaller portions, measured and the moisture content of the mixture adjusted for better additive adhesion. The mixture is further ground and mixed with an appropriate amount of mentioned additives [16].

By conventional materials are meant the most widespread building materials. Above all, materials from the primary raw materials and at the same time materials which can be compared with the recycled materials, because of their similar use.

4. RESULTS AND DISCUSSION

Using the information provided by the EPD, partial and initial comparisons of conventional and recycled materials are possible.

Tab. 1 *Environmental impacts for production phase (A1-A3)*

	Materiál	GWP [kg CO_{2eq}]	ADPF [MJ]	AP [kg SO_{2eq}]	EP [kg $(PO_4)^{3-}{}_{eq}$]
Load-bearing	RPL - recycled plastic lumber	30.3678 (m^3)	191.5907(m^3)	0.0926(m^3)	0.008(m^3)
	Thermoplastic composite	-	-	-	-
	Building debris concrete	-	-	-	-
	Wood (timber treated for outdoor use)	186.00 (m^3)	3110.00 (m^3)	1.24 (m^3)	0.579 (m^3)
	Concrete	271.00 (m^3)	1440.00 (m^3)	0.781 (m^3)	0.0782 (m^3)
Non-load-bearing	Plastic building blocks	-	-	-	-
	Layered tetrapack boards	-	-	-	-
	Glass foam granulate	15.2 (m^3)	194 (m^3)	0.0717 (m^3)	0.0347(m^3)
	Full burned bricks	198.909(m^3)	1826.023(m^3)	0.493 (m^3)	0.0597(m^3)
	Aerted concrete blocks	180 (m^3)	981 (m^3)	0.217 (m^3)	0.028 (m^3)
	Gypsum boards 12,5 mm	136 (m^3)	2000 (m^3)	0.352 (m^3)	0.0584 (m^3)
	Gravel (1,6t/m^3)	3.1 (m^3)	39.9 (m^3)	0.0433 (m^3)	0.00367(m^3)
Protective	Recycled brick (front facade 1600kg/m^2)	4.32 (m^3)	438.4 (m^3)	0.09872(m^3)	0.0216 (m^3)
	Recycled facade porcelain tiles (24,7 kg/m^2)	1875 (m^3)	30875 (m^3)	7.8875 (m^3)	0.6725 (m^3)
	Full burned brick (HELUZ š 17,5)	198.9086 (m^3)	1826.0229 (m^3)	0.4934 (m^3)	0.0597 (m^3)
	Facade ceramic tiles (25,1 kg/m^2)	1500 (m^3)	23375 (m^3)	3.0125 (m^3)	0.42125 (m^3)
Inulation	Blown glass mineral wool (35kg/m^3)	26.00 (m^3)	393.00 (m^3)	0.0969 (m^3)	0.0106 (m^3)
	Insulating boards from textile fibre	-	-	-	-
	Blown celulose insulation (55kg/m^3)	-66.775(m^3)	144.98 (m^3)	0.0591 (m^3)	0.0073 (m^3)
	EPS (ISOVER 100F, 100S)	58.00 (m^3)	1600.00 (m^3)	0.054 (m^3)	0.012 (m^3)
	XPS	94.44 (m^3)	2740.00 (m^3)	0.2661 (m^3)	0.02068 (m^3)
	Stone wool (Knauf)	53.70 (m^3)	671.00 (m^3)	0.173 (m^3)	0.0108 (m^3)

GWP – Global warming potential, ADPF – Abiotic depletion potential – fossil fuels, AP – Acidification potential, EP – Eutrophication potential

Table 3 shows the clear benefits of recycled materials in terms of comparing selected impacts on a designated functional unit. However, as with insulating materials, other material parameters must be taken into account in a more complex comparison. These can deepen or reduce the resulting impact when different volumes are required, while maintaining, for example, the thermal insulation parameters of the structure.

5. CONCLUSION

It is necessary to show benefits linked with wider use of recycled materials. Mainly because of the positive impact on reducing the environmental burden. Despite the rapidly growing waste production, there is not enough attention paid to this issue. The lack of data suggests a persistent lack of examined information associated with these materials. In view of the sustainability of construction and the reduction of the negative impact on the environment, further examination is needed in this area. One of the main conditions for the widespread use of recyclates in the construction industry is their thorough assessment in terms of technical - building standards, and also a comprehensive assessment in terms of environmental impact. Legislation, such as a mandatory proportion of recycled material in public buildings or green public procurement, could also help recycle construction waste more frequently. A proper understanding of construction and demolition waste as an economic category and environmental factor, not as something to be discarded, but as material to be recovered and reused, is the foundation of a circular economy in developed countries.

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PLENARY SESSION III

COMBINED LABELLING OF BUILDINGS

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Abstract

The paper demonstrates combined labelling of buildings, which includes energy, indoor environmental and well-being aspects. The development of the proposed combined labelling is in progress in TripleA-reno project, which aim is to encourage the deep renovation of residential buildings.

Keywords - indoor environment; well-being; combined labelling

1. INTRODUCTION

The TripleA-reno is a EU funded project, running from May 2018 until April 2021. The main objective of the project is to encourage the deep renovation of residential buildings, making the renovations attractive and affordable for the users. To this end, the project will develop a user-centered platform which helps users in the decision-making, in the implementation and even in the in-use phase of the renovation.

As part of the project, the aim is to create a combined labelling scheme, which includes energy, indoor environmental and well-being indicators. The indicators of the combined labelling scheme were defined according to the purpose of the project, therefore those energy and comfort characteristics of a residential building were focused that can be changed by (deep) renovation.

2. The TripleA-reno COMBINED LABELLING SCHEME

The methodology used in the main existing certification systems (LEED, BREEAM, WELL) and reporting framework (LEVEL(s)) was reviewed [1, 2, 3, 4, 5, 6, 7], including regulations and standards, in order to determine the relevant indicators and requirements. As a result of the assessment the "*Energy indicators*", the "*Qualitative well-being and IEQ indicator* (Related to the building system)" and the "*Measured well-being and IEQ indicator* (Related to the apartment and depending on occupant habits)" is being developed, which altogether results the combined labelling.

The qualitative well-being and IEQ rating include those indicators that characterize the building regardless of occupant habits. These indicators are evaluated based on the designed or implemented technical systems. The measured well-being and IEQ rating is related to the apartment and most of it depends on occupant habits and can be evaluated by on-site measurement.

The proposed combined labelling will give occupants insight not only into the energy efficiency, but also the indoor environmental and well-being aspects.

2.1. Energy indicators

The Energy Performance Certificate (EPC) has been introduced in EU countries according to the requirements of the EPBD. The EPC shows the characteristics of the building envelope and the HVAC systems and demonstrates the primary energy use of the building in a transparent manner. It is very useful when one would like to label the energy consumption. The EPC is an objective assessment, which helps end-users to get information on energy efficiency, therefore it makes sense to use EPC as energy performance indicator and complement it with IEQ and well-being performance indicators. In addition to the EPBD energy performance calculation, the delivered energy use (both calculated and measured) and the area weighted average thermal transmittance is shown in the labelling. The calculated total primary energy and the calculated delivered energy use is aligning with Level(s) reporting framework. The energy indicators, the units and the references are shown in Table 1 below:

Table 1 *Energy indicators*

Energy indicators	*Unit*	*Reference / Description*
Energy Class	-	Align with national energy performance certification (EPBD)
Calculated total primary energy use	kWh/m²a	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series.
Calculated delivered energy use (fuel)	kWh/m²a	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series.
Calculated delivered energy use (electricity)	kWh/m²a	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series.
Calculated delivered energy use (district energy)	kWh/m²a	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series.
Calculated delivered energy use	kWh/m²a	Sum of all calculated delivered energy use.
Measured delivered energy use (fuel)	kWh/m²a	Based on measurement or energy bills. Energy consumption without any correction.
Measured delivered energy use (electricity)	kWh/m²a	Based on measurement or energy bills. Energy consumption without any correction.
Measured delivered energy use (district energy)	kWh/m²a	Based on measurement or energy bills. Energy consumption without any correction.
Measured delivered energy use	kWh/m²a	Sum of all measured energy use.
Share of RES	%	Calculated renewable primary energy use divided by calculated total primary energy use.
Area weighted average thermal transmittance	W/m²K	Regarding above ground structures.

For residential buildings according to EPBD, the primary energy consumption takes into account only the energy consumption of heating, cooling, DHW and ventilation. Household electricity (plug load) is not taken into account when primary energy consumption of different residential buildings or building units are compared, because there can be many differences between one and another dwellings’ household appliances and the operation of them.

However, from end-user point of view the primary energy consumption may be too difficult to understand, furthermore there are big differences among primary energy factors of different energy sources. Therefore, it makes more sense to show also the delivered energy use. The delivered energy is a very useful indicator especially in case when somebody would like to monitor their energy consumption and the behaviour of a selected residential building (or building unit) and would not like to compare with other buildings (flats), only with itself – when the occupant of the residential building does not change. Typically, the energy sources in residential buildings are natural gas, oil, biomass, electricity and thermal energy from district heating. The energy consumption monitoring can be implemented based on measurements from the power and gas meters (gas and electricity) and thermal flow meter for district heating/cooling, or based on consumption bills (e.g. oil, biomass).

2.2. Qualitative well-being and IEQ indicators

The combined labelling includes not only energy use but other parameters, because the aim is to create an end user centric certification, which is easy to understand and expresses not only the sustainability of a building but also qualitative parameters as well. The well-being and the indoor environmental quality very much depend on the features of the technical building systems. For example, the central heating control in a building is worse than an apartment control or room control, because in the latter cases the occupant has the chance to control the indoor temperature according to her/his specific needs. Therefore, qualitative features of the technical building systems shall be rated as well. The most important features of the technical building systems were collected which on one hand influence IEQ and occupant well-being in residential buildings, and on the other hand these can be improved by renovation. The qualitative well-being and IEQ indicators, the units and the references are shown in Table 2 below:

Table 2 *Qualitative well-being and IEQ indicators*

Qualitative well-being and IEQ indicators	*Unit*	*Reference / Description*
Control of heating system	-	1. No control 2. Central (building) temperature control 3. Apartment temperature control 4. Room temperature control
Control of cooling system	-	1. No control 2. Central (building) temperature control 3. Apartment temperature control 4. Room temperature control
Fresh air flow (mechanical ventilation) per number of occupants	l/s	In case of mechanical ventilation the fresh air flow per number of occupants meets EN 16798-1 category I or II, or III.
Air tightness of windows and doors	-	1. Poor air-tightness: warped, poorly fitted or unsealed windows and doors. 2. Medium air-tightness: windows and doors with well fitted sealing. 3. Good air-tightness: factory-fitted shaped sealing profiles or certification document according to EN 12207 Class 4.
Exterior shading	%	Rate of the glazed building openings' surfaces with exterior shading to total surfaces of glazed building openings. Openings are taken into account only from East to West, the Northern openings are not considered.
Radiant heating and/or cooling system	%	Adapted from WELL labelling scheme. Radiant heating and/or cooling system operates in rooms at least 50% of the conditioned floor area.
Radiant temperature asymmetry	-	ISO 7730 Category II

2.3. Measured well-being and IEQ indicators

The qualitative well-being and IEQ indicators give feedback to the end user about the technical building systems and its capabilities from well-being and IEQ point of view, but do not give information on what figures are realized in the analysed residential building or apartment. Therefore, onsite measurements are needed to evaluate the realized status, giving information to the end-user which parameters are good and which should be improved in order to improve IEQ and well-being.

Those essential parameters are collected that have significant effect on occupant well-being and IEQ in residential buildings and on the other hand these can be improved by renovation. The measured well-being and IEQ indicators, the units and the references are shown in Table 3 below:

Table 3 *Measured well-being and IEQ indicators*

Measured well-being and IEQ indicators	*Unit*	*Reference / Description*
Operative temperature – heating season*	°C	Measured data compared to EN 16798-1 temperature ranges.
Operative temperature – cooling season*	°C	Measured data compared to EN 16798-1 temperature ranges.
Relative humidity of indoor air is between 30 % and 70 %	%	Measured data compared to CEN CR 1752 range (30 to 70 %RH).
CO_2 concentration	ppm	Measured data compared to EN 16798-1 categories.
TVOC	μg/m³	Measured data compared to the limit (500 μg/m³). Adapted from WELL labelling scheme.
Formaldehyde	ppb	Measured data compared to the limit (100 μg/m³). Adapted from WELL labelling scheme.
PM2,5	μg/m³	Measured data compared to the limit (15 μg/m³). Adapted from WELL labelling scheme.
PM10	μg/m³	Measured data compared to the limit (50 μg/m³). Adapted from WELL labelling scheme.

**During the site survey operative temperature in the heating season or in the cooling season has to be measured according to the actual season.*

2.4. Labelling

The energy indicators express the energy characteristic of the building one by one, therefore aggregating them into a single energy indicator is not recommended, but it is proposed to be shown to the end user one-by-one. The energy class (A B, C, ...) of the analysed building provides clear view on the energy efficiency of the actual status. The calculated figures, such as total primary energy use, calculated and measured delivered energy use, share of RES and area weighted average thermal transmittance, provide information on the main energy characteristics of the analysed building or building unit. The energy indicator contains both the energy class and the calculated or measured figures, which are displayed to the end user.

Concerning the joint assessment of well-being and IEQ, the output of the labelling should be one class in order to ensure easy understanding. However, the labelling should present not only the result (the achieved class), but all of the sub-indicators with its gained and theoretical maximum points, which details the result and provide information on what should be improved.

The steps of the labelling of the well-being and IEQ indicators are as follows:

1. Score calculating: the relevant well-being and IEQ sub-indicators gain points according to the Table 4 and Table 5.
2. Sum the gained scores of the relevant sub-indicators.
3. Sum the theoretical maximum scores of the relevant sub-indicators. These include maximum points for all the relevant sub-indicators. For example, if there is not cooling system, or mechanical ventilation system in the building, those won't be concerned when calculating maximum points that can be achieved.
4. Calculate the percentage of total gained points / total theoretical maximum points.
5. Labelling based on the calculated percentage of total and theoretical maximum points:
   - Excellent 90-100 %
   - Good 80-89 %
   - Acceptable 60-79 %
   - Weak 50-59 %
   - Very weak under 50 %

Table 4 *Scores for Qualitative well-being and IEQ indicators*

Qualitative well-being and IEQ indicators	*Scores*
Control of heating system	Room temperature control: 20 points Apartment temperature control: 10 points Central (building) temperature control: 5 points No control: 0 point
Control of cooling system	Room temperature control: 20 points Apartment temperature control: 10 points Central (building) temperature control: 5 points No control: 0 point
Fresh air flow (mechanical ventilation) per number of occupants	Fresh air flow per number of occupants meets EN 16798-1 category I or II - 20 points Fresh air flow per number of occupants meets EN 16798-1 category III - 10 points Fresh air flow is less than EN 16798-1 category III – 0 point
Air tightness of windows and doors	Good air-tightness: 10 points Medium air-tightness: 5 points Poor air-tightness: 0 point
Exterior shading	10 points for 100% of windows from East to West have exterior shading 9 points for 90%-99% 8 points for 80-89% ... 1 point for 10-19% 0 point for 0-9%
Radiant heating and/or cooling system	Radiant heating and/or cooling system operates in rooms at least 50% of the conditioned floor area: 10 points
Radiant temperature asymmetry	Radiant temperature asymmetry meets ISO 7730 Category II: 10 points

Table 5 *Scores for Measured well-being and IEQ indicators*

Measured well-being and IEQ indicators	*Scores*
Operative temperature – heating season	30 points - EN 16798-1 Category II 15 points - EN 16798-1 Category III 0 point - EN 16798-1 Category IV
Operative temperature – cooling season	15 points - EN 16798-1 Category II 8 points - EN 16798-1 Category III 0 point - EN 16798-1 Category IV
Relative humidity of indoor air is between 30 % and 70 %	5 points if RH is between 30 and 70%RH
CO_2 concentration	20 points - EN 16798-1 Category II 10 points - EN 16798-1 Category III 0 point - EN 16798-1 Category IV
TVOC	10 points - TVOC is under 500 μg/m³
Formaldehyde	10 points - Formaldehyde is under 100 μg/m³
PM2,5	5 points if PM2.5 is under 15 μg/m³
PM10	5 points if PM10 is under 50 μg/m³

3. EXAMPLE OF COMBINED LABELLING

In the TripleA-reno project there are 8 demo buildings located in Hungary, Spain, Italy, Netherlands and in Greece. In all demo buildings a monitoring activity and an ethnography research were performed in the existing status (before deep renovation). On the one hand, the aim was to collect information on user habits, energy practices, motivation factors and barriers regarding deep renovation. On the other hand, indoor environmental parameters and energy use was measured for analysis and for feeding them into the combined labelling scheme. The testing of the combined labelling has been started recently. An excel sheet was developed in which the user has to give administrative data (name of the building, date), the calculated and the measured energy parameters, furthermore the user has to select the qualitative parameters of the residential unit from a drop down menu, and finally has to evaluate the measured parameters also from a drop down menu.

The results of first test (new family house, built in 2017) of the combined labelling can be seen on the Figure 1 and Figure 2:

TripleA-reno

Combined performance label on Energy, IEQ and well-being

Building name / Apartment	Family house, Dunaszeg						DATE:	22.08.2019
COMBINED PERFORMANCE LABEL								
Season of mesurements	Energy Class	Calculated total primary	Calculated delivered energy use	Measured delivered energy use	Share of RES	Average U	Qualitative well-being and IEQ	Measured well-being and IEQ
Both heating and cooling season	C	119,75 kWh/m²a	115,59 kWh/m²a	115,7 kWh/m²a	0,23 %	0,33 W/m²K	100% Excellent	75% Acceptable

Energy indicator

Number	Name	Unit	Reference / Description	Value
1.1	Energy Class	-	Align with national energy performance certification (EPBD)	C
1.2	Calculated total primary energy use	kWh/m²a	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series	119,75
1.3.1	Calculated delivered energy use (fuel)	kWh/m²a	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series	112,75
1.3.2	Calculated delivered energy use (electricity)	kWh/m²a	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series	2,84
1.3.3	Calculated delivered energy use (district energy)	kWh/m²a	Align with EN 15603 and EN ISO 13790, or EN ISO 52000 standard series	0
1.3	Calculated delivered energy use	kWh/m²a	Sum of all calculated delivered energy use	115,59
1.4.1	Measured delivered energy use (fuel)	kWh/m²a	Based on measurement or energy bills. Energy consumption without any correction	102,8
1.4.2	Measured delivered energy use (electricity)	kWh/m²a	Based on measurement or energy bills. Energy consumption without any correction	12,9
1.4.3	Measured delivered energy use (district energy)	kWh/m²a	Based on measurement or energy bills. Energy consumption without any correction	0
1.4	Measured delivered energy use	kWh/m²a	Sum of all measured energy use	115,7
1.5	Share of RES	%	Renewable primary energy use divided by total primary energy use	0,23
1.6	Area weighted average thermal transmittance	W/m²K	Regarding above ground structures. Uavr = ΣAi*Ui / ΣAi	0,33

Fig. 1 *Combined labelling of a new family house built in 2017 (Part 1)*

Qualitative well-being and IEQ indicator						
Number Name	Unit	Classif.	Reference / Description	Points	Maximum
2.1 Control of heating system	-	5 cat	Room temperature control	20	20
2.2 Control of cooling system	-	5 cat	No cooling system	-	-
2.3 Fresh air flow (mechanical ventilation) per number of occupants	l/s	3 cat	No mechanical ventilation	-	-
2.4 Air tightness of windows and doors	-	3 cat	Good air-tightness: factory-fitted shaped sealing profiles or certification document according to EN 12207 Class 4.	10	10
2.5 Exterior shading	%	11 cat	100% of windows from East to West have exterior shading	10	10
2.6 Radiant heating and/or cooling system	%	2 cat	≥ 50% of the conditioned floor area	10	10
2.7 Radiant temperature asymmetry	-	2 cat	ISO 7730:2005 Category A or B	10	10
Total				60	60

Measured well-being and IEQ indicator					
Number Name	Unit	Classif.	Reference / Description	Points	Maximum
3.1 Operative temperature – heating season	°C	3 cat	EN 16798-1 Category II	30	30
3.2 Operative temperature – cooling season	°C	3 cat	EN 16798-1 Category II	15	15
3.3 Relative humidity of indoor air is between 30 % and 70 %	%	Y/N	30% ≤ RH ≤ 70%	5	5
3.4 CO_2 concentration	ppm	3 cat	EN 16798-1 Category III	10	20
3.5 TVOC	μg/m³	2 cat	TVOC ≥ 500 μg/m³	0	10
3.6 Formaldehyde	ppb	2 cat	Formaldehyde < 100 μg/m³	10	10
3.7 PM2,5	μg/m³	2 cat	PM2.5 < 15 μg/m³	5	5
3.8 PM10	μg/m³	2 cat	PM10 ≥ 50 μg/m³	0	5
Total				75	100

Recommendations:
- Ventilation system with heat recovery is suggested in order to improve indoor air quality or CO2 sensors which displays the measured CO2 so the occupant will know when to open windows - Installing PV panels on the roof is recommended in order to increase renewable energy use and decrease electricity use from the grid

Fig. 2 *Combined labelling of a new family house built in 2017 (Part 2)*

4. CONCLUSION

The TripleA-reno project has end-user centric approach. The main goal of the project is making the deep renovation of residential buildings attractive and affordable for the occupants. As part of the project, a combined labelling scheme is being developed for residential buildings and building units, which includes energy, indoor environmental and well-being indicators that can be changed by (deep) renovation. The proposed combined labelling will give feedback to the occupants about their energy efficiency, indoor environmental and well-being parameters. The labelling provides information on which parameters are good and which should be improved in order to improve energy efficiency, IEQ and well-being.

The validation of the proposed combined labelling is still in progress. The aim of the validation procedure is to test the effectiveness of the proposed scheme. Modifying or final tuning of the combined labelling process is planned based on the experiences of feeding the combined labelling scheme with real data of residential demo buildings located in several countries.

Acknowledgement
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FIRST RENOVACTIVE HOME IN SLOVAKIA OPENED IN 2019

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In Slovakia, there are about 950,000 family houses. About 20 % of these houses are old, damp and one in six Slovaks complain about unsatisfactory housing conditions which can have a severely negative impact on the health of the inhabitants.

Recognizing the potential to significantly improve the livelihoods of Slovakian families VELUX Slovakia partnered with peer companies in the construction sector, the city of Sala and the Slovak Green Building Council to demonstrate, that it is possible to renovate energy efficiently, user-centric and at an affordable price by applying the RenovActive principles to a real-life renovation project.

The result is a refurbished home which is healthier to live in with more daylight and fresh air and the living space has been increased from 75 m2 to 115 m2 through utilization of the attic. The energy consumption has reduced by 80 percent.

The design and construction principles of the RenovActive house in Sala are shared in a free online guide to inspire and guide similar renovation projects in Slovakia and neighbouring countries. During the next two years, the living conditions in the home will be monitored on key parameters in cooperation with the Department of Building Services of the Slovak University of Technology in Bratislava to gather data that can support future projects.

Fact box to RenovActive story:

RenovActive is a methodology developed by VELUX and partners for healthy, affordable and scalable renovation of one-family homes. RenovActive is based on the Active House principles and includes the following key parameters:

- Extension of living space
- Expansion of window area

- Improved energy efficiency
- Hybrid ventilation (natural/mechanic)
- Dynamic sun screening
- Stage by stage implementation approach

RenovActive was first tried out on a demonstration project in Brussels, Belgium, for a large estate of social housing, where 86 homes have been renovated according to the methodology over the past three years.
www.renovactive.sk

IV. SESSION

ENERGY EFFICIENCY AND MANAGEMENT OF BUILDINGS

CALCULATION OF ENERGY PERFORMANCE OF BUILDING USING BIM

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Abstract

BIM designing is establishing among AECO professionals. Advanced BIM software increase efficiency and coordination between disciplines, helps to avoid mistakes, perform analysis and more. Despite its benefits during the whole life-cycle, BIM is to the date used mostly in pre-construction stage. In the area of energy assessment, BIM increase energy performance of building by collaborative work between disciplines, starting by first conceptual design.

In this study, residential building modelled in BIM software Autodesk Revit was examined. The building is 7-storey block-of flats with HVAC systems typical for our region. Energy calculation model of Revit software was closely investigated, followed by conceptual design of building and HVAC.

Keywords – BIM; Energy Model; Conceptual Design; Revit

1. INTRODUCTION

The future of energy performance of building is determined by the emerging policies of countries. In the states of European Union adopted regulations lead to sustainability, low-carbon and environmentally-friendly building sector. Therefore, the means to predict and optimize building energy performance is becoming crucial in Architecture, Engineering, Construction and Operation (AECO) industry.

Today, Building Information Modelling (BIM) is becoming more adopted in building design, construction and operation process. It improves consistency and coordination of contributors integrated in the project, complete documentation with the possibility of optimizing design towards energy efficiency.

2. IMPLEMENTATION OF BIM IN AECO INDUSTRY

The acronym BIM stands for Building Information Modelling/Management [1]. According to National Institute of Building Sciences in the USA, BIM is described as a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition [2].

The main difference between traditional Computer Aided Design (CAD) software and BIM software is the modelling baseline. CAD software work as digital blueprints allowing higher level of punctuality and efficiency in drafting, or even 3D modelling. In BIM software, 3D elements containing real-world properties are used. This allows to export the model to other programs to produce higher-quality renderings, perform analyses, coordinate with other disciplines, fabricate parts etc. [3].

The popularity of BIM rises since 2002, when Autodesk released white paper entitled "Building Information Modelling". Since then, this tool has been gaining popularity among AECO professionals. Eastman describes various benefits of BIM, such as increasing building performance and quality, automatic low-level corrections when changes are made to design, earlier collaboration of multiple design disciplines. cost extraction, synchronizations of design and construction and many more [4].

The governments in UK, Denmark, Norway, Sweden, Finland, Netherlands, Singapore, Mainland China, Hong Kong, Korea and Japan are recognizing the key benefits of BIM for their AECO industry and mandating BIM for their government sector projects [5]. On the other hand, Dainty indicate that there is a gap between the positive predictions and the actual implementation of BIM, and that primarily research has focused on larger firms [6].

3. LEVEL OF BIM DEVELOPMENT

Different levels of the completeness of a digital model may be implemented. According to American Institute of Architect's Building Information Modelling Protocol levels of development (LOD) range from 100 (basic) to 500 (precise) [7].

UK based National Building Specification (NBS) recognises three levels of BIM, where Level BIM 0 stands for 2D drafting and blueprints, while Level BIM 2 is distinguished by fully collaborative work of all professionals [8].

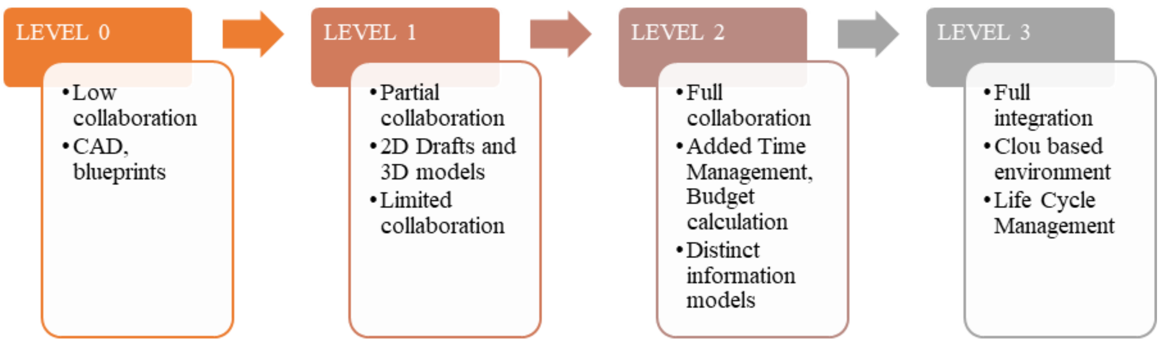

Fig. 1: *Level of BIM according to National Building Specification*

Widely used BIM software to the date are Autodesk BIM 360, Revit, Archicad, SketchUp, Allplan Architecture and many more. They differ in the level of BIM, user interface and compatibility with other designing and scientific tools.

4. BIM DATA FORMATS

Nowadays, numerous of designing tool, simulation programs and BIM software are accessible in the market. The industry has developed two data formats to enable building information exchange between software of various disciplines – IFC and gbXML.

The Green Building XML (gbXML) data format retrieves geometry and non-geometrical information from the model and saves it in a text format under pre-defined notations. The information is divided into three different categories: ShellGeometry, SpaceBoundary and Surface [9]. However, the use of gbXML is currently only on the energy and ecology simulation domain, as its main advatage is carrying building environmental sensing information. [10].

To unified the market, the official standard ISO 16739-1:2018 for data exchange model was established, called Industry Foundation Classes (IFC). IFC schema contains description of the built environment, including buildings and civil infrastructure. Each object´s data are standardized and put in a logical way – **identity** and **semantics** like name and machine-readable unique identifier, **characteristics or attributes** such as material and thermal properties, **relationship** with other object including location and connection, **abstract concepts** like cost or performance, **process** of its installation and operation and list of people who owns or contract the project [11].

5. ENERGY CALCULATIONS AND BIM

The energy performance of the building is calculated, or measured amount of energy delivered and exported used or estimated to meet the different needs associated with a standardized use of the building. According to Energy Performance of Buildings Directive [12], the energy performance of a building shall be expressed with a numeric indicator of primary energy use, based on primary energy factors per energy carrier. For apartment buildings, only heating and domestic hot water are considered, for other buildings also lighting and if applicable ventilation and cooling must be included. The criteria on the primary energy use for different types of buildings as defined in the Act. No. 324/2016 Coll. [13].

The most recent published standard EN 16798-1:2019 [14] focuses on setting new requirement for indoor environmental parameters, especially specifies criteria to be used in standard calculations for indoor environments meant for human consumption.

Senave and Boeykens [15] studied the process of energy simulations performed on BIM models, technical abilities, and pointed out issues concerning the relation between BIM and energy simulation in different stages of design. Authors proposed and investigated five energy building simulation examples:

- BIM model used for evaluation according Energy Performance of Buildings (EPB) regulation in EPB software
- BIM model used in an external Building Energy Simulation program
- Energy evaluation integrated within BIM software
- Tools for energy analysis in the early design stages and their link with BIM
- Mass modelling and early energy evaluation within BIM software

In general, the input data for energy assessment of the building are: building geometry and envelope properties, location on the site and weather data, indoor condition and internal loads and building services [16]. Optimization of these parameters may be performed during different stages of the design. However, the ideal and automated integration of multi-criteria design evaluation with BIM is not fully implemented yet. Instead of automatically generating Building Energy Model (BEM), manually re-entering of information into static calculation or dynamic simulation software is common practice [15].

6. ENERGY EVALUTAION OF THE BUILDING IN REVIT – A CASE STUDY

In this study, BIM software energy calculation possibilities are demonstrated on Revit Energy Model. Revit has been chosen for its complexity, involving architectural design, mechanical, electrical and plumbing (MEP) disciplines, structural engineering and construction for any type of building. However, in this study only basic design procedure is shown, and full potential of the software will be examined in my further work. The main object of this case study is to present simple way to evaluate energy performance of a building including user-friendly parametric optimization tool Adobe Insight.

6.1 Building description

The evaluated object is a detached, 7 storey residential building with floor area of 482,25 m^2. Height of one storey is 3,0 m, total height is 21,0 m. Buildings location is Bratislava. In this case study, no surrounding objects were considered.

The model was started as a conceptual design consisting of 2D elements and was later developed to detailed 3D element structure. The properties of the envelope were set as shown in Table 1. All structures meet the requirements defined in STN 73 0540-2+Z1+Z2.

Windows in the walls are identical with dimensions 1,5 x 1,5m and are placed evenly on each floor.

Tab. 1 *Overview of structures used in the model*

Type of Construction	Material	Thickness (m)	Thermal conductivity (W/(mK)	R- value ((m^{2}K)/W)	U-value (W/(m^{2}K))
Exterior wall	Brick	0,30	0,155	7,20	0,14
	Insulation - EPS	0,20	0,038		
Roof	Concrete	0,20	1,580	8,50	0,12
	Insulation - EPS	0,30	0,036		
	EPDM	0,005	0,138		
Floor	Laminate	0,01	0,209	4,36	-
	Concrete	0,05	1,160		
	Insulation EPS	0,15	0,036		
	Isolation	0,005	1,150		
	Concrete	0,15	1,58		

Air change per hour is considered 0,5. Default set of HVAC parameters for conceptional evaluation was selected, called Residential 14 SEER/8.3 HSPF Split/Packaged Heat Pump. Revit is based in the USA, therefore pre-set HVAC systems are created by their custom and is described by their standards. Selected HVAC system consists of:

- Efficient 14 SEER (Seasonal Energy Efficiency Ratio) /8.3 HSPF (Heating Seasonal Performance Factor) split/packaged heat pump system
- Residential constant volume cycling fan
- 2.0 inch of water gauge (498 pascals) static pressure Constant Volume duct system
- Integrated differential dry-bulb temperature economizer
- Domestic hot water unit (0.575 Energy Factor)

6.2 Creating Energy Model

Energy model was automatically generated from a mass model or architectural model. An energy model is a special form of geometry used for energy simulation engines. The energy model is an abstraction of a building's overall form and layout into a computational network. This network captures all the key paths and processes of heat transfer throughout the building and according to gbXML data format consist of 3 main components: spaces, surfaces, zones.

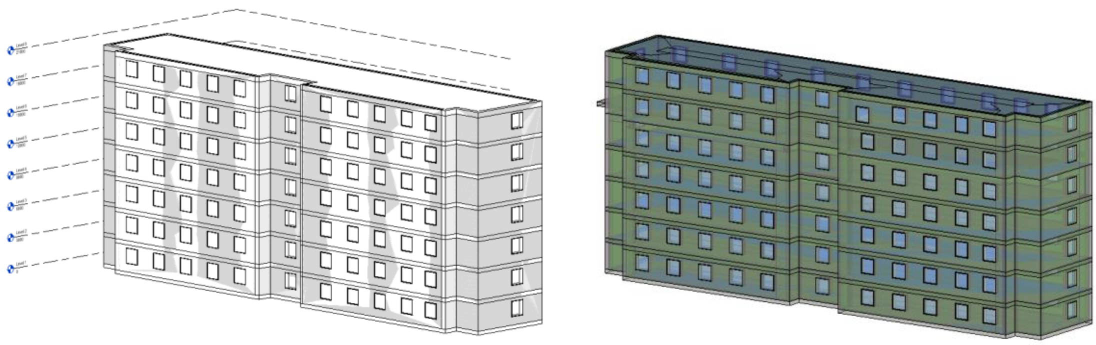

Fig. 2 *Geometry 3D model (left) transformed to Energy model (right)*

6.3 Result overview

Revit uses cloud simulation engines connected via A360 and Autodesk Insight analysis tool, which considerably shorten computational time. Additionally, Autodesk Insight plug-in offers visually pleasing output, overview of the areas, where is potential to gain higher efficiency and real time feed-back on the adjustment (building orientation, thermal properties of building envelope).

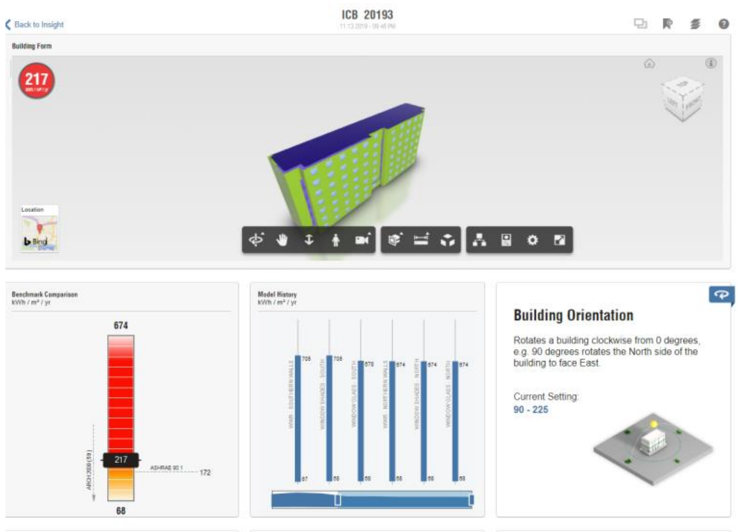

Fig. 3 *Graphic interface Autodesk Insight*

In the conceptual phase only roughly estimated energy performance is calculated. At the beginning, the software offers mean value of Energy Use Intensity (EUI) for multiple variables with different ranges. The user can additionally specify or adjust selected properties, like Building Orientation, Window-Wall-Ratio, Type of Construction or HVAC Properties, PV panel efficiency of PV surface coverage.

Calculated EUI is adjusted in the real time, offering immediate feedback on the main conceptional changes in the project. The changes can be compared in terms of the energy or cost. Results can be exported to Energy Plus, or other tools, for further examination.

Fig. 4 *A showcase of an automatic calculation and of EUI in Insight tool when manually adjusting design parameters during conceptional design stage*

7. RESULT OVERVIEW

BIM is a useful tool for unifying and automatizing processes within AECO industry. In different stages of design or operation, various model precision level may be used. In this study, use of BIM software for energy calculations during the first – conceptional – stage was presented.

Conceptual energy modelling does not produce the same accurate results as energy modelling with building elements. Rather, this is a process to evaluate and compare design decisions based on a rough schematic model comprised of mass elements representing rooms or zones of a building. While it might seem limited, if is a fast and effective way to predict potential effect of a design decision on the overall efficiency of a building.

Acknowledgment

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ANALYSIS OF NON-INVASIVE TEMPERATURE SENSORS IN TERMS OF HEAT METERING

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Abstract

The EU 2020 goals for reducing primary energy consumption and increasing energy efficiency also call for modern building technology to take action. This requires a holistic view of all systems and systems in the building. It is not enough to evaluate only individual subsystems, such as heat supply or heat delivery system in the balance sheet. Reducing primary energy consumption by increasing energy efficiency requires accurate knowledge of the energy flow distribution in the hydraulic distribution grids. In this work, the focus lies on non-invasive temperature measurement. Based on a simplified resistance model, a correction algorithm is developed, which is able to correct the measurement deviation between invasive and non-invasive temperature sensors. With this methodology, the metrological detection of tube surface temperature and ambient temperature is sufficient to determine the approximately true temperature of the medium flowing in the tube. The use of thermal insulation around the non-invasive measuring point will also be discussed.

Keywords - Energy/building monitoring, heat metering, non-invasive/clamp-on temperature sensor, fluid flow temperature

1. INTRODUCTION

Due to given energy policy activities at national and European level, clearly defined targets are set by 2020. These goals are set out in the EU Energy Efficiency Directive [1]. This goes hand in hand with the promotion of energy efficiency improvement measures. The savings in primary energy consumption of the Union, are clearly defined at 20 percent by 2020. In this case, a primary energy consumption of 1842 Mtoe in 2020 is assumed (ROE = crude oil equivalent). This figure should decrease to 1474 Mtoe with the planned increase in efficiency. At present, about 40 percent of total energy consumption in Europe is

attributed to the building sector. According to the European Commission's Energy Efficiency Plan [1], the building sector has the greatest savings potential.
(European Commission [2])

As part of the R&D project OptiMAS (cooperative FFG project) of Research Burgenland, the energy flow of existing building services systems is recorded, monitored, analyzed and optimized by means of a model-based approach with the aid of investment sensors. The OptiMAS approach can drive the optimization potential of single buildings to entire neighborhoods. By adapting essential system parameters, energy and resource efficiency should be increased. A quantification of efficiency measures requires the measurement of physical quantities. The energy distribution for cooling and heating purposes within buildings and entire areas is mostly based on hydraulic systems. Basically, it is necessary to measure both the volume flow and a characteristic temperature difference in order to determine the energy flow. The measurement-technical recording of these quantities can take place by means of invasive sensors (transducers are directly surrounded by the fluid) and non-invasive sensors (application sensors, without contact with the flowing medium). For commercially available heat meters ÖNORM EN 1434 [4] is used. This set of rules consider only invasive temperature measuring methods, such as directly immersed probes or temperature probes in immersion sleeves.

The use of non-invasive surface temperature sensors is not given any attention in the current version. The measurement of the volume flow can be carried out with invasive and non-invasive methods. Among other things, rotary, thermal or ultrasonic sensors have proved their worth in invasive procedures. In non-invasive procedures both clamp-on ultrasound systems and optical systems are used. The use of non-invasive sensors has proved to be useful due to the installation advantage (no interruption of ongoing operation, thus no disturbance for building users). The installation time as well as the complexity of the assembly can thus also be reduced for executing bodies. This is accompanied by a reduction in installation costs, or can be accomplished with a higher number of installed sensors with the same financial cost. (Heschl & Wenig [3])

2. CHARACTERIZATION OF THE RESISTANCE MODEL

The determination of the sensor temperature is explained in more detail here using a simplified model. Assuming a positive temperature difference between the water temperature Twater and the ambient temperature Tamb results in a heat transport outgoing from the pipe inside to the outside. The subsequent heat transfer mechanisms act here from:

- Forced convection (pipe inner surface)
- Heat conduction (through pipe and possibly insulation)
- Free convection and thermal radiation (pipe outer surface)

Non-invasive temperature measurement at the pipe surface of a hydraulic system results in a deviation with respect to the true fluid temperature Tfluid (Tfluid = Twater) and the measured sensor temperature Tsens. Fig. 1 explains the possible thermal relationships.

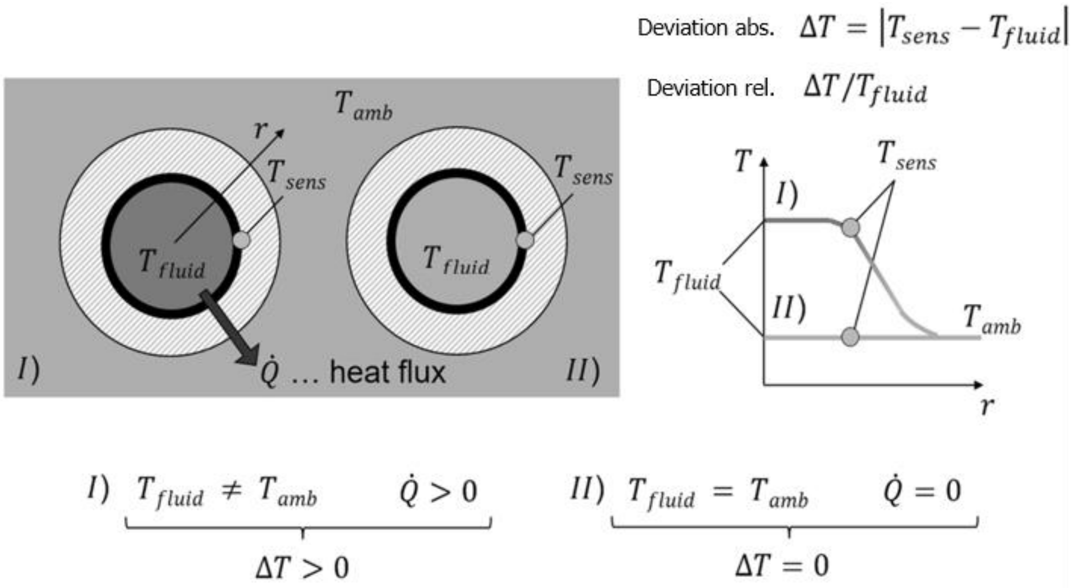
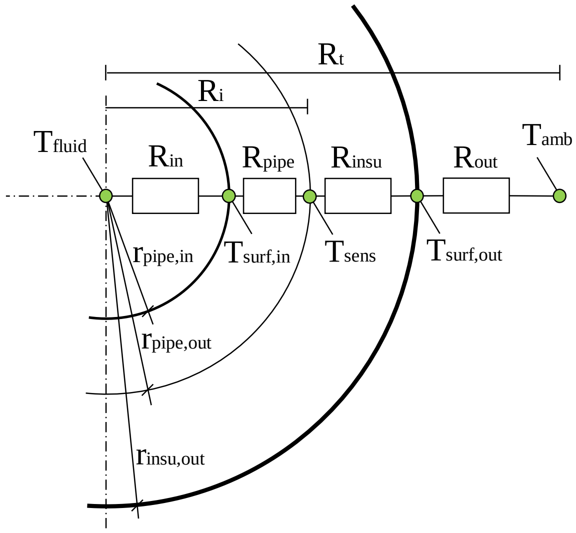


Fig. 1 *Deviation of measurement*

In the non-invasive determination of the fluid flow temperature Tfluid in a tube (with or without insulation), the tube surface temperature Tsens is measured. On the assumption of an ideal surface temperature measurement and the concept of a relative measurement error, it follows that the relative deviation between the measured temperature and the actual fluid flow temperature follows (Tfluid - Tsens) / Tfluid. This characterization with a typical measurement error is problematic because the temperature deviation is related to the heat flow between the fluid and the ambient temperature. Thus, the relative deviation over the measuring range of e.g. 0-70 ° C varies depending on the temperature. Based on a resistance model, the deviation between Tfluid and Tsens is defined by a simplified heat transfer model based on individual thermal resistances, seen in Figure 2. The model takes into account the heat conduction in the pipe and in the pipe insulation according to Fourier's law of heat conduction using the Rpipe thermal resistances and Rinsu defined by the coefficient of thermal conduction λ in W/mK. The heat transfer at the pipe inner wall between Tfluid and the pipe inner wall temperature Tsurf, in, and those outside the construction between the outside temperature Tsurf, out and Tamb is taken into account in the thermal resistances Rin and Rout. They are defined with a linear heat transfer coefficient h in W / m²K. The geometric information is given by the relevant radii r in m. In Equations (1) to (4), the individual thermal resistances are explained to calculate the steady-state heat transfer per meter of pipe length according to $\dot{q} = \Delta T / R$ in W/m.



$$R_{in} = \frac{1}{2 \cdot \pi \cdot r_{\text{pipe,in}} \cdot h_{in}} \quad (1)$$

$$R_{pipe} = \frac{log \frac{r_{\text{pipe,out}}}{r_{\text{pipe,in}}}}{2 \cdot \pi \cdot \lambda_{pipe}} \quad (2)$$

$$R_{insu} = \frac{log \frac{r_{\text{insu,out}}}{r_{\text{pipe,out}}}}{2 \cdot \pi \cdot \lambda_{insu}} \quad (3)$$

$$R_{out} = \frac{1}{2 \cdot \pi \cdot r_{\text{insu,out}} \cdot h_{out}} \quad (4)$$

Fig. 2 *Thermal resistance model of the heat transfer between the fluid temperature Tfluid and the ambient temperature Tamb*

If the resistance values are constant, the deviation between Tfluid and TSens can be characterized by a Tfluid independent resistance ratio, as shown in Equation (5). The thermal resistances are combined into an internal thermal resistance Ri (thermal resistance up to the surface temperature sensor) and a total thermal resistance Rt. The resistance ratio Ri / Rt describes the temperature deviation between Tfluid and TSens related to the temperature difference of Tfluid and Tamb, which can be seen as the driving force of the heat flow.

$$\frac{R_{in} + R_{pipe}}{R_{in} + R_{pipe} + R_{insu} + R_{out}} = \frac{R_i}{R_t} = \frac{(T_{fluid} - T_{sens})}{(T_{fluid} - T_{amb})} \quad (5)$$

3. EXPERIMENTAL HARDWARE

To characterize the described non-invasive temperature measurement approach, in particular for non-metallic tubes and typical HVAC-related temperatures, and to test the performance of the compensation algorithm, an experimental study was carried out on a test bench of the University of Applied Sciences Burgenland in Pinkafeld, Austria. The test rig consists of a hydraulic circuit in which a fluid with a defined flow rate and temperature is pumped through a test track with exchangeable 1.5 m straight tubes. The current fluid temperature is set and controlled by the cooling circuit Huber Unistat 510. The flow rate is determined by a constant speed pump and a 3-way controlled valve to ensure the steady state flow rates measured by the Coriolis Endress + Hauser flow meter Promass 300 with an expected basic accuracy below 0.05% of the measured value. In order to realize flexibility in the tested configurations, tubes of different materials and diameters can be installed in the test section. The results of test runs with a PVC-U TP water pipe measuring 32x1.9 mm are presented below, as shown in Fig. 3. Each test tube is equipped with a T-junction into which a single invasive Pt100 four-wire temperature sensor is inserted. In addition to the T-shaped, non-invasive temperature sensors, thermal paste with 10 W / mK is used upstream and downstream. Two types of non-invasive four-lead Pt100 sensors are tested. They differ in shape and geometric dimensions as well as in material, brass and aluminum. All invasive and non-invasive temperature sensors were calibrated with a linear calibration function at seven calibration temperatures between 10 and 70 ° C against the same reference sensor. The remaining temperature difference to the reference after the calibration is assumed to be below 0.05 °C. The straight test pipe sections, including the mounted clamp-on sensors and the T-fitting, were insulated with 32 mm closed-cell foamed polyethylene. The data acquisition was carried out with the embedded controller National Instruments CompactRIO CX 9067 with a sample rate of 1 Hz. The test bench was situated inside a conditioned laboratory hall with ambient temperatures between 20 and 25 °C located about 400 m above sea level. The indoor ambient temperature was monitored during the experiments with an additional four-wire Pt100 temperature sensor.

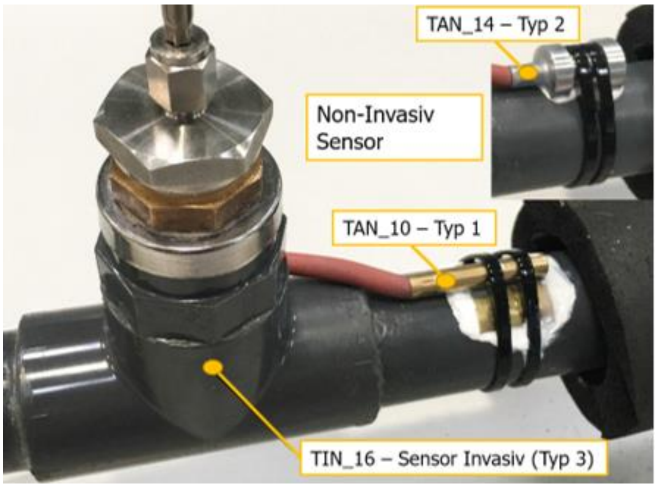


Fig. 3 *Measurement Position with brass sensor (TAN_10) and aluminium sensor (TAN_14)*

4. RESULTS FROM THE STATIC MODEL

Although several limitations of the considered compensation algorithm were already derived from the characterization of the clamp-on sensor installations, the results of a static error correction applied on the steady state values, which were used to identify the resistance ratios, is shown in Fig. 4. The correction algorithm is based on the described resistance model by applying it on the measured sensor data. Compared to the original temperature deviation between the measured clamp-on sensor value and the fluid temperature, the deviation after applying the compensation algorithm is significantly reduced for both installed sensors and over the entire tested temperature range. In detail, the absolute error after applying the correction algorithm is reduced to <0.2 K for 97 % and <0.1 K for 77 % of all 30 steady state values.

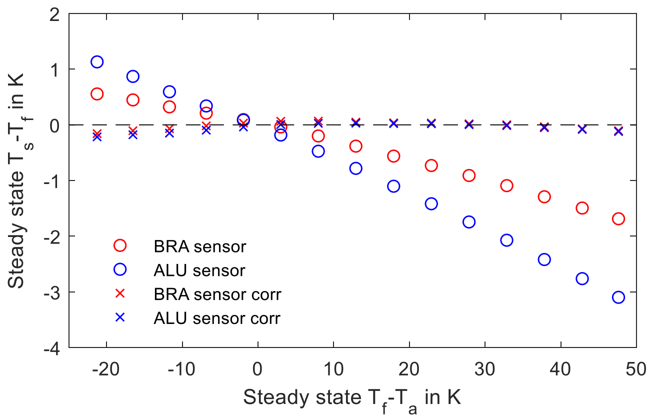


Fig. 4 *Measurement Position with brass sensor (TAN_10) and aluminium sensor (TAN_14)*

5. EXPERIMENTAL LABORATORY ANALYSIS

The various measurement scenarios on the laboratory test bench are based on the already described deviations between the invasively measured fluid temperature Tfluid in a pipe flow and the non-invasively recorded pipe surface temperature Tsens. The model parameters calculated in the previous chapters for the laboratory test bench, such as the resistance ratio Ri / Rt and the time constants T and Tt, are used. Basically, a distinction is made between static and dynamic correction calculation. Above all, border areas of the respective corrections are to be evaluated. The consideration of dead time Tt is also analyzed and evaluated. The main focus is on answering the key question, and on the knowledge of whether and in which embodiments this method of correction calculation is expedient. Fig. 5 shows a detailed extract of the results with or without correction calculation as well as a static and dynamic correction. The temperature jump is around 5 K. As expected, the deviations without correction on the PVC-U pipe section with an average of 1-3 °C are significant. For dynamic temperature changes, the limits of the static correction calculation are shown. The static correction (Fig. right) shows a good correction in the approximately stationary range, but once again the deviations in dynamic temperature changes can be seen, which in turn manifests itself within the limits of this methodology.

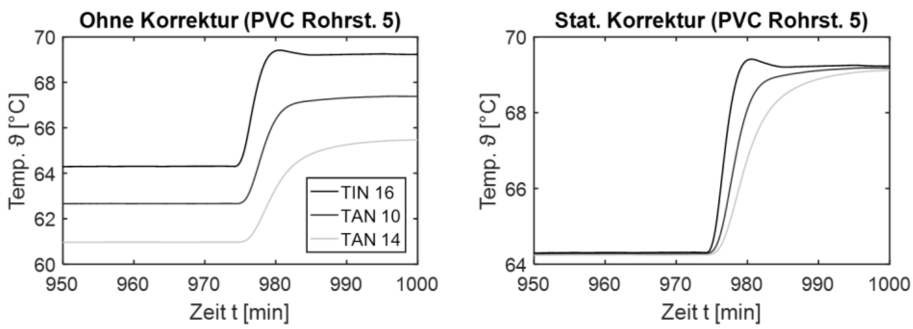


Fig. 5 *Detail extract without correction (Fig. left), with static correction (Fig. right)*

6. CONCLUSION

The EU 2020 energy efficiency targets also include the collection and analysis of energy flows from building services. The majority of these building services systems are designed rated load cases. However, these systems operate in part-load operation mode over a long period of time. The part-load operation mode reduces not only the efficiency of the system, also the energy flows in hydraulic distribution grids are subject to change. This work provides an insight into the prerequisites for the adequate use of non-invasive temperature sensors for energy stream acquisition. In addition to a sufficient knowledge of the measuring point, this also requires information regarding the pipe dimensions and pipe materials. When mounting these temperature sensors, ensure good thermal coupling between the temperature sensor and the test object, otherwise the measurement deviation of Tfluid - Tsens will increase due to an additional thermal measuring error. Three measurement scenarios were examined at the laboratory test bench. These show significant differences between pipe materials with high thermal conductivity of e.g. $\lambda >$ 300 W / (mK) and pipe materials with correspondingly lower thermal conductivity of e.g. λ approx. 0.15 - 0.7 W / (mK). The choice of these pipe materials was made in order to map both extremes. The results of the experimental laboratory analysis confirm the theoretical considerations of the model as well as the applicability of the computational correction algorithm. The use of non-invasive temperature sensors in subdevices of heat meters remains untreated in the currently valid regulation of heat metering systems [4]. However, the influence of temperature sensor pairs by mounting immersion sleeves is mentioned. The given deviation between the measurement results with and without immersion sleeves must be within the range of half the error limit (± 0.7 K). Future non-invasive fluid temperature measurement research activities will focus on a concept with a dynamic correction algorithm, which includes automated detection of model parameters, such as resistance ratios and time constants.

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THE APPLICATION OF RADIANT WALL COOLING IN NEW AND EXISTING BUILDINGS

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Abstract

The use of radiant wall cooling presents a potentially feasible solution to cover the cooling demand of buildings due to its suitability for combination with renewable energy sources at relatively high sensible cooling capacity. We define and directly compare four types of wall cooling systems, from which three are potentially suitable for building retrofit. Systems with pipes underneath the surface provide higher cooling output and are sensitive to pipe spacing. Systems with pipes embedded in the core allow thermal storage and are sensitive to insulation thickness. Thermal conductivity of the core material proved to be an important parameter to consider except for the system with the pipes separated from the core by thermal insulation. The system´s suitability depends on the requirements such as avoiding interventions in the interior, exploiting thermal storage, or providing fast thermal dynamics.

Keywords – wall cooling; radiant system; heat transfer; cooling output

1. INTRODUCTION

The installation of water-based radiant systems can help alleviate the negative effects of the continuously increasing cooling load of buildings. This should be possible due to the suitability of the radiant systems for combination with low-grade renewable energy sources such as heat pumps and solar collectors [1-3] at relatively high sensible cooling capacity [4]. In a moderate and dry climate and well thermally insulated buildings like, e.g., in Europe, only a fragment of the surface may be enough to create thermal comfort throughout the whole year [5-7]. This makes radiant walls potentially feasible systems for new and retrofitted existing buildings, which could be preferable to the more common radiant floors and ceilings due to the following benefits: (i) suitability for retrofitted buildings, (ii) comfortable thermal environment [8-10], (iii) higher cooling capacity for walls (70 W/m^2) than for radiant floors (40 W/m^2), (iv) the possibility of operation as a thermal barrier to reduce heat transmission through walls [11-13]. The aim of the present study is to directly compare four types of radiant walls that differ from each other by the configuration of their material layers, pipe location, and their suitability for installation in existing buildings. The effect of various parameters of the wall systems is also investigated to provide practical guidance to the system design.

2. PHYSICAL MODEL AND CALCULATION METHODS

Four types of radiant wall systems were investigated (Fig. 1), constructed either of aerated concrete with low thermal conductivity (0.19 W/(m.K)) or a thermally conductive reinforced concrete (1.58 W/(m.K)). Three out of the four systems have the active layer coupled to the concrete core and thereby represent thermally activated building systems (TABS), and three of the systems are potentially suitable for building retrofit.

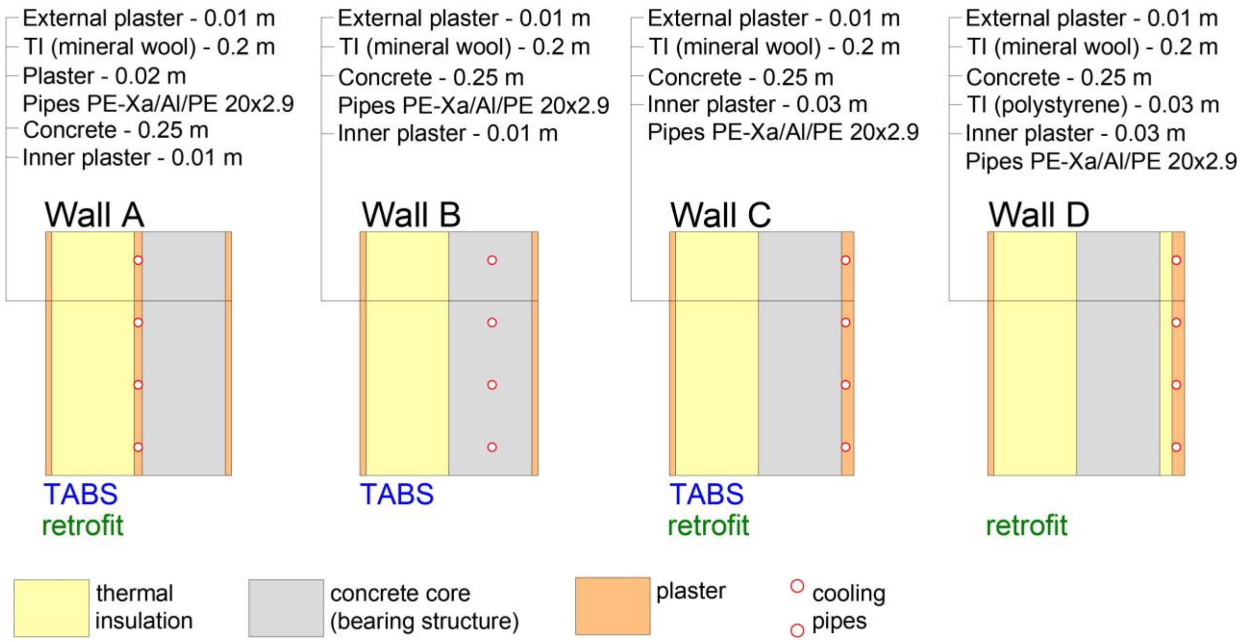


Fig. 1 *Wall cooling systems investigated*

The results were obtained by solving the equations of two-dimensional heat transfer by conduction, using a dedicated CalA software [14,15], which has been verified in accordance with EN ISO 10211 [16]. The heat flux and temperature distribution were calculated for a characteristic fragment of a radiant wall (Fig. 2). The combined effect of ambient temperature and solar radiation incident on the wall was replaced by sol-air temperature ($T_{sol\text{-}air}$) [17]. The course of sol-air temperature for the month of July and a southern wall is shown in Fig. 3 together with the input data. In the present study, the design value of the overall heat transfer coefficient on the inner wall´s surface of 8 W/(m^2.K) [18] was used in all the simulations. A heat transfer coefficient on the outer wall´s surface of 15 W/(m^2.K) which represents summer weather conditions was used as recommended by the national standard [19].

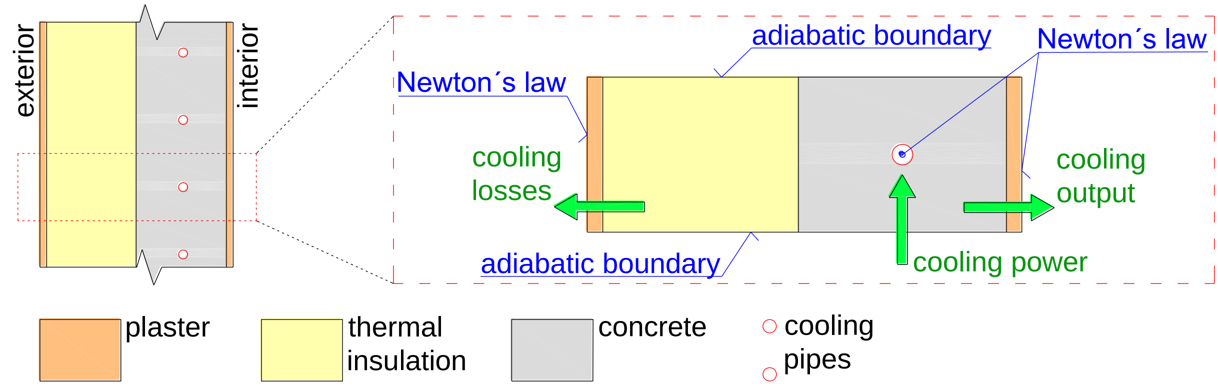


Fig. 2 *Boundary conditions defining specific heat flux on a wall surface*

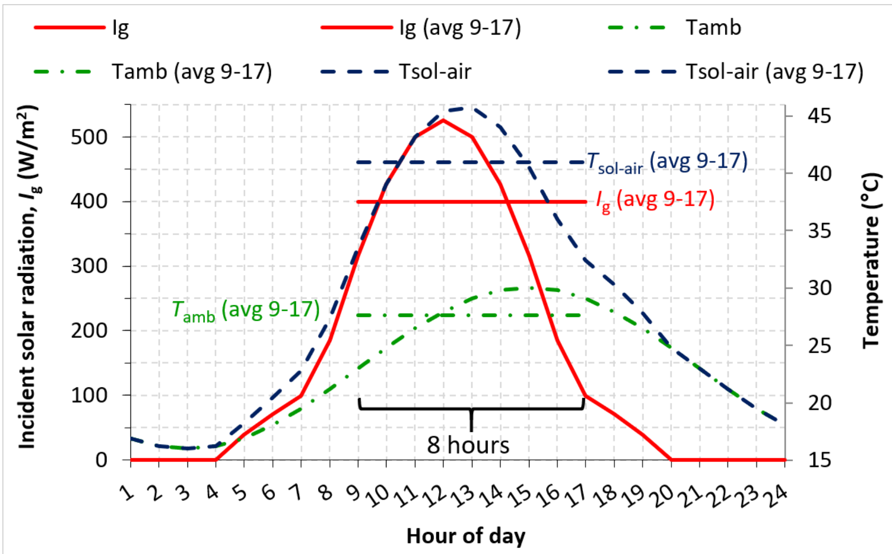


Fig. 3 *The course of ambient temperature, sol-air temperature and incident radiation on a southern wall in July [20], and their averages over eight hours*

3. DEFINITION OF HEAT TRANSFER EFFICIENCY

Heat transfer efficiency is a measure of how efficiently the heat or cool supplied from pipes is transferred to the inner surface of the wall where it is emitted to the conditioned space. The heat transfer efficiency can be calculated by the step-down method from a declining curve:

$$HTE_{\mathrm{stepdown}} = \left(100 - \frac{\delta_{\mathrm{n}}}{2\,.\,\langle\bar{\delta}\rangle}\,.\,100\right) \quad (\%) \tag{1}$$

where δ_{n} is the nominal time constant (h); $\langle\bar{\delta}\rangle$ is the wall mean age of heat flux (h). The age of heat flux means the time passed until the heat flux is stored in the wall structure after entering the structure through pipes. For a point within the wall, the local mean age of heat flux is the time it takes for the heat flux to be stored in the actual point after entering the wall. The structure mean age of heat flux is the mean age of all the heat flux in the structure. The heat transfer efficiency is defined through the ratio of the lowest possible mean age of heat flux $\delta_{\mathrm{n}}/2$ and the actual mean age of heat flux $\langle\bar{\delta}\rangle$. The lower the ratio, the less efficient the heat storage and the more efficient the heat transfer from the pipe to the inner surface of the wall. High heat transfer efficiency, therefore, indicates efficient heat or cool transfer from the pipe to the inner surface of the wall. In the step-down method, the nominal time constant is obtained from the following equation (Fig. 4):

$$\delta_{\mathrm{n}} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{i=n}} \frac{\theta_{\mathrm{i}} + \theta_{\mathrm{i-1}}}{2}\,.\,(t_{\mathrm{i}} - t_{\mathrm{i-1}})}{\theta_0} \quad (\mathrm{h}) \tag{2}$$

where t_i is the time that has elapsed since the heat flux was supplied in the wall through pipes (h); θ_i is the difference between the wall surface temperature at the time t_i and the steady-state wall surface temperature, i.e. $\theta_{\mathrm{s,i}} - \theta_{\mathrm{steady}}$ (K); θ_{i-1} is the difference between the wall surface temperature at the time t_{i-1} and the steady-state wall surface temperature, i.e. $\theta_{\mathrm{s,i-1}} - \theta_{\mathrm{steady}}$ (K); θ_0 is the temperature of the inner surface of the wall at the beginning (°C). The wall mean age of heat flux is calculated from the equation:

$$\langle\bar{\delta}\rangle = \frac{\sum_{\mathrm{i=1}}^{\mathrm{i=n}} \left[\frac{\theta_{\mathrm{i}} + \theta_{\mathrm{i-1}}}{2}\,.\,(t_{\mathrm{i}} - t_{\mathrm{i-1}})\,.\,\frac{t_{\mathrm{i}} + t_{\mathrm{i-1}}}{2}\right]}{\sum_{\mathrm{i=1}}^{\mathrm{i=n}} \left[\frac{\theta_{\mathrm{i}} + \theta_{\mathrm{i-1}}}{2}\,.\,(t_{\mathrm{i}} - t_{\mathrm{i-1}})\right]} \quad (\mathrm{h}) \tag{3}$$

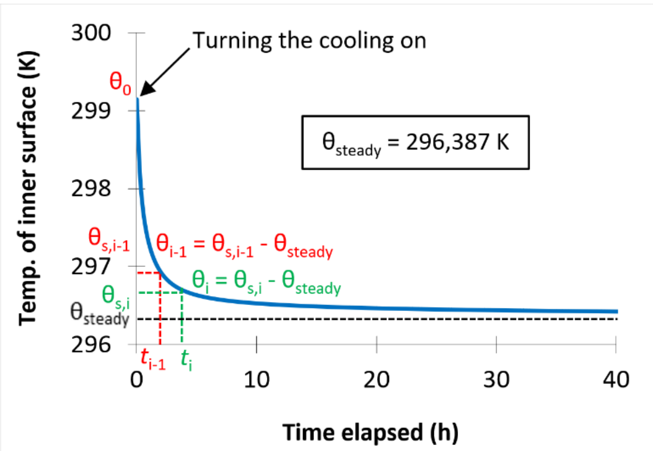


Fig. 4 *Decline in inner surface temperature of the wall after turning the cooling system on*

4. RESULTS AND DISCUSSION

4.1 Heat transfer efficiency

For each of the wall systems, the heat transfer efficiency was tested for a matrix of 3 x 3 realistic boundary conditions (Fig. 5). These involve combinations of the thickness of the concrete equal to 200 mm, 300 mm, and 400 mm and spacing of the pipes equal to 150 mm, 200 mm, and 250 mm. The thickness of thermal insulation was always 200 mm. The box plots in Fig. 5 represent the minimum, median and maximum values of the heat transfer efficiency.

The heat transfer efficiency was substantially lower for Walls A and B with pipes further from the wall´s inner surface than for Walls C and D with pipes underneath the surface. For Wall A, the heat transfer efficiency was always lower than 50% and it could be as low as 24%. The heat transfer efficiency has improved by moving the pipes from thermal insulation to the concrete core (Wall B), although the maximum was only about 50%. Moving the pipes closer to the interior (Wall C) improved the heat transfer efficiency considerably. In this case, the values were notably lower for the thermally conductive reinforced concrete than for aerated concrete. The heat transfer efficiency was best when the pipes were located underneath the surface and insulated from the core (Wall D).

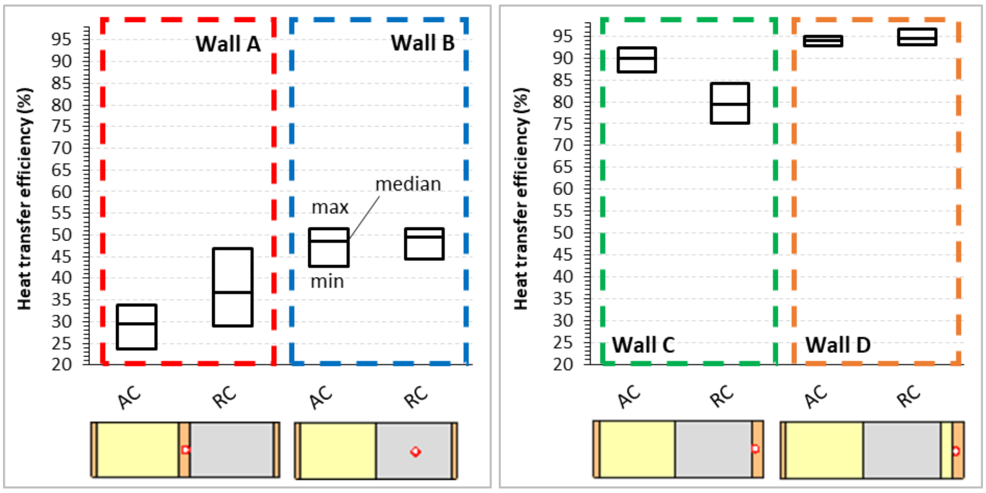


Fig. 5 *Results of heat transfer efficiency. AC – aerated concrete, RC – reinforced concrete*

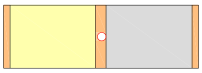
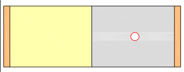
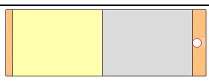
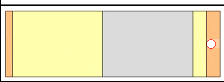
4.2 Thermal dynamics

In the tests of thermal dynamics, the cooling system was powered on at 9:00, and turned off at 17:00 o´clock. A control strategy was created where the cooling output was kept between 63% (q_{63}) and 90% (q_{90}) of its maximum value by turning the cooling system on and off. Although simplified as compared to real operating conditions, this control strategy allows evaluating thermal dynamics and controllability of the wall systems.

Regardless of the water temperature and concrete properties, at the end of the test interval, the cooling output of Walls A and B reached only a fraction of its maximum value (Table 1). Fig. 6 shows that concrete properties are crucial for the thermal dynamics of Wall C. Despite the cooling output being relatively high regardless of the core properties, the combination with reinforced concrete resulted in slow thermal dynamics. This contrasts with the results for Walls A and B, in which using reinforced concrete enhanced the thermal dynamics and cooling output.

Adding thermal insulation between the thermally active layer and the concrete core in Wall D resulted in a fast reaction of the system and high cooling output (Table 1). In this case, the number of operation cycles was highest among all of the wall systems because of the low heat capacity of the active layer. Consequently, even during a day with substantial variations in the cooling load, Wall D can keep the room temperature in a comfortable range, although it may require a high number of operation cycles.

Table 1 *Max. cooling output and power, and the number of operation cycles (T_{water} = 20°C).*

Wall		Concrete	Max. cooling output $q_{i,max}$ (W/m²)	Max. cooling power $q_{t,max}$ (W/m²)	Number of operation cycles
A		Aerated, λ = 0.19 W/(m.K)	3.6	8	0
		Reinforced, λ = 1.58 W/(m.K)	15.8	20	0
B		Aerated, λ = 0.19 W/(m.K)	6.0	10	0
		Reinforced, λ = 1.58 W/(m.K)	23.1	27	0
C		Aerated, λ = 0.19 W/(m.K)	26.2	29	3
		Reinforced, λ = 1.58 W/(m.K)	29.0	33	0
D		Aerated, λ = 0.19 W/(m.K)	25.4	28	6
		Reinforced, λ = 1.58 W/(m.K)	25.2	29	5

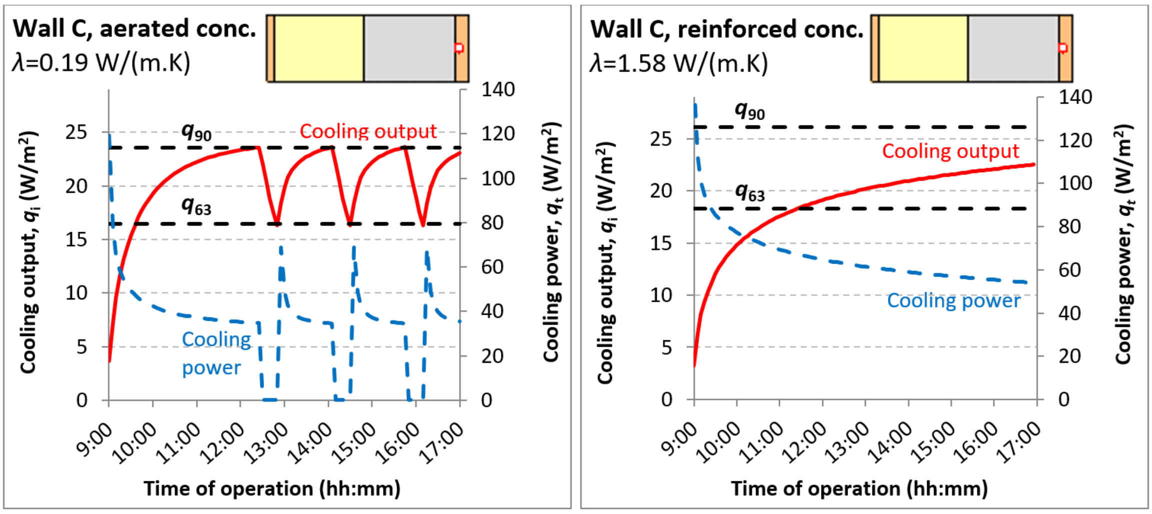


Fig. 6 *Effect of core material on the thermal dynamics of Wall C*

4.3 Cooling output

Fig. 7 shows the maximum cooling output and losses for the cooling systems located on an external wall. Walls A and B have the lowest cooling output, are most sensitive to the concrete properties, and their ratio of cooling loses to power (*L*) is highest. The maximum cooling output of the two systems with pipes underneath the surface, C and D, is higher than that for Walls A and B, and it is less dependent on concrete properties. Especially in Wall D, which has the active layer insulated from the concrete core, the effect of concrete properties is negligible. The cooling output of Wall C is superior to that of Wall D because the thermal coupling of the active layer with the concrete core allows a more even distribution of the cool throughout the surface layer.

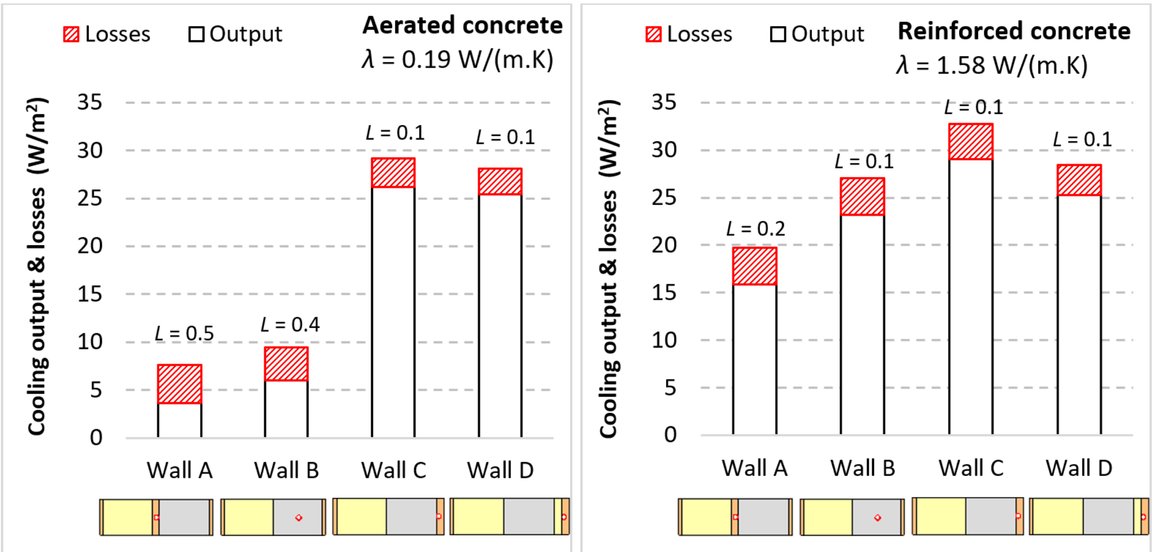


Fig. 7 *Cooling output and losses for the cooling systems located on an external wall. L = losses/power*

4.4 Thickness of wall and spacing of pipes

Fig. 8 shows the effect of wall thickness on the cooling output. The results refer to the concrete thickness (d_{conc}) of 200 mm, pipe spacing of 150 mm, and variable thickness of thermal insulation. Adding thermal insulation has minor effect on the cooling output when the core is made of aerated concrete. The negative cooling output for Wall A with no thermal insulation means that the wall system does not cool the room, but it absorbs heat from the exterior and transfers it to the inside. On the other hand, the effect is crucial when the core is made of the conductive reinforced concrete. The first centimetres of thermal insulation are critical. Increasing the thickness beyond 50 mm does not provide any considerable benefits. The exception is Wall D when the cooling output is high even without any insulation on the outer side of the wall. Fig. 9 shows the relationship between the cooling output and the spacing of the pipes. The results refer to the concrete thickness (d_{conc}) of 250 mm and insulation thickness (d_{TI}) of 200 mm. The spacing of pipes has an important effect on the cooling output of Walls C and D. The effect is much smaller for Walls A and B, and it is stronger when the core is made of the conductive reinforced concrete.

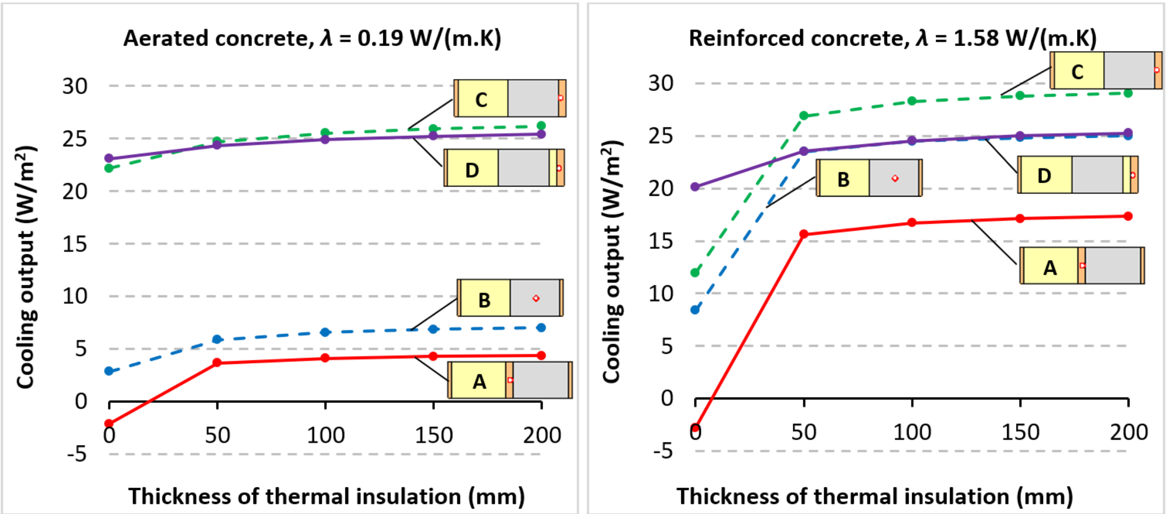


Fig. 8 *The effect of insulation thickness on cooling output,* d_{conc} *= 200 mm*

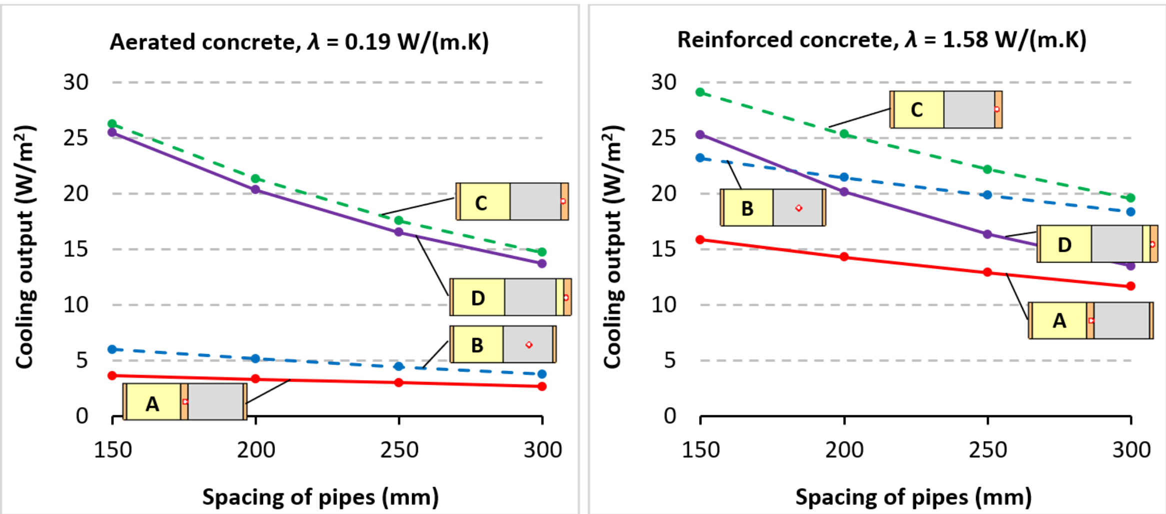


Fig. 9 *The effect of spacing of pipes on cooling output,* d_{conc} *= 250 mm,* d_{TI} *= 200 mm*

5. CONCLUSIONS AND RECOMMENDATIONS

The results facilitate the selection of the most suitable wall cooling system and provide practical guidance to the system design. The main conclusions that can be drawn from this study are as follows:

- Walls C and D with the pipes located underneath the surface have a higher cooling output than Walls A and B with the pipes embedded in the core. They, therefore, require a smaller area of active surface at the same temperature of cooling water, or a higher temperature of cooling water at the same area of active surface which improves the efficiency of the cool source.

- Wall A with the pipes located on the outer side of the thermally active core and Wall C with the pipes underneath the surface provide the potential for thermal storage in retrofitted buildings. Wall A helps avoid major interventions in the interiors of retrofitted buildings but has the lowest cooling output.
- The low heat transfer efficiency and slow thermal dynamics of Walls A and B with the pipes embedded in the core reduces the required cooling power and the number of operation cycles of the cool source. It also allows shifting its operation to times when the electricity is more affordable. Wall D with high heat transfer efficiency and fast dynamics requires continuous operation of the cool source or additional thermal storage. Wall C represents a compromise between these extremes.
- The appropriate operation strategy of the wall system depends on the location of the pipes, configuration of the material layers and material of the core. Wall C combined with a core with low thermal conductivity and Wall D allow fast changes in the cooling output and thereby good controllability of the room temperature. The other systems investigated require more sophisticated control strategies because of their slow thermal dynamics and lower heat transfer efficiency.
- The cooling output of Walls A and B with the pipes embedded in the core is sensitive to insulation thickness, whereas the cooling output of Walls C and D with the pipes underneath the surface is sensitive to pipe spacing. The sensitivity of Wall C to insulation thickness depends on the thermal conductivity of its core. Wall D functions well even without any thermal insulation on the outer side of the wall.

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V. SESSION

OUTDOOR ENVIRONMENT AND RENEWABLE ENERGY

INSTALLATION AND ARRANGEMENT OF BRANCH PIPES FROM THE POINT OF VIEW OF HYGIENE OF POTABLE WATER

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Abstract

Potable and hygienically suitable water supply is important for both residential and commercial buildings such as hospitals, schools, office buildings, hotels, sports facilities, retirement homes, restaurants and others. The contribution focuses on potable water hygiene from cold and hot water pipes routing point of view and its arrangement. The paper also provides the definition of potable water, basic factors affecting its quality and basic rules for its control. It is necessary to propose the proper water supply system solution in order to ensure the potable water hygiene, because there are usually not the ideal conditions for potable water in the buildings. The resulting hygienic risks can be reduced using the right technical solution. In the paper, the classical trunk-and-branch system with the hygienically more suitable installations are compared.

Keywords - potable water; cold water; hot water; hygiene of potable water

1. INTRODUCTION

Persons producing and supplying water intended for human consumption are obliged to ensure that the supplied drinking water meets health safety requirements and that the limits of potable water quality indicators are checked and observed. In a building, a building operator is responsible for the potable water quality. The basic factors affecting the potable water quality in buildings are: proper piping material selection, correct piping design, water stagnation prevention, proper system solutions for distributional system, and proper operation and maintenance. The contribution focuses on the potable water hygiene from the water stagnation prevention point of view using several variants of branch pipes installation.

2. POTABLE WATER HYGIENE REQUIREMENTS

We could define potable water as a "water intended for human consumption" [1]:

a) all water either in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a distribution network, from a tanker, or in bottles or containers;
b) all water used in any food-production undertaking for the manufacture, processing, preservation or marketing of products or substances intended for human consumption unless the competent national authorities are satisfied that the quality of the water cannot affect the wholesomeness of the foodstuff in its finished form [1].

Potable water has to meet the requirements that are in accordance with a valid legislation. The potable water quality requirements which are valid in all Member States of the European Union are laid down in Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. In 2015, a revised proposal for a Directive amending Annexes II and III on the quality of water intended for human consumption was prepared. Those Annexes set out the minimum requirements for monitoring programs for water intended for human consumption and specify the methods for analysing the various water quality parameters. In the Council Directive, there is a limit value of various chemical parameters which have to be controlled in the potable water [2].

In a building, a building operator is responsible for the quality of potable water and checking and observing the limits of potable water quality indicators. The range and frequency of water quality control is stipulated in the above-mentioned Council Directive 98/83/EC and depends on the amount of supplying water and number of people living in a supplied area - e.g. with a population of 5,000 people in the supplied area and volume of 1,000 m^3 produced water per day, the minimum number of analyses per year is 4 and the number of complete analysis is set once a year. The number of sampling points shall not be less than the number of minimum analyses. The water quality control and its health safeness is determined through the water quality indicators set representing the physical, chemical, biological and microbiological water properties [2].

3. BASIC FACTORS AFFECTING THE POTABLE WATER QUALITY

The most important factors affecting the potable water quality in buildings are:

- pipe material: the use of unsuitable materials and their unsuitable combination leads to an increased concentration of substances dissolved from the installed materials,
- water stagnation: the occurrence of too low water flow rate (oversized pipe diameter) or a disruption of water supply for a certain period of time cause a change in water quality due to greater stagnation, leading to an increase in solute concentration,
- technical solutions of the potable water distribution system in the building

From the technical point of view, it is necessary to propose the proper water supply system solution - correctly designed pipe material in terms of water contamination by microorganisms, correct dimensioning, routing and water pipes isolating with regard to water temperature, water volume in the pipeline, water flow rate in the pipeline, and water stagnation [3].

From potable water hygiene point of view, continuous building operation and regular water abstraction from all water taps would be ideal. Under these conditions, the water always moves and there is no danger of stagnation. These ideal conditions are usually not found in the building, but the resulting hygienic risks can be reduced using the correct technical solution - manual or automatic flushing systems. There are also methods of connecting the water supply branch pipe to the water taps so that the entire section of the branch pipe is flushed each time the water tap is used.

The branch pipe is a connecting pipe from the connection to riser pipe and it conveys water to the release valves. Branch pipes should be placed:

- in pre-wall system
- in slots or openings in a wall (there is a risk of noise)
- built in floor layers, installed in a protective sleeve and thermal insulation

If the potable water in branch pipe has stagnated for too long, it is prone to reach critical temperature ranges - cold water temperature can rise above 15 °C and hot water temperature can drop below 45 °C thus creating the ideal conditions for microorganisms growth. The endangered are the rarely used release valves such as guest toilet, fire water system or water connection to a garden hose. If both bathtub and shower are available in the bathroom at the same time, the regular use of both water taps is generally not guaranteed. Reasonably designed piping can significantly reduce the stagnation risk, especially in rarely used taps, thereby contributing to maintaining potable water quality [3].

4. ALTERNATIVE SOLUTIONS OF INSTALLATION OF BRANCH PIPES OF WATER

4.1 Trunk and branch system with a connection of valves using T-pieces fittings

Trunk and branch system consist of a branch pipe for hot and cold water. Release valves (water taps) are connected to the branch pipe by T-pieces fittings (Fig. 1). The T-pieces system is the most popular way to configure tubing for domestic water. Provided that all release valves are used regularly, suitable conditions are created for the hygienic operation of the potable water pipeline. Rarely used pipeline sections can create suitable conditions for bacteria that contaminate the rest of the pipeline network. Using the T-piece fitting is not enough to flush the entire installed system; water is not exchanged in all other parts of the pipe [4].

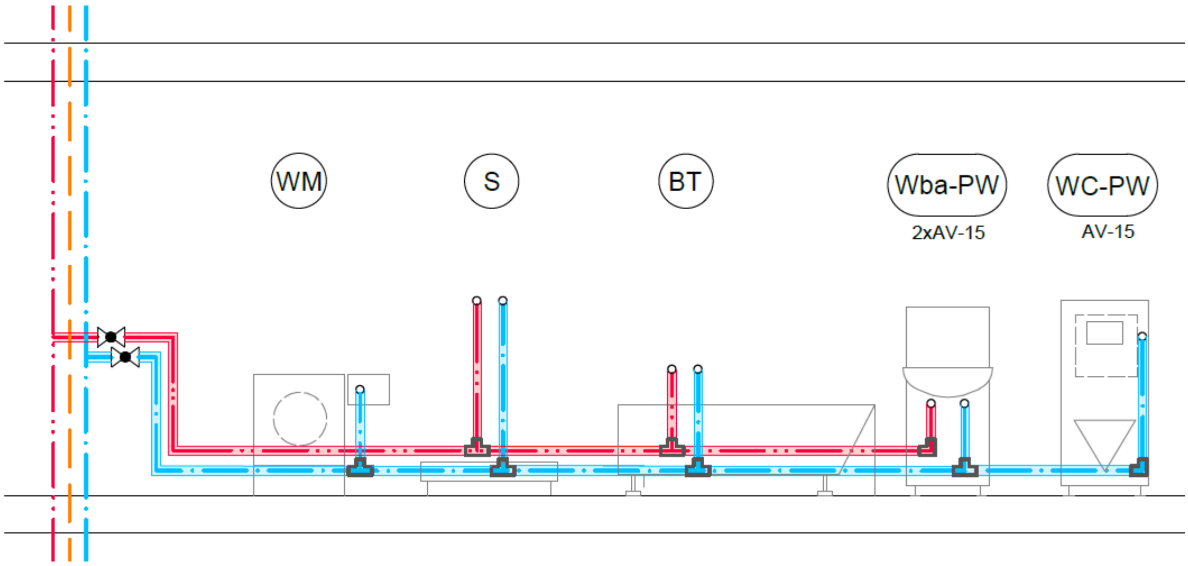

Fig. 1 *Trunk and branch system with a connection of valves using T-pieces fittings [author]*

cold water pipe,
hot water pipe,
hot water circulation pipe,
WM: wash machine, S: shower, BT: bath, WBa-PW: Wash basin with a pre-wall system, WC-PW: Water closet with a pre-wall system, AV: angle valve

Advantages:

- less material consumption
- the cheapest solution
- Branch pipes can be routed in the slots
- favorable hydraulics
- when all appliances are used regularly, the proper potable water hygiene is ensured

Disadvantages:

- large number of fittings make the installation slower and more likely to leak
- risk of stagnation in irregularly used pipe sections

Recommendation: A regularly used sanitary appliance, e.g. WC or wash basin, should be placed at the end of the branch pipe.

4.2 Branch pipes connected to a manifold with a separated pipes for each tap

This installation type consists of separate cold and hot water branch pipes for each water tap (Fig. 2). It requires the installation of a manifold for cold and hot water and each supply point is connected individually by a separate branch pipe.

Assuming that all water taps are used regularly, good conditions for the hygienic operation of the system are created. The solution presents a higher potable water hygiene standard with respect to the short pipeline flushing time. The solution's downside is that the entire installation can be overpriced as each release valve is connected by a separate pipe and there is a need to install manifolds. Using only one release valve is not sufficient to flush the entire installation. In the event of an operation interruption, all release valves (water taps) must be flushed. As with trunk and branch system, rarely used pipes are dangerous from the stagnation point of view [4].

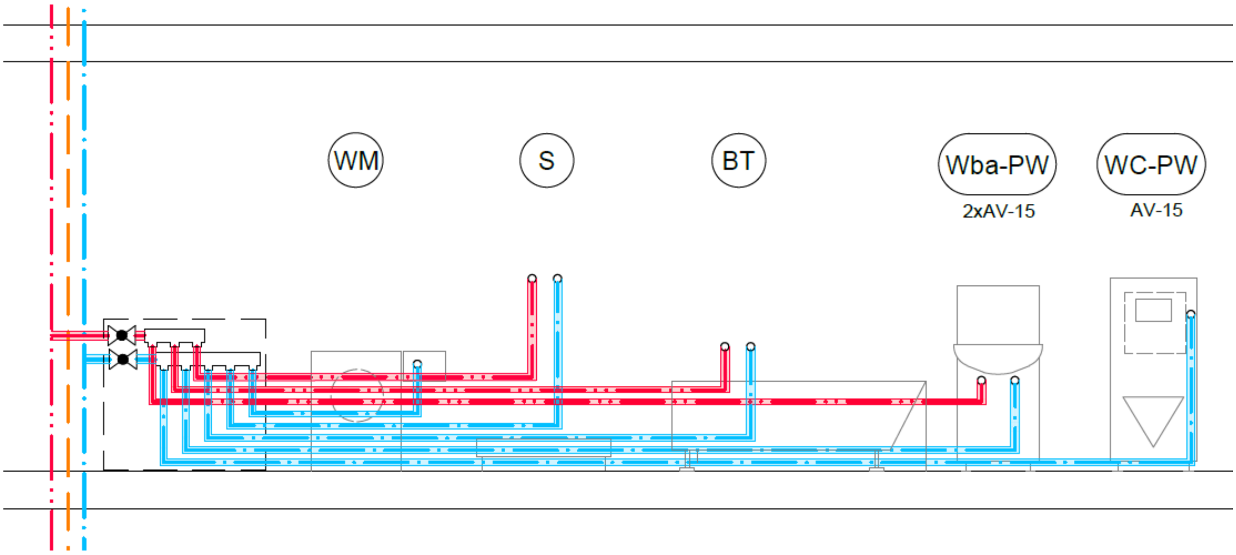

Fig. 2 *Branch pipes connected to a manifold with a separated pipes for each tap [author]*

Advantages:

- balanced hydraulics
- lower pressure losses
- smaller piping dimensions
- low water volume in the pipeline
- when all appliances are used regularly, the proper potable water hygiene is ensured

Disadvantages:

- greater material consumption
- more expensive solution
- risk of stagnation in irregularly used pipe sections

Recommendation: The arrangement of the sanitary appliances does not affect the potable water hygiene, therefore the sanitary appliances can be arranged randomly.

4.3 Continuous branch pipe connected to the release valve (tap) with a special flow-through valve

The third installation alternative consists of a continuous branch pipe installation (Fig. 3) with connection to the release valve via special flow-through valves (Fig. 4). When tapping water from the water tap, the water passes through all valves sequentially which significantly reduces the risk of water stagnation due to better water flushing in the pipeline installation. This installation type is not yet widespread, but it becomes increasingly important. The continuous installation is a hygienic improvement over the established variants described in the previous chapters [4].

Advantages:

- less material consumption
- better flushing
- the risk of water stagnation is significantly reduced

Disadvantages:

- increased pressure losses
- larger pipe dimensions
- more expensive solution due to the use of special flow-through valves

Recommendation: The last sanitary appliance should be the most commonly used one, e.g. toilet or a wash basin, since the complete water change is ensured by opening the last water tap.

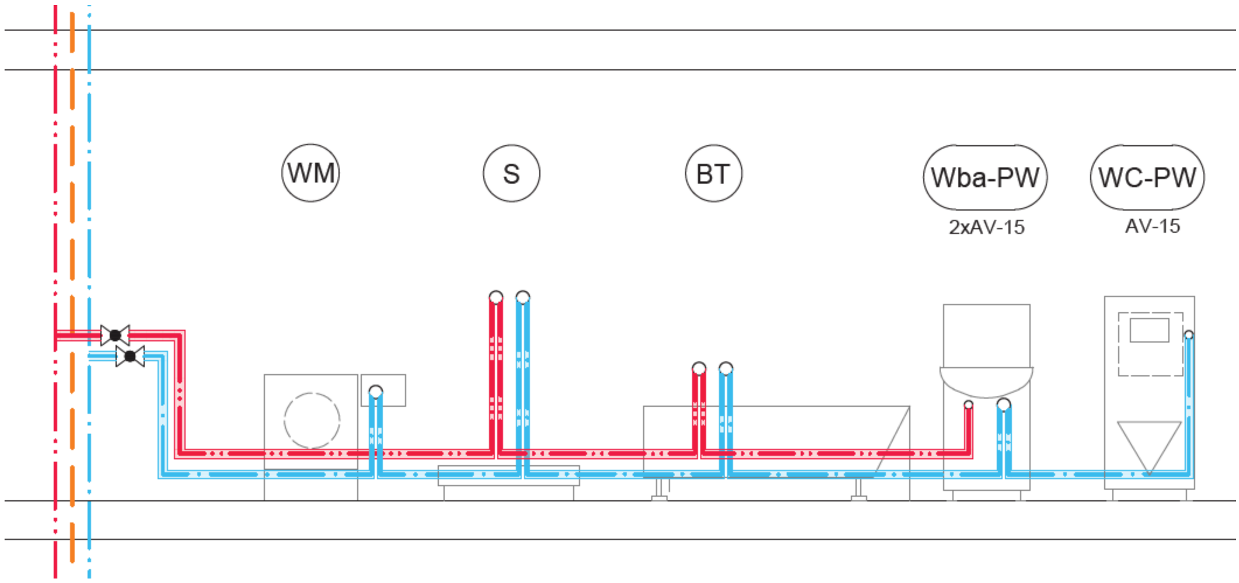

Fig. 3 *Continuous branch pipe connected to the release valve (water tap) with a special flow-through valve [author]*

Fig. 4 *Flow-through valves – brass and stainless steel alternative [5]*

4.4 Continuous branch pipe connected to the release valve with a special flow-through valve with a ring mains

In this installation type, each release valve (water tap) is connected to water supply from two sides via special flow-through valves while the branch pipe is circled (Fig. 5). As the water flows from two sides to each valve, the entire volume of water in the pipeline is actuated at each tap. Opening any mixer tap will change the water along the entire route, minimizing the risk of water stagnation. The water stagnation risk is minimal and the negative impact on the potable water quality is thus reduced as much as possible [4].

Advantages:

- pressure losses are minimized
- balanced hydraulics
- smaller piping dimensions
- low water volume in the pipeline
- better pipeline system flushing
- the water stagnation risk is reduced to the minimum

Disadvantages:

- higher material consumption
- more expensive solution due to the use of special flow-through valves

Recommendation: The arrangement of the sanitary appliances does not affect the potable water hygiene, therefore the sanitary appliances can be arranged randomly.

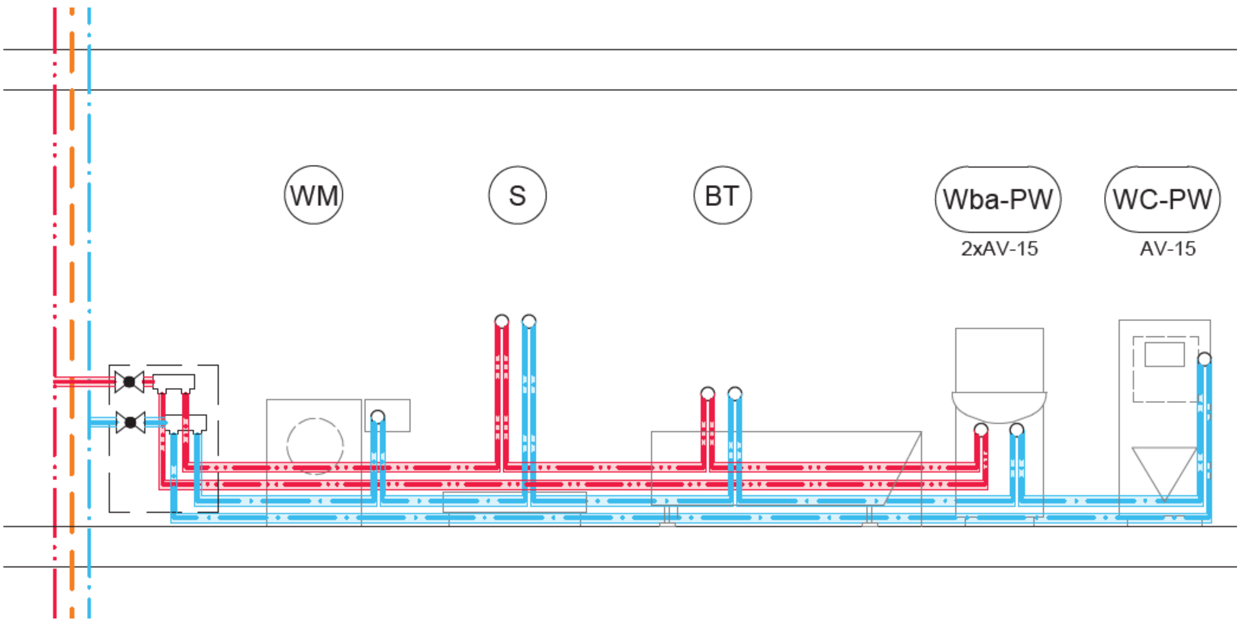

Fig. 5 *Continuous branch pipe connected to the release valve (water tap) with a special flow-through valve with a ring mains [author]*

4.5 Ring mains with a connection of branch pipes to the release valve with a special flow-through valve with a hot water circulation

The last installation type is a circuit continuous connection with a hot water circulation which is distinguished from the previously described solution in that the hot water is connected to the circulation system (Fig. 6). This installation type minimizes the risk of bacteria Legionella spreading and represents a very high standard of potable water hygiene solution. Its disadvantage is that using a circulation of hot water, the measure of hot water consumption is impossible, which can be a complication in billing the hot water consumption in some type of objects [4].

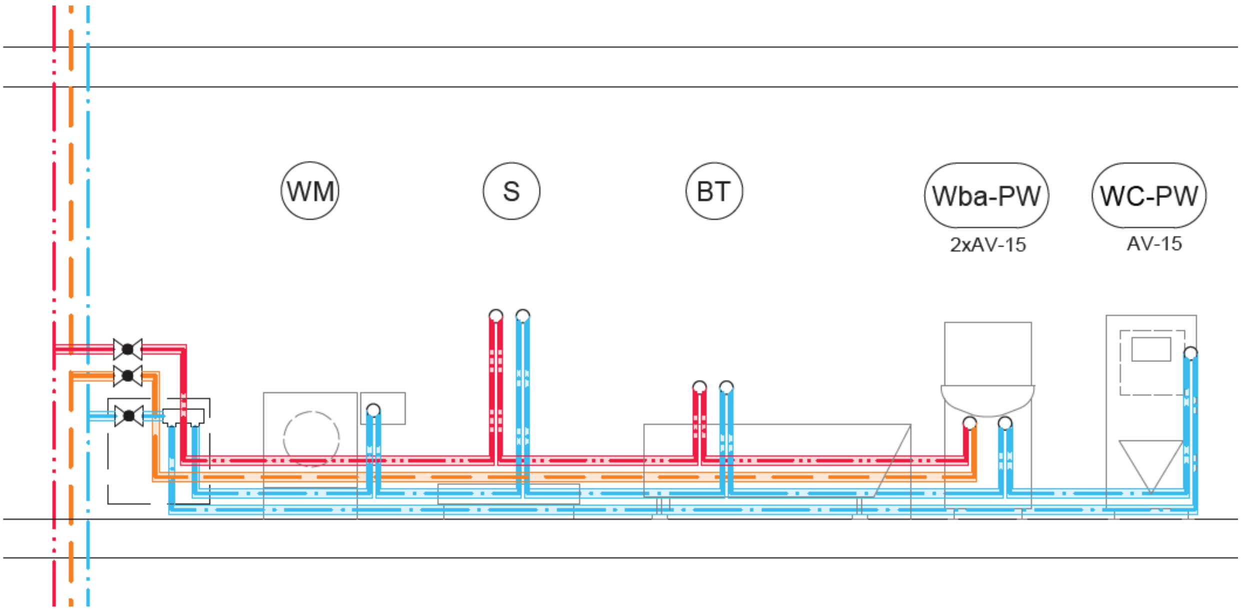

Fig. 6 *Ring mains with a connection of branch pipes to the release valve (water tap) with a special flow-through valve with a hot water circulation [author]*

Advantages:

- balanced hydraulics
- low water volume in the pipeline
- better pipeline system flushing
- the water stagnation risk and the risk of bacteria Legionella spreading is reduced to the minimum

Disadvantages:

- higher material consumption
- more expensive solution due to the use of special flow-through valves
- complications in measuring hot water consumption
- the need of regulating valves on the circulation pipe

Recommendation: The arrangement of the sanitary appliances may be random.

5. FLOW SPLITTER TO ENSURE THE WATER SUPPLY HYGIENIC OPERATION

For sanitary appliances that are less used in the building and in places where there is a risk of water stagnation (e.g. water connection to a hose (Fig. 7a), guest bathroom, etc.), a continuous branch pipe with a ring mains in combination with a Venturi flow splitter is recommended (Fig. 8c). These flow splitters allow the flow to be split into the main (rising) pipe and branching (ring) pipe without additional control valves. The operation principle (Fig. 7b) is based on the Venturi effect principle. Due to the narrowing of the pipeline's internal diameter, pressure difference is created and it forces the water flow to pass through the branch pipe (approx. 5-10 % of the total water flowing volume). This water proportion passes through the branch ring main pipe and flushes it without opening the release valve [6].

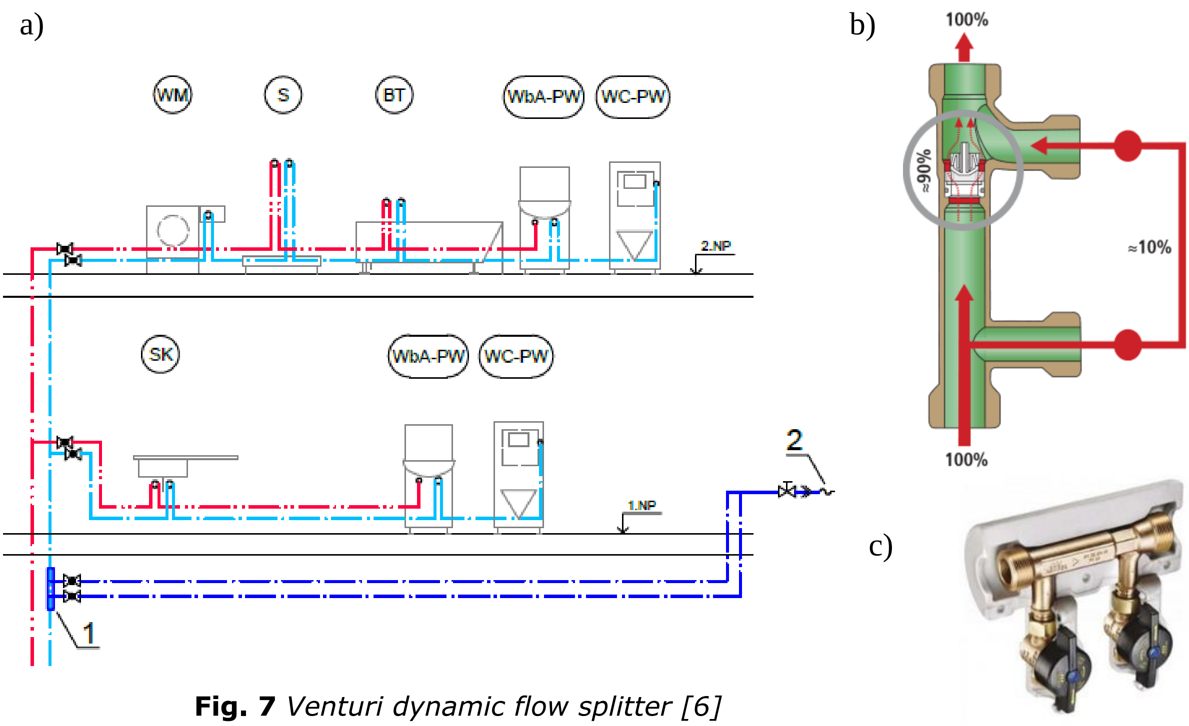

Fig. 7 *Venturi dynamic flow splitter [6]*
a) usage of flow splitter in a single family house in combination with a hose connection, b) principle of function [6], c) view to the flow splitter [6]
1 – Venturi dynamic flow splitter, 2– frost-proof outdoor fitting with hose connection

6. CONCLUSION

The branch pipes play a significant role in ensuring drinking water hygiene. The paper describes five variants of installing the branch pipe. For single-family houses and apartment buildings, a continuous (chapter 4.3) or ring mains installation (chapter 4.4) are recommended. For office buildings, it is recommended to install ring mains with a hot water circulation (chapter 4.5). For less used sanitary appliances, it is recommended to use a Venturi dynamic flow splitter (chapter 5). The cheapest alternative is connecting release valves with fittings by T-pieces making it the most commonly used one. However, there also exist better solutions for ensuring the potable water hygiene.

The question for the future is whether investors will want to switch from installing cheaper variants and using cheaper pipe materials to a more hygienically safe water supply system in the building.

Acknowledgment

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RECUPERATION OF WASTE HEAT PRODUCED BY PUBLIC POOLS

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Abstract

Slovakia is country relatively rich for geothermal resources. Geological researches showed, that all geothermal energy potential of Slovakia is around 400MW. At present there are 176 registered geothermal wells in Slovakia, with temperature of geothermal water reaching from 18°C up to 129°C. Big advantage of geothermal resources in Slovakia is, that there is not necessary to create artificial water circuits. Geothermal water (GTW) is located naturally under the ground. Using of geothermal resources for heating does not require high temperatures, unlike using it for geothermal power plants. This article is dedicated to the recuperation of waste heat produced by public pools.

Keywords – recuperation, geothermal, water, thermal pools, exchanger

1. INTRODUCTION

At present the geothermal energy is used to heat flats and civic amenities, but mainly for recreational facilities. Overall, in Slovakia is heating power of 215,6 MW used at 36 places. This means 3,1% of total geothermal energy potential. Geothermal energy is also used in industrial objects and agricultural objects for greenhouses heating.

Usage support of renewable resources is anchored in the directive number 31/2010/EU of the European parliament and the council about energetic economy of buildings, which assumes lowering the energy consumption by 20%, increasing the renewable resources usage by 20% and decreasing of greenhouse gasses production by 20%. By information from Public health authority of the Slovak republic (Mgr. RNDr. MUDr. Ján Mikas, PhD) about readiness of natural areas and artificial pools for the season 2018, was watched around 212 artificial pools (fully 657 pools), while 194 was with geothermal water and 463 with not geothermal water. Operating permit get only 98 swimming pools (363 pools). Swimming pools which get operating permit, reported on the basis of analysis satisfactory water quality.

2. SWIMMING POOLS TYPES

There are different types of pools in thermal bath. We distinguish:

- flow based pools – filled with GTW,
- flow based pools – filled with mixed GTW,
- circulation based pools – filled with GTW, without buffer tank,
- circulation based pools – filled with GTW, with buffer tank.

In this paper we will solve flow based pools saturation and service issues and pool water temperature will be reached by mixing GTW and cold water.

3. ENERGY BALANCE OF FLOW BASED POOL

Fictional pool with volume of V = 350 m3 was used for calculation of energy balance. Filling and service of this pool was analysed. Desired pool water temperature is ϴb = 38 °C. The walls and bottom of pool are heated while filling the pool. We used geothermal water temperature ϴV = 70 °C and cold water temperature ϴV = 15 °C in our calculation. Operating time of pool is 65 days. Pool will be out of order for 11 days. There is the scheme of filling of fictional flow based pool in Figure 1. The geothermal water is mixed with cold water in mixing chamber, to desired pool water temperature. Waste pool water with temperature ϴb = 38 °C is drained into the recipient, cooling pond or cooling canal without another usage.

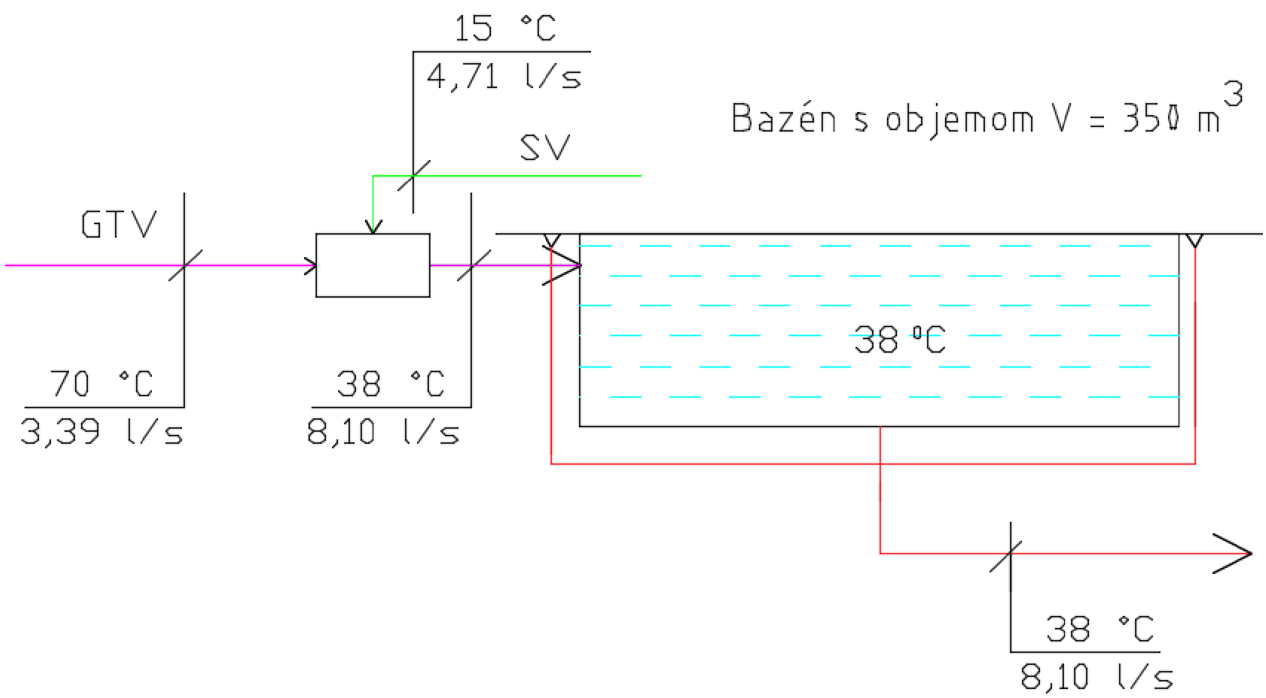

Fig. 1 *Scheme of flow based pool during filling without recuperation*

There is graphical display of geothermal and cold water energy, needed during filling and operating of pool in Figure 2. Blue colour is for cold water energy. Orange colour is for whole geothermal energy and green colour is for usefully used geothermal energy. Remaining orange area is geothermal energy without another usage. This is the waste energy, which leave pool and is drained into recipient. There is graphical display of pool water energy in Figure 3. In this case there is not any waste energy, because none waste water is drained into recipient during the filling of pool. After mixing geothermal and cold water is mixed water flow $m_{b,1}$ = 8,1 l/s. Which represents huge idle waste water potential. Usage rate of this system is 58%, and the rest 42% of energy potential is waste. Another problem is, that waste pool water temperature in this case is Θ_b = 38 °C, which is environmentally unacceptable. If requirements of environmental protection are to be met, the waste pool water needs to be colder than 25°C. The most operators are facing sanction for environmental pollution because the requirements are not met. Saved finances could be used for modernization of technological equipment of pool industry.

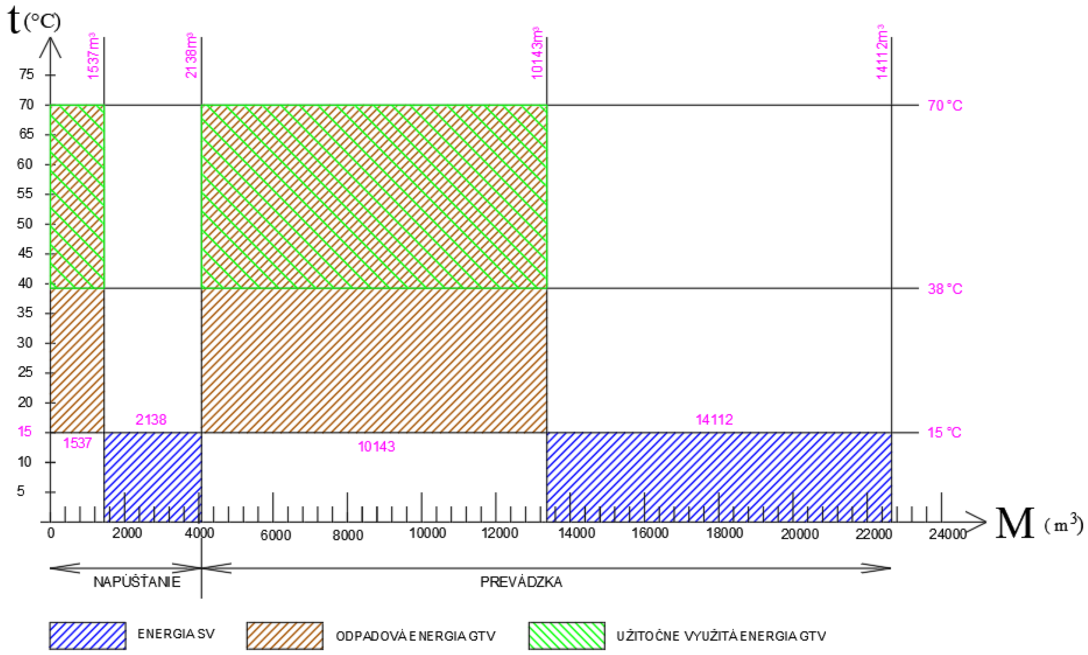

Fig. 2 *Graphical display of energy use during filling and service of pool without recuperation*

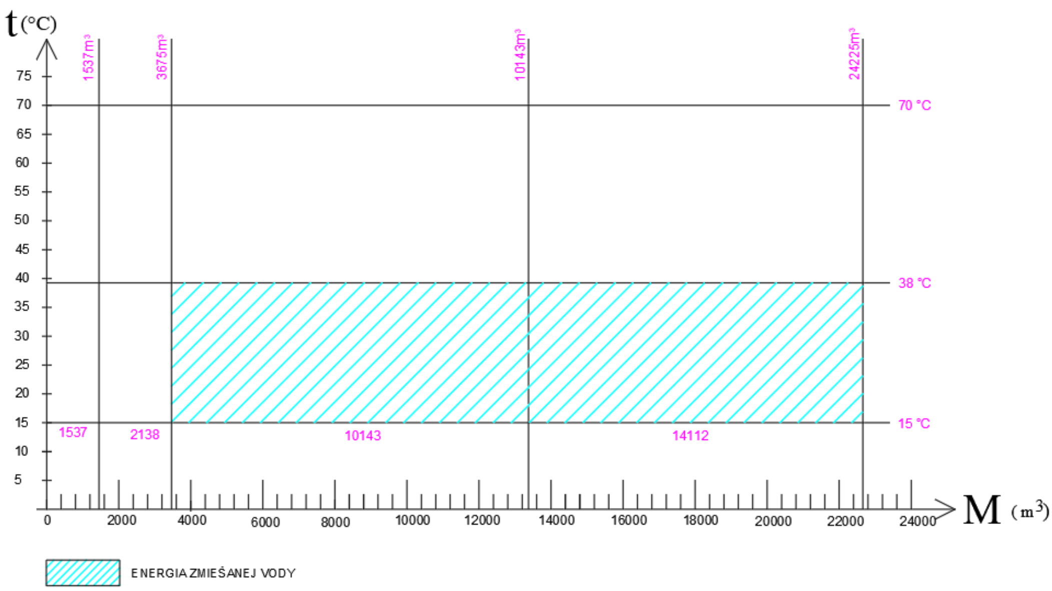

Fig. 3 *Graphical display of pool water energy without recuperation*

4. INCERASE EFFICIENCY PROPOSAL

We can add heat recovery exchanger into the circuit of waste pool water to achieve increasing rate of usage and decreasing waste pool water temperature. Waste pool water is passing through the heat exchanger and is cooled and transfers the heat to the cold water. Cold water is preheated, than is transported to the mixing chamber. Based on preheated cold water we achieved reduction of geothermal water volume. We can decrease geothermal water rate usage, because we are able to preheat cold water through energy potential of waste pool water. We will have no environmentally damage if we will decrease waste pool water temperature. By those arrangements we are able to increase the lifetime of whole open geothermal energy system. Increase efficiency proposal can be seen in Figure 4.

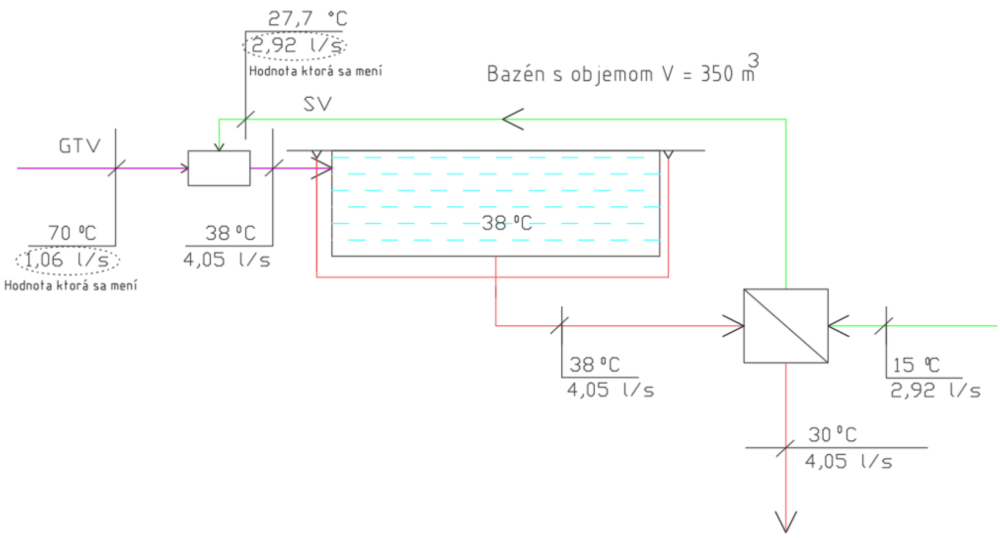

Fig. 4 *Scheme of fictional flow based pool during service with recuperation*

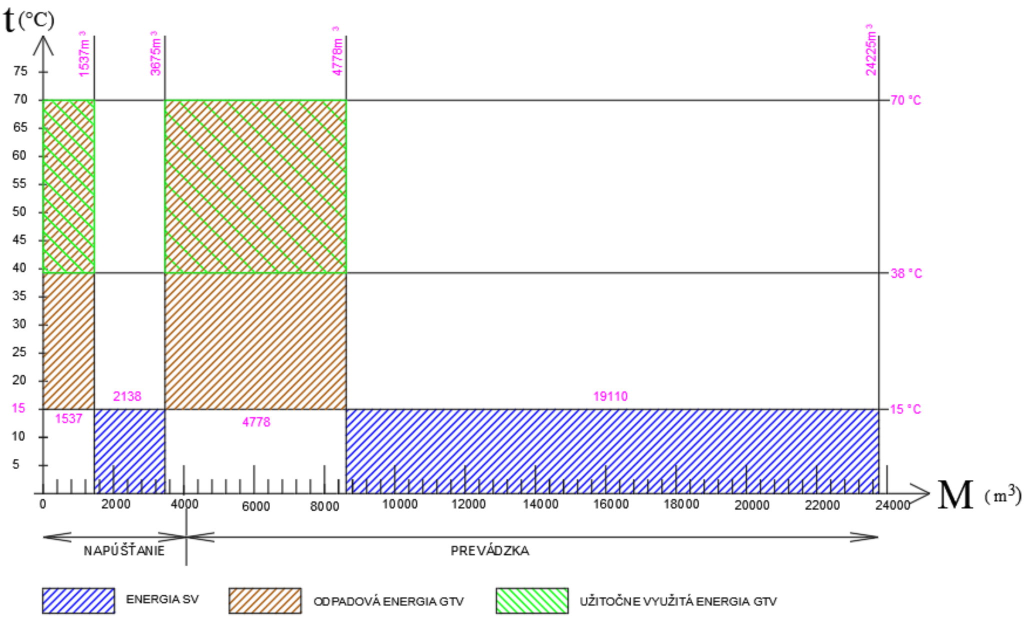

Fig. 5 *Graphical display of energy use during filling and service of pool with recuperation*

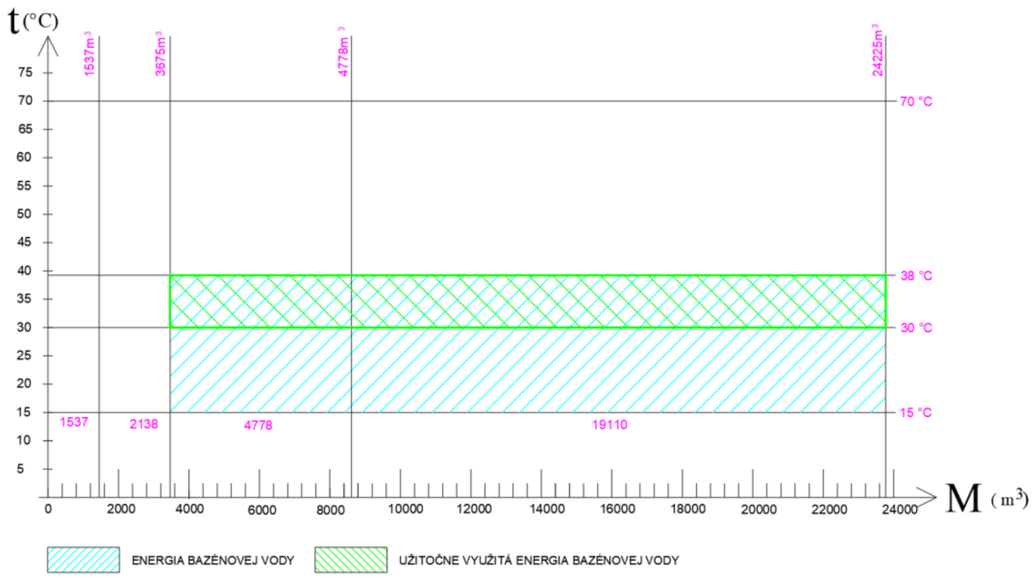

Fig. 6 *Graphical display of pool water energy with recuperation*

We need to know required waste water temperature to secure the right recovery exchanger proposal. The following graph, in Figure 7, can be used for exchanger proposal. The more water cooling we require, the more powerful exchanger is needed.

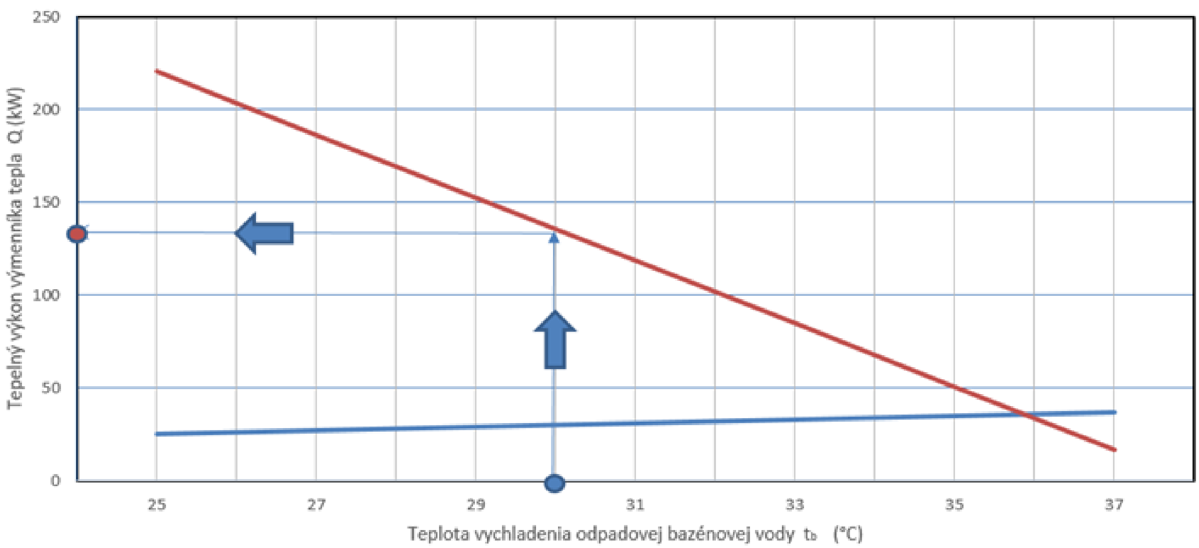

Fig. 7 *Graph for recovery exchanger proposal*

In our case we need exchanger with power Q = 140kW, which cools waste pool water from 38°C to 30°C and also preheat cold water from 15°C to 27,7°C. This action will secure increasing rate of usage from originally 58% to 69%.

5. CONCLUSION

Finally we summarized the actions that need to be applied to achieve higher rate of usage of so-called low temperature energy (low potential energy). There is enough low potential energy in thermal pools, but it is necessary to work out energy audits for the operation of thermal pools. We have to find out the real rate of usage of geothermal energy. After that we are able to propose increase efficiency arrangements.

We need to make certain measures to achieve these aspects:

- devise energy balance of the supplied pools,
- devise technological scheme for pool management,
- add detailed monitoring and control system into the geothermal energy system
- monitoring and evaluation of current pool management,
- evaluate current rate of geothermal water usage,
- optimize energy management,
- add heat recovery exchanger into the geothermal energy system.

In this example we can see recuperation of waste heat from waste pool water, which is in generall drained into recipient without another usage. We are able to secure three important aspects by adding heat recovery exchanger into the system. First aspect is to guarantee that pool waste water will not exceed 25°C and thus wont cause any damage to the environment. Second aspect is recuperation of waste pool water. Third aspect is decrease the volume of geo-thermal water. This will increase the lifetime of geo-thermal energy system.

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STREAMLINING THE OPERATION OF A HEAT SOURCE THROUGH RENEWABLE ENERGY SOURCES

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Abstract

The article deals with using of heat pumps and cogeneration unit in the design of streamlining the operation of a heat source for the West housing estate in Brezno. The existing operation of natural gas hot water boilers will be complemented by a cogeneration unit and water-to-water heat pumps. Operation of the cogeneration unit and heat pumps is proposed in island mode. The aim of the proposal is to align the power of the cogeneration unit with the consumption of heat pumps and their peripherals. The unit of the cogeneration unit and heat pumps will serve for the preparation of hot water in accumulation manner. The proposal is based on real operational data provided to me for the period 2016-2018. The flow of the heating heat transfer fluid passes first through the heat pumps and then through the cogeneration unit. If the temperature of the working medium is not sufficient the flow of heat transfer medium will pass through the boiler.

Keywords – heat source; heat pumps; cogeneration unit; hot water preparation; combined heat and power generation

1. INTRODUCTION

In recent years, the society have become seriously aware of the exhaustibility of fossil fuels, whose deposits are gradually depleted. [3] Another global risk is climate change and increasing levels of atmospheric CO_2. These facts make us think about the need to using alternative or renewable energy sources (RES), especially in buildings, as it is a sector with a dominant energy consumption. Member States of the European Union shall encourage high-efficiency and alternative systems such as: a) decentralized renewable energy supply systems, b) cogeneration, c) district heating or centralized heat supply d) heat pumps, as far as this can be technically, functionally and economically feasible. [4]

2. STREAMLINING THE OPERATION OF A HEAT SOURCE

Description of the current state of the gas boiler room

The solved heat source creates separately standing building, which is situated near the river Hron in the residential area of Ladislav Novomesky district. The proximity of the watercourse creates the assumption that there will be an excess of groundwater in the surrounding subsoil - low-temperature energy, which will be transformed to a higher temperature level by the design of a water-water heat pump. [3] The hot-water boiler room ensures the need for heating and hot water for 782 flats, a winter stadium, a restaurant and a pension for pensioners. During the heating season there is uninterrupted operation – 24 hours operation, in summer the boiler room is in operation from 4:00am to 11:00pm. The heat transfer fluid in this boiler room is hot water with a calculated thermal gradient of 90/70°C. The heat source are three hot water boilers with a total output of 6.76 MW. A flue gas heat exchanger is installed after each of these boilers. Hot water preparation is realized in plate heat exchangers in series connection as pre-heating and water heating with the circulation of these exchangers leading to better cooling of the boilers. The cold water is preheated in condensing economizers connected to a 6,300 liter pre-heated water storage tank to store heat at a time when there is little or no hot water withdrawal. [1]

Energy balance of the heat source

Hourly offtakes of natural gas in m^3 were provided for the period 2016-2018. By multiplying the values of offtakes of natural gas by the calorific value of the fuel, we reach the total amount of heat contained in the natural gas. By comparing the annual offtakes of natural gas and the total heat contained in the natural gas, we came to the conclusion that in 2017 the largest offtake of natural gas was the largest, and thus the value of total heat in the natural gas. On the contrary, in 2018 the consumption of natural gas was 11.6% lower compared to 2017, as evidenced by the graph in Fig. 1. [1]

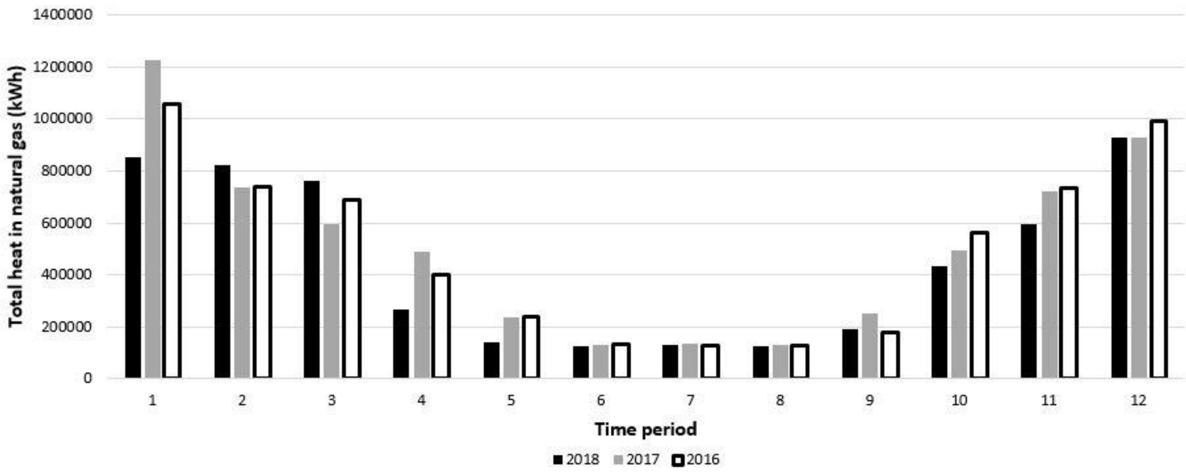

Fig. 1 *Monthly courses of total heat in kWh in natural gas during 2016-2018 [1]*

Design of cogeneration unit and heat pumps

The cogeneration unit and heat pumps shall be installed for existing hot water boiler operation. The power source for the cogeneration unit will be natural gas. The source of energy for driving heat pumps will be the electricity generated by the cogeneration unit. The set of cogeneration unit and heat pumps will serve for the preparation of hot water in an accumulation way. The storage tank will be located behind the cogeneration unit and the heat pumps and will heat up the water when the demand for hot water is reduced and will be fed into the grid at times of increased demand. The essence of the proposal is to ensure the regularity of the operation of the equipment, to work as long as possible and to have a minimum number of starts. In order to determine the optimal performance of the plant, it is good to know what the hot water consumption is over 24 hours. The capacity of the appliance can be determined on the basis of the average hourly consumption of heat for hot water preparation and it will be based on hourly consumption fot the month of June. The working days – Monday, Wednesday and free day – Saturday will be compared. From the graph of Fig. 2 shows that the hot water supply is between 4:00am and 11:00pm, thus 19 hours. On weekdays, hot water consumption is highest in the morning and evening hours, and on weekends hot water consumption is increased over weekdays and on average the same throughout the day. The average hourly heat consumption for hot water production in 2016 was 275 kW, in 2017 it was 280 kW and in 2018 the heat consumption for hot water production was 267 kW. [1]

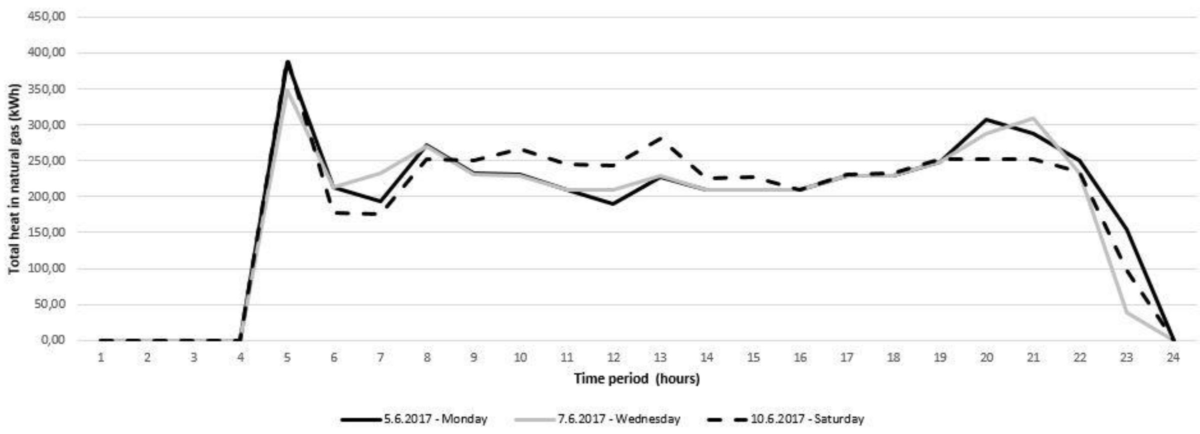

Fig. 2 *Comparison of hourly heat consumption for hot water production during 24 hours in 3 June days in 2017 [1]*

By comparing the data for the period 2016-2018, the heat output of the cogeneration unit and heat pumps was set at 270 kW. The cogeneration unit and heat pums will be installed in front of the boilers in the direction of flow of the return heating water. The return heating water has a temperature of 45°C. Our task is to produce water at 60°C. The temperature gradient in the system is therefore 60°C/45°C, which means that the temperature difference $\Delta\theta$ = 15K. A very important parameter in the design of plant performance is the volume flow rate that will flow through the system. It must be true that the volumetric flow entering the system must be equal to the volumetric flow leaving it. The volumetric flow rate at a thermal power of the system of 270 kW and a temperature difference of 15K is 15.48 m^3/h. The heat pump operates with a primary circuit temperature gradient of 5°C/1°C – that is, a low-temperature heat source enters the heat pump – ground water from the wells and transforms into a higher temperature in the heat pump. The heat pump is supplied with return heating water with a temperature of 45°C and heats in the heat pump by 10K, which means that the heat pump outlet will have a temperature of 55°C. This time we know the temperature difference $\Delta\theta$ = 10K and the volume flow M=15.48 m^3/h, which flows through the heat pump. The heat output of the heat pump at 180 kW was calculated. It follows that the heat output of the cogeneration unit will be 90 kW. Given that the cogeneration unit normally operates with a temperature gradient of 20K, which means that if a cogeneration unit enters the temperature of 55°C in the cogeneration unit, it will be heated and the temperature of the output of the cogeneration unit will be 75°C, determine the volume flow rate that the cogeneration unit must take in order to reach a water temperature of 60°C at the outlet of the unit and before entering the storage tank. The volumetric flow collected by the cogeneration unit is 3.87 m^3/h. For better controllability of the system two identical two-stage water-water heat pumps are designed. The advantage of the two-stage heat pump is that it has two power stages and can therefore be operated on one half-capacity compressor. Due to the cooling of the pumped water in the heat pump, it could freeze and cause icing on the heat pump, which would completely degrade after some time. Therefore, we have decided using a separator heat exchanger in the primary circuit, the task of which is to provide an intermediate circuit with antifreeze liquid between the pumped ground water and the heat pump. We have worked out a detailed calculation to design two identical heat pumps, the heat output of one being 89.6 kW. In order for the cogeneration unit to form a unit together with the heat pumps, it is necessary to harmonize not only their heat outputs but also the electrical input, as the cogeneration unit will supply electricity to the heat pumps. The interaction of the heat pumps and the cogeneration unit was simulated using calculation programs, thus determining the cogeneration unit at 90 kW.

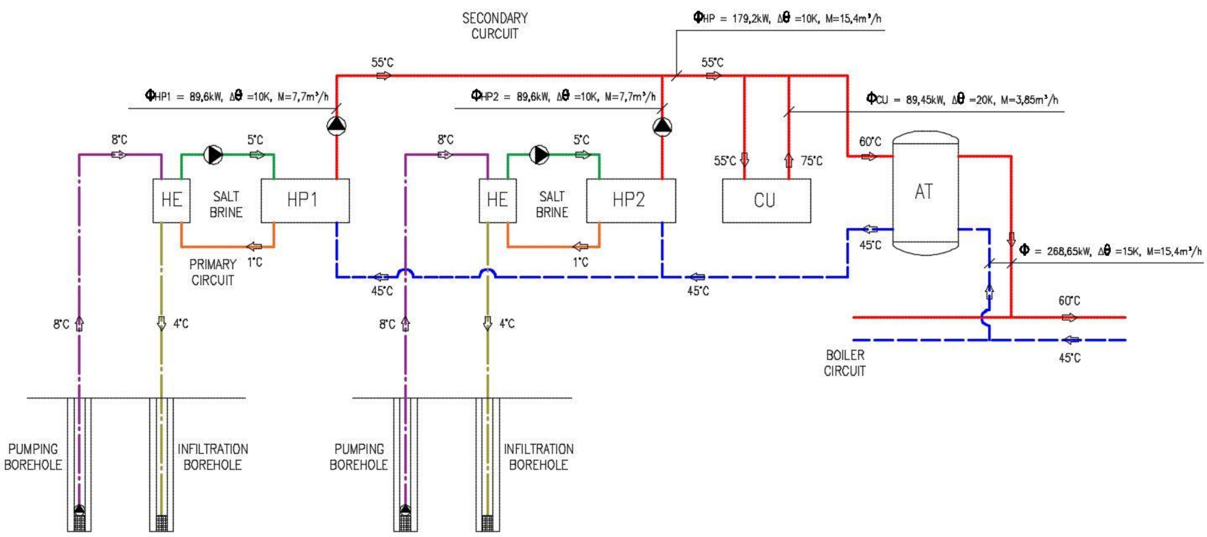

Fig. 3 *Principal circuit diagram of cogeneration unit and heat pumps [1]*
HE – heat exchanger, HP – heat pump, CU – cogeneration unit, AT – accumulation tank

3. DISCUSSION

The reason why I decided to apply the cogeneration unit and heat pumps in a given plant was that the district heating systems have the potential for highly efficient cogeneration and efficient using of environmental energy through heat pumps. The cogeneration unit could also be connected to the public grid, but at the time when the optimization was solved, the STOP-STATE applied to connecting new larger power sources.

Acknowledgment

Using of renewable energy sources in the form of environmental energy by means of a cogeneration unit and heat pumps saves a considerable amount of conventional energy sources of natural gas. The environment will not release pollutants, which would be incinerated classical primary energy sources. The obligations to Directive 2018/844 of the European Parliament and of the Council will be fulfilled.

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UTILIZATION OF GEOTHERMAL ENERGY IN HEATING SYSTEMS

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Abstract

In Veľký Meder, there is geothermal well – VM-1 which is projected for the heat supply of the local boiler house. Reconstructed heat source - hot water boiler house is equipped with natural gas boilers, which are also used as a backup heat source. Geothermal water (GTW) is used in two plate heat exchangers for heating (HEAT) and in two heat exchangers for preparing hot water (HW).

With this solution, we will contribute to meeting the obligations of EU Directive 31/2010 on energy efficiency in the use of renewable energy sources and reducing greenhouse gas emissions and increasing energy efficiency.

Key words – geothermal energy, natural gas, energetic system, hot water boiler house, centralized heat supply

1. INTRODUCTION

In Slovakia, there is approximatelly 171 geothermal wells with borehole head temperature from θ_0 = 15,7 to 126,0°C. Most of these geothermal areas in Slovakia has the temperature of the GTW suitable for space heating and preparing hot water for buildings, agriculture, industry and for balneological purposes – filling pools with geothermal or diluted geothermal water or for heating technology for spas.

This paper mentions the usage of geothermal energy (GE) for the system of centralized heat supply (SCHS). The GTW is used from the borehole in the boiler house, from which the heat is supplied to the housing area (1 300 flats) in Veľký Meder and the cooled GTW is used for heating the health clinic and then for filling the pools in the spa - Thermal Corvinus.

2. SOURCE OF THE GEOTHERMAL ENERGY

In 2015, the geothermal well - WM-1 was built in the courtyard of the central boiler house in Veľký Meder, because the original heat source from the 1970s no longer met the heat supply requirements of the surrounding housing area. Reconstruction of the boiler house was carried out in such a way that the dominant position for the heating of the housing area gained for a renewable energy source - well VM-1 before natural gas boilers. Energy parameters of this well (VM-1) are shown in Tab. 1.

Tab. 1 *Energy parameters of the well VM-1.*

Location	Well	Depth of well	Yield of GTW with pump	Borehole head temperature	Temperature of cooled GTW	Usable energetic potential
		(m)	(l/s)	(°C)	(°C)	(kW)
Veľký Meder	VM-1	2 450	16	98	25	4 890,4
Veľký Meder	VM-1	2 450	16	98	40	3 885,5

At the start, the GTW from the borehole is exploited by a free spillway and then is pumped with the depth pump from 200 m with a frequency converter, which achieves regulation of the GTW in each month.

The expected cooling of GTW is presented at two levels. To protect the environment, conservationists require cooling the GTW to 25 ° C (level 1), but the real cooling of the GTW from this system is 40 °C (level 2). Tab. 1 shows the usable energy potential from a well VM-1 for a cooled GTV at 25 and 40 ° C. The following figure (Fig. 1) shows the VM-1 borehole head.

Fig. 1 *Borehole head of well VM-1*

3. TECHNICAL SOLUTION OF THE BOILER HOUSE

GTW is first transported to a degassing and accumulation tank with a volume of 10 m^3 for degassing GTW. Subsequently, the GTW is transported to two G-MART plate heat exchangers with a power of Q = 1 549 kW. These exchangers are labeled as VT1 and VT2 and here GTW transfers heat to the heat transfer medium - heating water for the separator and collector (Fig.2).

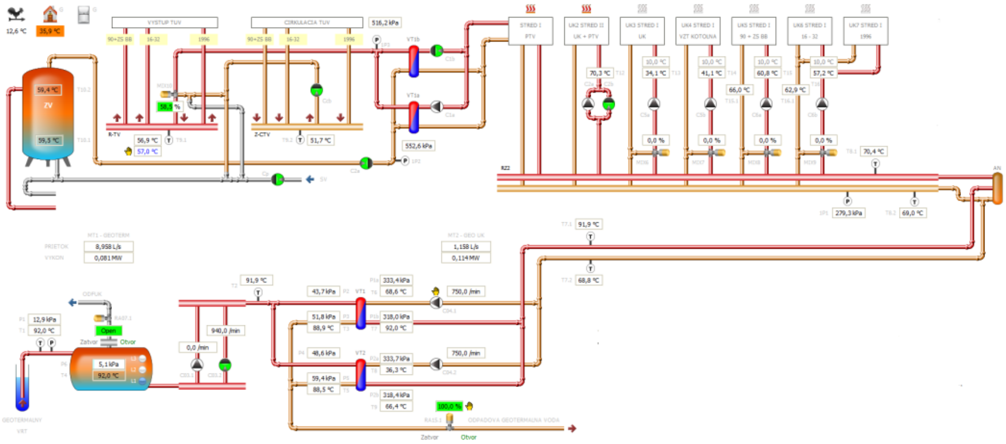

Fig. 2 *Track of the GTW from borehole through degassing tank to separator and collector*

From the separator and collector, the secondary heat transfer medium transfers this heat for the individual consumption points - 1 300 flats, kindergarten, primary school, children's home, cultural center, health clinic. The preheating of HW is carried out in two plate heat exchangers VT1a and VT1b, with a heat output of Q = 400 kW and then is accumulated in a standing storage tank with a capacity of 4 000 liters. Hot water is supplied from it. In Figure 3 we can see plate heat exchangers from this system.

Fig. 3 *Plate heat exchangers VT1 and VT2 and another PHE.*

After cooling in the VT1 and VT2 plate heat exchangers, the GTW is increasing to the VT1a and VT1b plate heat exchangers on the second floor of the boiler house, which is used to preheat the hot water. Then the pipes with cooled GTW decreasing under the ground and then is piped to the health clinic and then to the thermal spa. In this spa, pools are filled with diluted GTW.

The original source of heat in the boiler room were boilers from the 1970s, which were replaced with new ones. Today these boilers serve as a backup heat source. There are 3 hot-water natural gas-fired boilers with a pressure burner and a heat output of 1,000 kW and two modern natural-gas gas-fired boilers with a pressure burner and a heat output of 1,600 kW (Fig. 4).

The task of the hot water boiler house is to ensure sufficient thermal energy for heating and hot water preparation for all buildings. Both the original source and the heating systems were designed for a temperature gradient of 90/70 ° C. Practical experience, however, confirms that after construction work on apartment buildings and other buildings to meet it is need lower temperature gradients with the supply water temperature to the heating system from 70 to 75 ° C.

Fig. 4 *View on the hot water boilers on natural gas (NG).*

4. COMPARISON OF HEAT PRODUCTION FROM GE AND NG IN 2017 AND 2018

The reconstructed boiler room was put into operation on 15 October 2015. Since this year, data on heat production in the house have been recorded. For the purposes of this article, the table and graphically processed data for 2017 and 2018 will be presented.

4.1 Production of heat in 2017

Total heat production for 2017 in a hot-water boiler plant is summarized in Table 2. It shows the total amount of heat produced for heating and hot water preparation in individual months. A graphical representation of the amount of heat produced from natural gas (NG) and geothermal energy (GE) is shown in Figure 5.

Tab. 2 *Amount of the heat which was produced in boiler house in 2017.*

	1	2	3	4	5	6	7	8	9	10	11	12	overall
HW	288,3	281,1	364,3	295,0	308,9	247,7	272,3	308,9	262,2	141,2	177,6	182,0	3129,5
HEAT	1553,2	1162,0	795,6	676,3	170,9	0,0	0,0	0,0	286,4	500,8	1344,9	1078,4	7568,5
overall	1841,5	1443,1	1159,9	971,3	479,8	247,7	272,3	308,9	548,6	642,0	1522,5	1260,4	10698,0
NG	1331,3	570,5	139,3	40,1	0,0	19,9	0,0	0,0	4,0	25,8	364,4	237,8	2733,1
GE	510,2	872,6	1020,6	931,2	479,8	230,4	272,3	308,9	544,6	616,2	1158,1	1016,6	7964,9

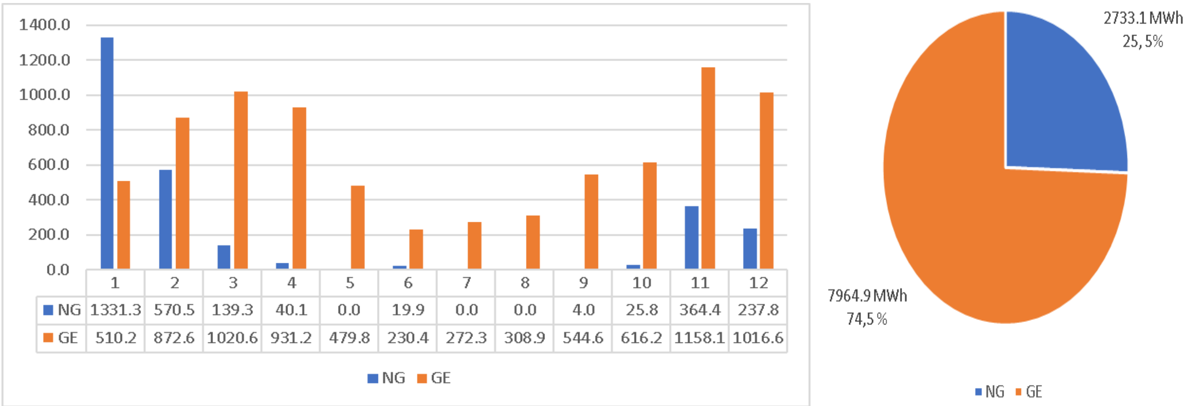

Fig. 5. *Graphical representation of the use of GE and NG for heat production in 2017.*

Fig. 5 shows that most of the heat produced in 2017 comes from the GE source - the VM-1 well, and heat production from natural gas is lower. However, in January, most of the heat was produced from natural gas boilers, as it was a very cold month.

The following table (Table 3) and figure (Figure 6) show the amount of natural gas saved, together with the numbering of the saved pollutants.

Tab. 3 *Amount of saved pollutants in 2017*

	1	2	3	4	5	6	7	8	9	10	11	12	overall
MWh	510.2	872.6	1020.6	931.2	479.8	230.4	272.3	308.9	544.6	616.2	1158.1	1016.6	7964.9
m^3	42279.2	80893.7	94613.9	86326.2	44479.5	21359.1	25243.4	28636.3	50486.7	57124.4	107360.8	94243.1	733046.2
CO_2 (kg)	81.2	156.9	181.7	165.7	85.4	41.0	48.5	55.0	96.9	109.7	206.1	180.9	1407.4
NO_2 (kg)	13.5	25.9	30.3	27.6	14.2	6.8	8.1	9.2	16.2	18.3	34.4	30.2	234.6

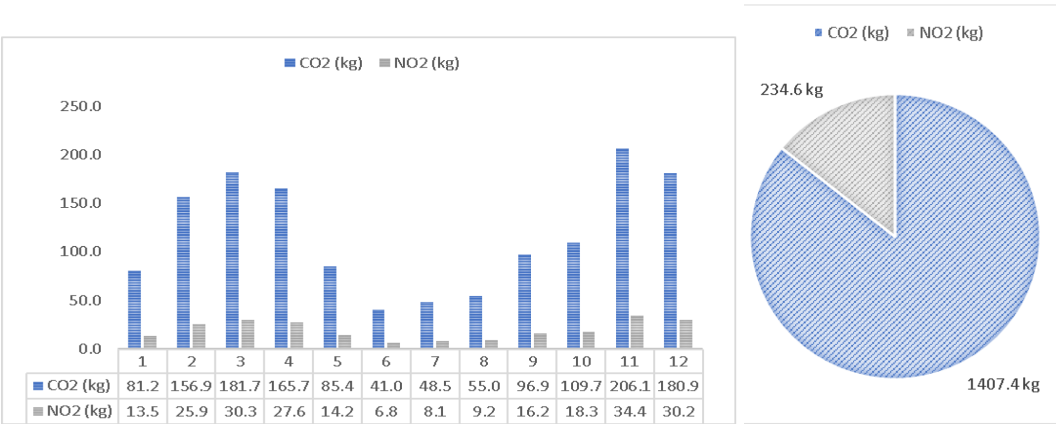

Fig. 6 *Amount of saved pollutants in 2017*

Based on Figure 6, we can conclude that the introduction of geothermal energy into thermal energy production in the boiler plant in Veľký Meder in 2017 saved 1 407,4 kg of CO2 and 234,6 kg of NO2, which were not released into the atmosphere.

4.2 Production of heat in 2018

Tab. 4 shows the need for heat for heating and hot water production in individual months in 2018 from GE and NG.

Tab. 4 *Amount of produced heat from GE and NG in 2018.*

	1	2	3	4	5	6	7	8	9	10	11	12	overall
HW	274,1	279,8	303,5	278,4	260,9	231,5	236,0	224,4	239,5	262,7	284,0	319,3	3194,1
HEAT	1285,9	1278,2	1167,5	363,6	0,0	0,0	0,0	7,9	108,1	493,7	856,5	1293,1	6854,5
overall	1560,0	1558,0	1471,0	642,0	260,9	231,5	236,0	232,3	347,6	756,4	1140,5	1612,4	10048,6
NG	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
GE	1560,0	1558,0	1471,0	642,0	260,9	231,5	236,0	232,3	347,6	756,4	1140,5	1612,4	10048,6

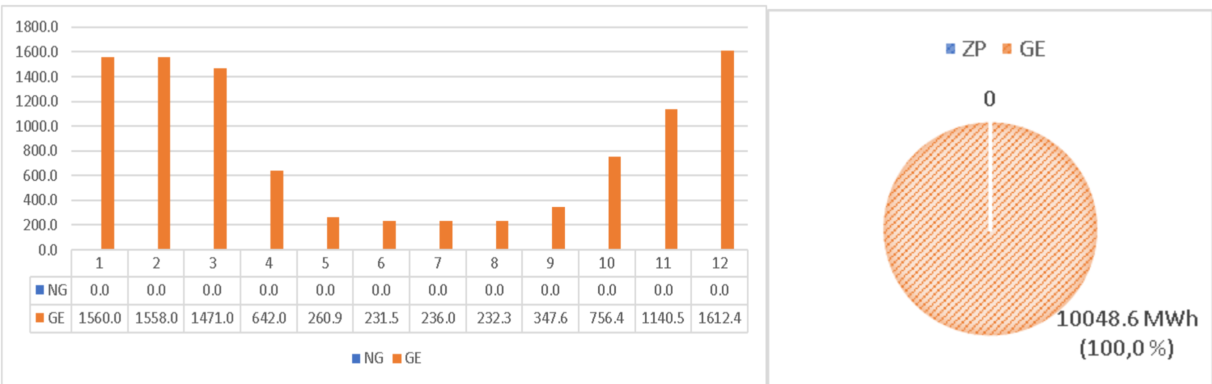

Fig. 7 *Graphical representation of the use of GE and NG for heat production in 2018*

Based on Tab. 4 and Fig. 7 we can state that in 2018 a geothermal borehole was sufficient to produce heat for heating and hot water preparation in the town of Veľký Meder. Thus, the total amount of thermal energy produced in 2018 was produced from geothermal water.

On Fig. 8 we can see amount of saved pollutants in 2018 – amount of saved CO_2 was 1 788,6 kg and amount of saved NO_2 was 298,1 kg.

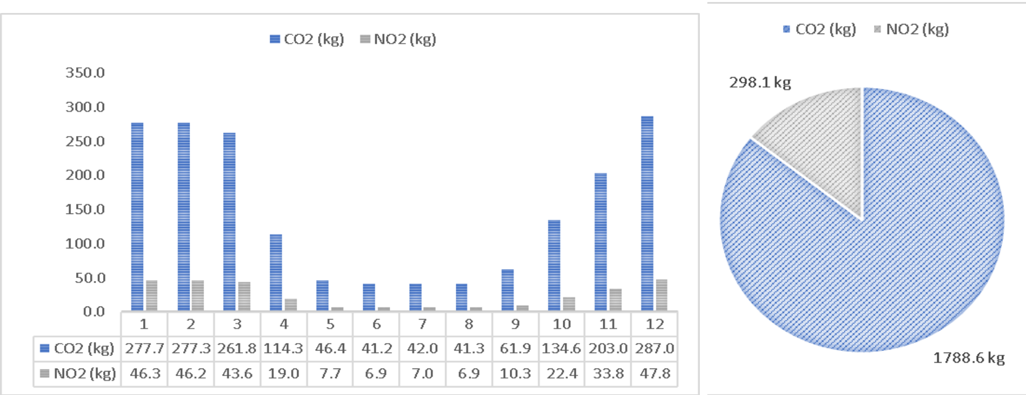

Fig. 8 *Amount of saved pollutants in 2018.*

5. CONCLUSION

In Velky Meder, a geothermal borehole was built in the yard of the local hot-water boiler house in 2015. At the same time, the heat source was reconstructed and the basic load of the heat source was taken by GE (RES). By comparing the heating periods in 2017 and 2018, I can conclude that the proposed solution for centralized heat supply is correct. The consumption of natural gas has been reduced, RES has been used and the production of pollutants in the form of emitted CO_2 and NO_2 has been substantially reduced. This system of RES utilization can be an example of how to meet the obligations set out in Directive 2010/31 / EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

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PREPARATION OF CONSTRUCTION MODELS FOR COMPACT HEAT STATION USING RES

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Abstract

The paper describes the mobile laboratory and its equipment for measurement of design models. The design models of the new compact station are based on the latest theoretical foundations of building technical equipment and their common control.

Keywords – mobile laboratory, compact station, design models

1. INTRODUCTION

Work with description, measurement and optimization of compact stations of the new S.M.A.R.T. type. Self-monitoring, analysis and reporting technology or S.M.A.R.T. is a technology monitoring system that detects and reports security reliability indicators in an attempt to predict failures.

The new smart-type compact heat station is a technological device with a control unit that can monitor, analyze, detect and predict failures, ensure the communication and collaboration of the technological components of the compact heat station with each other but also with external devices using software specially developed for this purpose remote control.

The technological development of technology in every field of science and technology is heading towards total networking. The reason is to use a huge amount of information to make decisions much faster and more accurate.

Tight connection of technological components of the compact station hot new smart type, heat sources, end elements energy systems, people like users to be achieved by reducing energy performance of buildings, increase the economic efficiency of technical building equipment, reduce operating costs and save the environment long term sustainable manner.

The compact heat station being developed also includes connections to heat sources and energy storage in addition to the connection and transfer nodes.

2. PROGRESSIVE TECHNOLOGIES IN CONSTRUCTION MODELS

Progressive technologies and materials for the application of renewable energy sources in buildings consist of the following basic components [1], [2], [3]:

a) Solar collectors (can be combined with solar roofs)

b) Long-term liquid-based heat storage units (heat transfer by coil to liquid), solids (heat transfer to eg soil through a pipe register) or phase change (coil transfer eg to paraffin)

c) Short-term heat storage tanks based on liquid or phase change

d) Cooling system, which is based on a pipe register located in the non-freezing depth of the soil (may be supplemented by an external cooler and a coolant accumulator)

e) A recuperative heating / ventilation system based on a recuperation air-handling unit with preheating or air cooling in single- or dual-pipe counterflow heat exchangers located at the non-freezing depth of the soil. The final heat treatment of the ventilation air is by means of liquid, gaseous or electric heat exchangers (heaters, coolers) integrated in HVAC units or external located in the HVAC distribution system. This system can be complemented by low-temperature heating and high-temperature cooling systems used to temper the interior of the building

f) Of building structures (roof and external walls) with internal energy source - active thermal protection consisting of a pipe system provided with a distribution layer (plaster, thermally conductive foil, thermally conductive coating or spraying) placed between the load-bearing part of building structures and thermal insulation layer

g) Peak (standby) heat source (electric coil in short-term storage tank, electric boiler, gas boiler, heat pump, fireplace, other heat source and combination of multiple heat sources)

h) Controller software (measurement and control), which controls all actuators and components of the combined building and energy system of the building

3. MATHEMATICAL-PHYSICAL MODELS OF COMPACT STATION ENERGY SYSTEMS

In accordance with Directive 2010/31 / EU on nearly zero energy buildings, the requirement to achieve energy class A0 of the primary energy of the building, the requirement for quality building envelope buildings with target thermal resistance in accordance with STN EN 73 0540, RES were developed technical solutions, which are presented:

a) **Utility Model No. 5749**: OPERATION OF COMBINED BUILDING-ENERGY SYSTEM OF BUILDINGS AND EQUIPMENT registered in Banská Bystrica in April 2011 (author doc. Ing. Daniel Kalús, PhD.) [4].

b) **European patent EP 2 572 057 B1**: THERMAL INSULATION PANEL FOR SYSTEMS WITH ACTIVE HEAT TRANSFER MANAGEMENT in October 2014 (doc. Ing. Daniel Kalús, PhD.) [5].

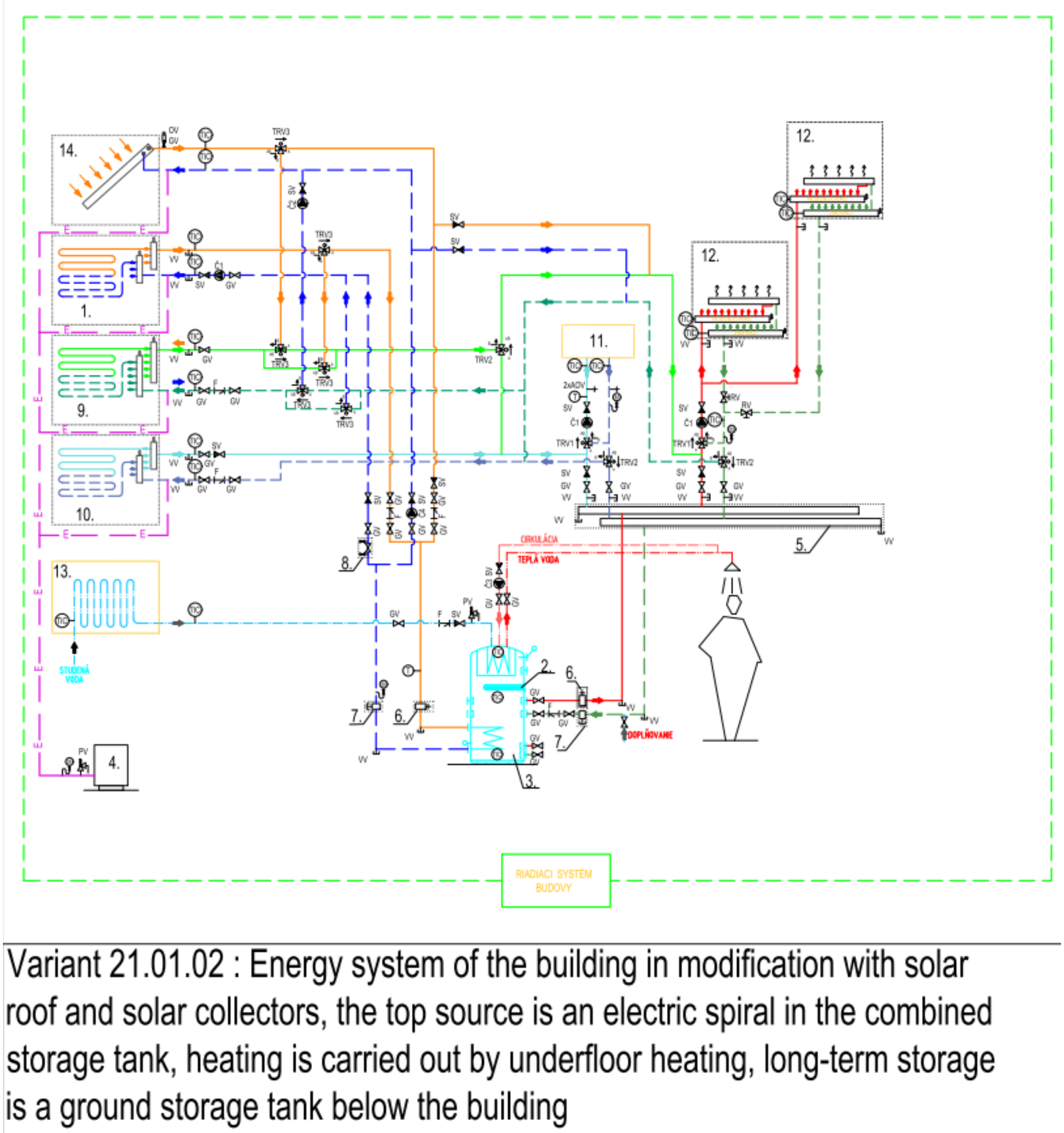

Fig. 1 *Mathematical-physical model - variant 27.02.08 [Author: Matej Kubica]*

When creating mathematical-physical models, we focus on variants of connection with devices offered on the Slovak and Austrian markets. From the variants of research and development involvement we choose the ones that are currently most used in individual housing development. One possible variant is shown in Figure 2, where the mathematical-physical model includes an alternative energy source (solar water heating, PV cells and others), a peak source (heat pump, electric boiler, biomass boiler), two short-term storage tanks, self-heating hot water tank, heat recovery unit, cooling circuit.

4. ADJUSTMENT MEASUREMENTS ON A MOBILE LABORATORY

Adjustment measurements in the laboratory and measurements of design models of compact stations of the new SMART type, will be performed on a mobile laboratory (simulator and optimizer of energy systems), which was designed and produced by REGULTHERM, s.r.o. based on utility model no. 5749 Method of operation of the combined building and energy system of buildings and equipment.

I actively participated in the design and execution of this mobile laboratory already during my studies at the engineering level and I continued continuously during my doctoral studies.

Based on the following measurements, we modified the composition of the mobile laboratory and the connection of the future compact device.

a) Starting the system
b) Calibration of the gauges and sensors
c) Cooling circuit modification
d) interventions in the process of operation
e) Heat pump control
f) The proposed procedure for the operation of the compact device
g) Installed power diagnostics

4.1 Technical equipment of mobile laboratory

The laboratory includes vacuum solar collectors, photovoltaic panels, an air-to-water heat pump with the option of producing heat or cold, and a heat recovery ventilation unit and a DHW tank with electric heating. Remote access allows you to monitor and set actual and desired quantities according to the needs of the measurements performed. The software records measured states at five minute intervals. The software can create various time graphs with temperature, humidity, consumption or battery charge status. If necessary, we can export all values to another calculation program.

Fig. 2 *Laboratory with erected solar panels [Author: Matej Kubica]*

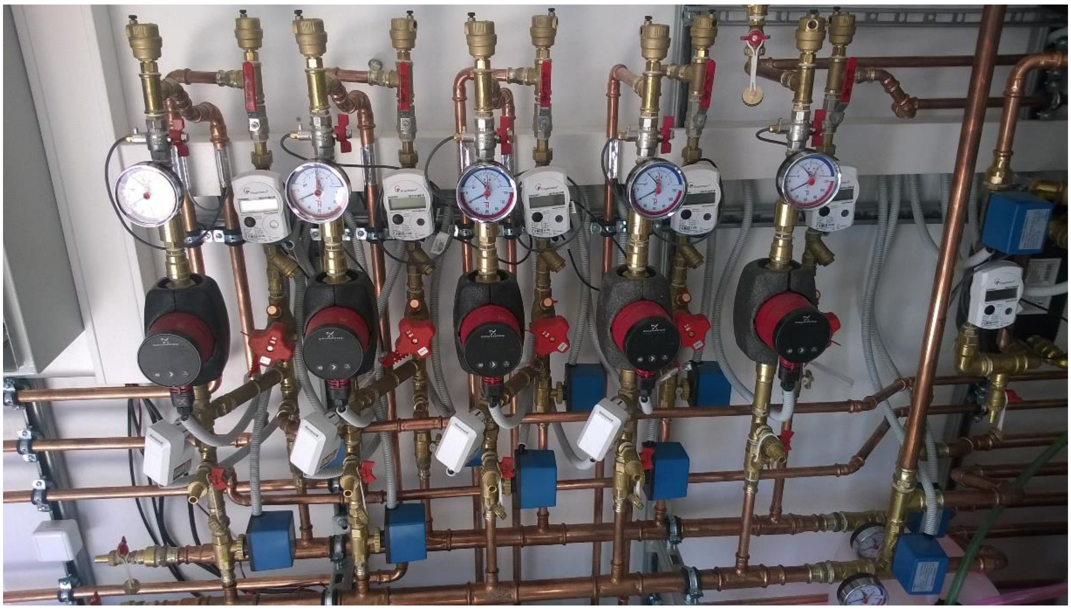

Fig. 3 *Distributor and collector with measuring instruments on the heat transfer side [Author: Matej Kubica]*

5. CREATION AND MEASUREMENT ON CONSTRUCTION MODELS

The newly created design models will be applied in the mobile laboratory. After configuring the wiring, we will start with field measurements.

5.1 Design model with heat production – tepor

Design of compact station without reversible heat pump and without ability to produce cold. The compact station has three outputs for the source, two with exchanger and one without exchanger. Due to the lack of cooling circuit, the compact station has only one short-term storage tank. This type of compact station can also be connected to a heat pump with production of cold, but it will have its own cooling circuit and will not be controlled by the compact station.

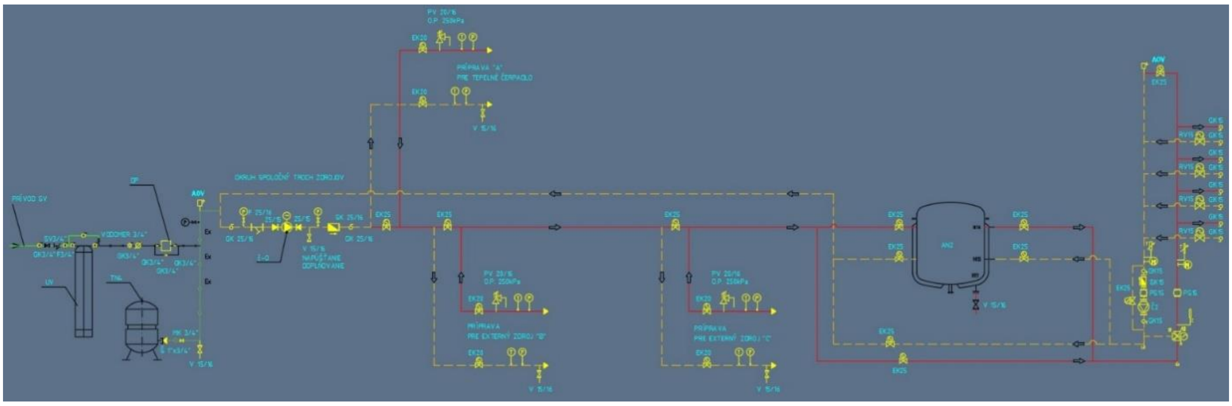

Fig. 4 *Construction model of a compact station with heat production [Author: Matej Kubica]*

5.2 Design model with heat and cold production

Compact heat pump station with reversible heat production capability, switching between heat and cold production. In this case, the compact station has a three-way valve system that divides the production of cold and heat into two circuits, allowing the heating system to use both cold and heat simultaneously. The heat and cold preparation itself takes place by switching the heat pump running.

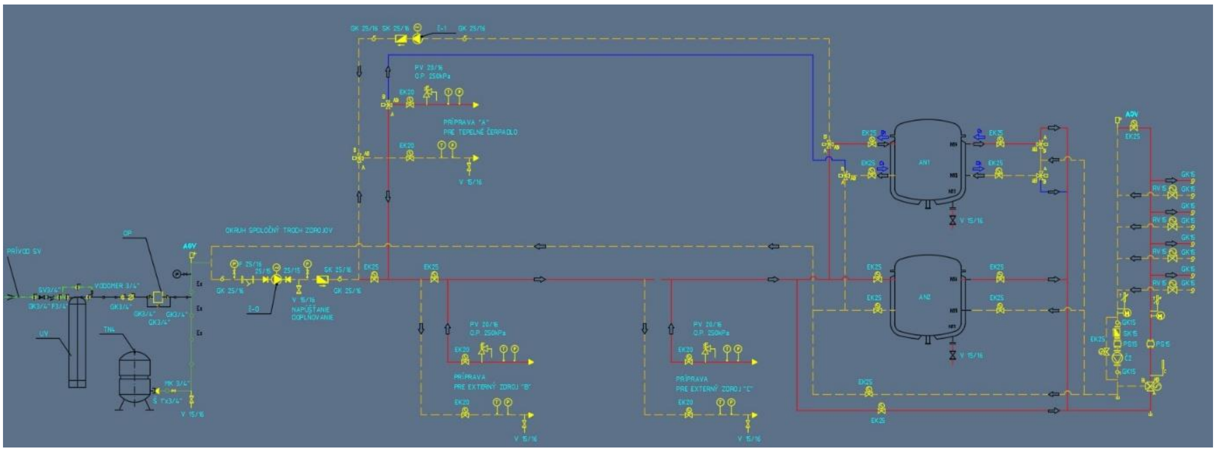

Fig. 5 *Design model of a compact station with heat and cold production [Author: Matej Kubica]*

7. CONCLUSION

Pre-installed and pre-programmed ultrasonic heat meters make it possible to create new ways of acquiring data and to compare design and actual conditions. Two sets of ultrasonic heat meters are installed in the compact station. The power pack can detect instantaneous power and the amount of energy stored in the heat and cold store. The set of heat meters recognizes the installed capacity of heating systems.

The measurement and control system is crucial for the proper functioning of the heating system. In addition to the qualitative and quantitative way of adjusting the power, the progressive measurement and control systems can also adjust the pressure conditions in the heating system. In addition to adjusting the operating characteristics of the system, the measurement and control system provides protection against damage to heating systems. Measurement and control monitors and sends feedback so that the software is updated in time for the next action.

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VI. SESSION

ENERGY PERFORMANCE OF HVAC-R SYSTEMS

EVALUATION OF VENTILATION SYSTEM OF LARGE LECTURE HALL IN TERMS OF CO_2 LOAD

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Abstract

The paper is oriented on the evaluation of ventilation system in the large lecture hall in terms of CO_2 load. Providing the optimal parameters of the CO_2 concentration is immensely important for the students in the interiors of a university. Meeting these parameters is inevitable not only from physiological point of view but also for achieving the desirable students' performance. The high CO_2 concentration is related to incorrect and insufficient ventilation in the lecture hall and causes distractibility and feeling of tiredness of students. Experimental measurements were carried out in the winter season in 2017 in the large lecture hall in order to evaluate the thermal comfort and the CO_2 concentration. The device Testo 480 was used for the measurements. Obtained values of air temperature and CO_2 concentration are presented in the charts. Mechanical ventilation system and operation system of the large university lecture hall were evaluated on the basis of the air temperature and on the basis of the CO_2 concentration. Based on the findings, design recommendations for new large university lecture halls are derived. Furthermore, there are presented recommendations how to operate the existing large university lecture halls.

Keywords - CO_2 concentration, design of mechanical ventilation and air conditioning system in large lecture hall

1. INTRODUCTION

Part of air conditioning system are vents for supply air and extract air, their correct position is very important in large lecture hall [1]. The good architectural design must enable the application of the optimal air conditioning system and correct position of supply air and extract air, which ensures acceptable CO_2 concentration [2]. Mechanical ventilation or air conditioning in the large lecture halls mean the exchange of the air in a room with the fresh outdoor air [3]. Insufficient supply of oxygen, a high concentration of CO_2, excessive air humidity, various types of odours, toxic pollutants, aerosol and microbial pollutants threaten students when there is insufficient ventilation or air conditioning of large lecture hall [4]. It can cause distractibility and feeling of tiredness, various skin diseases, respiratory diseases, the emergence of allergies, the emergence of oncological diseases and others [5]. Therefore, the correct and the sufficient ventilation of large lecture hall is very important because students spend most of their time in school in the lecture hall [6]. Sufficient exchange of air influences the CO_2 concentration; therefore, this is the most important point to consider when designing the air conditioning system or mechanical ventilation system [7]. The correct position and the distance of supply air vents and extract air vents from the floor in the large lecture hall are very important to consider when designing the air conditioning system or mechanical ventilation system [8]. The position of supply air vents and extract air vents significantly influences architectural design and eventually an architectural expression in large lecture hall. The major problem in the large lecture hall is the draught that is caused by incorrect position, a distance of supply air and extract air from the floor, and the incorrect velocity of the air flow. Therefore, this research was focused on the evaluation of CO_2 concentration in the large lecture hall.

Environment in large lecture hall is characterized by a high density of students and so the main problem is usually indoor air quality especially high CO_2 concentration, which is generated by human presence (metabolism, respiration). CO_2 levels that are unusually high in indoor climate may cause students drowsiness, headaches, or decrease of their activity. Humans are the main indoor source of carbon dioxide in the most of the buildings. Indoor CO_2 levels are an indicator of the adequacy of outdoor air ventilation relative to indoor student density and metabolic activity. In order to eliminate the most complaints, the total indoor CO_2 level should be reduced to a difference of less than 600 ppm above outdoor levels.

2. METHODOLOGY OF EXPERIMENTAL MEASUREMENTS

Experimental measurements were carried out in the large lecture hall – Fig. 1, Fig. 2 at the Slovak University of Technology in Bratislava, Faculty of Architecture.

Fig. 1 *Large lecture hall with the vents for supply air*

The aim of the measurements was to record the CO_2 concentration and air velocity.

The measurements were carried out in the large lecture hall with the sizes 15.7 x 14.4 m and with the height between 3.9 and 5.9 m in the centre of the room in the height of 1.1 m above the floor level. The large lecture hall is partially placed into the ground. It is heated with two large column radiators. The mechanical ventilation system has vents for supply air placed into the frontal wall Fig. 1 and the vents for extract air are placed into the back wall

Fig. 2. It also has new quality wooden windows with interior shielding. The first measurement was carried out without mechanical ventilation with twenty-eight students.

Fig. 2 *Large lecture hall with the vents for extract air*

The second measurement was carried out without mechanical ventilation in its first phase and with mechanical ventilation in its second phase. Sixty-four students participated in the second measurement. Mechanical ventilation unit of type BKL-KD was in operation during the second phase of the second measurement. In the second measurement, the performance was set to 50%, thus 3675 m^3/hour, which represents the air exchange three times per hour. Mechanical ventilation unit does not contain humidification component. Therefore, the air treatment was not complete. Both measurements were carried out from 8 to 9:45 in the morning during ordinary lectures. CO_2 concentration and air velocity were recorded with the device Testo 480. Outdoor air temperature and air relative humidity were measured and recorded by the separate device. Outdoor air temperature increased from value 6.1 °C to value 8.8 °C during the first measurement and from value 9.8 °C to value 11.5 °C during the second measurement. Outdoor air relative humidity decreased from the value 83% to the value 74% during the second measurement.

3. RESULTS AND ANALYSIS OF MEASUREMENTS

Fig. 3 shows the values of CO_2 concentration from the first measurement during 105 minutes in the height of 1.1 m above the floor level in the centre of the room. At the beginning of the measurement, the values of CO_2 concentration were sufficient, but the values were gradually increasing and at the end of the measurement, the admissible values of CO_2 concentration were exceeded. The large lecture hall has 210 seats; the inadmissible value of CO_2 concentration was already reached with twenty-eight students after two hours. This concludes that the large lecture hall cannot be operational without mechanical ventilation or air conditioning.

Values of air velocity were measured individually in the centre of the air flow between supply air openings and extract air openings. The value of air velocity fluctuates in the range from 0,0 to 0,02 $m.s^{-1}$ which are sufficient values. It was caused by the switched-off mechanical ventilation, so there was no air flow.

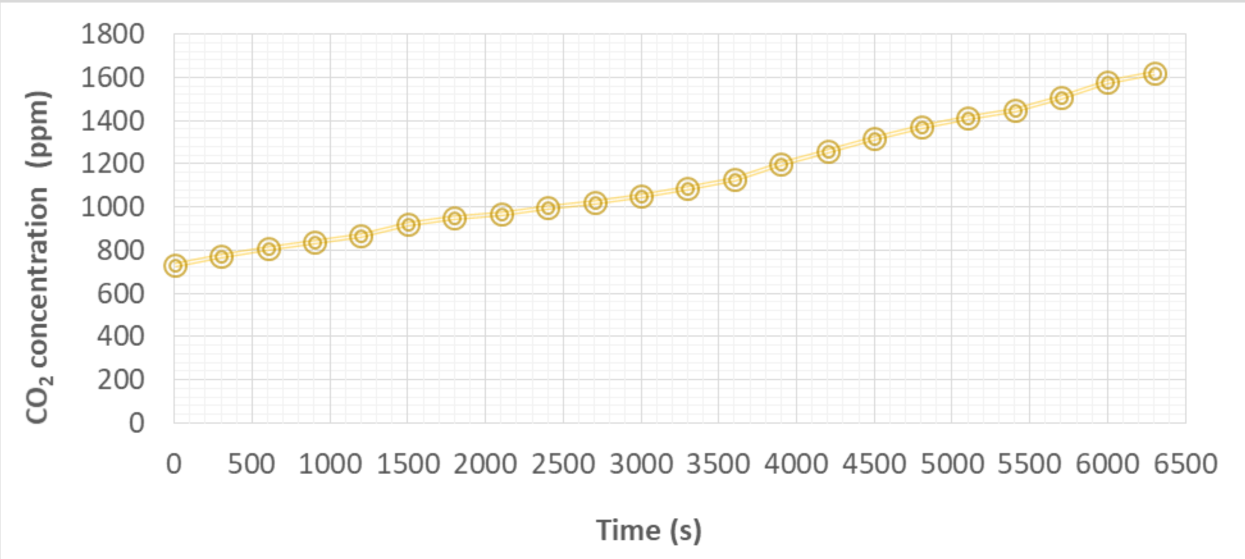

Fig. 3 *Values of CO_2 concentration during the first measurement*

Fig. 4 shows the values of CO_2 concentration from the second measurement during 105 minutes in the height of 1.1 m above the floor level in the centre of the room. At the beginning of the measurement, the values of CO_2 concentration were increased and quickly reached inadmissible values. The large lecture hall has 210 seats and the inadmissible value of CO_2 concentration was already reached with sixty-four students after thirty minutes. Then, the mechanical ventilation was turned on and the value of CO_2 concentration gradually decreased on admissible values. This measurement showed the necessity of mechanical ventilation in the large lecture hall. Only correctly designed and operated air conditioning system can bring the optimal solution for the fully occupied large lecture hall.

Values of air velocity were measured individually and intentionally in the centre of air flow between supply air and extract air vents where most of the students were seated. At the beginning of the measurement, the values of air velocity were admissible but after turning on the mechanical ventilation, the values gradually reached inadmissible high values. The students started complaining about the unbearable draft. This was caused by the incorrect design of mechanical ventilation which creates the air flow in the incorrect trajectory through seated students. The outputs from the measurements showed that it is very important to correctly place the supply air vents and extract air vents such that the values of air velocity are admissible during the operation of mechanical ventilation or air conditioning system in the places where the students are seated.

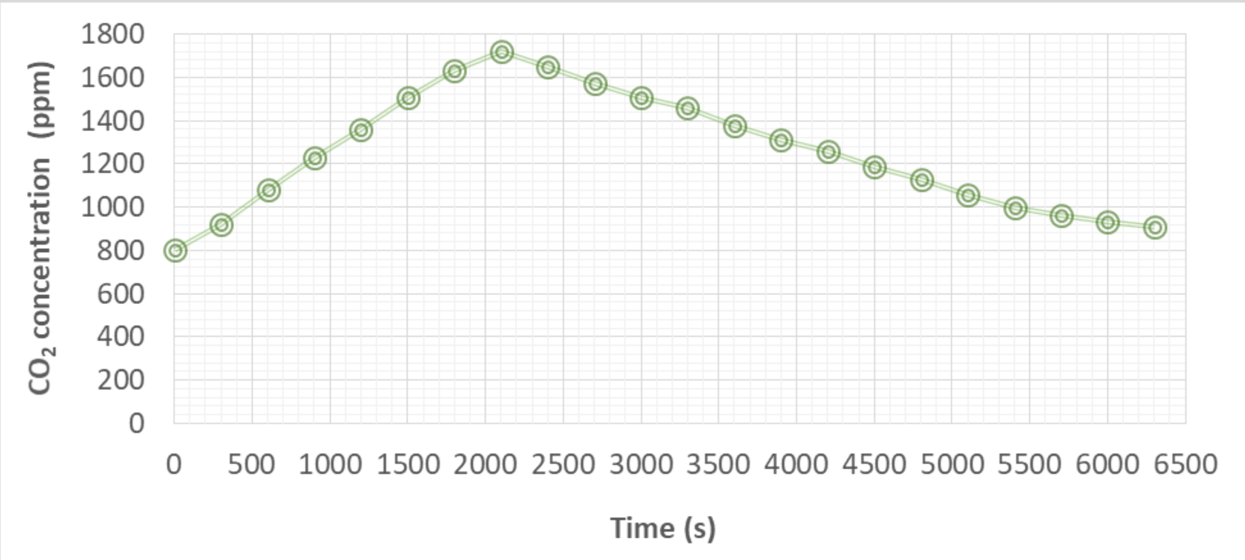

Fig. 4 *Values of CO_2 concentration during the second measurement*

4. CONCLUSION

Air conditioning system is inevitable part of a large lecture hall. This fact is supported by experimental measurements. Inadmissible values of CO_2 concentration were already reached with 13% occupancy after two hours without mechanical ventilation or air conditioning system. Conclusions of the second measurement show that air conditioning system is more suitable than just mechanical ventilation system – does not include humidification component because it can ensure the optimal value of air relative humidity. The second measurement showed that the correct operation of mechanical ventilation or air conditioning system is very important to ensure the parameters of CO_2 concentration at the beginning of a lecture in the morning and then later according to the number of students. The intensity of the air exchange could be regulated by a lecturer who would type the number of students into a control panel placed on a desk or a wall. The second measurement proved that it is very important to correctly place the vents for supply air and extract air during the design of mechanical ventilation or air conditioning system such that the values of air velocity are admissible in the area where students are seated and the unpleasant feeling from the draft is avoided. The second measurement also proved that the air distribution system through seated students, where the vents for supply air are in the frontal wall of the large lecture hall and vents for extract air are in the rear wall, is not suitable and outdated. In older buildings, it is needed to design new air conditioning system and new air distribution system for large lecture halls. These systems must have modern controlling and regulation system.

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EVALUATION OF ENERGY SOURCES AND THEIR OPERATION ON THE INDOOR CLIMATE AND ENERGY PERFORMANCE OF A BUILDING

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Abstract

The paper belongs to the field of research of efficiency of renewable and low-potential energy sources of buildings. It is based on numerical simulations of an office building and its heating and cooling systems in DesignBuilder. There are compared variant sources of energy and the ways of operating heating and cooling systems. The results are evaluated in terms of the time during which the required comfort in the building was not achieved, and also in terms of energy consumption and price.

1. INTRODUCTION

One possibility of renewable energy sources is the installation of heat exchanger loops in piles, at lower levels depending on subfloors larger buildings can be established, in so-called energy piles, which provide the country's declared body for heating and cooling. In winter, when the object needs to be printed, it can be used as a source of energy for the heat pump. Advantages in summer, the excess money is transferred to the target and thus the object cools.

Contribution with no influence of selected HVAC system (heating, ventilation and air conditioning) on indoor climate, energy efficiency and economic efficiency of a particular high-rise office building in Brno [Sikula et al, 1]. This study is eligible for energy simulation and energy performance calculation of buildings according to [EN ISO 52016-1, 2]. You will kill yourself with advantageous basic pilots, limit the administration buildings as heat exchangers with different temperature differences to heating and cooling.

Modeling in dynamic year-round simulation software DesignBuilder 6, which uses the EnergyPlus 8.9 computing core. It is a robust tool for optimizing the energy of buildings and is therefore suitable for this purpose. A comparison of simulated and energy-intensive buildings and the use of DesignBuilder is discussed in [Tronchin et al, 5].

Solar heat gains play a major role in the energy balance of buildings with a significant percentage of glazing. Your effects on daylight, savings on heating, but also on load effects are discussed in [Sikula et al, 6], [Hraska, 7]. The effect of internal gains on energy simulation is discussed in [Sojkova et al, 8]. Simulations of HVAC heating, ventilation and air conditioning systems affecting thermal comfort in office buildings are discussed [Szabo et al., 9], [Petráš et al., 10], [Nemethova et al., 11].

DesignBuilder simulation results are presented in a graphical view to evaluate the relationship between thermal comfort and energy savings in a building.

2. DESCRIPTION OF THE BUILDING, ENERGY SYSTEMS AND OPERATIONBUI

The administrative building is located in the southern part of Brno - see [Pichova et al, 12], [Horka et al, 13]. Stacked floors from two underground floors and fourteen aboveground floors. Underground floor suitable as a garage space. The above-ground part consists mainly of office space, where the floor area kills up to 1,000 square meters of floor space, restaurant and machined.

The building is designed as a reinforced-concrete skeleton with the walls of the cladding zonal on the piles.

The demand for printing and cooling a typical winter week in January and a summer week in July is determined by internal gains (lighting, computers and people) and external conditions (weather conditions).

The source of heat for heating are gas condensing boilers. Two are Broetje SGB-106 and two Broetje SGB-250. The minimum output of condensing boilers at a temperature gradient of 75/55 ° C is 38.6 kW, the maximum output of boilers is 677.0 kW. The temperatures are transferred to the room by means of plate radiators. The boilers also supply water heaters in the AHU (Air Handling Unit).

The cooling sources are two liquid coolers (coolers), each with two compressor circuits and a separate air-cooled condenser. The cooling capacity of one cooling source is 292 kW with four-stage power control (25/50/75/100). The minimum cooling capacity of the chiller is 73 kW and the maximum capacity is 584 kW. The capacitors are double-circuit with an output of 2 x 148 kW, designed for a condensing temperature of 50.3 ° C. Heat carriers are at temperatures endangering 6/12 ° C.

Office hours are Monday to Friday from 07:00 to 18:00. In winter the premises are heated during operation to 20 ° C, outside working hours heated to 16 ° C. In summer they are cooled to 26 ° C, outdoor working hours are only cooled to 28 ° C.

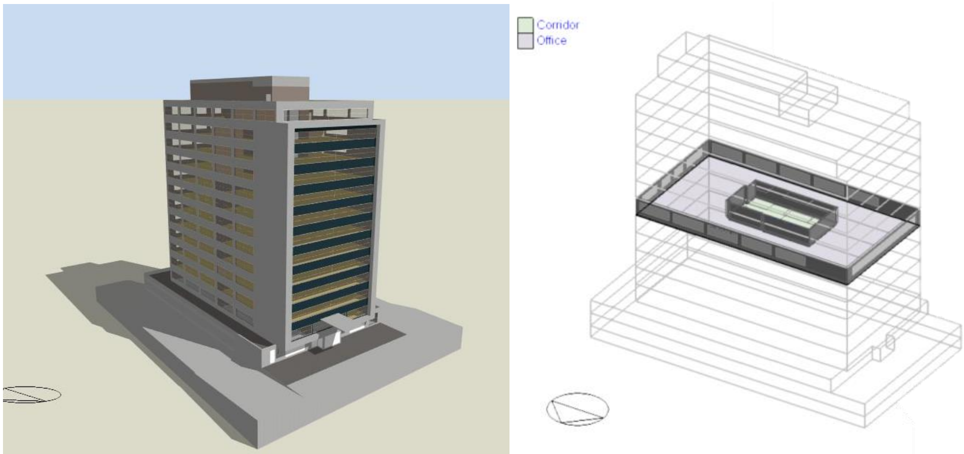

Fig. 1 *Model of buildings and temperature zones of individual floors in DesignBuilder 6*

3. VARIANTS OF ENERGY SOURCES

In DesignBuilder 6, an energy model of an office building was created in which three zones were monitored: office, corridor and restaurant (Figure 1). The existing priority 2 heating and cooling system has been complemented by heat pumps using GHE (Ground Heat Exchanger) priority 1 of 72, speed 20m, speed 1m according to your variant

- V1) GHE, heat pump for heating and cooling with temperature differences of 75/55 ° C and 6/12 ° C
- V2) GHE, heat pump for heating and cooling with temperature differences of 75/55 ° C and 15/17 ° C.
- V3) GHE, heat pump for heating and cooling with temperature differences of 45/35 ° C and 12/16 ° C.
- V4) GHE, heat pump for heating and cooling with temperature differences of 45/35 ° C and 9/15 ° C.
- V5) GHE, heat pump for heating and cooling with temperature differences 55/45 ° C and 15/17 ° C.
- V6) GHE, heat pump for heating and cooling with temperature differences of 65/45 ° C and 6/12 ° C.
- V7) GHE, heat pump for heating and cooling with temperature differences of 45/35 ° C and 15/17 ° C.
- V8) GHE, heat pump for heating and heat exchanger for cooling with temperature differences 75/55 ° C, 15/17 ° C.

Heat pumps were selected Rated heating capacity 2,000 W, Rated heating capacity 1,200 W for heating and rated heating capacity 1,000 W, Rated heating capacity 600 W for cooling, so that the maximum thermal temperature over the entire geothermal loop length is 16 ° C.

The wiring diagram of the power sources is shown in FIG. 2.

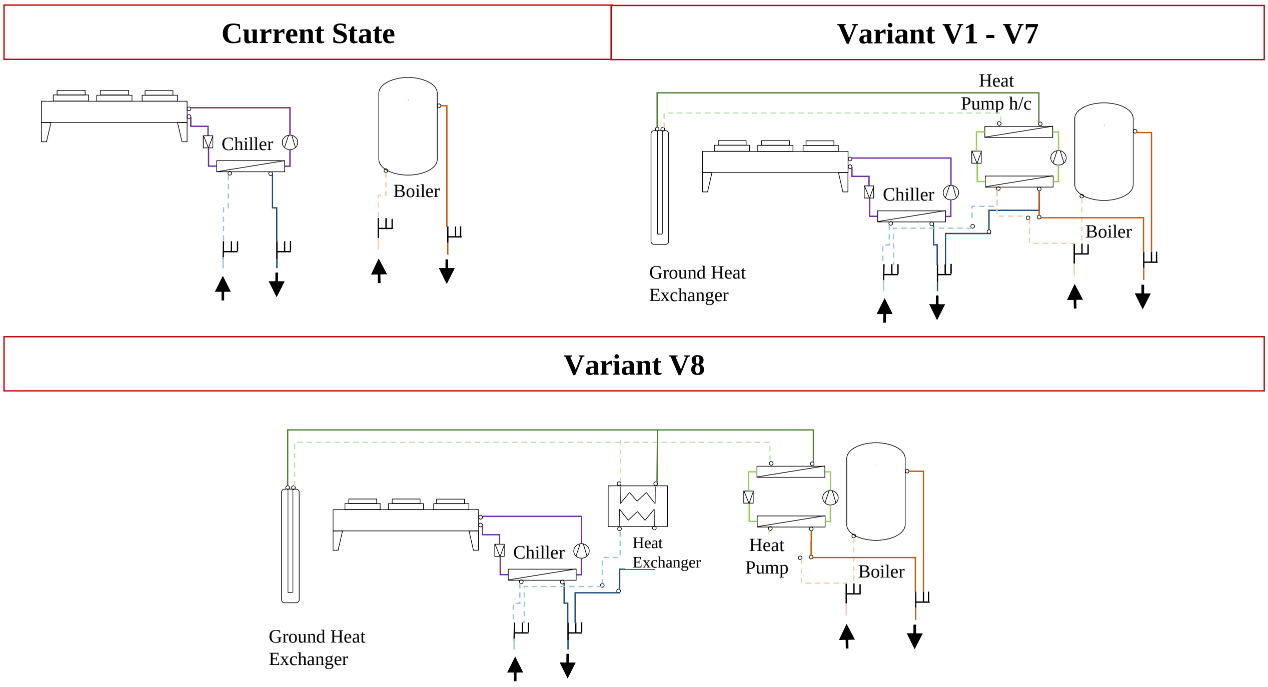

Fig. 2 *Variants of energy sources*

4. RESULTS

Selected temperatures that can be evaluated after the test year are shown in Fig. 3. A comparison of the heating and cooling energy sources during the year for the current state is shown in the Fig. 4.

The evaluation of selected variants was demonstrated on the basis of comparison of consumables for boiler and electric energy for cooling, heat pump for cooling and heating and for pumps and fans AHU - see Fig. 5. Electricity price was considered as CZK 3 / kWh and gas 1.5 CZK / kWh.

Fig. 6. shows the expected number of hours when it is not possible to pay the comfort of the building.

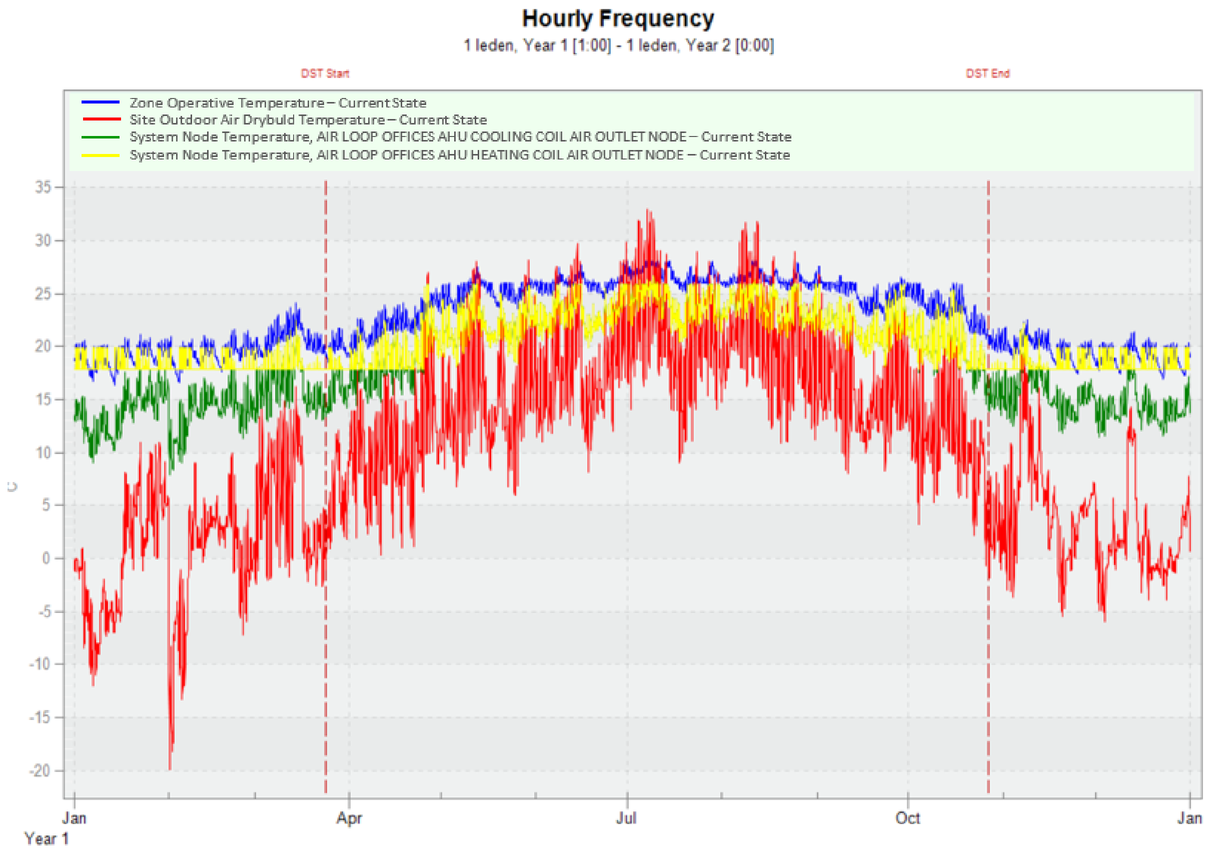

Fig. 3 *Course of selected temperatures - current status in EnergyPlus 8.9*

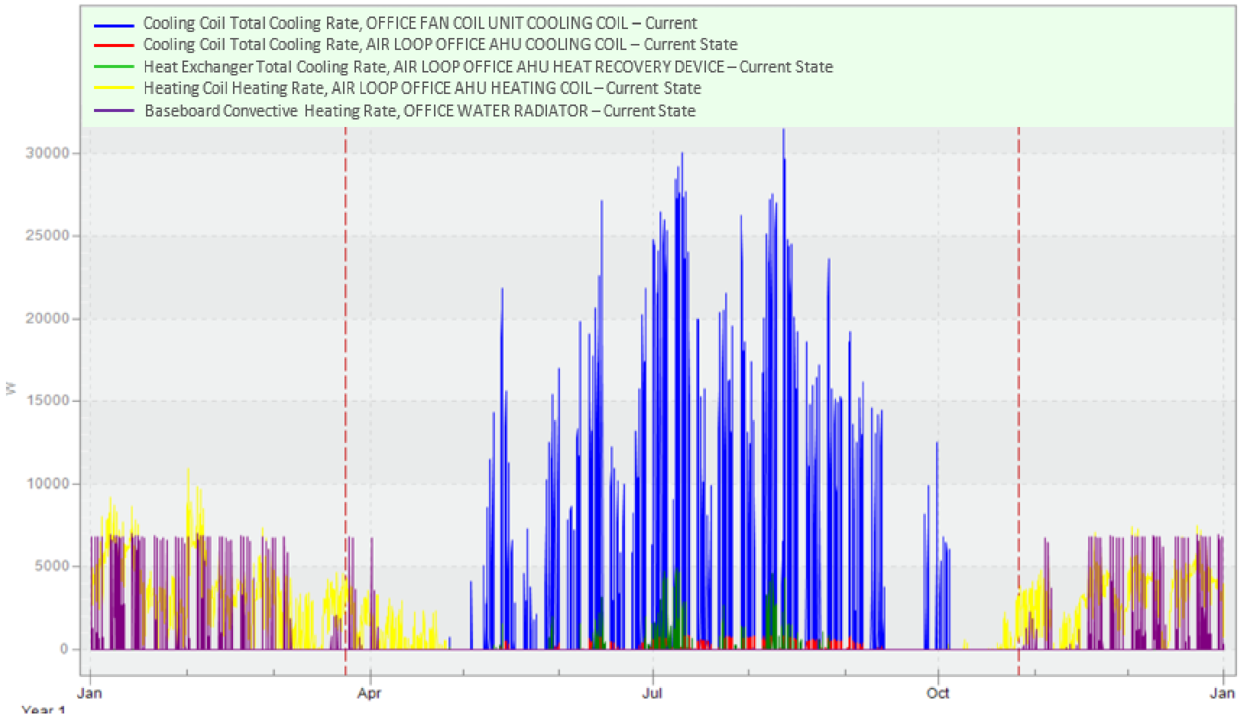

Fig. 4 *A course of selected heating and cooling capacities – current state, EnergyPlus 8.9*

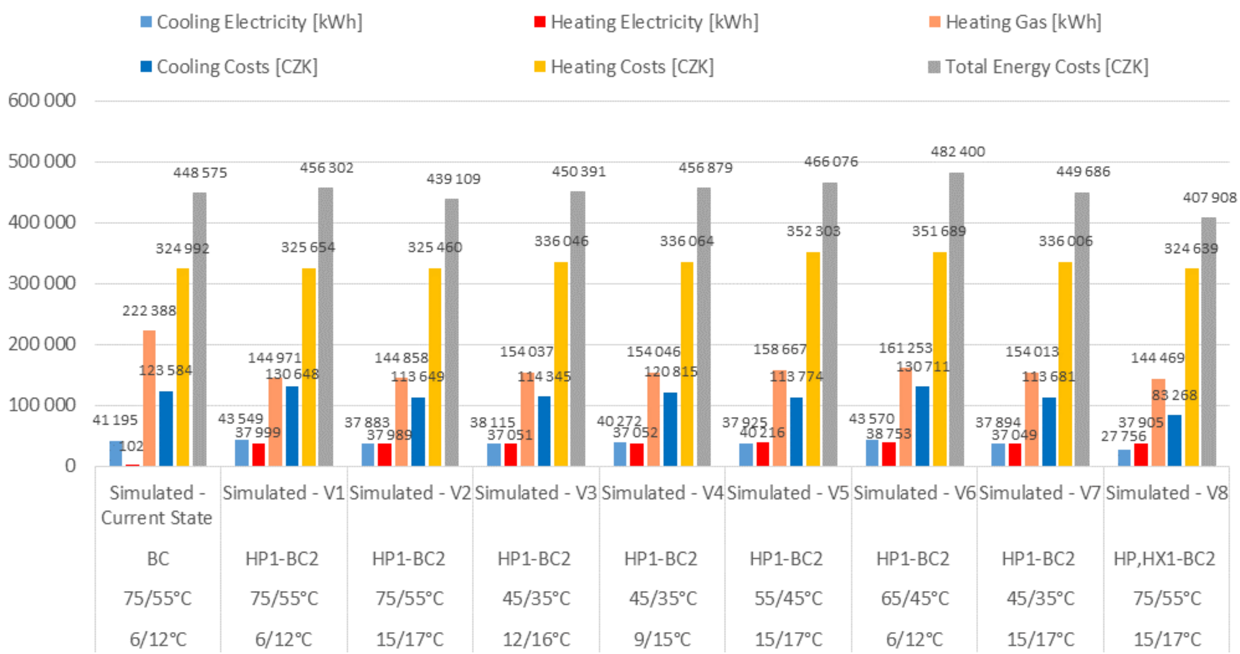

Fig. 5 *Energy and cost comparison*

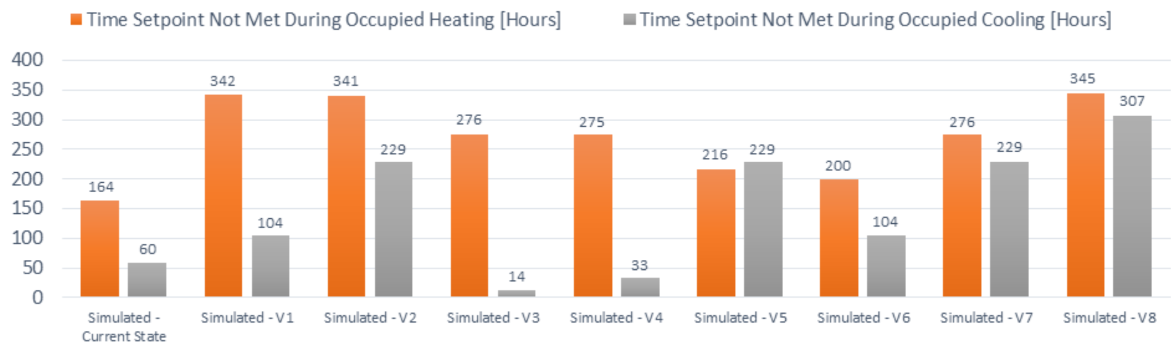

Fig. 6 *Number of hours when the comfort criteria were not met*

5. CONCLUSIONS

The test shown by DesignBuilder 6 affects selected variants of GHE heat pump energy sources for energy consumption and the cost of specific office buildings at a time when there is no comfort advantage. Although we used advantageous operations and expected thermal comfort in all considered variants, they expected great differences.

From the searched results it is possible to find out that for the current system of heat consumers 222,490 kWh (here I added the heating + electric gas), sources of cooling 41,195 kWh and possible costs 448,575 CZK is the most advantageous variant of heat pumps for heating and cooling V2 by more than 2%, especially in the case of high-temperature cooling modes.

In variant V8 a temperature gradient of water from variant V2 was required. Changed heat exchanges for cooling and reduced heat pump heat pumps to dispense as much energy as possible. The possible cost reduction of the original original variant is thus 9%. The achieved results confirm the effectiveness of geothermal systems.

The evaluation of selected variants was proved on the basis of comparison of consumables for the boiler and electric energy for radiator, heat pump for cooling and heating and for pumps and fans AHU - see Fig. 5 CZK / kWh.

In the initial state of the building, when the start of full heating and cooling operation was started with the start of operation at a time when it was not possible to reduce the temperature to heating 164 hours and to cooling 60 hours. With the most cost-effective V8 variants, this is a great advantage of hours when it is not possible to gain comfort in a building.

Acknowledgment
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THE IMPACT OF ENERGY PERFORMANCE CONTRACTING MEASURES ON THE QUALITY OF INDOOR ENVIRONMENT OF BUILDING

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Abstract

The main purpose of the energy auditing is to reduce energy consumption and increase energy efficiency of a building. Every energy auditor should be aware of the problem with the quality of indoor environment of a building after the building renovation, which is mostly building insulation and windows reconstruction. This could have an impact on the comfort of building users. The experts always say that the building does not breathe after the building insulation.

Keywords – indoor climate, energy auditing, sick building syndrome

1. INTRODUCTION

There is no building in whole world which is perfectly constructed, without any sign of a problem. This means that it is important to choose the correct materials for building and it is important to ensure the right balance of the indoor climate of building. Often, we can see the building where it is too hot or too cold and people who inside it, are feeling sick, for example they have a migraine, they experience neck pain etc. This problem is also known as a "Sick Building Syndrome" and has an impact to their work performance.

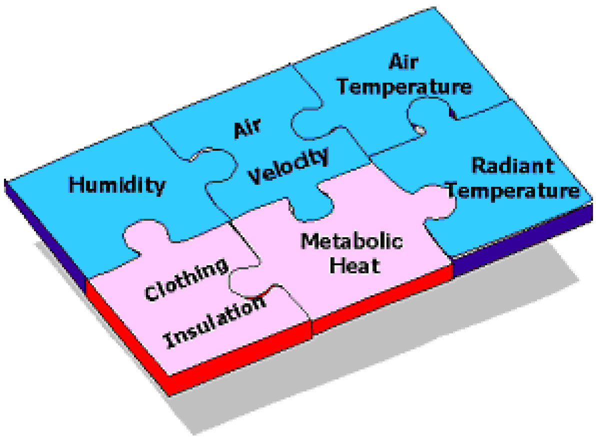
2. THERMAL COMFORT

Thermal comfort is defined as a condition of mind that expresses satisfaction with the thermal environment. Due to its subjectivity, thermal comfort is different for every person in the building. It is maintained when the heat generated by the human metabolism can dissipate at a rate that maintains thermal balance in the body and any heat loss or gain beyond this balance means significant discomfort.[1] Basically, to reach this balance, heat produced must equal heat loss.

Feeling hot or cold does not depend jus on air temperature. There are six primary Thermal comfort factors

- Environmental factors
    - Air temperature
    - Radiant temperature
    - Humidity
    - Air velocity
- Personal factors
    - Metabolic heat
    - Clothing insulation

All these parameters must be combined, then the thermal storage is equal to zero.



Pic. 1 The six basic factors of thermal comfort [3]

2.1.1 Metabolic heat

The metabolic rate varies with the activity. It is expressed in the met unit or in W/m². The metabolic rate of a relaxed seated person is one 1 met = 59,2 W/m². The metabolic rates vary from person to person and the intensity of the activity. The surface area of an average person is about 1,8 m².

Activity	Metabolic rates W m^{-2}	met
Reclining	**46**	**0.8**
Seated, relaxed	**58**	**1.0**
Sedentary activity (office, dwelling, school, laboratory)	**70**	**1.2**
Standing, light activity (shopping, laboratory, light industry)	**93**	**1.6**
Standing, medium activity (shop assistant, domestic work, machine work)	**116**	**2.0**
Walking on the level:		
2 km/h	**110**	**1.9**
3 km/h	**140**	**2.4**
4 km/h	**165**	**2.8**
5 km/h	**200**	**3.4**

Pic. 2 Metabolic rates of different activities [5]

2.1.2 Clothing insulation

Clothes insulate a person from exchanging heat with the surrounding air and surfaces as well as affects the loss of heat through the evaporation of sweat. Clothing can be directly controlled by a person, for expamlpe they can put their jackets on/off, whereas environmental factors may be beyond their control.

	I_{cl}			I_{cl}	
Work clothing	**clo**	**m² ·K W^{-1}**	**Daily wear clothing**	**clo**	**m² ·K W^{-1}**
Underpants, boiler suit, socks, shoes	**0.70**	**0.110**	**Panties, T-shirt, shorts, light socks, sandals**	**0.30**	**0.050**
Underpants, shirt, boiler suit, socks, shoes	**0.80**	**0.125**	**Underpants, shirt with short sleeves, light trousers, light socks, shoes**	**0.50**	**0.080**
Underpants, shirt, trousers, smock, socks, shoes	**0.90**	**0.140**	**Panties, petticoat, stockings, dress, shoes**	**0.70**	**0.105**
Underwear with short sleeves and legs, shirt, trousers, jacket, socks, shoes	**1.00**	**0.155**	**Underwear, shirt, trousers, socks, shoes**	**0.70**	**0.110**
Underwear with long legs and sleeves, thermo- jacket, socks, shoes	**1.20**	**0.185**	**Panties, shirt, trousers, jacket, socks, shoes**	**1.00**	**0.155**

Pic. 2 Thermal insulation for some clothing combination [5]

3. PMV PPD MODEL

The first hypothesis of human thermal comfort was expressed by Povl Ole Fanger. He hypothesized that human thermal comfort was based on human skin temperature and its sweat secretion. There is a great number of techniques for estimating likely thermal comfort, including effective temperature, equivalent temperature, Wet Bulb Globe Temperature (WBGT), resultant temperature and so on and so forth, and charts exists showing predicted comfort zones within ranges of conditions. However thermal comfort can be expressed in terms of Predicted Mean Vote also known as PMV and Percentage People Dissatisfied also known as a PPD. [2]

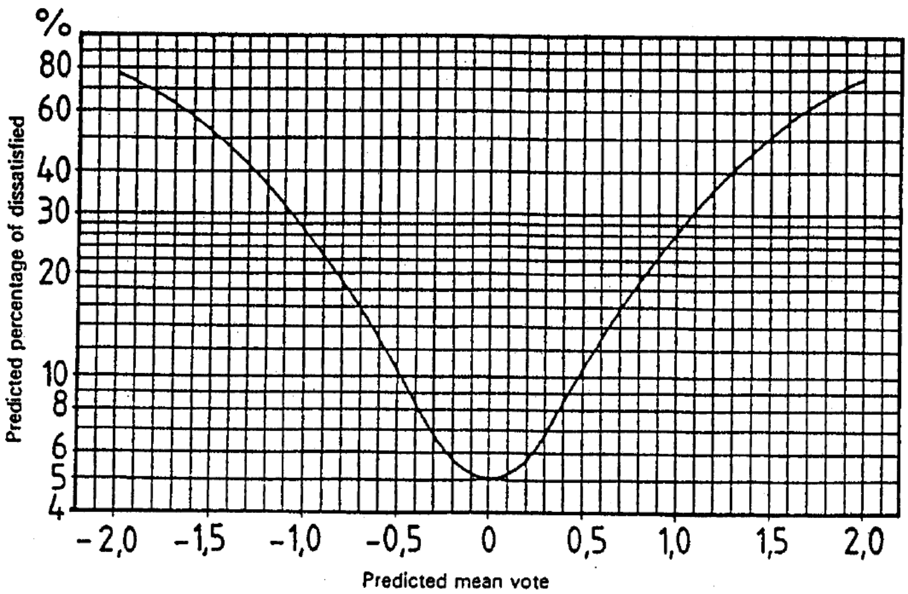


Fig. 1 Predicted percentage of dissatisfied (PPD) as a function of predicted mean vote (PMV) [6]

Pic. 3 Fanger seven-point scale [4]

3.1 Thermal discomfort

Besides the general thermal state of the body, a person may find the thermal environment unacceptable. It may be caused by asymmetric radiation, vertical air temperature differences or contact with hot or cold surfaces (floors, machinery, etx.).

3. ENERGY PERFORMANCE CONTRACTING AND INDOOR CLIMATE OF BUILDINGS

Energy performance contracting (EPC) is an energy study of the building, in which the EPC project will be prepared (description of the current state of the building, calculation of the building's energy performance, suggestion of austerity measures, economic evaluation of the building).

For instance, recuperation and EMS[1] are effective ways of improving the indoor climate of buildings. Their implementation can be financed under GES under certain conditions, in combination with other energy and operational cost savings measures.

6. CONCLUSION

It is very important to feel good in every building and so it is very important to ensure perfect conditions, which have an impact on people. Sometimes it is very difficult to build a building which suits everyone. One of the ways is use of recuperation, but for someone this could be an expensive solution. This problem can be solved with EPC project.

Acknowledgement
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[1] EMS – energy management system - system for measuring, recording, comparing and evaluating energy consumption at the level of the whole buildng, for the purpose of designing, implementing and evaluating austerity measures. The estimated costs and benefits associated with the design and implementation of the EMS are based on the estimated savings and the estimated number of meters and sensors installed in the building. In the economic evaluation it is necessary to consider operating costs in addition to investment costs and generated savings.

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DESIGN AND ASSESSMENT OF PERSONALIZED VENTILATION SYSTEMS

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Abstract

The aim of the paper is to bring a wider notion of personalized ventilation systems and their use in design of a building indoor environment. In the first part the paper presents the main advantages and limits for designing this kind of ventilation in new buildings and reconstructions. The second part summarizes known types of personalized ventilation systems and makes a comparison based on research of a state of art knowledge. The comparison is composed of three main elements crucial for design: impact on indoor environment, energy consumption and investment costs.

Keywords - personalized ventilation; assessment; comparison; design;

1. INTRODUCTION

Personal ventilation is a system of direct air distribution which can increase an indoor environment quality of a building occupants and potentially could be also really energy efficient. It is one of the modern alternatives to contemporary common systems of air distribution. But despite its advantages, there are just a few systems of personalized ventilation installed in the world. Why is that so? And is there any chance for us to change that fact? For beginning, lets sum up what can we get by installing a personalized ventilation system and what are the main limits of installation.

Advantages of personal ventilation

The first idea of direct distribution of fresh air is connected to indoor environment quality. Personalized ventilation system can gain access to the fresh and unpolluted air to anyone even in the largest open space room, where common mixed ventilation just dilutes the indoor exhausted air with some fresh air and makes one uniform environment with uniform distribution of odors and potentially dangerous pollutants without possibility to change it.

Unlike that, personalized ventilation supplies the unpolluted fresh air to every user and lowers the odors and infection spreading [1]. Besides, the air distributed into the personal environment increases air movement around the body and increases the perceived air quality [2]. The amount of fresh air is usually easy to control by the user so the user can adjust his personal environment to his individual needs, which leads to better satisfaction with indoor environment [1][3]. This effect can be further enhanced by adding the ability to adjust the supply air temperature. It is assumed, that possibility of adjusting temperature about ±3 K can lead to 99 % people satisfied with their environment [4].

Another great advantage of personalized ventilation is a possible reduction of energy consumption for building ventilation. The main point is again in direct and more effective supply of the fresh air. It can reduce the amount of fresh air conditioned in the air handling unit. Another possibility is to change the amount of fresh based on the actual occupancy of the room [5]. This advantage can differ in different building operations. The last-mentioned way is to lower the energy need to cool or heat the interior of the building and increase or decrease the ambient temperature,

Limits of personalized ventilation

On the other hand, there are of course some real difficulties connected with personalized ventilation. One of them is the increased investment cost of the installation. It is caused by more complicated distribution of the air to the personal diffusers and it's also necessary to buy one special device for every workplace. The price can vary, simple devices won't price so much, but won't help much. Complex systems can be perfect in creating an indoor environment, but they could be expensive.

Another limit of a personalized ventilation is the lack of support in legislative. Nowadays, the amount of fresh air in standards does not really includes the efficiency of the ventilation. It lowers the advantages of personal ventilation and makes the investment costs a bit pointless, unless you want to achieve the highest standards of indoor environment quality.

The last complication is missing information for anyone who want to design a personalized ventilation in a building. There are so many ways this kind of ventilation affects the ventilation design and almost no way to look at it from a holistic perspective. And that is the reason why we are trying to create the analytic tool to compare the possibilities, gains and costs of as many approaches to personalized ventilation as possible.

2. DEVELOPING THE ANALYTICS SCHEME

Our goal in that part of the research was to create a useful tool for comparing different personalized ventilation systems. It should be used as a first preview of how personal ventilation affects the design and basic help for a decision making and should be helpful to identify the appropriate application for specific situation and buildings. Unfortunately, there is no unified system of assessment that could be used to compare that complex systems of ventilation with all their aspects and nuances. Especially if you don't want to use advanced computing or simulation methods or you don't have precise information about the building.

The holistic analysis created in this research is based on the collected information and data from the literature and attempts to relate the individual aspects of personalized ventilation. It has the form of extended multicriteria analysis, because it tries to numerically express and compare different kinds of data.

Effects on the efficiency of personalized ventilation

The first step of the analysis was to find the links and connection between all the phenomena affecting the personalized ventilation system and the user. At first form the perspective of a single unit, at second from the whole system. The main aspects influencing the efficiency of personalized ventilation and the user comfort are shown in the Fig. 1. The user breathing zone is marked as zone A, and that's the place we want to supply the air. But there are two zones we must be aware of, eyes (B) and hands (C). Increasing air velocities in those zones make a user feel less comfortable and can cause a health issues.

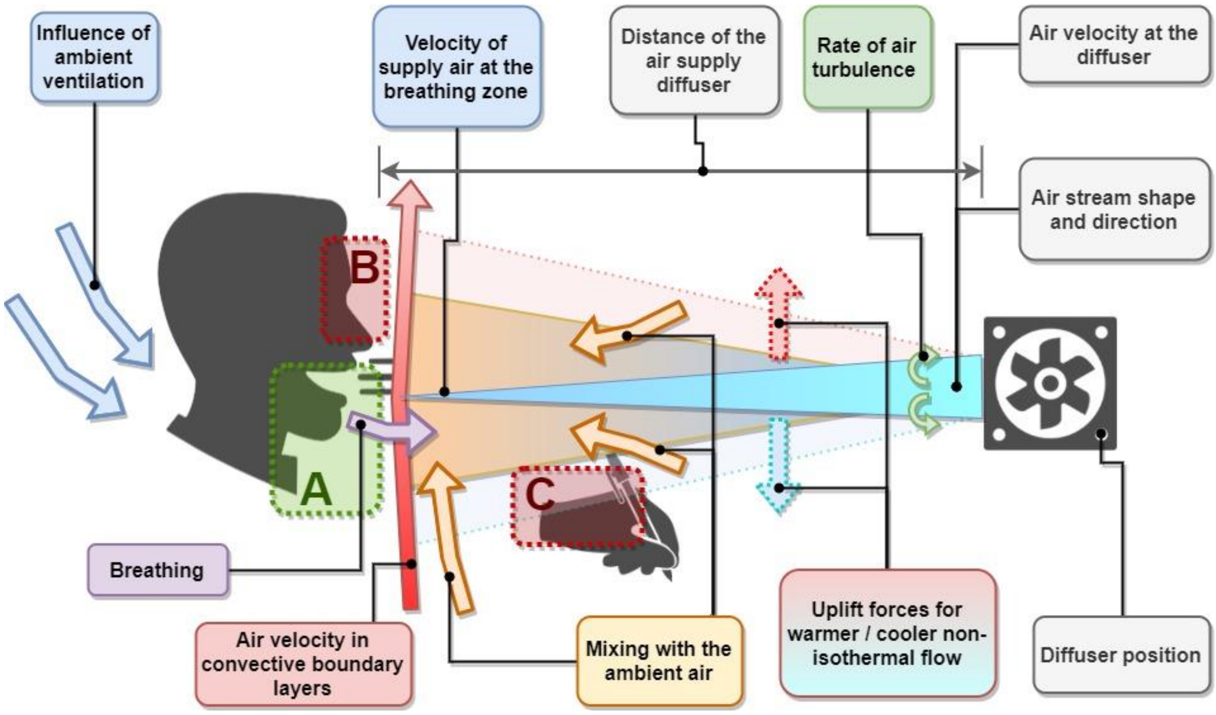

Fig. 1 *The main aspects influencing the efficiency of personalized ventilation and the user comfort. Marked zones are: breathing zone (A), eyes (B) and hands (C).*

From the holistic perspective

From the holistic perspective we can't see only the effect of personalized ventilation on user and his comfort. We have to take a wider view and include all benefits and limits those systems have. In order to more accurately express and evaluate it we have divided the impacts and influences into three categories:

- *Indoor air quality*
- *Energy consumption (ventilation and thermal comfort)*
- *Investment costs*

We also had to find main technologies and principles of personalized ventilation systems known in the literature and sort them by their impact on all three categories. The exact links are shown in the Fig. 2 for indoor environment quality, in the Fig. 3 for energy consumption and in the Fig. 4 for investment costs. The last mentioned was the most difficult to quantify, because there are just a few real installations of personalized ventilation.

For the quantification of connections, more precise specification of principles was used. For example, personalized air diffusers are divided into categories by distance from the user (ergo efficiency of the ventilation). The calculation method was designed using average values in an average space without specification of the building. The results of the assessment are extended multicriterial analysis. Every parameter has a scale from 0 to 6 points, where 6 is always the best possible outcome and 0 is the worst. Those parameters are then averaged for every category with different weight of every parameter. The weight can be specified during the calculation in order to adapt the result to the preferences and needs of the specific operation.

Unfortunately, the exact description of the quantification of all links and formulas in the tool computing core goes beyond the scope of this article.

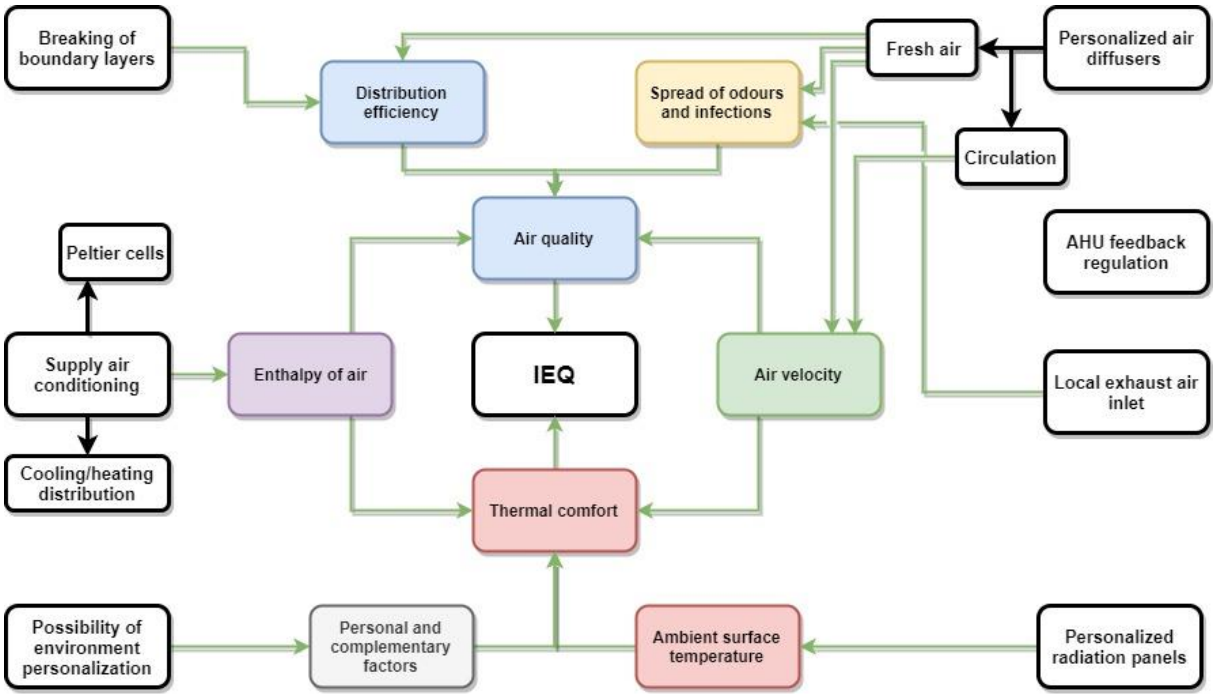

Fig. 2 *display of effects of individual elements of personalized ventilation systems on specific parameters and the main category related to indoor environment quality.*

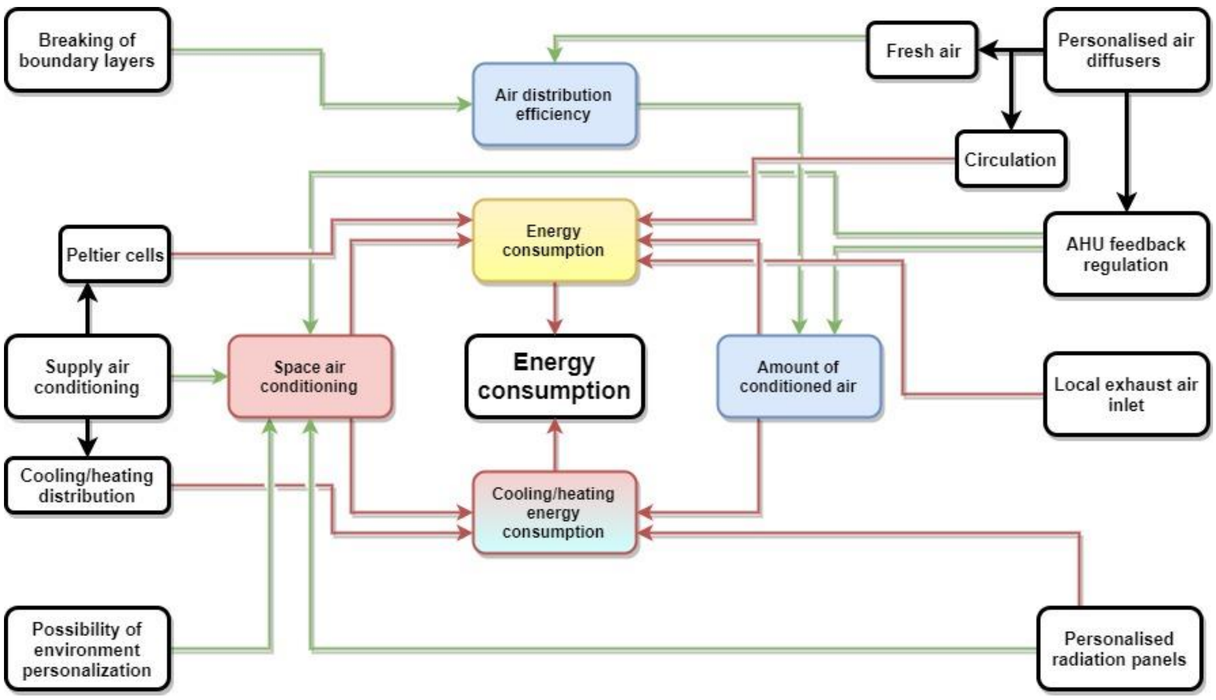

Fig. 3 *display of effects of individual elements of personalized ventilation systems on specific parameters and the main category related to energy consumption.*

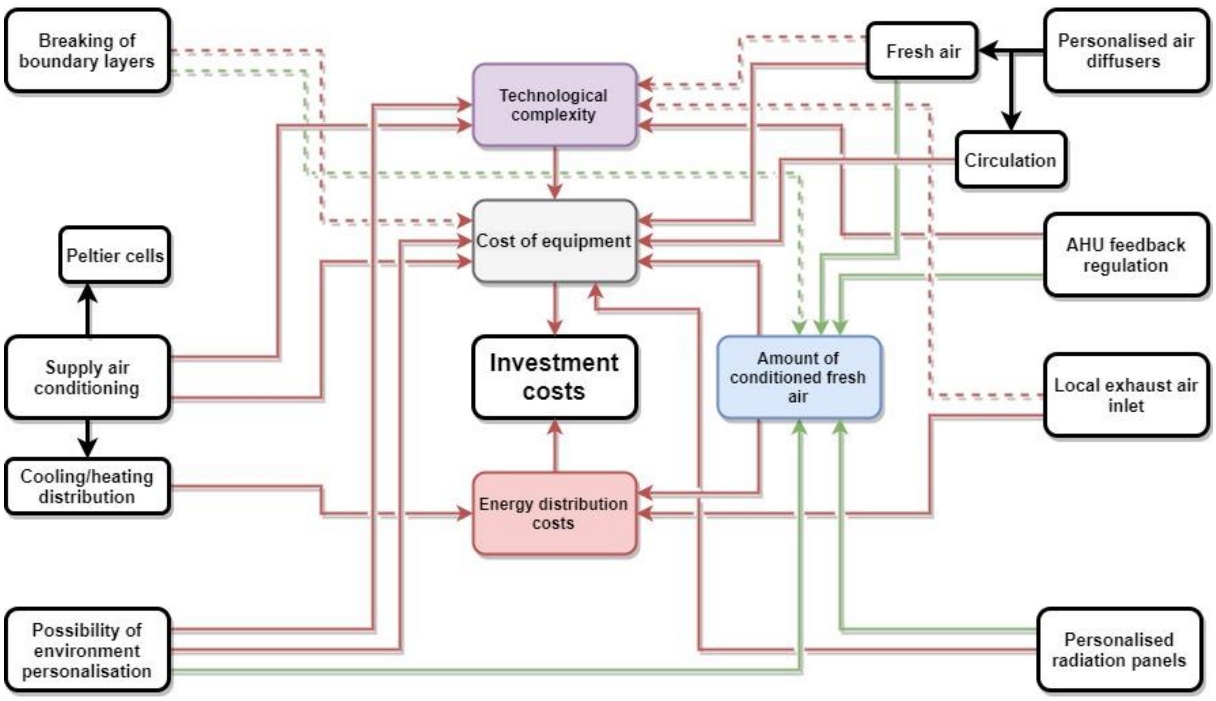

Fig. 4 *display of effects of individual elements of personalized ventilation systems on specific parameters and the main category related to investment costs*

3. USING THE ASSESSMENT TOOL TO COMPARE DIFFERENT SYSTEMS

We have chosen three different ventilation systems to demonstrate the use of the assessment tool. Two of them are personalized ventilation system designed by the authors, the last one is a common mixing ventilation, which is used in the assessment as a possible ambient ventilation and is used as a complement for both assessed systems of personalized ventilation.

MKJ1 micro air handling unit

This system is based on authors previous research [6] and is made for dispatcher room at Air Traffic Control center in Czech Republic. This system is focused on creating better indoor environment. It connected to the fresh air and can adjust its temperature about ±4 K using a set of Peltier modules. The fresh air is supplied from diffuser on the side of the monitors (medium distance) and the amount of air and its temperature is fully controllable by user. For energy saving there is possibility to control the amount of fresh air by the room occupancy.

MKJ2 personal circulation unit

The second system is using local circulation units and was created for large open-space office with a difficult access to the fresh air connection. It was designed to increase the indoor environment quality without a larger structural intervention and for affordable cost. This personal unit increases the air velocity in the personal environment and can adjust temperature of supply air similar to MKJ1. Air velocity and temperature are controllable by the user and units are connected to the central air conditioning system, adjusting a room temperature conditioning by average choices of users. It could potentially adjust the amount of fresh air by occupancy to better energy consumption, but It could worsen the air quality too much in this kind of large space.

Comparison results

Result of the computioned comparison is shown in the Fig. 5. There is a point score for every individual computed parameter and weight average of parameters for every category. The point score are shown in the result table and diagrams.

We can easily see, that the mixing ventilation has the best investment costs compared to both personalized ventilation systems. But personalized ventilation has better performance in the indoor environment parameters. In the potential energy savigns the MKJ1 system has slightly better result because it could save a lot of energy on conditioning fresh supply air from the perspective of conditioned amount of air and temperature of the room, which balances the increased energy demand for its operation. On the contrary, MKJ2 unit shows increased energy demand in comparison to mixing ventialtion, but its investment cost is not that high as MKJ1 is.

		Potential energy saving	Potential indoor environment quality	Potential investment costs saving	Overall rating
	parameter weight	*1*	*1*	*0,6*	
Var1:	**MV**	1,36	1,29	3,00	**1,71**
Var2:	**MKJ1**	1,86	4,66	0,54	**2,63**
Var3:	**MKJ2**	0,91	3,47	1,70	**2,07**

		Energy saving in operation	Energy saving in air supply	Energy saving in cool./heat.	Air quality	Acoustic environment quality	Air velocity	Thermal comfort	Air distribution systems	Energy distribution system	Cost of equipment
	parameter weight	*1*	*0,7*	*0,5*	*1*	*0,3*	*0,6*	*1*	*1*	*0,5*	*1*
Var1:	**MV**	3	0	0	0	5,5	1	1,5	2	5	3
Var2:	**MKJ1**	1	3	2	4	5	5	5	-0,7	3	0,55
Var3:	**MKJ2**	1	0	2	1	3,5	5	5	2	3	0,75

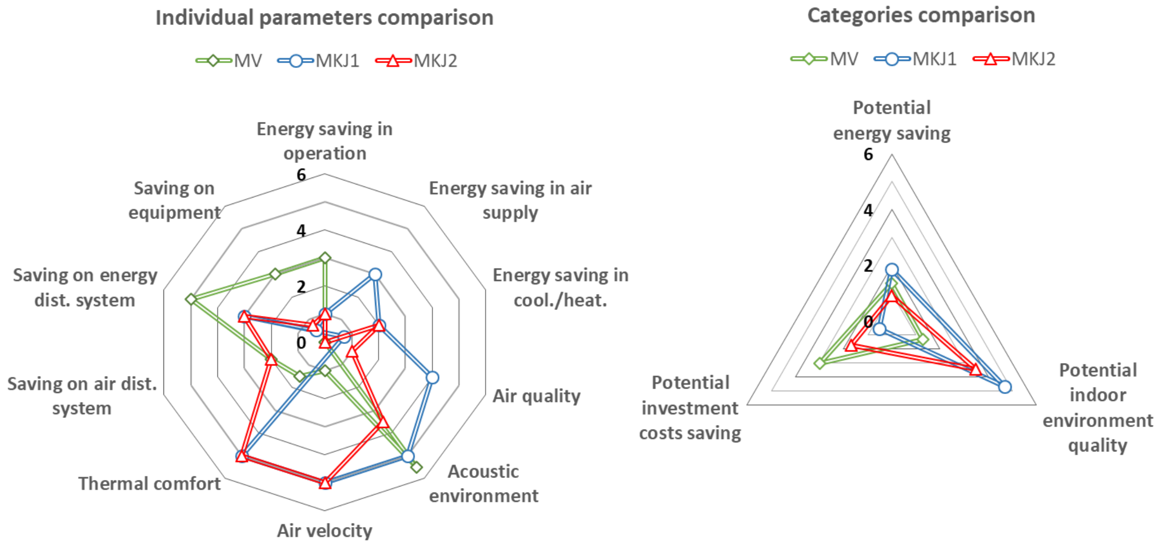

Fig. 5 *Results of the assessment of three different ventilation systems, common mixing ventilation and two different personalized ventilations*

4. CONCLUSION

The assessment tool we created in this research is an extended multicriterial analysis which summaries the main links between different principles of personalized ventilation systems. It could be used to compare different systems of personalized ventilation on the beginning phase of designing building HVAC systems or for a design of new personalized ventilation system.

There is not yet possible to calculate exact numbers of energy savings or investment costs, because there is not yet possible to input specific building data (as a room space or occupancy) to the assessment tool. But this tool is just a base of knowledge we plan to extend. The goal of the research is to create more complex software which could be used by HVAC designers to more exactly approximate profits and costs of the personalized ventilation.

Acknowledgment

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ASSESSMENT OF BUILDING RETROFIT MEASURES: A CASE STUDY WITH LIMITED RETROFIT BUDGET

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Abstract

The article deals with the preliminary assessment of building retrofit measures of a culture house using building performance simulations. There was a limited budget available for the refurbishment of the building object built in 1960s that currently serves as a place for cultural events. Three variants of retrofit strategies of the cultural house according to the investor's requirements were assessed. A complete model of the investigated building was created using software BSim, calibrated and the proposed austerity measures were implemented. The reduction of consumption of the proposed variants ranges between 35-60% depending on the type of the austerity measure.

Keywords – Building Performance Simulation; Transient simulation; Retrofitting; BSim

1. INTRODUCTION

With the computer advancement, numerical simulations are quickly becoming an integral part of a design procedure of buildings, building systems and technologies. These methods allow us not only to evaluate the building energy demands and internal microclimate but also to study influences of various design parameters [1]. Our simulations were performed with the software BSim, which is a software tool simulating the dynamic behaviour of transient systems, an integrated PC tool used to analyse buildings and their installations [2].

The examined object is a building serving as cultural house (House of Culture) for small city Letohrad located in Orlické Foothills in the Czech Republic. In the Eastern bloc in Europe, House of Culture is the name for an establishment for several recreational activities such as sports, theatre, cinema, etc. The tasks of this case study were to decrease energy demand in the object. The major investor of the object’s refurbishment was the city itself; therefore, there was strong emphasis on investment costs.

2. BUILDING DESCRIPTION

The examined building is located in Letohrad in the Czech Republic and serves for city purposes as cultural centre with several cultural activities and events being held inside the object throughout the year. There are also private companies and services based in the building, such as restaurant, dance hall and theatre scene. The House of Culture construction was finished in 1968 and it had fallen into disrepair since. It is a two-storey building, partially with underground storey (see Fig. 1). The composition of building elements is described in Table 1. Gross volume of the object is 16995 m^3 and the built-up area 1350 m^2.

Table 1 *Compositions of building elements used for BSim simulation*

Structure	Material	Thickness [mm]	Thermal conductivity λ [W/m.K]	Specific heat capacity [J/kg.K]	Bulk density [kg/m^3]
Floor structure in contact with ground	PVC floor Concrete	3 300	0.900 1.340	1200 1020	1200 2400
External wall	Brick	450	0.750	900	1300
Internal wall 1	Brick	150-400	0.750	900	1300
Internal wall 2	Plasterboard Mineral wool Plasterboard	12.5 100 12.5	0.220 0.036 0.220	1060 800 1060	1150 25 1150
Floor structure between two floors	Linoleum Concrete	2 450	0.200 1.340	1260 1020	1200 2400
Uninsulated roof	Beech	40	0.170	1800	600

Heating of the building is provided by the two gas boilers located in the technical room with total heating power 187 kW. To find out the maximum heating demand throughout the reference year, heating power was set up to unlimited power.

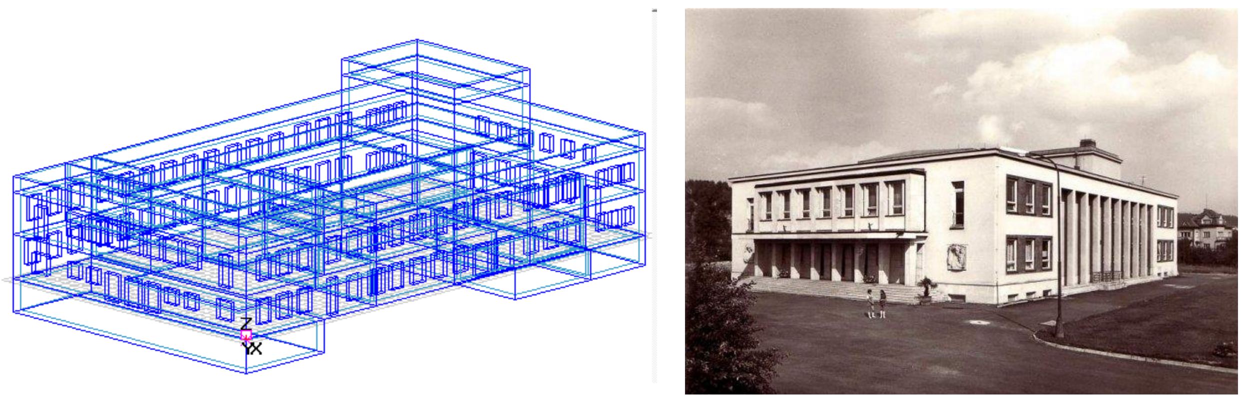

Fig. 1 *Geometrical model and historical photo of examined building (photo courtesy of www.kultura.cz; retrieved on the 30th of November 2019)*

3. BOUNDARY CONDITIONS

Internal gains were determined from information given by the investor and operator of the building, scheduling of people load was based on the actual distribution of cultural events and activities, lighting scheduling on real consumption of electricity. Internal heat gains generated by office equipment and computers were assessed by the inspection *in situ* and questionnaire method. The real weather data continuously collected by a weather station located at the Ústí nad Orlicí airport (about 10 km away from the examined House of Culture) were used; therefore the model could be validated by these data to create the calculation model as exact as possible.

Internal boundary conditions and setup of heating was based on real operation of the building:

- Operative temperature in major (heated) part of the building: t_o = 20 °C
- Operative temperature communication areas: t_o = 18 °C
- Operative temperature in underground storey: t_o = 15 °C
- Rest of the building without heating

4. CALCULATION METHODS

Simulations were carried out in software BSim 2002. BSim is based on law of conservation of energy and law of conservation of mass with calculations solved non-stationary. Heat is described by equations of heat balance, using heat balance formula balance for the zone:

$$\Phi_{constr} + \Phi_{wind} + \Phi_{sol} + \Phi_{sys} + \Phi_{vent} + \Phi_{inf} + \Phi_{mix} = 0$$

where Φ_{constr} represents heat flows from adjoining constructions, Φ_{wind} symbolises heat flows through windoors, Φ_{sol} solar radiation through windoors, Φ_{sys} heat flows from air penetration from outdoor air (infiltration, venting), Φ_{vent} heat flows from air supplied from ventilation systems, Φ_{inf} stands for heat flows from air transferred from other zones [3].

There were 35 steps per hour and Petersen solar radiation model selected for the simulation due to complexity of the model and the building construction properties.

5. CALIBRATION

The BSim model was calibrated to comply with the real consumption for heating per month from tax documents (containing information about actual heating energy consumption) supplied by the investor from years 2013 and 2014. The calibration was carried out by changing the amount of exfiltration/infiltration into exterior. The value of infiltration is configured in BSim by setting the value of a basic air change [/h]. We have tested the infiltration for the following values of a basic air change: 0.1, 0.2, 0.3 and 0.4.

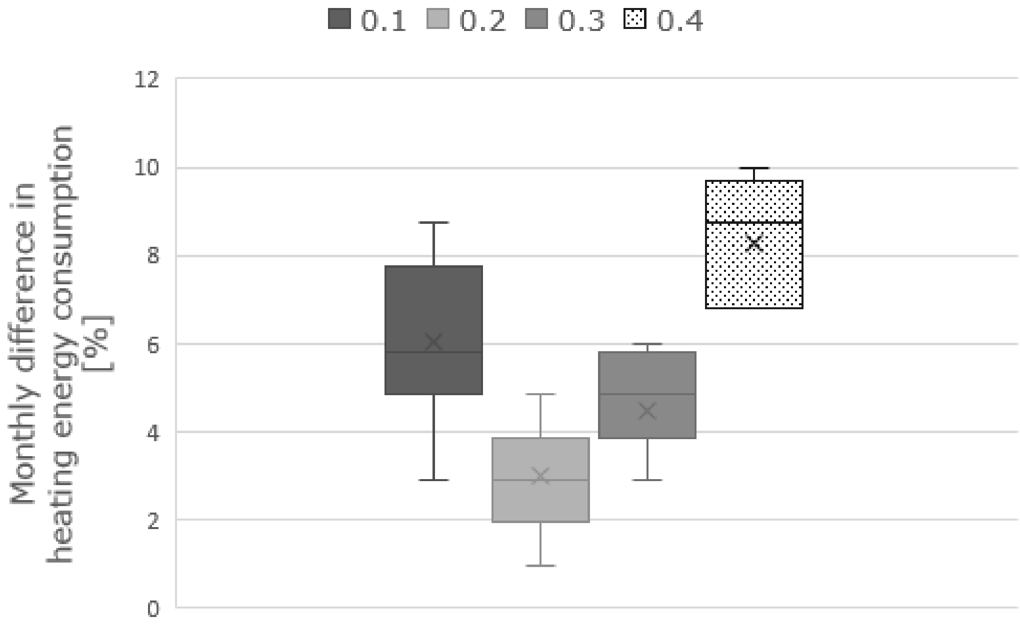

Fig. 2 *Configuration of BSim models using different value of basic air change [/h] – Tukey boxplots with band inside the box representing second quartile (median)*

Fig. 2 shows the monthly percentage difference between the heating consumption of model with set value of basic air change and the values obtained from tax documents.

According to Shapiro-Wilk normality test, KS normality test and D'Agostino and Pearson omnibus normality test, the data of temperature difference do not evince Gaussian distribution; therefore median was used as a decisive statistical factor. Therefore, the model with the basic air change 0.2 was selected as a reference model for the following simulations.

6. RETROFIT MEASURES AND VARIANTS

Three variants of building modifications of the cultural house according to the investor's request were examined:

1. Thermal insulation of the roof by EPS at the recommended value of thermal transmittance with prevailing room design temperature in the range from 18 °C to 22 °C
   - roof: $U_{rec,20}$ = 0.16 W/(m^2·K)
   - working name: Variant 1 - only roof at the recommended U-value
2. Insulation of façade and roof by EPS at the recommended value of thermal transmittance with prevailing room design temperature in the range from 18 °C to 22 °C
   - roof: $U_{rec,20}$ = 0.16 W/(m^2·K)
   - outer wall: $U_{rec,20}$ = 0.25 W/(m^2·K)
   - working name: Variant 2 - roof and walls at the recommended U-value

3. Insulation of façade and roof with EPS at the required value of thermal transmittance with room internal design temperature in the range from 18 °C to 22 °C

- roof: $U_{N,20}$ = 0.16 W/(m²·K)
- outer wall: $U_{N,20}$ = 0.25 W/(m²·K)
- working name: Variant 3 - roof and walls at the required U-value

For all variants, the replacement of existing unsatisfactory hole fillings (doors, windows) was assumed for the new standard $U_{rec,20}$ = 1.2 W/(m²·K).

Standard values of heat transfer coefficient of individual structures according to ČSN 73 0540-2: 2011 Thermal protection of buildings - Part 2: Requirements were used [4]. The geometrical model, material properties, internal thermal gains, losses, and their scheduling are same in all variants.

7. RESULTS

Fig. 3 and Table 2 demonstrates the heating energy savings of all three variants depending on boundary conditions. Scenarios 2013 and 2014 show actual and fictive consumptions in the respective years. In case of these scenarios, the retrofit measures were applied at the building model and the real weather data were applied as boundary conditions for selected period. Therefore, the heating energy consumption was simulated as "what-if" scenarios. This approach was chosen on the basis of the investor's request to showcase the possible savings during the actual climate conditions. TMY (typical meteorological year) scenario dataset is based on local measurements from 1991 to 2010.

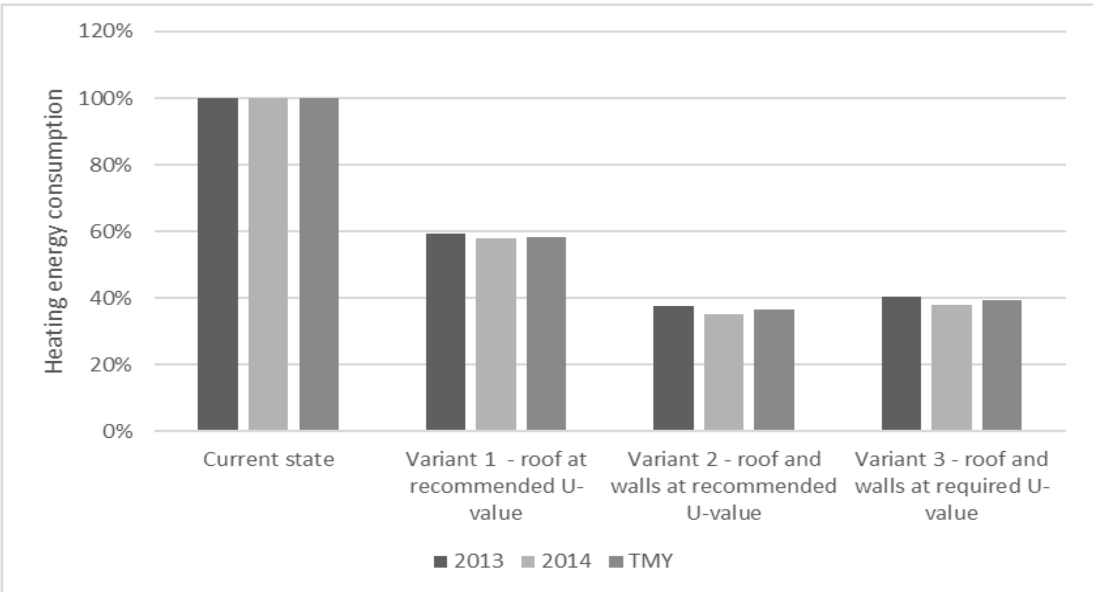

Fig. 3 *Heating energy consumption comparison between current state of the building and three variants of retrofitting*

Table 2 *Heating energy consumption comparison*

Weather data set	2013	2014	TMY
Current state	100%	100%	100%
Variant 1 - roof at recommended U-value	59,3%	57,7%	58,3%
Variant 2 - roof and walls at recommended U-value	37,7%	35,1%	36,5%
Variant 3 - roof and walls at required U-value	40,4%	38,0%	39,5%

8. DISCUSSION AND SUMMARY

This contribution describes a case study of the refurbishment of the current House of Culture in Letohrad, Czech Republic. This building represents the typical cultural house built in small cities in Eastern Bloc in 1960s and 1970s. Advanced transient simulations of the behaviour of the cultural centre carried out using software tool BSim. The complete model of the assessed building was created, and the proposed austerity measures were implemented. The simulated consumption was compared with the actual consumption in 2013 and 2014. The reduction in consumption of the proposed variants is in the range of 35-60%, depending on the type of austerity proposed. It should be noted, however, that these austerity measures do not reflect the change in the way the building is operated. In the process of the model's calibration it was found that a significant part of the heat loss comes from infiltration resulting from insufficient tightness of the building openings. Therefore, during the planned construction work it is necessary to eliminate this infiltration by proper sealing of the building openings.

A lot of the building objects of the same type built in post-communist countries still await major retrofit. These cultural centres are often owned by local municipalities possessing very limited budget. Representatives of these municipalities must decide carefully where to invest money and the decision is usually very difficult and complex. This case study indicates possible heating energy savings using different retrofitting approaches and can serve as background for further studies.

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