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Scandinavian HVAC

The HVAC Associations in Scandinavia have an umbrella organization called SCANVAC, which stands for Scandinavian Federation of Heating, Ventilation and Sanitary Engineering Associations in Denmark, Finland, Iceland, Norway and Sweden. Total number of members in these associations is about 20 000, which is in the relation to population (about 27 million) highest in Europe.

There are good explanations for the high interest in HVAC -technology in Scandinavia. Good heating has always been a necessity due to cold climate. Most of the energy is imported in Denmark, Finland and Sweden. As the primary energy use of buildings is about 40% of energy demand, the good energy efficiency has been on agenda for decades. The harsh climate has also made people to demand a good and comfortable indoor environment, which again has boosted the R&D work of industry. Active role of Scandinavian industry can be seen also in REHVA. The first REHVA industrial supporters were from Scandinavian countries, and still 40% of REHVA supporting members are from Scandinavia.

Currently the focus of R&D work in Scandinavia is on energy efficiency, renewable energy sources and indoor environment. But after the Paris climate agreement in 2016 more and more focus has been on the measures to reduce the greenhouse gas emissions. The future buildings must be real zero energy buildings over their lifetime. When moving more and more towards the use of renewable energy sources, the demand side management becomes vitally important. The use of the energy should match with the production. ICT applications with reliable building simulation and control systems become more and more important. This again turns focus to the acceptable control of the indoor environment in respect to the variations in temperature swings. In long run the EU, with Scandinavian countries in first row, will stop combustion as a source of heating energy, first coal and later the other fuels. The Finnish government has already decided to place a ban on the burning of coal for energy production by 2029. This will lead to innovative new use of integrated energy systems, not only on building level but also on the community level. In Scandinavian countries this development will be the fast, as there are no extensive natural gas networks to supply cleaner fuel for heating. One of the big problems is how to convert district heating systems to supply heat for the cities without coal fired plants. The challenge is huge but offers also opportunities for industry to develop innovative solutions for the changing market. To boost this development, City of Helsinki is preparing the international one million-euro Helsinki Energy Challenge, a competition to find a solution for replacing coal in the most sustainable way possible. This is a challenge in a city where currently about 90% of buildings are heated mainly with coal fired power plants.

This issue of the REHVA Journal presents Scandinavian HVAC technology and its recent trends. The articles are submitted by the personal members of the Scanvac Member Associations. Hopefully the Scandinavian technology is also useful in other parts of Europe. ■

OLLI SEPPÄNEN
Guest editor
Professor emeritus
REHVA Fellow

Nordic Countries

The Nordic countries, or the Nordics, are a geographical and cultural region in Northern Europe and the North Atlantic. The term includes Denmark, Finland, Iceland, Norway, and Sweden, as well as Greenland and the Faroe Islands – which are both part of the Kingdom of Denmark – and the Åland Islands and Svalbard archipelagos that belong to Finland and Norway respectively. The term Scandinavia in local usage covers the three kingdoms of Denmark, Norway, and Sweden. The majority national languages of these three belong to the Scandinavian dialect continuum and are mutually intelligible North Germanic languages. Finnish language is completely different, related to Hungarian and Estonian languages.

The Nordic countries are sparsely populated and characterized by cold climate (see **Table 1**). Regarding the energy use and sources, they are very different. Energy use per capita is quite high except in Denmark. This is mainly due to energy intensive industry (forest and metallurgy) in Finland, Norway and Sweden. Main source of electricity generation in Norway is hydro power. Finland has high percentage of nuclear which is still increasing. In all countries the share of renewable sources is much higher than in EU on average, but from different reasons. In Norway it is due to hydro power, in Finland and Sweden it is due to the forest industry, which uses all waste material from the wood processing for electricity generation. In Denmark the high percentage of electricity is mainly due to wind power.

Table 1. Some basic information of Nordic countries and their energy use.

	Denmark	Finland	Norway	Sweden
Population, million	5.8	5.5	5.4	10.3
Land area, 1 000 km²	43	338	324	450
Population density, people per km²	135	16	17	23
Member of EU since	1 973	1 995	non member	1 995
Heating degree days, °Cd, base 18°C	3 072 Copenhagen	4 331 Helsinki	4 465 Oslo	4 005 Stockholm
NZEB primary, HVAC energy requirement for apartment buildings, kWh/m², a	30+1000/A (A=heated floor area)	56	66	82
Energy use, MTEO	13	24	21	32
Share of renewable sources in energy use	33	43	58	53
CO_2 emission, ton per capita per year	5.8	8.8	9.4	4.5
Electricity use, kWh/capita per year	5 720	14 732	24 006	12 853
Production capacity of electricity by energy source in %	Fossil 46 Nuclear 0 Hydro 0 RES 54	Fossil 41 Nuclear 17 Hydro 20 RES 23	Fossil 3 Nuclear 0 Hydro 93 RES 4	Fossil 5 Nuclear 22 Hydro 42 RES 32

Table 2. HVAC associations in Nordic countries.

	DANVAK	FINVAC The Finnish Association of HVAC Societies FINVAC ry	NORWAC NemiTek - Norsk VVS Energi- og Miljøteknisk Forening	SWEDVAC Swedish HVAC Society - Society of Energy and Environmental Technology
Number of members	2 000	4 associations with totally 5 500 members	4 700	7 000
Who can be a member	All persons in the HVAC- branch	All persons in the HVAC-branch (in FINVAC´s member associations)	All persons in the HVAC- branch	All persons in the HVAC- branch
Membership fee	150 euro	70–120 euro	130 euro	75 euro
Established	1946	1930	1924	1909
Number of supporting members	none	200 (in FINVAC´s member associations)		none
Journal(s)	• The HVAC Magazine (in cooperation with TechMedia)	Journals of FINVAC´s member associations: • Talotekniikka (HVAC Journal in Finnish language) • vvs värme- och sanitets-teknikern (HVAC Journal in Swedish language) • Sisäilmauutiset (Indoor air Journal in Finnish language)	• Norsk VVS • Rørfag • Byggdrifteren • Kulde • Norsk Energi • Maleren • Matindustrien	• Energi & Miljö (Energy and Environment, Journal of Heating, Ventilating and Sanitary Techniques, Indoor Climate)
Major annual events	Yearly Danvak Day and Installation conference	Yearly Energy seminar and Indoor climate seminar	Yearly Operations conference and HVAC-days	Biannually Nordbygg Expo and yearly seminars in Stockholm
Most important source of funding	Courses and conferences	Projects, courses and seminars	Journals and conferences	Membership fees (and for the journal, advertising revenue)

Co-generation and district heating have very significant role in all Nordic countries. Natural gas is not used as much in heating of buildings, due to limited gas pipe network.

Energy efficiency of buildings has traditionally been good, partly due to cold climate, but also due to dependency on imported fuels, except Norway. The NZEB criteria are quite stringent, however, could be better.

Due to cold climate and demand for good indoor environment the teaching of HVAC technology has been for long time in the curricula of the universities. The professors from Nordic Universities have been well recognized in the academic world like prof **Ole Fanger** from Denmark, prof **Eystein Rodahl** from Norway, prof **John Rydberg**, **Folke Peterson** and **Tor-Göran Malmström** from Sweden. The long tradition for HVAC has also been one reason to establish engineering societies. The oldest is the Swedish society, 110 years old, youngest Danish one, close to 70 years old. The number of members in the Nordic societies is high, almost one from one thousand inhabitant is a member (**Table 2**).

Due to cultural similarities there has also been interest in collaboration between the Nordic societies. Already in 1948, the Danish Association initiated Nordic cooperation and in 1953 the first Scandinavian HVAC conference was arranged in Copenhagen. Two Scanvac conference series are running still today. RoomVent conference, focusing on air flows in rooms and buildings, was held the first time in 1987 in Stockholm and the Cold Climate HVAC conference in 1994 in Rovaniemi, Finland.

SCANVAC (Scandinavian Federation of Heating, Ventilation and Sanitary Engineering Associations in Denmark, Finland, Iceland, Norway and Sweden) was established the same year as the Cold Climate HVAC conference, to get a better structure and rules for the cooperation. **Ole Fanger** was elected as the first president of SCANVAC, followed by **Per Rasmussen** and then **Olli Seppänen**. ■

OLLI SEPPÄNEN, President of SCANVAC
SIRU LÖNNQVIST, Secretary General of SCANVAC

NZEB requirements in Nordic countries

National NZEB values are challenging to be compared because of differences in primary energy factors, energy flows included and input data. A reference apartment building was set up to benchmark NZEB requirements against European Commission's NZEB recommendation. Only one national requirement out of four complied with the recommendation whereas the other ones showed significant deviation by the factor of 1.3 – 1.7.

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Deadlines for nearly zero energy buildings (NZEB) set in EPBD [1] have practically been reached. In public buildings the requirement is already in force and from January 2021 all new build construction should reach the target NZEB as defined at national level. From January 2021 means that the building handed over and getting the use permit should be NZEB. Therefore, NZEB requirements have been applied 1 – 2 year earlier as national deadlines are connected to building permit process. In the countries analysed, NZEB requirements are either already in force or will be in force from the 1st of January 2020.

As the comparison and assessment of national NZEBs is challenging, the European Commission (EC) published EU 2016/1318 recommendations [2], to ensure that NZEB targets are met by 2020. These reflect the EC concerns regarding unambitious national NZEB targets and the little time left to deliver NZEB. The EC stressed the high level of ambition required in the national definitions of NZEB, which should not be below the cost-optimal level of minimum requirements. Similarly, the EC recommended the integration of renewables in buildings and optimal indoor environment to avoid low levels of indoor air quality and comfort for building users. To make easier the achievement of the NZEB ambitions, the EC set benchmarks for NZEB primary energy use in four climate zones for new office buildings and single-family houses, as shown in **Table 1**.

The primary energy values in **Table 1** have been calculated from delivered energy without considering on-site renewable energy generation. Net primary energy is obtained when on-site renewable energy generation is subtracted. For Nordic residential buildings the upper limit energy performance (EP) value is EP = 90 – 25 = 65. In this calculation, all on-site renewable energy generation is taken into account, either it used in the building or exported. Energy calculation steps needed for the net primary energy calculation are shown in **Figure 1**.

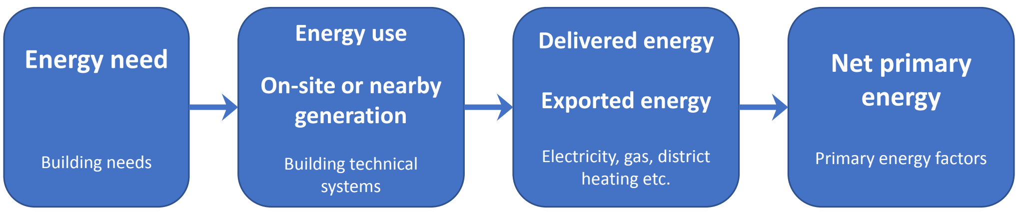

Figure 1. Energy calculation steps to obtain net primary energy EP-value.

The net primary energy values in **Table 1** cannot be directly compared with national NZEB values shown in **Table 2** because of different primary energy factors, input data and energy flows included.

To distinguish the countries with the easiest requirements to the strictest ones, and to assess the compliance with EC recommendations the analyses were performed for the reference apartment building as follows:

1. The reference apartment building was set up so that it closely corresponded to EC primary energy recommendation with standard use input data from the EN 16798-1:2019 [10] including ventilation, appliances and lighting and occupancy schedules;
2. The energy use of the reference building was simulated with the national input data and corresponding climate files of four selected North European countries;
3. The building and system parameters were changed so that as close as possible compliance with the national NZEB requirements was achieved;
4. The national NZEB configurations given at step 3 were used for energy simulations fed with the EN 16798-1:2019 input data and the ISO 52000-1:2017 primary energy factors in order to assess the compliance with the EC recommendation.

Table 1. *European Commission's recommendations of energy performance (EP) for NZEBs in different climate zones [2].*

NZEB level of energy performance	Mediterranean Zone 1: Catania (others: Athens, Larnaca, Luga, Seville, Palermo)	Oceanic Zone 4: Paris (Amsterdam, Berlin, Brussels, Copenhagen, London, Prague)	Continental Zone 3: Budapest (Bratislava, Ljubljana, Milan, Vienna)	Nordic Zone 5: Stockholm (Helsinki, Tallinn, Riga, Gdansk, Tovarene)
Offices, kWh/(m² a)				
net primary energy	20–30	40–55	40–55	55–70
primary energy	80–90	85–100	85–100	85–100
on-site RES primary energy	60	45	45	30
New single-family houses, kWh/(m² a)				
net primary energy	0–15	15–30	20–40	40–65
primary energy	50–65	50–65	50–70	65–90
on-site RES primary energy	50	35	30	25

Table 2. *National NZEB requirements and primary energy factors for apartment buildings. EU Nordic primary energy factors are default values from ISO 52000-1:2017 [3].*

	Energy flows included	NZEB kWh/(m² a)	NZEB, HVAC only*	Primary energy factor
EU Nordic [2]	Heating, DHW, ventilation, auxiliary	65	65	Electricity 2.3 District heating 1.3 Natural gas 1.1
Estonia [4, 5]	Heating, DHW, ventilation, auxiliary, lighting, appliances	105	47	Electricity 2.0 District heating 0.65 Natural gas 1.0
Finland [6]	Heating, DHW, ventilation, auxiliary, lighting, appliances	90	56	Electricity 1.2 District heating 0.5 Natural gas 1.0
Sweden [7]	Heating, DHW, ventilation, auxiliary, facility lighting	85	82	Electricity 1.6 District heating 1.0 Natural gas 1.0
Norway [8, 9]	Heating, DHW, ventilation, auxiliary, lighting, appliances	95	66	—

* NZEB, HVAC only is the primary energy requirement from which the contribution of appliances (small power plug loads) and lighting is subtracted.

A reference apartment building with seven stories as shown in **Figure 2** was used. The net floor area, envelope area and windows area were 3071, 2787, and 694 m², respectively. To comply with EC EU Nordic EP=65, the following configuration was used:

- The specific fan power (SFP) was 1.5 kW/(m³/s) and the balanced heat recovery ventilation system with electric reheating coil was operated 24 hours a day;
- The heat recovery temperature ratio was 80% with a minimum exhaust air temperature limit of 0°C to avoid frosting;
- The U-value of the external walls, roof, external floor, and internal floor were 0.14, 0.1, 0.12, and 1.5 W/(m² K), respectively;
- Three pane windows with a total U value of 0.9 W/(m² K), and solar heat gain coefficient of 0.45 were used;
- The linear thermal bridge between the external walls and the internal slab, the external walls, the roof, the external slab, windows perimeter, and the roof and the internal wall were 0.06, 0.03, 0.05, 0.05, 0.024 and 0.024 W/(m K), respectively;
- The air leakage rate of the building envelope was 1.0 m³/(h m²) at pressure difference of 50 Pa.

With this configuration and EU input data (**Table 3**) the reference building with gas boiler and Estonian TRY climate file resulted in 65.9 kWh/(m² a) primary energy.

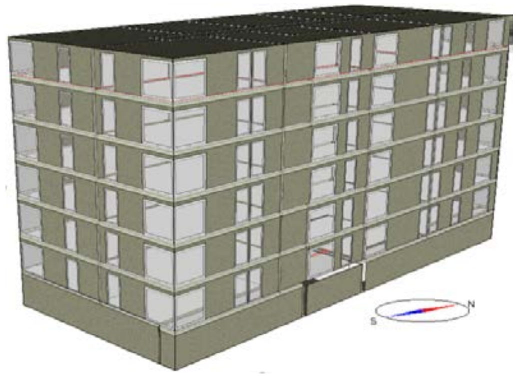

Figure 2. Simulation model of the reference apartment building.

The energy calculation input data and system efficiencies are shown in **Table 3**. DHW values include typical losses, and for Sweden, an additional heating energy use of 4 kWh/(m² a) of window airing was taken into account according to [7]. A well-validated simulation software IDA-ICE 4.7 was used to perform dynamic whole year simulations. More details of the analyses are reported in [11].

Delivered energy results of the reference building simulated with national input data (**Table 3**) and climate files are shown in **Figure 3**. Swedish and Norwegian slightly lower ventilation rate values, high DHW value of Finland and also climate differences explain the difference brought by national input data. In Estonia,

Table 3. *EN 16798-1:2019 and national energy calculation input data.*

	EU	Estonia	Finland	Sweden	Norway
Occupants, m²/person	28.3	28.0	28.0	28.0	78.0
Appliances, W/m²	3.0	*3.0	4.0	4.4	3.0
Lighting, W/m²	9.0	8.0	9.0	8.0	1.95
Usage time	0:00–24:00	0:00–24:00	0:00–24:00	0:00–24:00	0:00–24:00
Ventilation operation hour	0:00–24:00	0:00–24:00	0:00–24:00	0:00–24:00	0:00–24:00
Lighting usages rate	0.14	0.1	0.1	0.1	0.67
Occupancy usages rate	0.6	0.6	0.6	0.6	0.67
Appliance usages rate	0.6	0.6	0.6	0.6	0.67
Domestic hot water use, kWh/m² a	25	30	38	29	29.8
Ventilation rate, l/m² s	0.5	0.5	0.5	0.35	0.33
Heating set point, °C	20	21	21	21	21
Boiler efficiency, gas boiler, –	0.95	0.95	1.0	0.95	0.86
Boiler efficiency, district heating, –	1.0	1.0	0.97	1.0	0.98
Distribution & emission efficiency, –	0.91	0.97	0.85	0.97	0.97
Circulation pump, kWh/(m² a)	2.0	0.5	2.0	2.0	2.0

* Internal heat gain value which is divided by factor 0.7 in order to obtain the electricity use.

it was needed to add on-site electricity generation in order to reach Estonian national requirement. When calculating primary energy, the lowest primary energy factors in Finland and the exclusion of lighting and appliances in Sweden affect the results, **Figure 4**. In Norway, 1.0 factors for all energy carriers were used as primary energy factors are not in use.

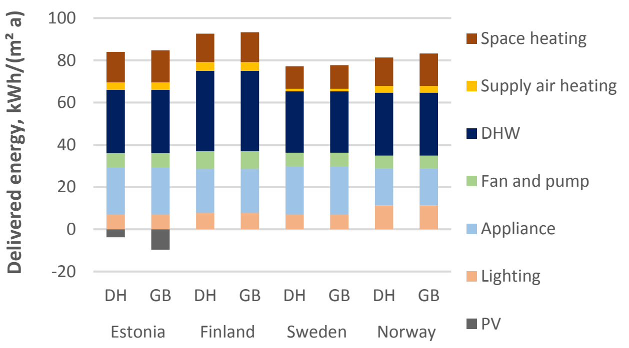

Figure 3. Delivered energy of the reference apartment building calculated with national input data and climate. DH = district heating, GB = gas boiler.

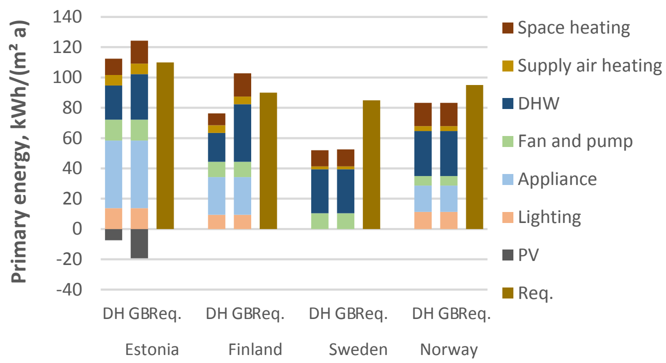

Figure 4. Primary energy of the reference apartment building calculated with national input data and climate. DH = district heating, GB = gas boiler.

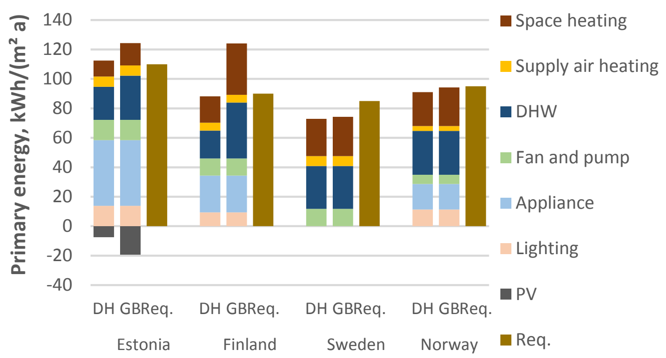

Figure 5. Primary energy in NZEB apartment buildings with changed technical solutions aiming at the close compliance with national NZEB requirements.

Primary energy values in **Figure 4** are below national limits for Finland, Sweden and Norway. For Finland, the results with district heating were considered only, because the gas boiler result is rather theoretical as gas networks are almost not existing in Finland. In Estonia, especially with gas boiler, significant amount of photovoltaic has been needed to install in order to comply with national limit. Therefore, in Finland, Sweden and Norway there is a room to change some technical solutions in order to end up with primary energy closer to the national NZEB requirements. The following changes were made and the results are shown in **Figure 5**:

- In Finland, Sweden and Norway, the U-value for external wall, external floor and roof were increased to 0.2, 0.17, 0.14 W/(m² K) respectively, and glazing U-value was increased to 1.2 W/(m² K);
- In Finland and Sweden, glazing U-value was increased to 1.6 W/m²K and the specific fan power of ventilation system was increased to 1.8 kW/(m³/s);
- In Sweden, the heat recovery efficiency was decreased to 0.7.

The results with changed technical solutions show that after Estonia, the Norwegian NZEB requirement can be considered as the second strictest regulation followed by Finland and Sweden, as a lesser number of changes were made in Norway than in the other two countries.

To compare national NZEB requirements with the EC recommendation, the reference building configurations with changed technical solutions (= national NZEB, **Figure 5**) were simulated with input data from the EN 16798-1 (**Table 3**) and primary energy factors from ISO 52000-1:2017 (**Table 2**). These final results with normalized input data and primary energy factors show that the Estonian NZEB requirement is the only one which complies with EC recommendations, **Figure 6**.

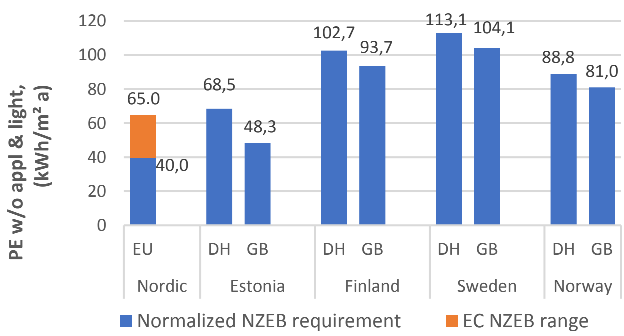

Figure 6. National input data and primary energy normalized national NZEB requirements. Estonian TRY climate file was used for all countries as a reasonable climate normalization within the same climatic zone.

In the other three countries with the district heating the normalized primary energy was higher than the EC recommendation by approximately a factor of 1.3, 1.5, and 1.7, in Norway, in Finland, and in Sweden, respectively.

Conclusions

- The results show that because of differences in primary energy factors, energy flows included and input data, the national values cannot be directly compared, but an energy calculation with a reference building is needed for the comparison.
- Benchmarking national NZEB requirements of apartment buildings against European Commission's NZEB recommendation showed that the Estonian NZEB requirement was the only one complying with the recommendation.
- With district heating, the other NZEB requirements were higher than the EC recommendation by a factor of 1.3, 1.5, and 1.7, in Norway, in Finland, and in Sweden, respectively.
- The deviation is unexpectedly high in Finland and Sweden. Some explanation is provided by the fact that in these countries the draft regulation was much stricter than the final NZEB requirements.
- In Finland, very low primary energy factor values, and in Sweden, not including lighting and appliances, are the main technical reasons explaining a low ambition of the requirements. ■

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[2] Recommendations – Commission recommendation (EU) 2016/1318 of 29 July 2016 on guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings.

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Geothermal energy use in the Nordic countries

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(Photo credit: Svenskt Geoenergicentrum)

Geothermal energy – or **geoenergy** – can be extracted either from deep geothermal resources, typically reaching kilometers below the ground surface, or from shallow geothermal resources in the uppermost few hundred meters below the ground surface. Deep geothermal resources originate from heat transferred from the center of the Earth as well as from nuclear processes in deep geological formations. Such geothermal resources may be used for geothermal power production, or directly for heat. Shallow geothermal energy may be used for heating as well as for cooling, and mainly originates from passively stored solar energy. In some systems, heat or cold is actively stored in the ground utilizing a variety of sources, such as solar radiation, indoor air, outdoor air, or thermal waste from industrial processes. A vast majority of shallow geothermal systems utilize heat pumps. Shallow geothermal energy systems have the ability to store thermal energy over seasons.

Figure 1. Examples of shallow geothermal energy use. Top left: Aquifer thermal energy storage (ATES), top right: bore hole thermal energy storage (BTES), bottom left: horizontal loop and bottom right: vertical borehole heat exchanger. [Original pictures by Geotec]

Geothermal energy contributes significantly to the energy supply in all five Nordic countries (Sweden, Norway, Finland, Denmark and Iceland) where it has a strong position as an efficient and environmentally beneficial renewable energy resource. The Nordic countries together have a total installed capacity of nearly 13 GW_{th} and in 2018 provided some 40 TWh_{th} of geothermal heating and cooling. This accounts for 34% of the total installed capacity and 43% of the total geothermal energy use in Europe. Of this, the main part, 11 GW_{th} and 34 TWh_{th}, comes from shallow geothermal energy. Iceland is the only Nordic country that has geothermal electric power production. The 2015 Icelandic installed geothermal power capacity of 661 MW_{el} and geothermal electrical energy production of 5003 GWh_{el} accounts for 22% and 27%, respectively, of the European geothermal installed capacity and electrical energy production. Sanner (2019) provides an overview of the geothermal energy use in 32 European countries including the Nordic countries.

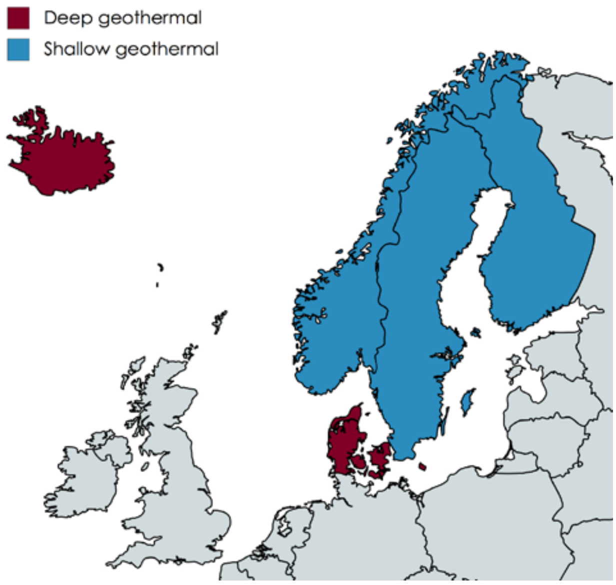

Figure 2. Geothermal energy in the Nordic Countries. Shallow geothermal energy use is predominant in Sweden, Norway and Finland, while deep geothermal is predominant in Iceland and Denmark. [ILLUSTRATION BY SIGNHILD GEHLIN]

Although the climate in the Nordic countries does not vary widely, there are major differences between the countries in the way geothermal energy is applied (**Figure 2**). Deep geothermal energy resources are readily available and utilized in Iceland and, to a lesser degree, in Denmark. However, so far, Sweden, Norway and Finland only utilize shallow geothermal energy. The reasons for this are not only due to geological factors, but also such factors as differences in available alternative energy sources and typical building energy distribution systems have an impact. **Table 1** shows some key figures for the five Nordic countries. Country-wise updates on the geothermal energy use and market for a number of

Table 1. *Summary of key factors for the five Nordic countries.*

	SWEDEN	NORWAY	FINLAND	DENMARK	ICELAND
Population [Million people]	10.3	5.4	5.5	5.8	0.35
Area [km^2]	450 000	324 000	338 000	43 000	103 000
Energy consumption 2015*** [Million tonnes oil equivalents, MTOE]	32	21	24	13	2.9
Geology	Mainly crystalline rock, and sedimentary rock in the south	Crystalline rock, sparsely covered with marine clay and quarternary deposits	Crystalline rock and smaller areas with sandstones	Unmeta-morphosed sediments	Volcanic rock
Geothermal gradient [°C/100 m]	1.5–3	1.4–2.7	0.8–1.5	2.5–3	5–15*
Number of GSHP systems 2018	580 000	55 000	140 000	40 000	70 (in 2014)
Geothermal power	None	None	None	None	661 MW_{el}** 5 003 GWh_{el}**
Geothermal direct use (heat) 2018	None	None	None	33 MW_{th} 98.7 $GWht_{h}$	2 130 MW_{th}** 7 676 GWh_{th}**
GSHP heating/cooling 2018	6 520 MW_{th} 22 950 GWh_{th}	1 023 MW_{th} 4 103 GWh_{th}	3 000 MW_{th} 6 000 GWh_{th}	400 MW_{th} 598 GWh_{th}	1 MW_{th}** 5 GWh_{th}**

* (Flovenz & Saemundsson, 1993) ** Values for 2015 (Ragnarsson, 2015) *** (Nordic Energy Research, 2019)

European countries are published every three years at the European Geothermal Congress. In the following sections, short descriptions are given of the characteristics of the geothermal energy situation at the end of 2018 in the Nordic countries based on the country updates for Sweden (Gehlin and Andersson 2019), Norway (Kvalsvik et al 2019), Finland (Kallio 2019) and Denmark (Poulsen et al 2019). The description of Iceland is based on the country report for World Geothermal Congress 2015 (Ragnarsson 2015), as Iceland did not report at the European Geothermal Congress in 2019.

Sweden

Swedish geology is largely characterized by crystalline rock with thermal properties that are highly suitable for shallow geothermal systems, especially vertical ground source heat pumps (GSHP) and borehole thermal energy storage (BTES). Groundwater in the form of aquifers are mostly found in eskers along the river valleys and in limited numbers in sedimentary rock, mostly in the southern parts of the country. These aquifers are of interest for groundwater-based shallow geothermal applications, so-called aquifer thermal energy storage (ATES). The geological conditions in Sweden are not favourable for deep geothermal power and heat production, but there is a budding new interest in deep geothermal energy for district heating, following a current pilot project in Finland.

Sweden has been an active country in the development of shallow geothermal energy use since the 1970s and is rated number three worldwide in use of geothermal energy (Lund et al 2015). There are more than a half million shallow geothermal energy systems installed in Sweden, most of them using vertical boreholes in rock for space heating and domestic hot water heating for single-family buildings. While the market for small GSHP systems has decreased over the last decade due to market saturation, the market for larger shallow geothermal energy systems for residential as well as non-residential buildings is expanding. By the end of 2018, GSHP systems provided some 23 TWh of heating in Sweden of which approximately 17 TWh is renewable heat from the ground. The total installed GSHP heating capacity was 6.5 GW. These figures include the contribution of 250 GWh of geothermal heat produced by a geothermal energy plant, using large heat pumps and 20°C water from a thermal resource at 700 m depth, connected to the district heating network in Lund. In addition to the heat from the ground, approximately 1 TWh is provided as ground source direct-cooling. There are two high-temperature borehole thermal energy storage systems in operation in Sweden – one residential solar heat storage in Stockholm and an industrial application in Emmaboda. BTES applications in Sweden tend to be designed with increasing size, deeper boreholes and increasing capacities.

Norway

The Norwegian geology is characterized by crystalline rock, suitable for shallow geothermal systems and unfavourable for deep geothermal energy utilization. There is no geothermal power production or deep geothermal energy used in Norway, but shallow geothermal energy applications are increasingly common and accounted for some 4.1 TWh in 2018. This is an increase of 28% compared to 2015. The estimated number of installed geothermal energy systems in Norway is 55 000. The abundance of inexpensive and clean hydropower in Norway is both favourable and a challenge for geothermal energy use. Many small residential buildings have direct electric heating installed, and a conversion to a GSHP system with hydronic heat distribution may be regarded as too costly.

Most shallow geothermal energy systems in Norway are GSHP systems with vertical boreholes. As in Sweden, there is a general trend towards increasing borehole depth in Norwegian geothermal energy applications. A recent geothermal installation at the Oslo airport Gardermoen, used for de-icing without the use of heat pumps, has two boreholes of 1 500 m depth. A high-temperature borehole thermal energy system for residential use is currently being built in Drammen and another such high-temperature application is planned in Oslo.

Finland

The geology in Finland is similar to that of Sweden, with crystalline rock, localized sandstone formations and deposits of glaciofluvial origin. These conditions are highly suitable for shallow geothermal systems, but less so for deep geothermal utilization and power production. Since around 2005 the market for heat pumps in general has increased rapidly, mostly for replacement of oil burners and direct electric heating in small residential buildings. Although the majority of the 900 000 installed heat pumps in Finland are air-source heat pumps, some 140 000 GSHP systems are in use for heating of small residential buildings as well as for heating and cooling of large commercial and institutional buildings.

In Finland also, there is a definite trend with increasing numbers of GSHP installations and larger systems.

Several shopping malls, both new and existing, have recently had large-scale BTES systems installed. Residential GSHP systems show the fastest growth rate. Many new GSHP installations are seen to keep previous district-heating connections and solar systems as back-up systems. Another trend is the development of new business models and service models, where investments are done by the providing company, and the customer pays for the used energy.

In 2015 the private company St1 Nordic Oy initiated a first deep geothermal pilot project in Espoo. The idea is to drill two deep geothermal wells to 6 000–7 000 m depth for a district heating network, and the expected capacity is 40 MW of geothermal heat extraction. The first borehole has reached the final depth of 6 400 m, and the second borehole has been drilled to 3 300 m. Decision whether to continue the project will be made in 2019.

Denmark

Unlike Sweden, Norway and Finland, the Danish geology is mainly sedimentary, with moderate geothermal gradients and vast geothermal aquifers suitable for deep geothermal utilization. Aquifers identified close to urban areas have been calculated to have enough capacity to sufficiently cover 20–50% of the heating demand in these areas for centuries.

An extensive district heating network, reaching most of the urban areas supply district heating to 60% of the Danish residential buildings today. Three deep geothermal plants, extracting geothermal heat at 40–75°C from 1.2–2.6 km depth, are connected to this network, providing some 33 MW_{th} and 98.7 GWh_{th} in 2018. There is an increasing interest in deep geothermal energy among district heating companies and municipalities. Several district heating companies are presently considering deep geothermal plants and are conducting exploration. There is no geothermal power production in Denmark, due to low temperature levels in the aquifers.

Shallow geothermal energy use is utilized, although not to a large extent, in Denmark since the late 1970s following the oil crisis. These GSHP systems, used for small residential buildings, are primarily horizontal ground loops. There are also some GSHP systems using vertical borehole ground heat exchangers, and a few examples of ATES systems, mostly used for cooling of e.g. hospitals and larger office buildings. The Brædstrup district heating plant runs a borehole storage with

48 boreholes, used for seasonal heat storage. Shallow geothermal energy applications are expected to increase in Denmark in the future, in particular in areas without district heating or natural gas supply.

Iceland

In Iceland, with its young and volcanic geology and abundant supply of geothermal resources, geothermal energy has played a major role in the energy supply for heating as well as power generation for several decades. In 2015 geothermal energy accounted for more than two thirds of the total energy use. Geothermal electricity generation started in the 1970s and accounts for a third of the total electricity generation in the country. Geothermal water is used for space heating (covering 90% of all energy used for house heating), domestic hot water, swimming pools, snow melting, industry, greenhouses and fish farming. Due to the abundance of high temperature geothermal resources, GSHPs are not very common in Iceland. Less than 100 such systems were in operation in Iceland in 2015, most of them horizontal ground loops.

Conclusions and future

With over 40% of the geothermal energy share, and a market growth that exceeds most other European countries, the five Nordic countries have and will continue to have a dominating position as geothermal energy providers in Europe. The Nordic countries have contributed considerably to geothermal R&D since the 1970s and continue to do so. Several of the world leading ground source heat pump manufacturers have Nordic origins, and several early shallow geothermal energy design models, simulation tools and pilot projects were developed here. Iceland has been leading the way in deep geothermal energy utilization for decades.

Interesting future trends in the Nordic countries are R&D on deeper boreholes for GSHP systems with and without heat pumps, direct heating and direct cooling applications (not using heat pumps) with shallow geothermal energy and various solutions connected to thermal networks and so-called Smart Grids, where underground thermal energy storage will play a central role.

A long tradition of public awareness and concern for environmental issues and energy efficiency, as well as for indoor comfort and human health among the Nordic countries partly explains the success of geothermal development in this part of the world. Abundant hydro-electric resources have also facilitated use of heat pumps to take advantage of shallow geothermal energy. ■

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Renovation of ventilation in apartment buildings – Estonian experience

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Introduction

This study discusses Estonian experiences in renovating the ventilation systems of old apartment buildings. Most commonly used ventilation renovation measures have been single room ventilation units (SERU), ventilation radiators with exhaust heat pump (EAHP) and central heat recovery ventilation (CHR) with ductwork installation on the façade. The paper is based on the ventilation performance analyses of long-term field studies during two different grant schemes. The technical conditions of the support grant and the correct ventilation renovation measures to guarantee necessary air change rate are presented.

Old apartment buildings in Estonia were originally built without mechanical ventilation systems. Ventilation shafts were used for extract air. Lower apartment buildings (up to 5–6 floors) had a separate ventilation shaft for every apartment. Higher apartment buildings (more than 9 floors) had a separate ventilation shaft only for apartments in the two upper floors. Supply air intake was designed from air leakages, mostly through the windows.

The systematic research and renovation of apartment buildings started at the beginning on 1990s. Several typical renovation solutions were developed and pilot renovations were conducted. Renovation of apartment buildings during 1990 – 2000's was based mainly on end-user's cost efficiency principle. Insulation of end-walls, changing of windows, balancing of heating systems were the first typical renovation measures. In many cases, the renovation of ventilation was left undone, which resulted in worsened indoor climate. Soon it was realized that financial support for renovation works will be required to make the inhabitants understand the importance of a better indoor climate and make the decision to install a proper ventilation system even though it might seem costly at first sight.

Typical solutions for additional insulation of building envelop and renovation of ventilation have been developed for different types of buildings (Kalamees et al., 2016). Estonian requirements set by renovation grant schemes and cross-sectional measurements were used in the study. This study also analyses how requirements on ventilation influences achievement of ventilation airflow after renovation. Lessons learned from Estonian experiences can be used to make decisions in building renovation strategies and funding programs in other countries.

Requirements, support and practice of renovation of apartment buildings in Estonia

During the period of 2010 – 2014, a total of 663 apartment buildings underwent renovation work in Estonia under the umbrella of a financial support handled by Fund KredEx and during 2014 – 2017, a total of 460 additional apartment buildings followed (Kuusk and Kalamees, 2016). Renovation support depended on achieved energy performance class (EPC) based on primary energy (PE) use (**Table 1**). Pikas et al. (2015) showed that renovation support was useful to Estonian economy as 17 jobs per 1 M€ of investment in renovation were generated per year and direct tax revenue was between 32 – 33%, depending on the renovation project.

Requirements on ventilation have been varied. Before state financial support there were no specific requirements on renovation of ventilation. Fresh air inlets were installed into new windows or in the external walls in some cases. With the creation of financial support, the state also set requirements on renovation solution's indoor climate and performance of ventilation, **Table 1**. During the first grant period (2010 – 2014), there was a requirement to ensure the airflows according to the standard EN-15251 (2007) ICC II requirements. In second grand period the air change rates in apartments had been calculated according to the principles shown in **Table 1**. There were also some additional requirements, see **Table 1**.

After the renovation, ventilation airflow was measured with anemometer and by tracer gas (human CO_2 production) in at least 3 – 4 apartments of selected buildings (altogether 120 apartments). Indoor air CO_2 concentrations, temperature, relative humidity, supply air temperatures and sound pressure levels were also measured.

Experience with installed ventilation systems

These are the main four types of ventilation systems that have been installed during renovation of Estonian apartment buildings (**Table 2**):

- Centralized balanced ventilation with ventilation heat recovery (CHR);
- Exhaust ventilation with heat pump (EAHP);
- Renovating the old natural ventilation systems (without heat recovery) (NV);
- Room based supply/exhaust room units with ventilation heat recovery (SERU).

Table 1. *Overview of financial support and requirements on energy performance, indoor climate and ventilation of renovating Estonian apartment buildings using the state support.*

Time period		Requirements on energy performance
2010 – 2014	**Financial support:** 15%, 25%, 35% depending on renovation solution **Requirements on indoor climate and ventilation:** Indoor climate according to EN-15251 (2007) ICC II requirements	**Requirements on energy performance:** • 15% support: heating energy reduction ≥ 20% (<2000 m^2) and ≥ 30% (>2000 m^2), PE ≤ 250 kWh/(m^2·a); • 25% support: heating energy reduction ≥ 40%, PE ≤ 200 kWh/(m^2·a); • 35% support: heating energy reduction ≥ 50%, PE ≤ 150 kWh/(m^2·a). **Typical ventilation renovation measure:** • Fresh air inlets to natural ventilation • Single room supply-exhaust ventilation units • Exhaust ventilation with/without exhaust air heat pump • Central heat recovery ventilation
2014 – 2018	**Financial support:** 15%, 25%, 40% depending on renovation solution **Requirements on indoor climate and ventilation:** Indoor climate according to EN-15251 (2007) ICC II requirements	**Requirements on energy performance:** • 15% support: PE ≤ 220 kWh/(m^2·a); • 25% support: PE ≤ 180 kWh/(m^2·a); • 40% support: PE ≤ 150 kWh/(m^2·a). **Typical ventilation renovation measure:** • Ventilation radiators with exhaust air heat pump • Central heat recovery ventilation with ductwork installation on the facade

Performance analyses have shown that the best ventilation renovation measure for old apartment buildings is CHR with ductwork installation on the façade. Ventilation unit of this system is put on the roof or in the attic, see **Figure 1a**. Flat or round shaped supply ducts are installed inside the additional insulation of external walls (**Figure 2**) and roof (**Figure 1b**). Old ventilation shafts are used to extract the air from apartments. As the air tightness of old ventilation shafts is often low, new ventilation ducts should always be installed inside the old shafts. The fresh supply air is given to the living rooms and bedrooms and polluted air is extracted from

Table 2. *Ventilation airflow rate calculation according to the II grant requirements, 2014 – 2018.*

Apartment type	Floor area	Extract airflow rate, l/s				Supply airflow rate, l/s					Air change
	m^2	WC	Bathr.	Kitch.	Total	Living	Bed1	Bed2	Bed3	Total	h^{-1}
Single room	35	-	10	6	16	10	-	-	-	10	0.63
1 bedrooms	55	-	15	8	23	10	10	-	-	20	0.58
2 bedrooms	70	10	15	8	33	10	10	10	-	30	0.65
3 bedrooms	80	10	15	8	33	10	10	10	10	40	0.69

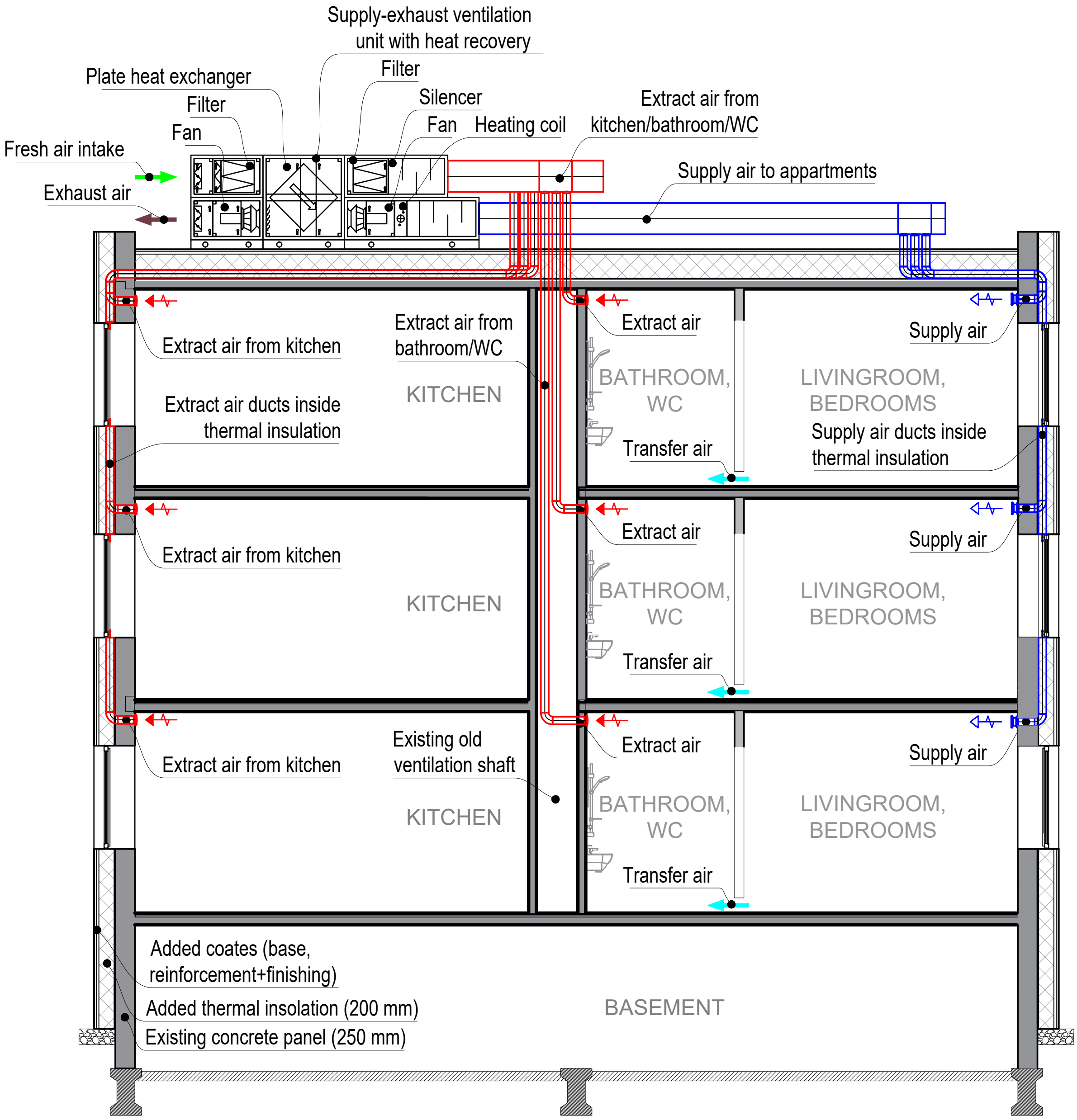

Figure 1a. Working principle of centralized balanced ventilation with heat recovery system (CHR).

toilets, bathrooms and kitchens. Installing ventilation ducts inside the additional insulation layer helps to avoid the visible ducts inside the apartments. The supply air grilles are installed on the external wall of the living room and bedroom and extract air valves are on the wall near the ventilation shafts. This technical solution means that the volume of the ventilation work inside the apartment is minimal and it does not disturb people much.

Ventilation ducts on the roof should be installed inside the insulation layer of roof or should be covered with a separate insulation layer. To ensure high heat recovery efficiency and avoid spreading of odours, the counter flow plate heat exchanger is commonly used. According to the requirements of the support grant, a water-based heating coil should be used to reheat the supply air. The detailed working principle of the CHR with ductwork installation on the façade is shown in **Figures 1a**, **1b** and **2**.

Exhaust ventilation with heat pump heat recovery and ventilation radiators has also been actively used

Figure 2. Supply ventilation ducts in additional insulation of external wall.

(40%) in renovation of apartment buildings. During the first grant period, the fresh air inlets were used for supply air, but due to people complaining about the cold draught, the requirement to preheat the supply air was added in the conditions of the second grant. To preheat the air, ventilation radiator system is used. The supply air enters through ventilation radiators where it is filtered and heated at the same time. Extract air moves through ventilation shafts to air to water heat exchanger of ventilation unit where the heat is transferred through a brine loop to water to water heat pump. The heat pump provides heat to the domestic hot water and space heating system. The annual average coefficient of performance (SCOP) is 3.0 – 3.5. The main problem of this renovation solution is using old natural ventilation shafts without inserting new ducts inside the old shafts. The air tightness of old shafts is too low and therefore, the ventilation systems are often unbalanced and very noisy. That, in turn, means that the air flow

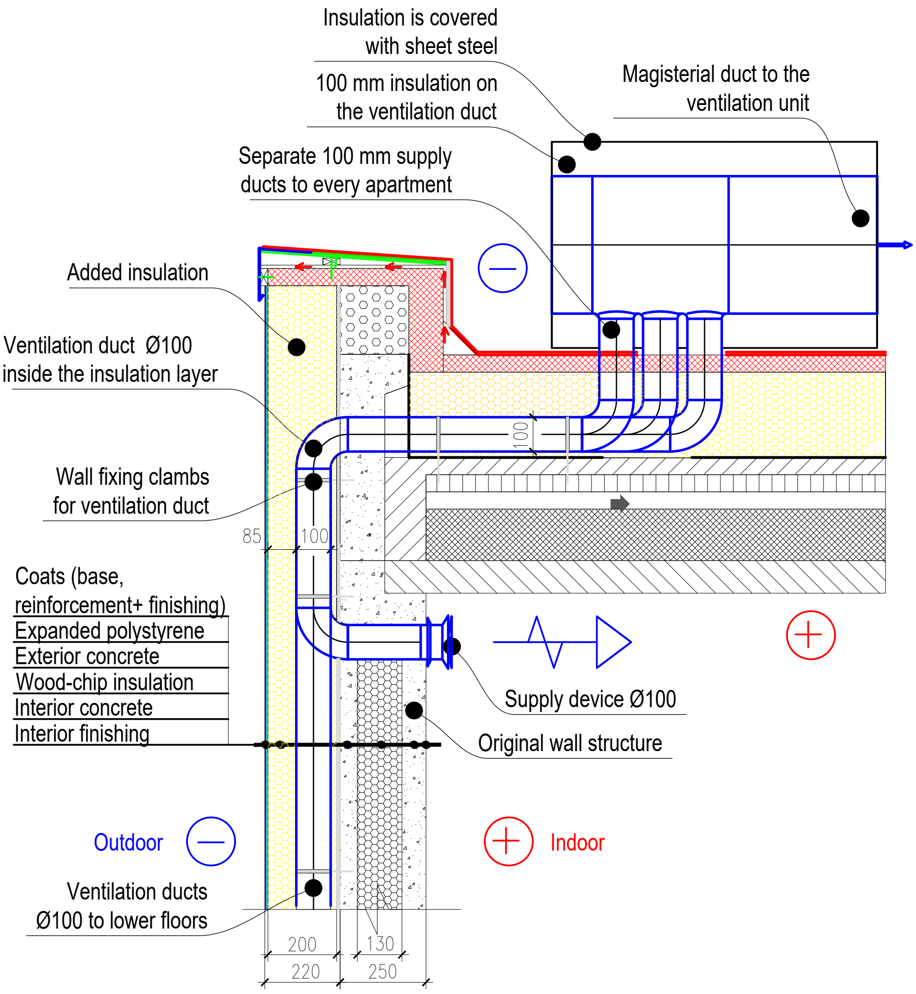

Figure 1b. A section of CHR system with ventilation ducts inside the building façade.

rates are reduced. The main principle of EAHP system is described in **Figure 3**.

Single room-based supply/exhaust room units with ventilation heat recovery (see **Figure 4** left) have also been used for ventilation renovation during first grant period. Mainly the SERU with regenerative ceramic heat exchanger was used. The single-fan-based units work in cycles, switching between supply and exhaust mode in every 60 – 70 seconds. During the exhaust

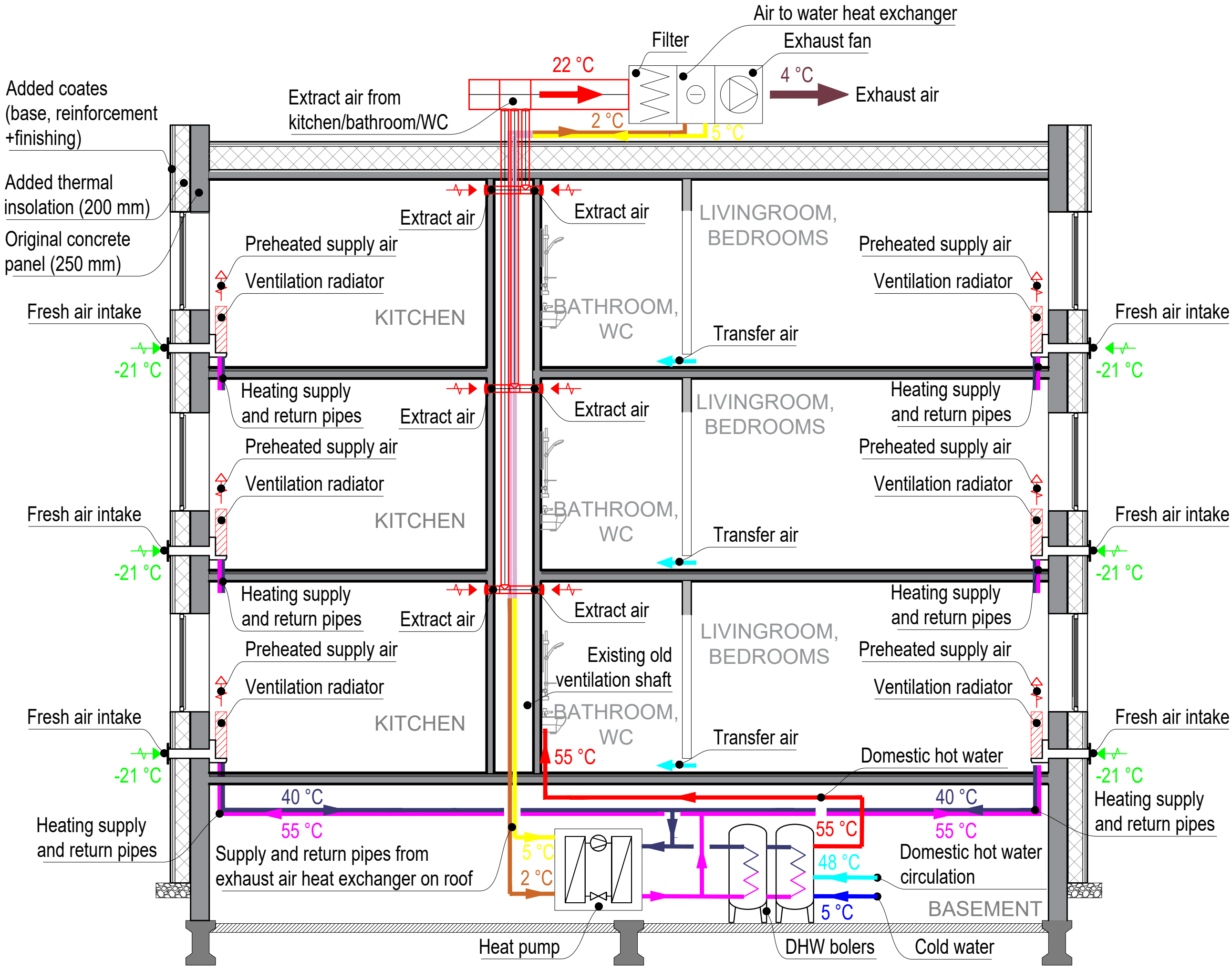

Figure 3. Ventilation radiators with exhaust heat pump heat recovery.

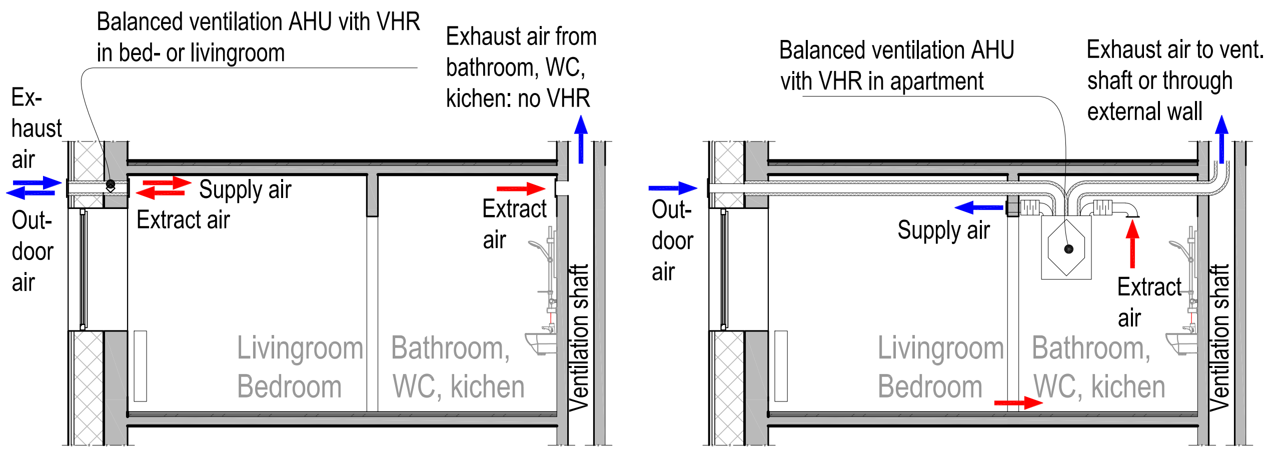

Figure 4. Room based supply/exhaust room units with ventilation heat recovery (left) and apartment based balanced ventilation with ventilation heat recovery (right).

cycle heat from the warm exhaust air is accumulated in the ceramic comb-like heat exchanger and is then used to heat up cold outdoor air during the supply cycle. The field measurements have shown that this system does not ensure sufficient air change rate and efficient heat recovery (Mikola et al., 2016, 2019). The main problem is related to the large negative pressure in the lower floor apartments. The fans used in SERUs are not capable of working in typical pressure conditions occurring in multi-story buildings in cold periods (Mikola et al., 2019). Since the results of using SERUs as a ventilation renovation measure were disappointing, this solution is no longer being used.

Apartment based balanced ventilation with ventilation heat recovery has also been used (see **Figure 4** right). The ventilation unit of this system is installed to staircases, corridors or sanitary rooms, under the ceiling or on the wall. Plate or rotary heat exchanger is used in ventilation unit. The air is extracted from kitchen hoods, toilets and bathrooms. Supply air devices are installed in living rooms and bedrooms. Since installing this system to apartment requires space and construction work in apartment, it is used very rarely (≈ 1%). The use of apartment based balanced ventilation is still so small, that it is not possible to make any conclusions about its use in renovation of apartment buildings. Still, this solution is actively used in renovation of detached houses in Estonia.

The air flow has been measured before renovations and during both grant periods (see **Figure 5**). The average air change rate before renovations was 0.24 h^{-1} (Mikola et al., 2017). During the first grant period, the average air change rate was 0.16 h^{-1} for renovated natural ventilation (NV), 0.18 h^{-1} for single room ventilation units (SERU), 0.20 h^{-1} for mechanical exhaust ventilation with exhaust air heat pump heat recovery (EAHP) and 0.57 h^{-1} for centralized balanced ventilation with heat recovery (CHR). During the second grant period the average air change rate of mechanical exhaust ventilation with and without exhaust air heat pump heat recovery (EAHP) was 0.32 h^{-1} and for centralized balanced ventilation with heat recovery (CHR) 0.73 h^{-1}.

Comparing the performance of different ventilation renovation measures during two grant periods, we can see that the air change rate of EAHP and CHR systems have significantly improved. The main reasons for better performance of these measures were more strict requirements for air flows and sound levels, quality survey for design documentation and mandatory airflow measurement report. Renovating natural ventilation and using single rooms units did not ensure sufficient air change rate and were exclude from second grant support measures.

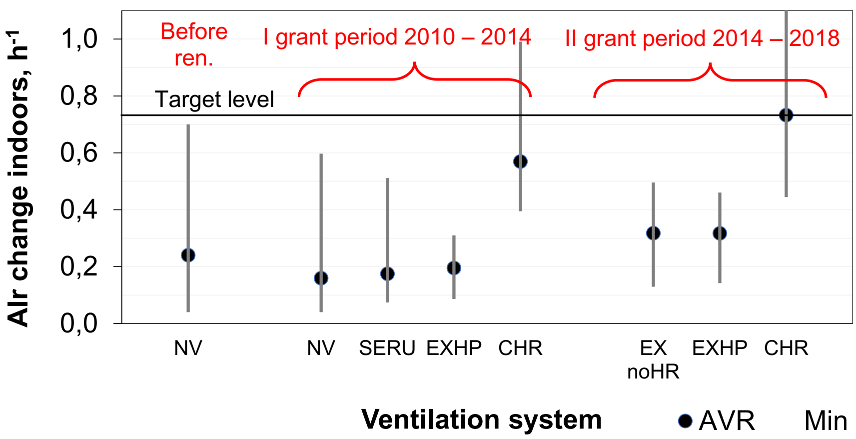

Figure 5. Average ventilation airflow in Estonian apartments before renovation (left) and after renovation during the two renovation grant period.

Conclusions

The centralized balanced ventilation with ventilation heat recovery ensured the necessary air change rate in renovated apartment buildings. This is the most widely used solution in renovation of up to five-storey apartment buildings in Estonia today.

Although the average air change rate of mechanical exhaust ventilation with heat pump heat recovery was lower than in the requirements, in some cases (mostly for tall buildings) this solution can be the only possible technical solution to provide the extract air heat recovery. We recommend this solution for buildings were the CHR cannot be technically used or where it is economically not viable.

The renovation of old, natural ventilation systems or using single room ventilation units cannot guarantee sufficient air change rate and acoustical quality, therefore, these ventilation renovation measures are not suitable.

Achievement of sound pressure levels ≤ 25 dB(A) was not a problem, when that target was considered already during design process.

Only the general requirement to ensure indoor climate category II does not guarantee compliance. As a result, since the 2014, the requirements have been clarified and made more specific. A significantly better solution is:

- **to specify** the calculation methods of airflow rates and ventilation noise levels in the regulations,
- **to ensure** the project undergoes an expert review to verify that the design solution meets the conditions,
- **to require** the airflows to be measured at the end of the renovation.

It is important to have clear and unambiguous requirements and to require control and verification of the result achieved. ■

Acknowledgement

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Articles

Validation of a simulation model of a plant equipped with ground source heat pumps

This case study is made with the purpose to create a plant model that can serve as a test bench for model predictive control systems. The plant consists of ground source heat exchangers and heat pumps that deliver heat and cooling to a small district. These major components are calibrated using measured data from the actual plant. This article is focused on the validation of the total plant model. Measurements of delivered heating and cooling from the plant in operation are used as input to the simulation model that shows good agreement with the measurements.

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Model predictive control systems uses models as a part of control algorithm. These models are used with some sort of optimization algorithm to present the best momentarily control action that, for example, gives the lowest expected energy use over the next year. This case study is made in the framework of the research project DEBORAH with the purpose to create a plant model that can serve as a test bench for such control systems. The plant as seen in **Figure 1** is owned by Husvärden AB in Mölndal Sweden and delivers heating and cooling to a mix of newly built apartment buildings, commercial buildings and old refurbished industrial buildings converted to commercial buildings.

The plant is built up around three 500 kW heat pumps (1) that use two set of ground source heat exchangers (3) of 80 holes and 35 holes respectively as main source for collecting heat. However, during the summer the cooling system of the buildings is used as source for the heat pumps. As the use for heat is limited in the summer a 665 kW dry cooler (4) is installed to reject the surplus heat. To even out the heat load on the hot side, there are five tanks (2) of 10 m^3 each.

Method

The study was carried out using the following workflow with five steps:

Step 1. Based on drawings and control description from the plant designer, a first model of the plant was created using standard models of IDA ICE.

Step 2. The initial simulations of the plant model were analyzed to see if the standard models of IDA ICE were suitable for this study or if additional models had to be created. During this step three models were identified that had to be created:

- The first model was a heat pump. The heat pump manufacturer didn't provide the type of data needed to use the standard heat pump model included in IDA ICE.
- The second model was a model of tanks coupled in series. This model was needed due to loading/unloading through the same pipes creating reversible flows which isn't allowed in the standard models of IDA ICE.

- The third model needed was a simplified borehole model that could be calibrated with reasonable effort. The advanced model in IDA ICE was too detailed to be calibrated when the number of holes is as large as in this study.

Step 3. To extract measurements from the plant a SQL database was created. Measurements from the control system was logged to the data base with 10 minutes sampling time. From the control system about 200 points from temperature sensors, valve positions and fluid flows were logged. The heat pumps are equipped with a tool for analyzing their performance, ClimaCheck. From this system about 156 data points of more detailed information about the heat pumps were logged, COP for each compressor, energy used by each compressor, evaporator and condenser temperatures etc.

Step 4. The system of ground source heat exchangers and the heat pumps needed to be calibrated before the model of the plant could be expected to cope with the measurements. The data set for calibration was from the period Jan 1st 2018 to June 30th 2018.

Step 5. To verify if the simulation model of the plant is valid to use as a test bench two cases were simulated using the calibrated subsystems from step 4. During this step a data set of measurements ranging from July 1st 2018 to April 30th 2019 was used. In the first set-up, Case 1, the simulation model was controlled by measured signals of control signal to the heat pumps, valve positions and fluid flows. In the second set-up, Case 2, the plant was simulated using simulated control based on the control description from the plant designer.

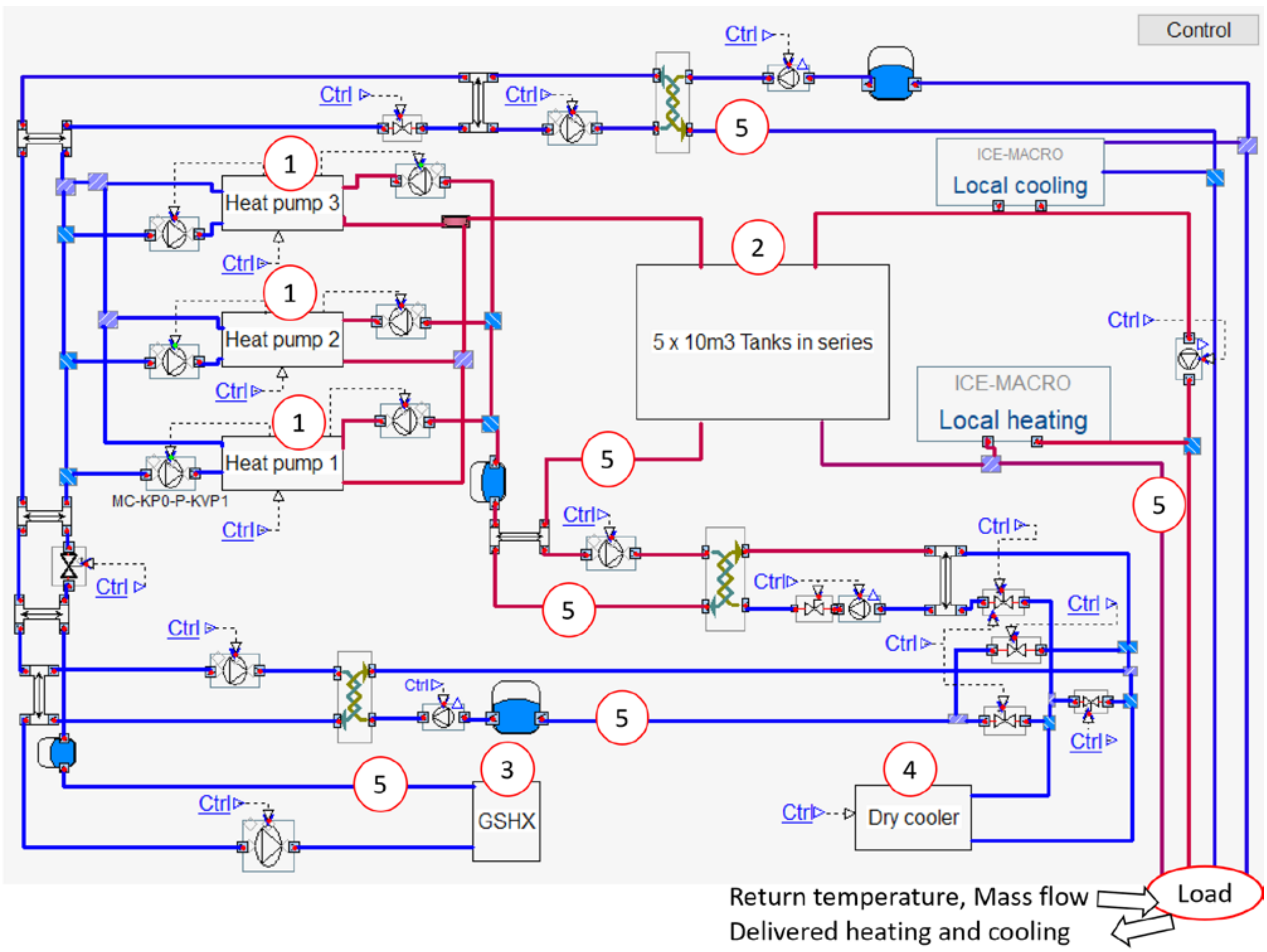

Figure 1. Simulation model of plant. A few components are removed to increase its readability. The model is based on a schematic drawing (Bengt Dahlgren AB) of the plant. The main features pointed out. ① Three 500 kW Heat pumps. ② Five 10 m tanks. ③ Two separate groups of GSHX, 80 holes (in use since 2015) and 35 holes (in use since 2018). ④ Dry cooler, 665 kW. ⑤ Energy meter.

Step 4. Calibration of subsystems

The first of the two sub systems to be calibrated was the ground source heat exchanger. In **Figure 2**, the IDA ICE model used for GSHX calibration is shown.

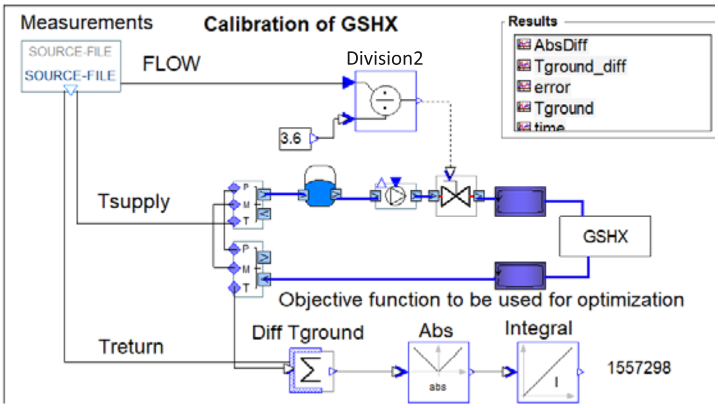

Figure 2. The set-up of the calibration model of the GSHX using IDA ICE.

The fluid flow and supply temperature to the ground was used as input. Then the integral of the difference between calculated and simulated return temperature from the ground was used as an objective function to be minimized.

The ground source heat exchangers needed to be calibrated for two reasons. The first reason is the deviations between the proposed layout of the bore holes and the actual bore holes drilled. Also, although there are thermal response tests (TRT) performed on the site, the site is so large that they can't represent the entire site. The second reason is that there are two different sets of boreholes that were taken into use at different stages. The first set of 80 holes with single U-pipes were taken in to use 2015 and the second set of 35 holes with double U-pipes a few years later, 2017. The usage history of mostly the first set was unknown when the measurements started. Hence, there are two problems in one. Estimating the temperatures in the ground to be used as starting point for the simulation and calibrating the performance of the GSHX. Looking at hourly mean values of the return temperature from the ground, the maximum deviation between the calibrated model and the measurements, is about ±0.4°C.

The three heat pumps have two compressors each which are used according to an internal control system. This internal control makes the calibration of them important as there is no information available describing this control. In **Table 1** some of the results from the calibration are shown. As can be seen the difference between the calibrated and un-calibrated models is substantial.

Table 1. *Results from calibration of heat pumps. The deviation calculated is difference in energy during the simulated period. The deviation before calibration is quite different among the heat pumps. After the calibration the deviation is less than 1% for all cases.*

	Heat pump 1	Heat pump 2	Heat pump 3
Evaporator energy			
Uncalibrated, %	8.2	0.2	18
Calibrated, %	–0.026	0.224	0.178
Compressor energy			
Uncalibrated, %	4.3	8.3	8.6
Calibrated, %	0.499	–0.959	0.187

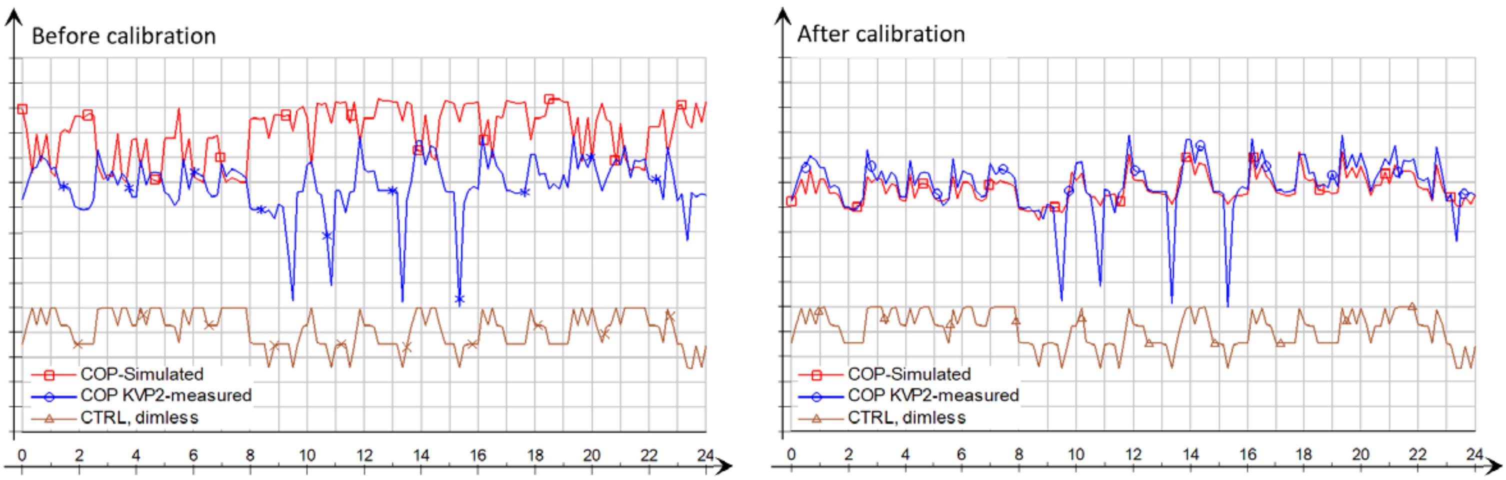

Figure 3. An example of model behavior before and after calibration. The catalog data implied better performance at part load than the actual performance.

Step 5. Plant simulation for verification of performance

The final step in this study was to see if the simulation of the entire plant could match the reality. To do this, two cases was studied. In Case 1, the plant was controlled by measured signals and in Case 2, the plant was controlled using a simulated control based on information from the control description. As driving data for the simulation, the return temperature and mass flow from the heating circuit and the cooling circuit are used. To verify the performance, the measured heating and cooling power are used to compare the simulation result with the measurements. In **Figure 1**, the simulated plant is shown.

Figure 5. Results comparing the case with uncalibrated heat pumps to the measurements.

In Case 1, the simulation is performed using measured signals to control the plant. In **Figure 1**, at each point where "Ctrl" is written in blue, a signal from the measurements is used. The signals used are control signals to the heat pumps and valves and where available the actual fluid flow. The fluid flow is available at each point where an energy meter is located, see **Figure 1**. The comparison of delivered heat and cooling between measurements and simulation is shown in **Figure 4**. The mean error during the simulated period is 5.1% for delivered heat and 1.4% for delivered cooling. Due to measurement problems the compressor power was only logged from April 3rd. The mean error during this period was 6.6%. A more detailed analysis shows that the larger errors occur at small compressor powers.

In Case 2, the simulation is performed using simulated control. However, the actual setpoint signals for the supply temperature for heating and cooling are used in the control. In the results below shown in **Figure 4**, the error is less than in Case 1. The mean error during the simulated period is –0.7% for delivered heat and 1.3% for delivered cooling This is due to the simulated control that corrects for some of the modelling faults.

Was a calibration of the subsystems really needed? To answer that question a complimentary simulation was performed equal to Case 1 with measured signals as control but leaving the heat pumps uncalibrated. The deviation during the simulation period regarding heat delivered from the plant is 18%, it can be seen quite clear in **Figure 5**. The compressor energy of April had an 8% error which is similar as with the calibrated model. This implies a better COP in the model than the measurements.

Conclusion

The result states that it is possible to create reliable simulation models of small district plants using IDA ICE and the model provides a perfect test bench for alternative controls. In this kind of system where a measured load is used, the driving data for plant simulation must contain the return temperature otherwise the temperature level of the system may drift. As heat pumps have internal control, a simulation model needs calibration to capture their real performance. ■

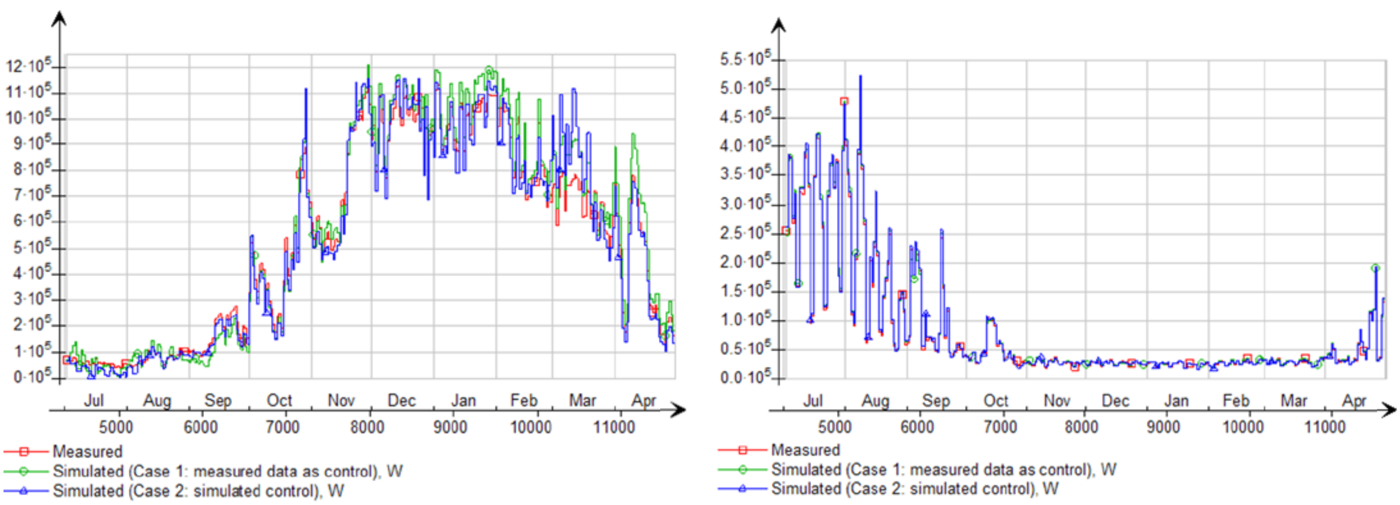

Figure 4. The graphs show the daily mean of the supplied heating and cooling from the plant. Red is measured data. Green represent Case 1 and blue Case 2.

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The potential for utilizing energy flexible buildings to reduce district heating peak demand

The transition towards a less environmentally damaging energy system requires not only increased energy efficiency, but also requires an increased energy production from renewable energy sources. The volatile nature of the most prevalent renewable energy sources (wind, solar) introduces a much higher need for balancing services than the conventional energy production based on burning biomass of fossil fuels. In this article, we demonstrate how buildings in heating-dominated climates can contribute with flexibility in district heating systems.

Keywords: Energy flexibility, Demand response, District heating, Demand modelling, Smart-meter data

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Our need for flexibility

Building energy efficiency has been a societal priority in Denmark for almost five decades. The oil crisis in the early 1970s was the starting point for what would become a series of revisions made to the national building regulations, each increasing the requirements for the energy performance of building envelopes. These requirements have now reached a point where the agenda is set by our climate ambitions more than the real financial gain associated with the last centimetre of insulation material in the outer walls. Despite these strict requirements of the current building regulations, the reality is that for many years a large part of the building stock will continue to be characterized by the much more lenient requirements of previous building regulations. For the majority of these buildings, it will be expensive or practically impossible to achieve significant reductions in energy consumption through energy renovation measures. It is therefore clear that we cannot hope to solve our climate issues by further insulating and air tightening our buildings alone, but that our efforts to improve energy efficiency must also be complemented by other measures such as the ongoing transition to a greener energy production.

The challenge of an energy system based on a large share of renewable energy is that the production is directly dependent on weather phenomena and thus fluctuating by nature. The fluctuating supply of energy necessitates a high degree of flexibility in the rest of the energy system. This may be achieved by either establishing a large capacity for short-term storage of energy, or by making parts of the energy consumption itself flexible. In recent years, researchers have therefore investigated which energy-consuming activities in our society that could potentially deliver this flexibility. Since a degradation of consumer comfort is rarely a successful route to take, the task is therefore to identify the parts of consumption that can be manipulated without imposing additional costs or a loss of comfort for the consumer. Some of these potential sources of energy flexibility include chargers for electric vehicles and home appliances that can be configured to start only when production is sufficient, and the electricity grid is not overloaded. Research is also being conducted on the extent to which the heat consumption in our buildings can be made flexible due to the large amounts of energy involved; 27% of all energy use in European Union is for space heating according to euroheat.org. Since the electricity grid is particularly sensitive to imbalances between production and consumption, most of the research on the potential of energy flexibility focuses on the electricity-based heating forms. Nevertheless, flexibility is also relevant in district heating, where, for example, flexible consumers can help to reduce peak loads, thereby lowering the necessary capacity in the heat production and the associated distribution networks. Freeing up capacity in distribution networks is highly relevant as it opens up the possibility for lowering the supply temperature in the district heating network, thereby lowering heat losses in the distribution grid and increasing the efficiency of the overall district heating system.

Energy flexible buildings

In district heating systems, the morning peak caused by the many coincidental showers of consumers is a recurring daily phenomenon. The morning peak on the dimensioning day results in a direct increase in the necessary production and distribution capacity in the district heating network. Since the consumption of domestic hot water, which together with night setback schemes is the primary cause of the morning peak, is closely related to the daily routines in the household, we do not consider this part of district heating consumption to be flexible in practice. Therefore, if we want to reduce the morning peak in order to lower the necessary capacity in the system, we must do so by creating a corresponding valley in the second of the main components of district heating consumption: space heating. Part of this consumption can be made flexible if we part with the practice of setting a *temperature set point* for our heating systems, but instead specify the *range of temperatures* that we as consumers consider comfortable. Such a comfort range can be adapted to the preferences of the individual consumer, and could for instance define that room temperatures should be maintained between 20°C and 23°C at all times throughout the heating season. The fact that such a comfort range allows us to use advanced control schemes to impose subtle and controlled temperature fluctuations in the building creates opportunities for shifting heating consumption in time - for example by preheating the building prior to the morning peak in consumption. The Danish building tradition's large use of heavy building materials such as bricks and concrete creates favourable conditions for this passive storage technique where thermal energy is stored directly in the thermal mass of the heavy building components.

To demonstrate the potential of energy-flexible buildings, we have modelled the district heating consumption in 159 detached single-family houses located in the city of Aarhus, Denmark. We have used time series of hourly consumption data has been made available to us for research purposes by the local district heating supplier *AffaldVarme Aarhus*. This consumption data, derived from remotely read *Kamstrup* heat meters, is used to calibrate and validate mathematical models of the thermodynamic properties of each individual building together with an associated model for the daily distribution of domestic hot water consumption. The building model thereby describe the weather-dependent consumption, while the models for hot water consumption describe the weather-independent consumption. **Figure 2** presents the consumption predicted by the models and compares it to the measured consumption – first for two individual single-family houses and finally for the aggregated 159 buildings. In the case of the depictions of individual buildings, we have highlighted some of the peculiarities that inevitably make their way into consumption data from in-use buildings. The highlight in the first graph shows an event where the consumption seizes for a short dura-

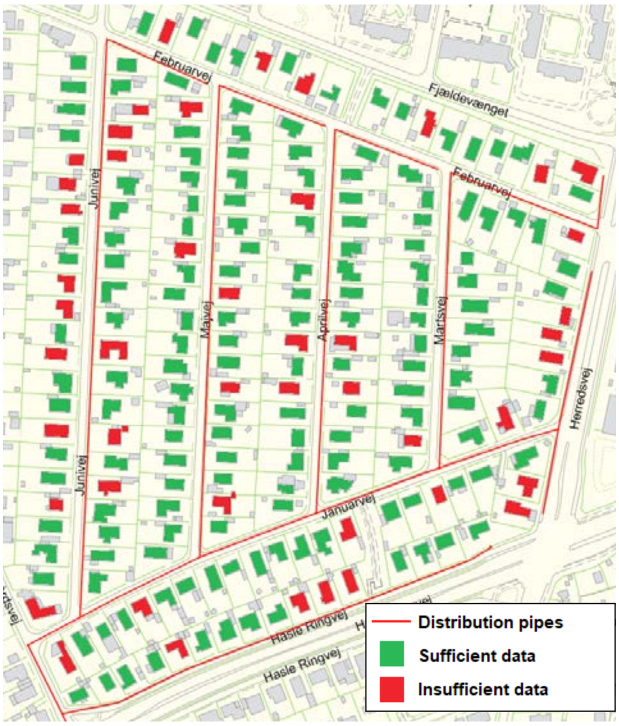

Figure 1. Map of the modelled residential area.

tion followed by a kickback where the heating system is likely reheating the building. Since this temporary drop in consumption was seen for multiple buildings simultaneously, we assume maintenance work in the district heating network a likely cause. The highlight for the second building marks a Danish holiday week, where the sudden absence of domestic hot water peaks would suggest that the building is indeed vacant.

From comparing the measured and predicted time series on the single-building scale, it is clear that the stochastic nature of especially the domestic hot water consumption is a cause of discrepancy between the models and the actual measurements. A part of this is due to the assumptions made in the model of domestic hot water consumption, in which we assume that the domestic hot water consumption follows the same daily pattern on all weekdays. Similarly, we assume a separate consumption profiles to apply to all weekend days. While the method of calibrating the average daily weekday and weekend profiles inevitably simplifies the true stochastic consumption patterns of residential occupants, these effects are averaged out once we move to a larger scale. This is evident from the third graph in **Figure 2**,

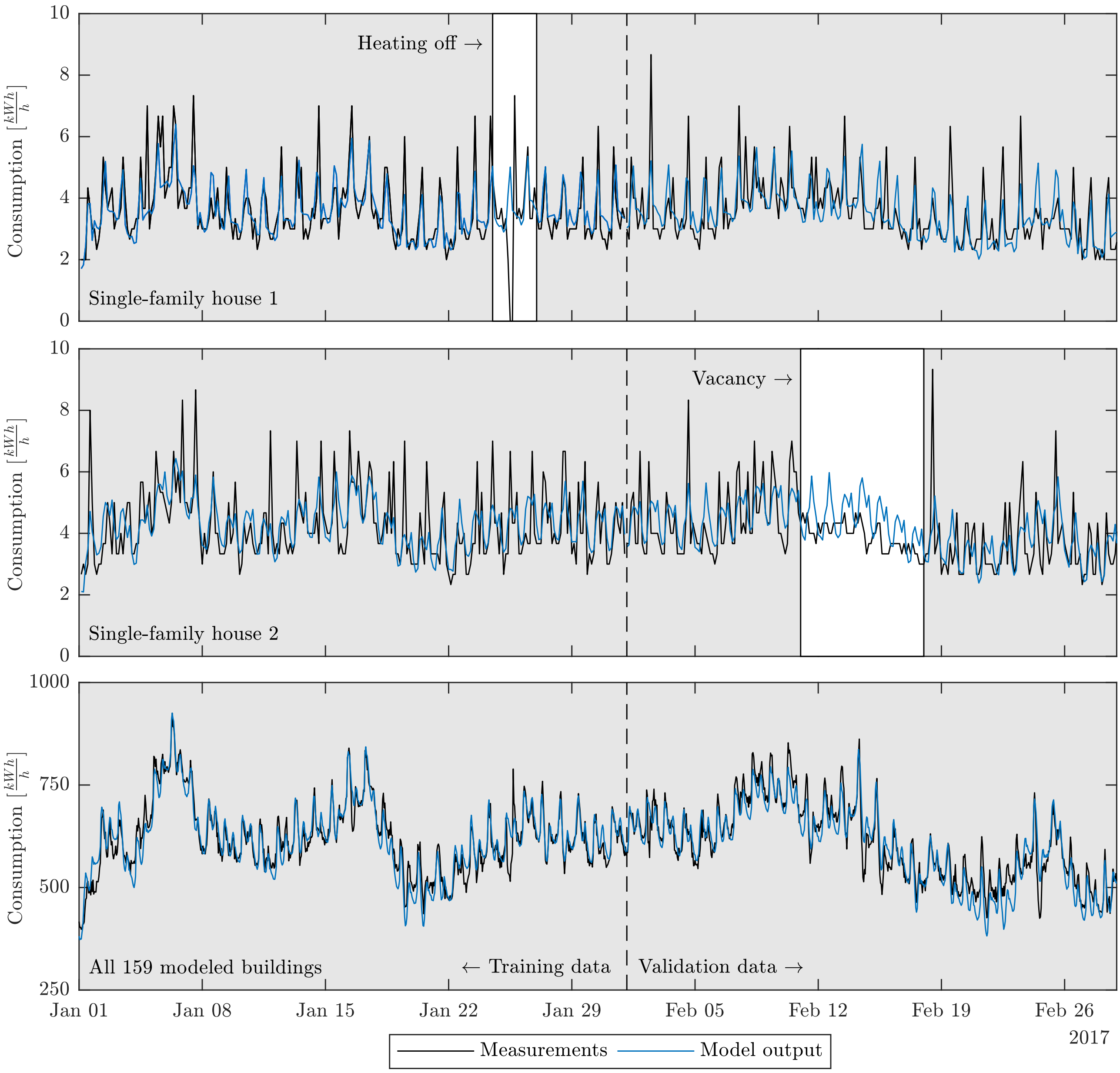

Figure 2. Comparison between measured consumption and model predictions. The top and middle graphs depict time series for two single-family houses, while the third depict the aggregated neighbourhood (159 single-family houses). The vertical dashed line separates the data used to calibrate the models (left side), and the data used for validation purposes (right side).

in which we depict the combined consumption of all of the 159 buildings. Here, the models are capable of predicting the daily variation caused by domestic hot water consumption with a high level of accuracy. Since the combination of the models of building thermal dynamics and domestic hot water usage describes the district heating consumption in the single-family houses quite accurately, we can use them to test different strategies for utilizing energy flexible buildings and thereby map the potential associated with them.

Smoothing the morning peak

In Aarhus, the coldest hour of the 2016/2017 heating season fell in the early morning hours of January 6, 2017. **Figure 2** shows a simulation of the 159 single-family houses' total district heating consumption in the surrounding days, separated into the space heating component and the hot water component respectively. The figure shows the starting point where all the buildings are heated to a constant temperature throughout the day and where the highest aggregated consumption for the group of buildings reaches an hourly average of 925.3 kW. The red mark indicates the proportion of space heating consumption that is moved as we utilize flexible consumption to reduce the buildings' maximum district heating demand by 10 percent.

In order to avoid creating a new peak in the hours when we preheat the buildings, it is important to coordinate which buildings to preheat - and just as importantly when to begin preheating them. The blue marking in **Figure 3** shows how our preheating efforts may be coordinated such that we can eliminate the consumption in the red making on **Figure 4** without causing a formation of new peaks, and thereby achieve the 10 percent reduction of the maximum demand for district heating. The energy stored in the thermal mass in the activated buildings during the preheating process is released slowly as soon as the space heating is lowered and the room temperature begins to drop towards the lower limit of the comfort range. When the lowest permissible temperature is reached, the building's heating system ensures that the temperature does not drop any further. One consequence of this storage technique is that some of the stored heat is released only after the morning rush is over, as can be seen by the elongated tail of the red marking in **Figure 4**.

The example shows that energy-flexible buildings are not only relevant in the smart electricity supply of the future, but can also contribute to value creation in the district heating sector and, by extension, district heating consumers. One challenge associated with activating the flexibility potential associated with space heating in buildings is that predictive control schemes are necessary to ensure that the flexibility is utilized in the most appropriate way. One of the reasons for this is that it is not free to move energy consumption in time: in the example, it required on average 1.31 kWh preheating (the blue mark) to move 1 kWh out of the morning peak (the red mark). This energy loss is due to

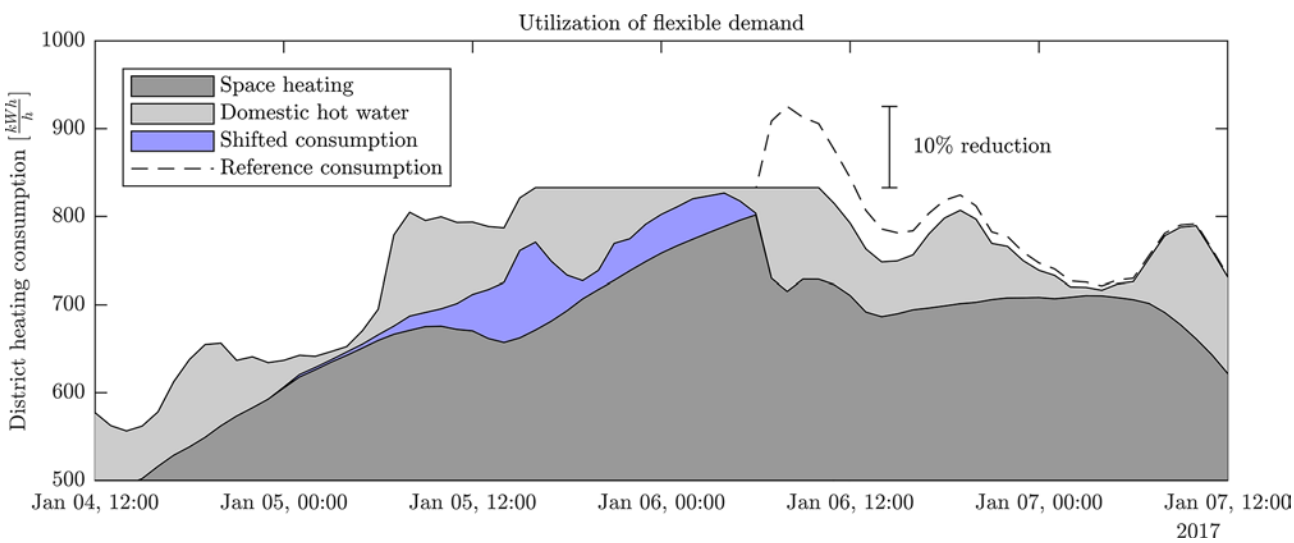

Figure 3. Simulated consumption under utilization of flexible consumers. The blue marking highlights the consumption dedicated to preheating a group of the buildings in the area in such a way that a 10% decrease in the peak demand is achieved.

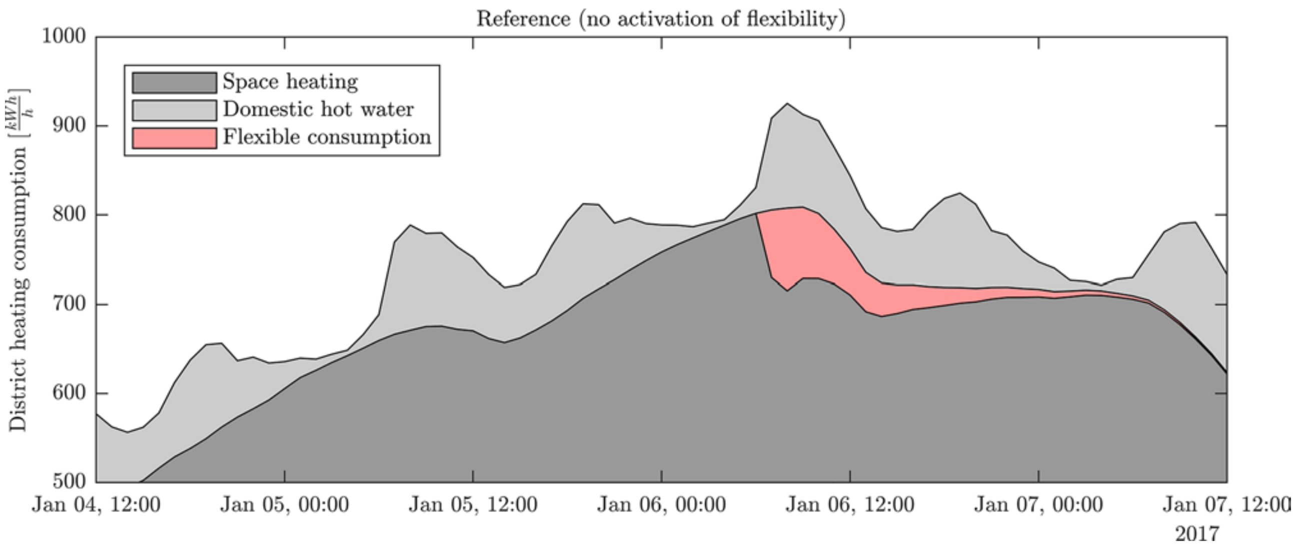

Figure 4. Simulated district heating consumption in the modelled 159 residential buildings. The models of building thermal dynamics and domestic hot water consumption are used to depict the consumption as the potentially flexible demand for space heating and the inflexible demand for preparation of domestic hot water. The red marking shows the part of the reference consumption that will be shifted in time in this example (see **Figure 3**).

increased heat loss during preheating, and thus depends both on the energy efficiency of the buildings and on how early it is necessary to start preheating. Another reason is that, especially during transitional periods, we can easily risk that preheating of the building in the early morning hours will end up causing the building to overheat in the afternoon due to solar heat gains, thus resulting in comfort-issues for the occupants. To avoid these issues, predictive control strategies combine a model of the building's thermal dynamic properties with forecasts of weather and internal heat loads to optimize the control strategy in terms of both economy and thermal comfort. Obtaining models sufficiently precise for control purposes is therefore a concrete obstacle to realizing this so-far untapped flexibility potential. As seen in this article, the availability of time-resolved consumption data is a good starting point to be able to map the potential in more detail and develop methods for establishing the necessary building models. ■

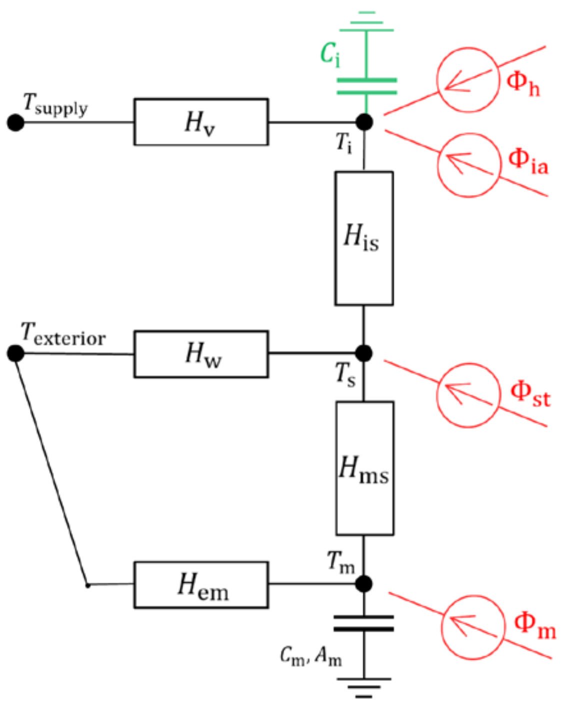

Figure 5. Second order resistance-capacitance model structure used to describe space heating demand.

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Thermal Comfort Risks in District Heating System Controlled by Demand Response

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In future, demand response (DR) will play a significant role in smart district heating system. By utilizing dynamic energy price and thermal mass of building, it is estimated that the heat energy cost saving of DR for building owner is around 5%, when room air temperature is accepted to vary between 20 – 24.5°C. However, it is important to note that thermal comfort should not be sacrificed when DR is introduced in district heating.

Keywords: Demand response, district heating, thermal comfort, field test

Demand response with district heating system

Demand response (DR) consist of a group of methods where the end-user's energy load is modified to decrease the aggregated overall CO_2 emissions of the energy production and to enhance the efficiency of the whole energy system. The end-user´s load may be shifted from expensive peak load periods to cheaper off-peak periods, the peak load may be cut, or extra load may be induced to off-peak periods. As a result, the aggregated load in the energy system will be stabilized and the demand for the fossil-fuel intensive peak-power plants will decrease.

While DR has been explored commonly for electricity grid, it has not been used commonly in district heating system. Earlier demand response studies have predominantly dealt with the electricity loads. However, there is a potential to save energy costs and reduce CO_2 emission with district heating.

During the heating season, production cost of the district heating power varies quite a lot. In **Figure 1** shows an example of district heating hourly price in Finland containing both energy and transfer costs (Salo et al. 2018). The prices remain stable during summer time (i.e. April to middle of November (hours 2,100 – 7,900 in **Figure 1**) with an average value of 40.5 €/MWh and a standard deviation of 7.7 €/MWh. During winter time, the corresponding values are 68.0 €/MWh and 29.7 €/MWh.

Within DR controlled space heating, loading is typically executed when the energy is cheap. The room air temperature is then increased to load heat into the structures, which can be used during more expensive hours by lowering the indoor air temperature setpoint. **Figure 2** presents the principle of DR control, where heating power is controlled by the known price trend (e.g. for 24 hours in advance).

The control strategy itself could be rule-based or model-based. In the rule-based control algorithms studied at Aalto University, the decision-making was based on the outdoor and indoor air temperatures and the control signal generated from the dynamic price information (Martin 2018). The studied model predictive algorithms utilized sophisticated optimization algorithm (e.g. NSGA-II) where user can optimize contradictory functions e.g. energy costs and thermal comfort (Mäki 2019). However, based on the aforementioned studies, the saving potential of both rule-based and model-based control strategies is the same.

In an educational building, the simulated heat energy cost saving potential of DR with the dynamic district heating price (see **Figure 1**) is about 5% for a building owner, when room air temperature is accepted to vary between 20 – 24.5°C. At the same time, annual heating energy consumption decreased 3 to 5% in the studied building depending on the DR algorithm.

In the water radiator system, the heating power could be controlled at centralized or decentralized levels. Decentralized control refers to adjustments of mass flow of water radiators on room level (e.g. electronic radiator valve control), while centralized control refers to adjustments on system level (e.g. inlet water temperature control). By introducing room or zonal based decentralized control, it is possible to reach highest savings and decentralized control guarantee the set targets of thermal comfort in all rooms even when heat loads varied.

Overall thermal sensation with centralized DR control

In the centralized DR control strategy, inlet water temperature of district heating system is adjusted based on the price signal. Based on the energy price trend, the controls have effect on the inlet water and further on room air temperatures. Centralized strategies were studied in one of the wings (13,800 m²) of a campus building at the Aalto University (Mistra et al. 2019). The goal was to examine how much deviations could be incurred in the inlet water temperature and how, if at all, that affected occupant perceptions.

The building was refurbished in 2014 when ventilation, heating, and building management systems were upgraded. The original 2-pane windows were renovated and the renovated windows have a U-value of 1.0 W/m²K. The wing is equipped with mechanical supply and exhaust ventilation system with regenerative heat recovery. It is a variable air volume (VAV) system, controlling air flow rates based on the dual inputs of room air temperature and carbon dioxide concentration.

In testing the DR scenarios, an inherent assumption was that dynamical pricing would be available for district heating and a moving 24 hours, hourly price, would be known in advance, at any point in time. The district heating price used in the study is shown is **Figure 1**. The principle of the control strategy used is as described in **Figure 2**.

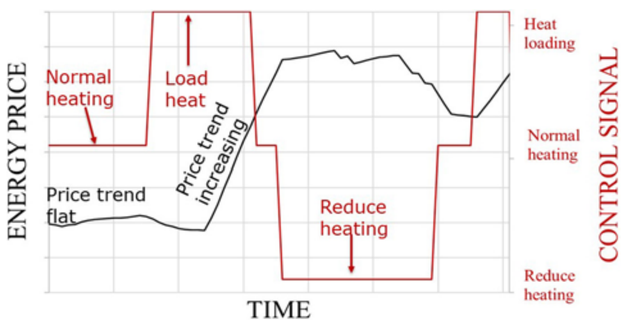

Figure 2. The principle of demand response control during changing price trend.

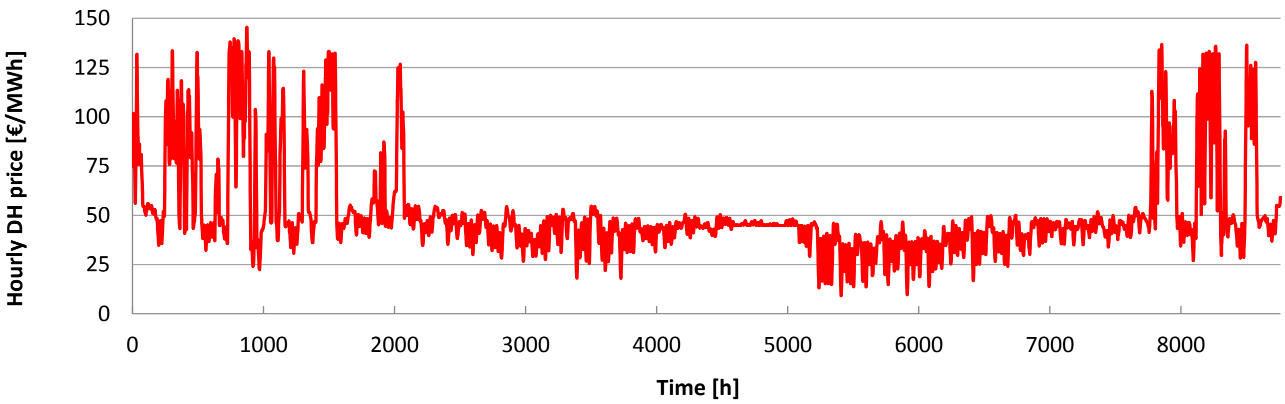

Figure 1. The dynamic district heating price of a typical producer in Finland.

During the test, the heating water supplied to every radiator in the wing was altered, where the maximum deviations of +11/−21°C were allowed for inlet water temperature between actual and standard values (see **Table 1**). The minimum and maximum outdoor temperatures for each weekly period are summarized in **Table 1**. The algorithm aimed at keeping room air temperature within 20 – 24.5°C

To ensure that all the occupied rooms kept within the required comfort zone, the algorithms depended on the mean air temperature of the coldest and warmest rooms. The coldest rooms were defined as rooms whose temperature was lower than 90% of the permanently occupied rooms of the wing and the warmest rooms were defined as rooms whose temperature was higher than 90% of the permanently occupied rooms in the wing. When mean air temperature of the coldest rooms fell below 20°C, or mean air temperature in the warmest rooms rose over 24.5°C, the standard control curve for inlet water temperature was used.

The recorded room air temperature data covered all the rooms in one wing, where some of these spaces were hallways, in the basement, housed equipment/machineries etc. Excluding such rooms, which were not meant for occupancy, left 115 rooms. The temperature data for these rooms was analyzed together to provide a summary view of indoor thermal conditions during the observation periods. **Figure 3** provides the mean, minimum, and maximum temperatures at each instant of record across all 13 weekly periods, for the 115 rooms.

Figure 3 depicts that the maximum and minimum temperatures show a broad range of variation. The current work was not intended towards narrowing

Table 1. *Ranges for outdoor temperature and heating water inlet temperature and deviations during the weekly DR control periods.*

Period	P2	P3	P4	P5	P7	P8	P9	P10	P11	P12	P13
Minimum outdoor temperature (°C)	1.0	1.1	−1.2	−1.5	1.1	0.4	−0.1	−3.2	−0.3	−10.1	−6.7
Maximum outdoor temperature (°C)	12.5	15.3	7.3	6.2	7.0	7.5	7.5	6.0	5.8	6.2	5.3
Range of deviation (°C)	−2.7	−3.8	−5.2	−5.5	−3	−5.8	−4.9	−6.1	−3.6	−21.1	−20.7
	2.1	5.7	5.8	5.7	0.8	5.2	5.8	5.5	7.3	10.7	10.9
Range of inlet water temperature (°C)	30.8	25.0	37.2	36.9	36.5	33.7	32.9	37.3	38.4	21.4	25.8
	45.1	48.4	54.1	52.4	46.8	50.2	52.3	51.5	55.1	66.6	62.8

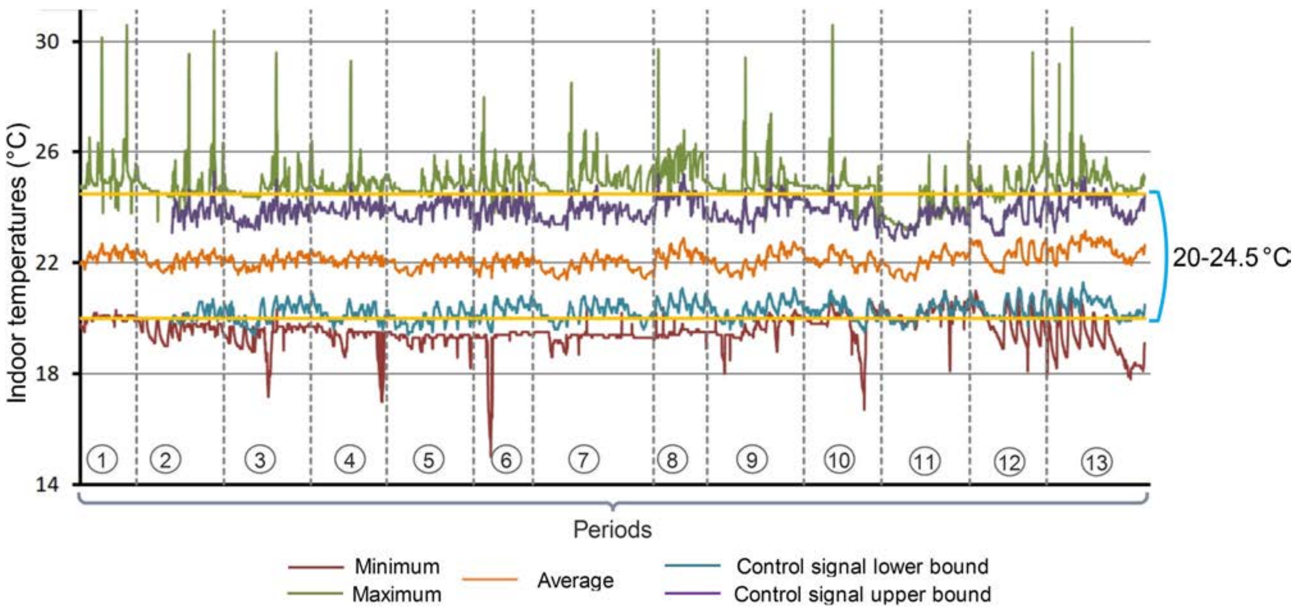

Figure 3. Summarized room air temperature conditions of the observed rooms.

Table 2. Occupant acceptance on thermal comfort during different periods.

Period	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
Number:													
Negative	8	11	1	1	3	2	55	35	54	61	46	13	5
Positive	9	3	1	0	1	0	66	39	107	127	51	36	12
Percentage (%)													
Negative	47	79	50	100	75	100	45	47	34	32	47	27	29
Positive	53	21	50	0	25	0	55	53	66	68	53	73	71

down to the causes of such variations but, some possible reasons could be: higher/lower heat load than designed, balancing problem of water network or too high/low airflow rate for demand in certain spaces.

The results for room indoor temperatures show that the mean temperature pattern during the periods without DR control (P1 and P6) did not drastically deviate from the other periods when the DR strategies were implemented.

During the test periods, occupant acceptance on thermal comfort were collected (**Table 2**). Periods 12, and 13 fared particularly well with the occupants, each securing over 70% positive feedback in spite of the fact that much larger deviations in inlet water temperatures were allowed during these two periods.

It should be noted that during certain periods of implementations, very few feedbacks were received. However, based on the previous comfort studies, if the perception on thermal comfort is very low level, people start to compline anyhow. It seems so that it could be possible that the changes in the inlet water temperature can be as high as +10/–20°C without sacrificing thermal sensation of users. Because relatively low level of responses, more measurements are required to confirm this conclusion.

Conclusions

Based on simulations, demand response of district heating in public buildings gives around 5% heating energy cost savings, if room air temperature is accepted to vary between 20 – 24.5°C. Using centralized control strategy, the room air temperature of individual rooms is not possible to control accurately. In the studied building, the temperature variation is between 18 – 26°C in different rooms even demand response is not introduced. That makes challenging to get full benefit of demand response if there is no room or even zonal level decentralized control system. It seems so that it could be possible to change inlet water temperature quite a lot (about +10/–20°C) without users notice it. However, because relatively low level of responded persons, more measurement is required to confirm this conclusion. ■

Acknowledgement

The authors are grateful for the funding provided by Business Finland for "Reino", "Smart ProHeat" and "Smart Otaniemi" projects. Special thanks to Aalto University Properties (ACRE), Fidelix Oy, Granlund Oy and Fourdeg Oy for the assistance with the measurements and the arrangement of the measurement setup.

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NeGeV: Phase Change Materials for Innovative Cooling Solutions

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Background

Cooling and heating technologies employed in the HVAC industry range from simple natural cooling to advanced Direct Expansion (DX)-solutions. The majority of current active cooling solutions are still dominated by the use of refrigerants in compressor-based technologies, with continuous improvements targeting higher performance compressors, better components integration and less harmful refrigerants. The introduction of 'Eco Design' concepts renders many of the existing product lines obsolete, forcing the industry to develop new, more efficient products (European Union 2016). Thus, there is an increasing need to improve the energy efficiency of the built environment without compromising the indoor air quality and thermal comfort levels. In addition, with the tight regulations and standards regarding HVAC systems and the limitations on the use of conventional systems with harmful refrigerants and working fluids, there is a large potential for environmentally friendly HVAC solutions making use of efficient and innovative technologies. In this context, utilizing Phase Change Materials (PCM) as a short-term storage medium for thermal energy emerges as an innovative and environmentally friendly alternative.

PCMs are special substances capable of absorbing or releasing large amounts of 'latent' heat when they undergo a change in their physical state. They are characterized by specifically designed phase change temperatures, allowing for larger energy storage densities compared to sensible storage mediums and techniques. Large amounts of energy can be stored in the isothermal process of solidifying the PCM and then later discharged by melting the material.

The potential of PCM as an eco-friendly solution for thermal energy management and in balancing energy oscillations in buildings has been addressed in a number of scientific articles and experimental cases (Kasaeian et al. 2017). The majority of the work concerning the use of PCM for air conditioning in buildings have been concentrated on passive solutions (Ning et al. 2017), mainly integrating the PCM within the building envelope components. On the other hand, active integrated solutions and systems are still less mature, where PCM-based products in this section are generally at a research and laboratory testing level (Stein und Partner 2018). So far it has been tested in laboratory settings with promising results and in a few one-off projects (Khan et al. 2011).

Proposed Cooling Concept

While the use of PCM for heat recovery in active ventilation systems has been investigated in a few studies demonstrating promising potential, such solutions have yet to find a way to the market as additional investigation in terms of design, control and optimization of the system is still needed and major challenges are to be dealt with. To overcome the current technical and market challenges, the proposed system concept makes use of an innovative PCM based module, as a thermal energy management unit, to provide the cooling needs and replace the conventional energy-intensive cooling techniques. This will cause an unprecedented increase in energy efficiency and will decrease the need for environmental harmful refrigerants and working fluids. The work is carried out under the 'The Next Generation Ventilation (NeGeV)' project, funded by EUDP, aiming to develop the next generation of HVAC systems by demonstrating an innovative, cost-effective and scalable solution to provide thermal comfort in buildings.

The project will develop a prototype where PCM is used in a module as an energy storage and thermal energy management unit in a decentralized HVAC solution. The overall system concept is illustrated in **Figure 1**.

The heart of the proposed system is a PCM module containing an appropriate mass of PCM material in a rack of panels that ensures proper conditioning of the ventilation air. The PCM module, shown in **Figure 2**,

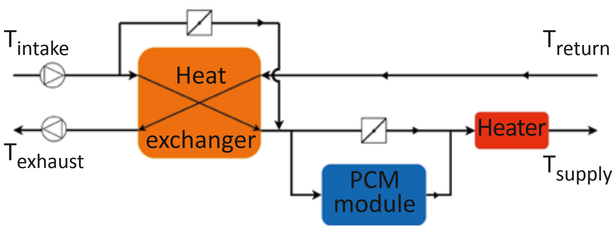


Figure 1. NeGeV Project Concept.

benefits from the necessary outdoor temperature difference between night and day, and is charged during the night, by having the cold outdoor air directed around the PCM panels, lowering the temperature of the phase change material employed. During the charging phase, the PCM will solidify, and the outlet air from the PCM module will be heated up and can either be used as heat recovery in the building if necessary or expelled outside. In case of cooling demand during the day, the supply air is directed through the PCM module which absorbs heat and thereby discharges the module while cooling the ventilation air, resulting in melting of the PCM. The only additional energy requirement is the load on the Air Handling Unit (AHU) fan. due to the integration of the PCM module and the corresponding increased pressure drop.

Regarding the PCM design, the development in the last two decades has mostly targeted available melting temperatures and long-time stability of the PCMs, where the specific storage capacity has been almost stable. NeGeV considers the latest developments in the field and focuses on applying the concept on the smaller

Figure 2. The NeGeV prototype PCM module with the CSM casings from Rubitherm inside.

air volume products – eg. the compact AHU family from the project partner Exhausto (https://www.exhausto.com/). By developing a full-scale prototype of the PCM module suitable for an AHU, the project demonstrates the true feasibility of the concept in a commercial application. The PCM panels have a lifetime depending on the number of charge/discharge cycles, but the design will show an easy replacement and the PCM panels can be regarded as spare parts.

The full-scale prototype of a HVAC-solution will in part be built on an existing HVAC-platform (VEX308) which is a low volume stand-alone HVAC solution for classrooms and offices, currently developed by the project partner Exhausto, shown in **Figure 3**. This existing platform is chosen to reduce costs and technical risks. The current VEX308 unit has been widely implemented in school classes and teaching rooms but with limited applications in office buildings. This is due to the high cooling demands in offices and the need for a cooling system. Thus, the proposed NeGeV prototype with its cooling capability will help providing large potential in terms of implementations in office buildings.

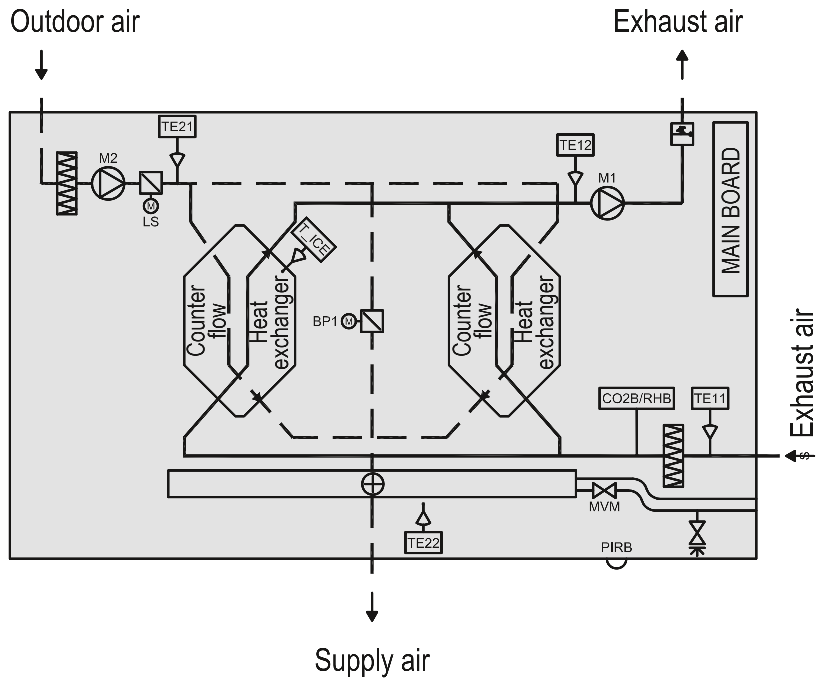


Figure 3. Exhausto VEX308 system layout.

Phase Change Material Selection and Design

The PCM selection is critical for the efficiency and effective utilization of the latent thermal energy. There are three different PCM candidates developed and produced by the project partner Rubitherm for the system (https://www.rubitherm.eu/). The basic material properties are documented by test and measurements in Rubitherm's laboratories. The PCM candidates are of salt hydrate type with comparable thermal properties. The main difference lies in the melting and freezing temperatures of the materials, the properties of the candidates can be seen in **Table 1**. The PCM casing is an already developed and well tested Compact Storage Module (CSM) plate casing, and is shown in **Figure 4**. The CSMs comes in different sizes, the largest with a height of 15 mm.

Table 1. *Thermal and physical properties of three PCM Candidates.*

	SP 21	SP 22	SP 24
Specific heat capacity [kJ/kg]	2	2	2
Conductivity [W/(m·K)]	0.5	0.5	0.5
Density (solid) [kg/m^3]	1 500	1 500	1 500
Density (liquid) [kg/m^3]	1 400	1 400	1 400
Latent heat of fusion [kJ/kg]	140	140	150
Melting temperature [°C]	22–23	22–24	24–25
Freezing temperature [°C]	19–21	21–22	23–21

Figure 4. The CSM casing from Rubitherm.

System Performance Preliminary Assessment

To quantify the added benefit of the PCM module and demonstrate the expected performance of the system concept, a detailed dynamic energy performance model for the proposed ventilation unit, consisting of the VEX308 and the PCM module is developed. In the system modelling process, the VEX308 is considered as a counter flow heat exchanger with an overall heat transfer coefficient calculated based on the number of transfer units method. The heat transfer in the PCM module between the PCM and the air is calculated through estimation of the convective heat transfer coefficient, using correlations for the Nusselt number for flow between two isothermal plates (Arnold et al. 1976). The latent part of the storage is modelled using an apparent heat capacity method, where the specific heat capacity includes the latent heat of the PCM and the melting/freezing temperature.

A case study of a small office of 30 m² in Denmark was considered to assess the system performance, with a maximum occupation of 4 people, the small office performance has been simulated for a standard Design Reference Year (DRY).

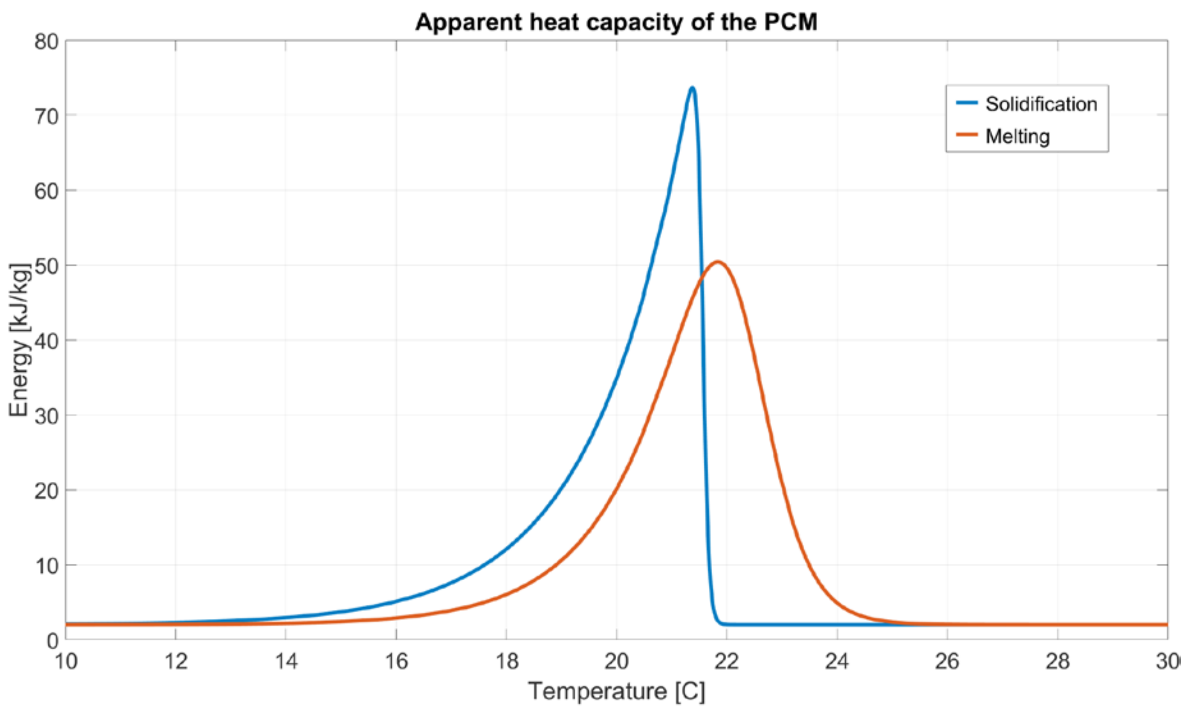
For this case study the Rubitherm PCM SP 21 has been chosen based on its melting/freezing temperature combination, that is inside the desirable range, below the temperatures during summer days and above the normal night time temperatures during summer nights. A PCM mass of 100 kg has been utilized for this system performance assessment.

The internal temperature inside the office space, the PCM temperature as well as a multitude of other variables have been modelled using a large number of inputs; internal heat generation, solar radiation, ambient temperature profile, PCM thermal properties, etc. A room thermal comfort range of 21°C – 24°C has been adopted.

The performance of the system has been evaluated based on the thermal indoor climate requirements as specified in the Danish Standard: DS469:2013 – "Heating and cooling systems in buildings". Here among others two indoor temperature requirements are specified:

- Room temperatures should not exceed 26°C for more than 100 hours a year,
- Room temperatures should not exceed 27°C for more than 25 hours a year.

These room temperature requirements have been utilized to define a Key Performance Indicator (KPI) based on thermal Comfort Violations (CV) that



Energy content in melting and solidification of SP21 PCM, as a function of temperature.

multiply all violations of these requirements with the time period in which they occur and add all the violation time periods up.

Based on the successful performance simulation, it has been shown that the room temperature exceeded 27°C for 13.6 hours and exceeded 26°C for 19.6 hours, over a year period. This has resulted in no violations for thermal comfort and a CV of 0.00°Kh. A reference simulation where the PCM module has been removed has been conducted using the same inputs resulting in a CV of 86.8°Kh, demonstrating the substantial added value of the proposed cooling solution in terms of thermal comfort improvement.

An extreme case simulation has been conducted where the year input data has been replaced with a five-day time period measured at the University of Southern Denmark campus during the record-breaking summer of 2018, where the day temperatures exceeded 30°C and night temperatures were close to 20°C. In this case the DS469:2013 does not apply, but the CV can still be evaluated for measuring performance. The system manages to provide substantial additional thermal comfort. For this period the system obtains a CV of 111°Kh. Again, a reference simulation where the PCM module is removed is conducted here a CV of 228.3°Kh is achieved, which again shows the added value of implementing the PCM module.

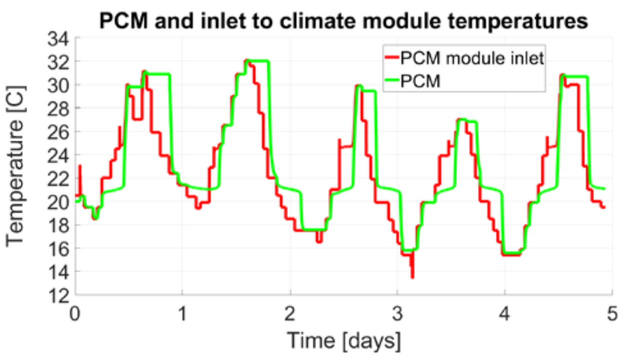


Figure 5a. PCM module inlet and PCM temperature.

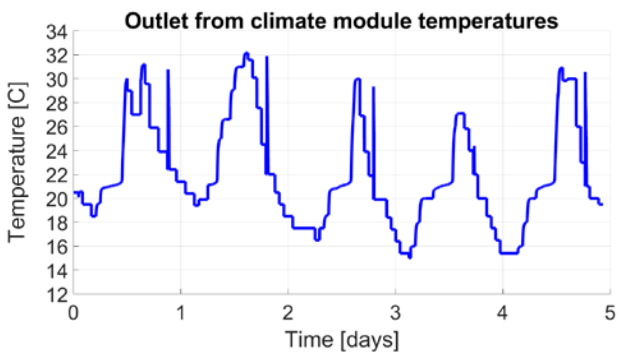


Figure 5b. Outlet from climate temperature.

The PCM temperature, supply temperature and the inlet temperature to the PCM module for the extreme case can be seen in **Figure 5a** and **Figure 5b**. The PCM reduces supply temperature close to the PCM temperature during the first part of the day. It can be observed that during the night, the PCM is solidified, enabling the system to provide cooling during the day.

In order to achieve better performances in these ambient temperature ranges, a PCM with higher melting/freezing temperatures would make a better alternative.

System Energy Performance Assessment

Considering the technical and economic perspectives, the proposed system feasibility has been investigated by comparing the yearly electricity consumption of the NeGeV solution to the Best Available Technologies (BAT). In most cases the BAT would be DX, refrigeration based cooling. The DX system is assumed to have a unit pressure drop of 15 Pa and an average COP over the entire year of 2. The pressure drop in the PCM module was found to be highly dependent on the flow rate and varies between 20 Pa for the lowest flow rate of 150 m³/h to 125 Pa for the highest flowrate of 850 m³/h.

Moreover, the DX solution used a total of 220 kWh of electricity for the entire year while the NeGeV solution used a total of 109 kWh (including ventilation fan power), thus a substantial energy reduction is possible. Both systems maintained the same degree of thermal comfort for the simulation meaning that the provided service is the same. Combining this with the low material and maintenance costs of the system, a low payback period of a few years can be expected. The accumulated energy consumption for the ventilation system for the two solutions can be seen in **Figure 6**. The energy consumption for the winter, early spring and late autumn are very comparable for the two systems, but during the hot summer months the proposed NeGeV solution uses substantially less electricity, since only the added pressure losses have to be compensated for.

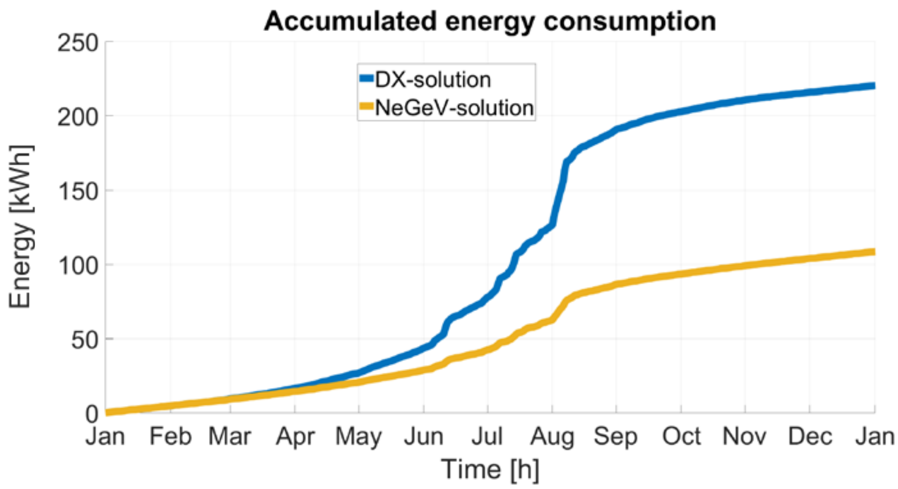


Figure 6. The accumulated energy consumption for the DX- and NeGeV-solution for one-year simulation.

Conclusion

The proposed innovative PCM-driven ventilation solution is intended to be used in small/medium sized offices environments as a base for further expansion. For this scope it was demonstrated that it is substantially less energy intensive than the current available BAT while being cheaper to manufacturer and maintain. This comes at a price, as the proposed system requires different control and management scheme, considering full and part charging and discharging of the PCM.

Historically one of the issues with PCM systems have been the spatial requirements which are especially an issue when the solution is decentralized and placed inside the building. However, with no need to store the energy seasonally, but instead just in cycles of 1 day, allows for a drastic reduction in the amount of PCM required for the proposed solution. Therefore, the size of the PCM module is comparable or smaller in size to that of a standalone ventilation unit.

Major challenges are dominating the ventilation and cooling sector at present including high energy consumption, low energy efficient products, high emissions and less flexibility. Utilizing high latent energy content in PCMs for cooling in an integrated PCM module has the potential to serve as an alternative technology for active cooling in buildings, while completely avoiding the use of refrigerants. ■

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Ventilation Radiator

– Combination of Heating and Ventilation

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Introduction

The most common ventilation systems in modern buildings are a mechanical exhaust ventilation and a mechanical supply and exhaust ventilation. In mechanical exhaust ventilation heat recovery, required in energy efficient buildings, takes place through an exhaust air heat pump, whereby the heat of the extract air is transferred to heating and domestic hot water systems. In mechanical supply and exhaust ventilation, heat recovery is achieved by means of a heat exchanger from the extract air to the supply air.

The Ventilation radiator is an outdoor air intake device for mechanical exhaust ventilation systems. It allows the supply of air to be filtered and heated and brought to the room without any draft or noise. At the same time, the ventilation radiator acts as a normal heating radiator. In fact, the ventilation radiator is a modern panel radiator equipped with an air unit (**Figure 1**).

Ventilation radiator function

Ventilation radiators are mostly used in the Nordic countries, and especially in Sweden where there is an installed base of one million units. Low pressure ventilation radiators are also used in hybrid ventilation systems, where the required negative pressure needed for outdoor air intake is achieved by exhaust air fans when the natural temperature-pressure differences are not available.

Figure 1 shows the cross-sectional projections at the wall duct level of two frequently used wall ducting options, a straight wall channel and a telescopic channel under the window frame.

In addition to outdoor air filtration and heating, an important feature of the ventilation radiator is its low air pressure drop. The filter options of PurmoAir are F9, F7 and coarse filter.

The total pressure drop across the building envelope to the room depends on three main resistance factors: the external grille plus the wall ducting Δp_2 and the air unit, filter plus radiator, Δp_1 (**Figure 2**).

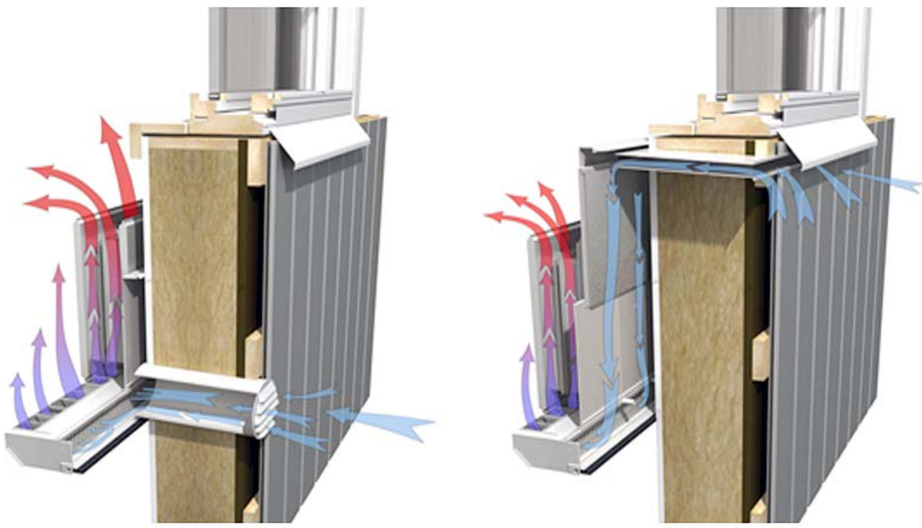

Figure 1. Straight wall duct and telescopic duct.

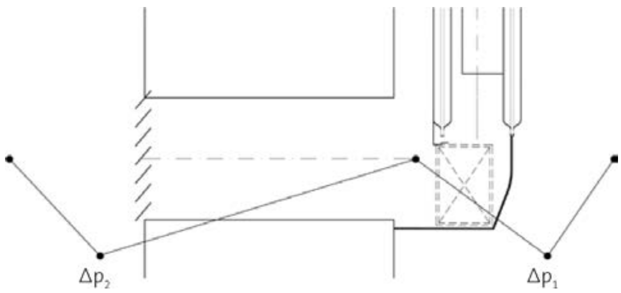

Figure 2. Pressure drop schematic of ventilation radiator.

For example, the total pressure drop of PurmoAir with an outdoor air flow of 10 L/s with a Ø 100mm wall duct, open rate of 75% at the inlet grille and a filter type F9 is 11 Pa. If using a Ø 125mm wall duct the total pressure drop is 8 Pa. These values are obtained from PurmoAir's sizing system. The air flow can be adjusted and, if necessary, also shut off.

Flow resistance of incoming air is low and much lower than in normal air vents. This is necessary for hygienic reasons in order to avoid air infiltration and influx of microbes and impurities, e.g. from the old building structures.

When PurmoAir's own 38 dB_A noise reduction is not sufficient for example, in areas with heavy traffic, silencer tube inserts of $Ø_{in}$100mm/$Ø_{out}$160mm are available, providing noise insulation levels of over 50 dB_A. Even larger sound insulation can be achieved with Z-type silencers built into the outer wall.

Proper ventilation

How to achieve adequate ventilation, economically, energy efficiently and without drafts, is a key issue for the housing health, and the well-being and productivity of the occupants. Residential buildings have been given instructions and regulations, for example, with minimum flow rates of 4 L/s up to 7 L/s per occupant and a reasonable total outdoor air flow of 0.35 L/s to 0.5 L/s per dwelling floor m². Typically, the whole apartment needs to have at least 0.5 air change per hour, i.e. the air in the dwelling changes at a rate of once every two hours: 0.5 1/h.

These guidelines are based on removal of body odours, material emissions, humidity and adverse health effects and occupant symptoms reported in the scientific literature. Carbon dioxide and moisture yields, and emissions of living and building materials must be removed from the dwelling through ventilation. It is especially important that the bedrooms have enough ventilation and that the exhaust air flow is continuous and controlled from the bathrooms, toilets and through the kitchen hood, in accordance with the need. The so-called controlled ventilation is emphasised in energy efficient and airtight buildings, both new and extensively renovated older buildings.

Principle of controlled ventilation: The air flows from the "cleaner" rooms to the "less clean" ones, such as bathrooms and toilets, which have extraction (**Figure 3**).

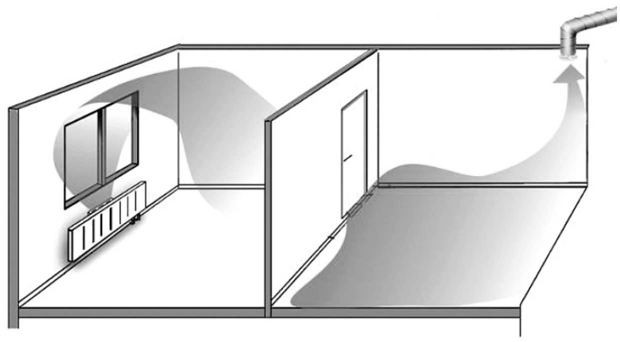

Figure 3. Controlled ventilation with central exhaust.

Self-heating effect and draft-free operation

The Ventilation radiator has a self-heating feature. When the room temperature rises above the setpoint, for example 20°C, the thermostat valve automatically closes the radiator water circuit. The incoming outdoor air cools the radiator and after a while the radiator temperature can drop to below room temperature. Then the radiator starts to absorb the heat of the room through radiation and convection: The radiator water heats up and in turn heats the supply air. **Figure 4** shows a PurmoAir self-heating case: The outdoor air flow of 10 L/s at minus 15°C warms up and stabilizes after one and a half hours to plus 8°C due to the self-heating phenomenon. Panel radiator type was 22-500-1400.

The thermostat re-opens the radiator's water circulation when the room temperature drops below 20°C.

Often the thermostat opens the water circulation much earlier than previously described, and thereby the supply air is significantly warmer – PurmoAir works virtually draft-free, and the supply air is heated even when the thermostat is in shutdown mode.

Figure 4. When the radiator temperature drops below room temperature the radiator starts to absorb heat from the room and the supply air warms up.

Other features of the ventilation radiator

- The heat output capacity of the radiator is high compared to a traditional radiator, often 30 – 40% higher. Due to its high thermal output, it is ideally suited for very low temperature heating systems.
- Typical design temperatures: flow 50°C and return water 40°C. At the normal heating conditions the water temperatures are significantly lower, which provide perfect working conditions for heat pumps, for example. Even lower design temperatures can be used, for example, in warmer climates.
- Reacts faster than a conventional radiator, resulting in more accurate room temperature control.
- The return water temperature is often extremely low, even lower than room temperature, thanks to the thermostat function. This is useful for heat production efficiency.
- Is hygienic and easy to clean, no long ductwork systems.
- Can cool a room space, for example in spring, when free heat gains are high, typically from solar, people and electrical appliances, and when outdoor temperatures are still low.
- Serves as a great source of free cooling during summer nights due to its low pressure drop to cool the dwelling with cool outdoor air.

What types of buildings are suitable for the ventilation radiator system?

In principle, ventilation radiators are suitable for both new and old buildings that have a mechanical ventilation system, provided that the building is airtight. Exhaust air heat recovery is a must in modern buildings. With the help of an exhaust heat pump, the energy of the ventilation exhaust air is transferred to the domestic hot water all year round, and depending on the design, it can often almost entirely cover the heating requirements of the premises. When required, additional heat can be provided from sources such as electricity from a grid, a building's own solar energy systems or micro-CHP, a combustion boiler or district heating. The annual COP_a of the heat pump is high because the heat source has a constant room temperature throughout the year.

Ventilation radiators are among the best for deep-energy renovation. Renovation can be carried out even when residents are present in the dwelling, without the need for larger construction of ductwork, and with only the exhaust ducting needing to be renovated.

Ventilation radiators are especially suitable for apartment buildings. Together with the exhaust air heat pump, a very cost-effective and energy-efficient refurbishment concept can be achieved. ■

Phyn Plus: New approach to water management in homes

Introduction

United Nations projects that 68% of world population will live in urban areas by 2050. It is also anticipated that global water use will increase by 20–30% during the same period [1]. This will put considerable pressure on the performance and capacity of urban water distribution systems, both in terms of the municipal infrastructure and in terms of managing water distribution and use within buildings.

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Many European consumers do not consider water as a scarce resource. This is in particular the case in northern parts of Europe with relatively dense population and relatively high access to water resources. This traditional frame of mind has influenced consumer behaviour, construction technology choices and building management practices in a way that has not been favourable to water efficiency.

It should be noted, however, that while there is on average abundant access to freshwater resources in Europe (long-term average of 3 500 m³ per inhabitant and year), these are both highly variant and unevenly distributed in time and geographically. According to the European Environmental Agency, this resulted during 2015 in 33% of the European population to be exposed to water stress conditions. [2]

A European Commission's estimate [3] from 2014 states that "in about half of the Member States, more than 20% of clean drinking water is lost in the distribution network before it reaches consumers' taps, while for some Member States the proportion is as high as 60%". A EurEau study from 2017 puts the mean value of distribution losses in EurEau member countries to 23% of distributed water and 2 171 m³/kilometre of network/year [4]. Unnecessary consumption due to hidden or catastrophic leakages in water systems within buildings is a much less studied topic, but it is an established fact that water damage due to leakage is one of the largest sources of insurance claims from building owners. Consequently, most insurance companies will provide a discount to insurance payments if a leak detection system is installed.

Higher standards of living have changed water demand patterns in Europe. This is reflected mainly in increased domestic water use, especially for personal hygiene. Most of the water use in households is for toilet flushing, bathing and showering, and washing machine and dishwashing (**Figure 1**). The proportion of drinking water for actual cooking and drinking purposes is minimal, compared with the other uses of potable water. [5], [6]

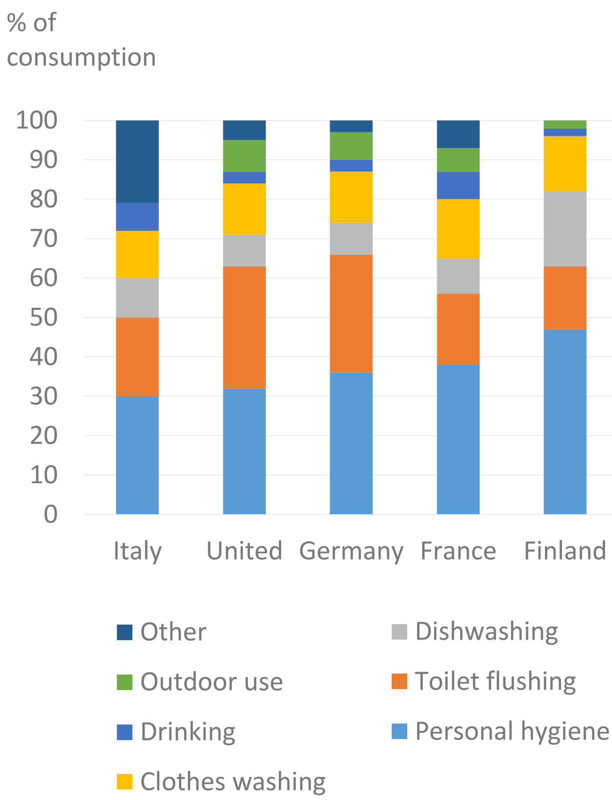

Figure 1. Household water use by activity in selected European countries [6].

The consumer problem

Current investment in developing, maintaining and upgrading water distribution systems within buildings and in communities is unfortunately not on the level required to sustain efficient and reliable water distribution and resource management. This is the case both in developed economies - such as most of Europe and North America – and particularly in emerging and developing economies in Asia, Africa and Latin America.

While there is a clear need for more efficient and affordable water management tools and practices for building owners and occupants, a strikingly low level of development effort by the industry has addressed this need. This is partially related to the value and unit price of consumed water: as the initial resource is free of charge to water suppliers, the consumer price of water has remained relatively low and consequently incentives to invest in water management practices have been low.

With the rapid increase in environmental awareness, and with the more frequent water shortage or water stress situations occurring also in different parts of Europe, there is now also a clearly emerging need from the consumers' and building owners' side for solutions to water management, in particular intelligent detection of hidden leaks and other unnecessary water consumption.

The consumer requirements for such solutions are relatively clear:

- Cost effectiveness: the value provided by detecting unnecessary consumption needs to be in acceptable relation to the cost of detection, including technology costs, installation, maintenance and use;
- Ease of installation and compatibility: the solution needs to be easily retrofitted to existing installations, in order to have sufficient coverage across the whole installed based of plumbing systems; also, installation technologies, sensoring and measurement technologies, and interfaces of these technologies need to be compatible with varying market and installation practices across Europe;
- Predictive performance: in order to have actual value for a leakage detection and water use analytics system, it needs to be capable of predicting leaks before catastrophic failures in the network actually occur;
- Intuitive guidance: in addition to providing technical detection of leaks and other unnecessary consumption, a relevant technology will also provide feedback and guidance to end consumers on consumption patterns, ways of influencing unnecessary consumption, the impact of alternative changes to the water bill, etc.

According to a consumer survey carried out in early 2019 across 500 respondents in Finland [7], there is a clear demand for efficient solutions meeting these requirements. A third of the survey respondents expressed concern regarding the condition of their home plumbing system and showed interest in purchasing water monitoring equipment. Every tenth respondent had already installed a leakage detection device. For most of the respondents the maximum acceptable cost of such an installation was 500 euros.

Most attractive water monitoring features identified in the survey were leakage detection (24% of respondents), water quality monitoring (14%), the possibility to remotely shut off the water (14%) and monitoring total water use (13%). Approximately 8% of the respondents were interested in monitoring and disaggregating water use between different consumption points in the home.

The technological solution: intelligent water fingerprinting

When a faucet or other water outlet connected to the plumbing system is opened or closed the pressure within the piping system fluctuates in a particular way. The Phyn Plus technology measures pressure in the network 240 times a second to track these individual pressure variations at one single installation point, typically adjacent to the main water meter (**Figure 2**). The data collected from pressure measurements is analysed by an artificial intelligence algorithm capable of detecting and learning the individual fingerprints of each outlet connected to the system.

The first two to four weeks after installation is a learning period for the artificial intelligence algorithm. A typical learning period requires approximately 1,000 opening and closing events to learn and double check the different combinations of water outlets in the building.

This leads to a unique feature of the technology. As every faucet (or any other water-using device in the plumbing

Figure 2. The Phyn Plus unit is installed at the main water inlet of the house and monitors the pressure fingerprints of each consumption point from this single location.

system) causes a distinctive set of pressure variations, the artificial intelligence of the Phyn Plus application identifies which water outlet is being used. As the system learns the fingerprints of the outlets connected to the system during their daily use, it will also recognise exceptional situations when the pressure fingerprints deviate from those that have already been identified. These cases are highly likely to be a either leaks or other types of unintended water use and will cause an alarm (or a prompt for action) to be sent to the homeowner.

A further unique feature of the pressure fingerprinting technology is that it can identify such anomalies even when several water outlets are being use simultaneously. This is due to the fact that the individual pressure fingerprints never occur exactly at the same moment, and the 240 measurements per second frequency is sufficient to separate the openings and closings of individual faucets.

The algorithm is also able to provide early warnings of freezing in cold climate plumbing systems. Ice crystal formation causes particular kinds of pressure variations which can be recognised by the system. As such variations are detected, the system is shut off remotely if the risk of freezing is evident.

The Phyn Plus hardware itself does not store monitoring data. It communicates with a dedicated cloud service via the homeowner's Wi-Fi connection. Data stored in the cloud is used to provide consumers with aggregated insights on water use and benchmarking data on a completely anonymized basis. Through the availability of data from multiple installations around the world, Phyn Plus includes a preset basic pool of fingerprints to make the learning period shorter and more effective.

The system also performs a daily plumbing condition check that will reveal even the smallest leaks. The user can select at which times these checks are carried out, preferably at times when water is normally not used, for example during very early morning hours. During the condition check water supply is shut off for 45 seconds. The system monitors the development of the pressure level in the system and reacts to very small reductions in pressure implying even the smallest leaks in the system.

Open innovation as implementation approach

The concept behind Phyn Plus was created approximately ten years ago at the University of Washington. Similar technology had already been successfully used to monitor electricity consumption in buildings based on voltage and current fingerprints of individual appliances. A research group at the University of Washington embarked on a study regarding the application of the same approach to monitoring water systems.

Fundamental research and evaluation of the technology concept led to patents based on successfully applying the methodology to water monitoring. At this point Belkin, an American corporation specialised in consumer electronics, mobile device accessories, IoT and network technologies, entered the partnership. Belkin has long experience in smart home appliances and their technology capabilities provided a good

Table 1. *Comparison of technical features of Phyn Plus and alternative leak detection technologies.*

	Leak sensors	Leak sensors + Shut Off	Connected device + Shut Off	Smart Water assistant + Shut Off (Phyn Plus)
Automatic shut off	X	✓[1]	✓[2]	✓[3]
Real time notification via app	X/✓	X/✓	✓	✓
Low risk of false alarms	✓	X	X	✓
Daily diagnostic on drip leaks (Plumbing Check)	X	X	✓	✓
Immediate leak detection	X/✓[7]	X	X	✓
Freeze detection	X/✓[4]	X	X/✓[5]	✓[6]
Fingerprinting / Water consumption by fixture	X	X	X	✓
Water left running alert	X	X	X	✓
One device for the entire home	X	X	✓	✓

1 Automatic Shut off only on preset aggregate values (total flow, consumption per day etc.)

2 Automatic Shut off only on aggregate values - adjustable remotely or historical patterns

3 Automatic Shut off triggered by any not recognized water event (no preset)

4 Freeze detection limited, based on room temperature

5 Freeze detection limited, based on water temperature

6 Freeze detection based on pressure, water & outside temperature algorithm

7 If sensor placed in the place where leak happens

platform for taking the technology from a laboratory concept to a first industrial prototype.

However, introducing a new technology to the plumbing market is not the same thing as developing and launching a new consumer electronics product. Uponor's experience in plumbing system development and access to the plumbing market provided the final missing piece of the puzzle.

As the technology for online plumbing system performance monitoring was something new for both Belkin and Uponor, a separate and dedicated joint venture seemed to be the best solution for finalising the technology development and for introducing the technology to the market. This led to Phyn being established as an independent company in 2016, with currently equal ownership stakes in the joint venture shared between Uponor and Belkin.

This setup is a prime example of open cross-industry innovation in practice. The final commercial implementation of the technology would not have been possible without the combination of basic scientific development capabilities, knowhow in consumer electronics, IoT and machine learning, and long experience and insight to the design, installation and management of plumbing installations.

Lessons learnt from pilot installations

Since 2018 the Phyn Plus technology has been available on the North American market. During 2019 it has also been launched in selected European markets, and it was introduced in Europe during the ISH trade fair in Frankfurt in March 2019.

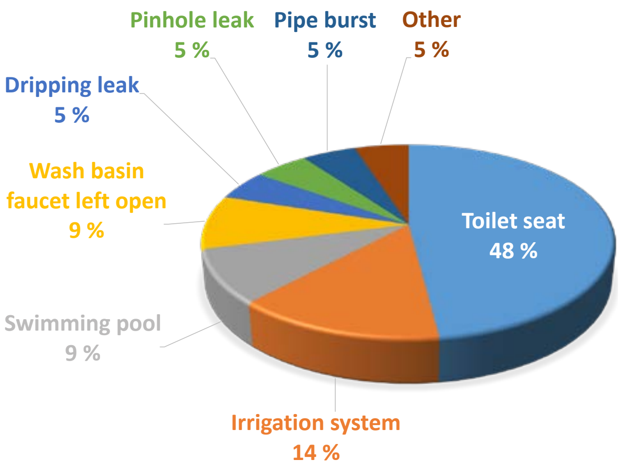

Figure 3. Distribution of leaks and unintended water consumption identified during the Phyn Plus pilot installation period.

Before launching the technology, a pilot installation and testing program was carried out in North America. The program covered 300 single family home installations and one full year of system operation.

During the pilot test period Phyn Plus detected 65 leaks in the 300 test cases, with an accuracy of 99%. The leaks detected ranged from catastrophic pipe bursts to pinhole leaks and faucets accidentally left open by children. (**Figure 3**)

Phyn Plus is in its first stage available for single family and semi-detached houses. The technology has considerable potential also in apartment and non-residential buildings, but it requires further development to apply to more complex network layouts. According to current planning it will be developed and launched to these more requiring segments during 2021. ■

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Renovation of room system control – a step towards smart buildings

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A service platform for smart buildings is demonstrated in seven meeting rooms of an educational building. This concept is easy to utilize in retrofit of existing buildings. The main benefits of the system are: improved monitoring of the system performance, guaranteed indoor climate conditions and higher users' perception on the indoor climate.

Keywords: Service platform, smart buildings, IoT, field demonstration

Demand for improved smartness

Smart buildings refer to the capability of a building to sense, interpret, communicate and respond to changing conditions, which are introduced by requirements of occupants to indoor climate, operation of technical building systems and demands of intelligent energy systems. Possibility to adapt in response to the perception of the occupants and further empower end-users makes possible to enhance users' satisfaction to indoor climate.

Merged together with smart energy systems, building technical system should be able to adapt its operation to the needs of the occupant and the energy systems and to improve its energy efficiency and overall performance. Technical solutions are then able to optimize dynamic energy prices in the part of demand response control and thus enhance the flexibility of energy systems.

Readiness to facilitate maintenance and efficient operation of technical building systems guarantee optimal performance of systems. In smart buildings, this should happen in cost and environmentally efficient way by adapting in response to the smart energy grid. All this requires paradigm shift in commercial buildings where passive users are amended to be prosumers (Kosonen et al. 2018).

Recently, it has realized that the actual system performance is not as designed in many buildings. There are lot of technical faults in HVAC- systems like unbalanced air flow rates, wrong set points, stuck actuators, dirty measurement devices etc. Some of those faults can be avoided with proper monitoring of building management system. Still, it should be noted that some of faults are not possible to note easily with the standard building automation measurements. In those cases, continuous time retro-commissioning process should be implemented.

In the existing building stock, it is quite well-known fact that standard building systems are not able to give high users' satisfaction on indoor climate. It is quite typical that users' dissatisfaction on indoor air quality and thermal comfort is 30% in A- class commercial buildings. This indicates a need for both systematic facility management process and also the development of more sophisticated systems that make possible to control user's local micro-environment (Kosonen et al. 2019).

The current norm of having comfort conditioning systems that are designed for an average person, where the thermal comfort and indoor air quality conditions of individuals are deemed to be impossible to fulfil, are changing fast. The development of more advanced smart systems should be, and are being, introduced to improve indoor climate conditions for all the occupants of a space, not just the mythical average man.

Retrofit solution for room where occupancy vary

In meeting rooms of educational buildings, water radiator heating system with thermostats and variable air volume systems are commonly used in Nordic countries. **Figure 1** shows a typical heating and ventilation system in Nordic. Water radiators are equipped with thermostats that are able to prevent the premises from overheating. Still, the set point of the water radiator is not possible to control accurately with mechanical thermostats. In practice, this means that ventilation cooling and heating setpoints overlap each other in many cases. This can create indoor climate problem and lead to unnecessary high energy consumption.

In the demand-based ventilation system, the air flow rate control is typically based on occupancy sensor, room air temperature and CO_2-level that boost ventilation if the spaces are occupied. The control of ventilation system is centralized and users are not able to control their indoor air quality.

There is urgent need to develop the controllability of the aforementioned system. The performance of the whole system should be improved so that overlapping of heating and ventilation systems is not possible. Also, the users should be able to control their own micro-environment conditions.

In the part of the cutting-edge solution, the water radiators are equipped with IoT thermostats that makes possible to control room air temperature accurately. The set point of heating system could be adjusted based on user's perception and/or dynamic energy price. Typically, the performance of ventilation is controlled only by building management system. In a service platform, information of building management systems is merged together with separate IoT based controls and measurements into a cloud server. (**Figure 2**).

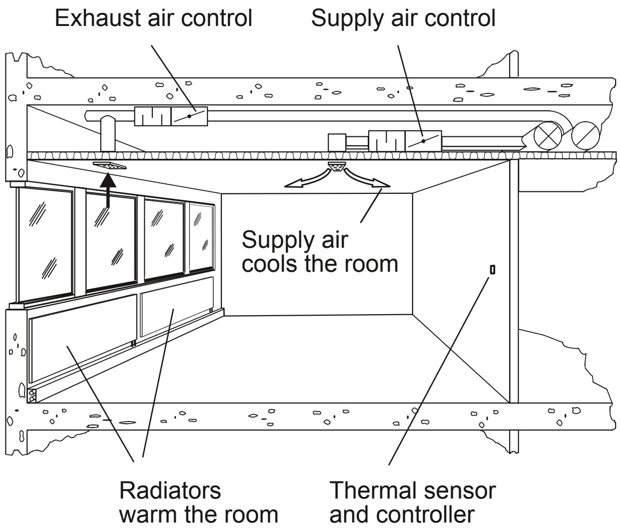

Figure 1. A typical heating and ventilation concept in Nordic.

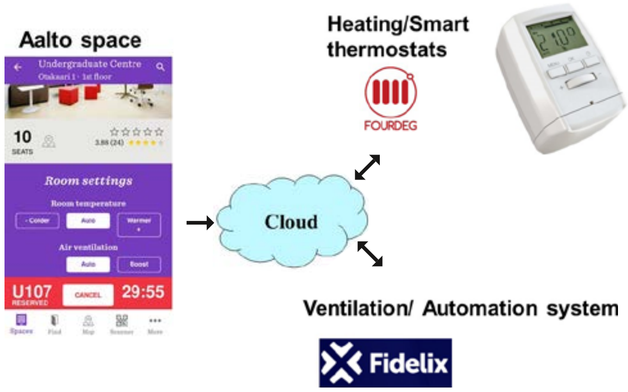

Figure 2. A retrofitting concept of heating and ventilation system where users are able to control indoor condition with apps.

The previous service platform was demonstrated in seven meeting rooms of an educational building at Aalto University campus. In this concept, users are able to control their own room air temperature and if they wish, boost ventilation with the Indoor Climate Service of the Aalto Space Campus Application. Based on their perception, the room air temperature is possible to change ±2°C with the app. It's possible to boost ventilation to the maximum air flow rate from the normal occupancy mode.

As a separate service, the performance of VAV could be monitored with separated IoT sensors by measuring pressure difference over building envelope that indicates the possible unbalance of supply and exhaust air flow rates.

The implemented service platform enables also the collection of the feedback of actual comfort perceived

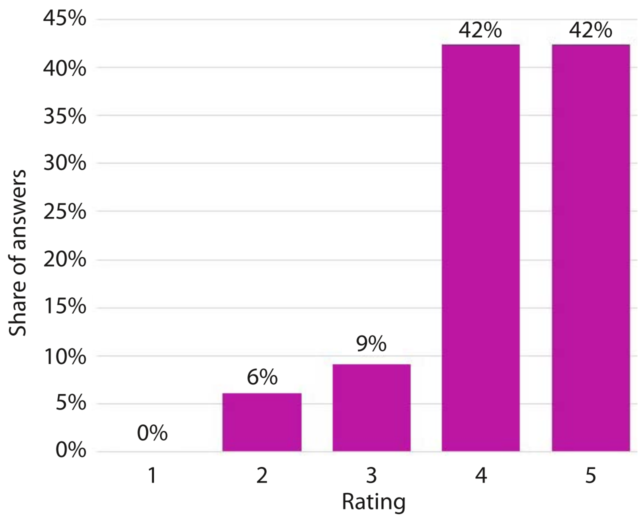

Figure 3. The feedback of users' satisfaction on indoor climate.

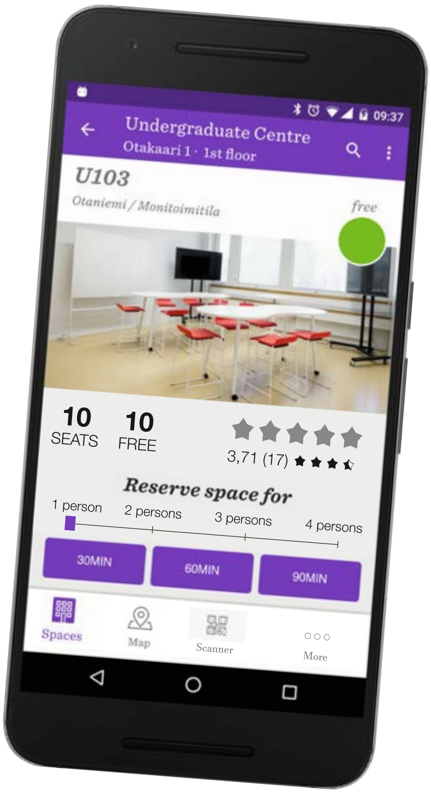

Figure 4. The interface of the Aalto Space Indoor Climate Service.

by the occupants on the indoor conditions together with physical parameters measured in spaces (**Figure 3**). Based on the conducted study, the general perception of users on indoor climate was quite good. More than 80% of the users ranged condition on the level of 4 or 5. This can be considered as a good result because it is quite difficult to reach over 80% satisfaction in a field study.

In the service platform, the core is the space reservation interface (**Figure 4**). It integrates smart campus IT infrastructure with the building automation services. It is important to note, that building services engineering is not a separate small islet, but it is integrated seamlessly together with the building real estate business platform. For the future smart buildings, it is not anymore enough to integrate just only building technical systems: building services should be integrated with a business platform.

Conclusions

Smart buildings refer to the capability of a building to sense, interpret, communicate and respond to changing conditions. Smart buildings should also give a platform to integrate building technical systems with real estate core processes. That makes possible to make buildings capable to sense, interpret, communicate and respond to changing conditions. The carried out demonstration study indicate that it is possible to enhance service level of old buildings by introducing a cloud integrated platform. When users are able to control their own set points for room air temperature and indoor air quality, the satisfaction on indoor climate conditions increased significantly. ■

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SSO User Insight Toolbox for employees' health, well-being and productivity

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Users have significant impacts on building energy consumption and can interact with indoor environments. Identifying user needs, behaviour, and preference is crucial for the design of both new and the renovation of existing buildings. Offices are important since people spend on average one-third of their life at work. It also accounted for a larger share of the energy use and the floor area of non-residential buildings in Europe. Moreover, more ambitious regulations and the increasing popularity of voluntary building certification schemes require the construction of more energy-efficient buildings, but in reality, a 'performance gap' is often observed. Therefore, deep insights in user perceptions and experiences can provide the knowledge basis for developing a new generation of office buildings that provide a healthier and more productive indoor environment guided by a user-centric approach. In this article, we will introduce the web-based application of the Questionnaire and Diary Apps and a Virtual Reality (VR) design tool developed to support the interactive co-creation session with users and designers.

Buildings are responsible for 40% of energy consumption and 36% of energy-related CO_2 emission in the EU. In the European building stock, offices have a large share of 26% of the total energy use and 23% of the total floor area of non-residential buildings [BPIE, 2011]. Aiming for the 2030 climate and energy framework, office buildings play a key role with the targets of cutting greenhouse gas emission and improving energy efficiency in the building sector. The office environment is also important to the employees and society as a whole. We spend 80-90% of our lifetime in buildings, and office dependent working results in 90000 hours on average. Providing an agreeable indoor environment plays a key role in the building energy consumption and is a vital part of human well-being existing in buildings [Bluyssen et al., 2011; Jin and Wallbaum, 2018]. Moreover, in line with the UN Sustainable Development Goals 3 "Good health and well-being" and Goal 8 "Decent work and economic growth", a sustainable indoor environment needs to be understood further to improve user comfort, health, and work performance. Even if we have standardized information for design and operation of desirable indoor climate, a "performance gap" is often observed between designed, measured and perceived indoor environmental quality (IEQ) as well as designed and real energy consumption in buildings [Altomonte et al., 2019]. Despite the knowledge existing within architecture, mechanical and civil engineering, facility management etc. to construct high-performance buildings, the results not always match with our expectations, e.g. that low energy building or green buildings are not so livable, and the smart buildings cannot control the indoor climate for occupants' real needs. One of the main reasons is that we still have a very blurry and fragmented knowledge of the different user behaviours in real buildings [Hong et al., 2017]. Users can have significant impacts on building energy consumption as they interact with the indoor environment in many ways. To achieve a higher building performance concerning both the energy perspective and indoor climate, we have to consider the user demands more comprehensively. Therefore, deep insights in user experiences can provide the knowledge basis for developing a new generation of office buildings that provide a healthier and more productive indoor environment guided by a user-centric approach. Consequently, user insight tools gain importance and several of them have been developed around the world. The paper will introduce two innovative tools that have been developed, validated and customized in different climate zones in Europe within the smart and sustainable offices (SSO) project funded by the EIT Climate-KIC.

The approach of "SSO"

The SSO approach is holistic a mixed-method approach of qualitative and quantitative measures, gathered in a so-called SSO User Insight Toolbox. See **Figure 1**. It combines comprehensive Apps of a web-based questionnaire, a web-based diary study, a user observation tool, deep and focused group interviews as well as IEQ physical measurements [Cobaleda Cordero, et al., 2018]. The SSO User Insight Toolbox covers a broad scope of users' health-related factors and captures their current

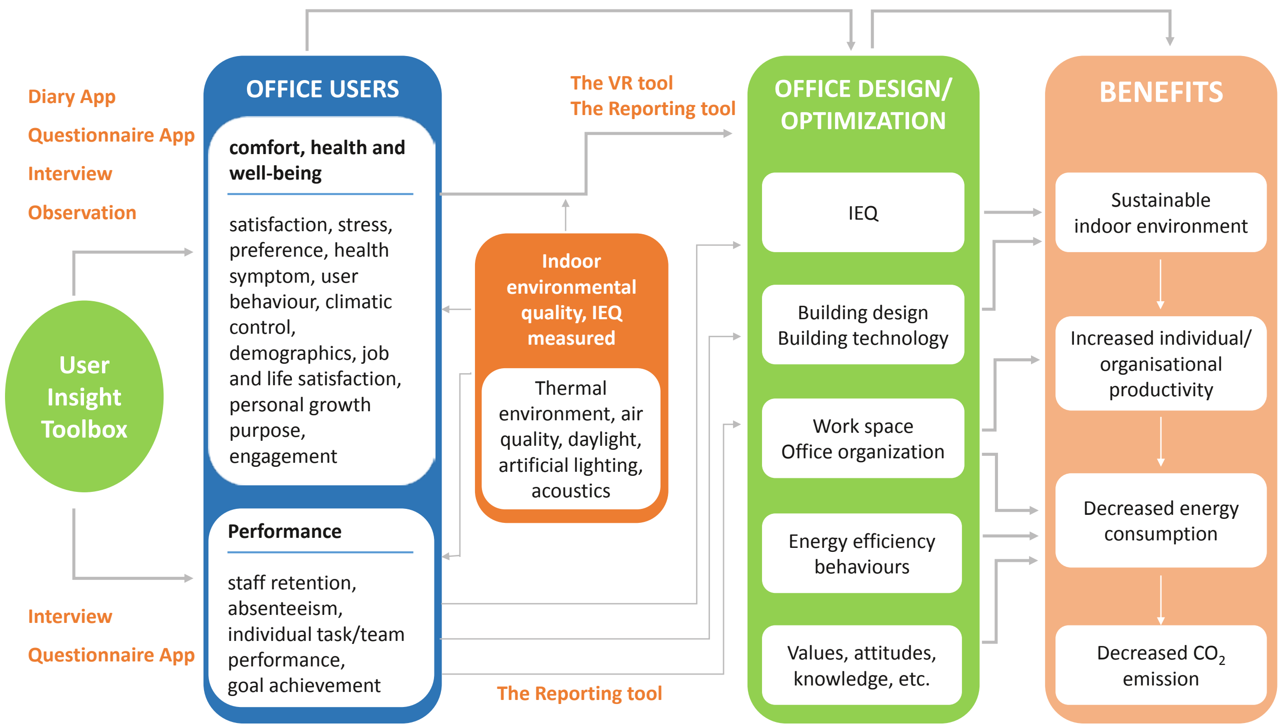

Figure 1. The approach of "SSO": A mixed-method approach of qualitative and quantitative measures.

and general well-being and their productivity. It aims to pioneer a diagnosis and strategy implementation for a new generation of user-oriented, lower carbon footprint, and resilient building design solutions to provide empirical evidence for future offices. One main focus is put on user experiences regarding the indoor environment, individual control and energy-related behaviour, such as thermal environment, air quality, lighting and daylight, and acoustics. Different web-based tools are used to collect the qualitative data from the user and building, and IEQ measurements collect the quantified data from the physical environment. Furthermore, the Reporting tool and the VR tool integrate both qualified and quantified results and provide recommendations for new office design or optimization.

Results

The Web-based SSO Questionnaire App is the insight tool to gain a holistic picture of the user's general experience in the office environment. The login interface is shown in **Figure 2**. This includes among others indoor climate, space design as well as the social work environment. Users' responses are collected on themes like e.g. of satisfaction, stress and preference. Furthermore, energy-related behaviour, perceived health, and self-reported work performance is also gathered. Individual context-factors and the character of work can also be observed with the tool. Finally, the insights in employees' general experience are gained alongside with additional insight in topics like mood, job- and life satisfaction.

The Web-based SSO Diary App is an innovative tool to track the daily changes of users' behaviour, perceived comfort, perceived health as well as occupancy and space use. The diary insight tool is used to identify the current experience, work pattern and user behaviour, more accurately related to the perceived and measured indoor environments. Furthermore, it can diagnose the factors of the stress and complaint from multi-perspectives such as physical indoor environment and job satisfaction. See **Figure 2**.

The Observation and focused group Interview are one-step of gaining in-depth user insights based on the web-based SSO Apps. An initial observation for each office is required to collect data regarding the physical environment. In the semi-structured interview, additional information is collected regarding the identified factors from the Questionnaire and Diary App studies and the observations.

The Reporting tool is adapted for the practitioners and users to help the building stakeholders including the planners (architects, designer, building engineers) to fully integrate the SSO insights into their own re-design processes. Therefore, a translation of these insights into a building information modelling (BIM) tool for architects/developers is vital for successful further entry of sustainable office design. The reporting tool shows the insight results at different levels, including the first level of fact and figure of user satisfaction, comfort, health and performance, the second level of diagnosis of IEQ

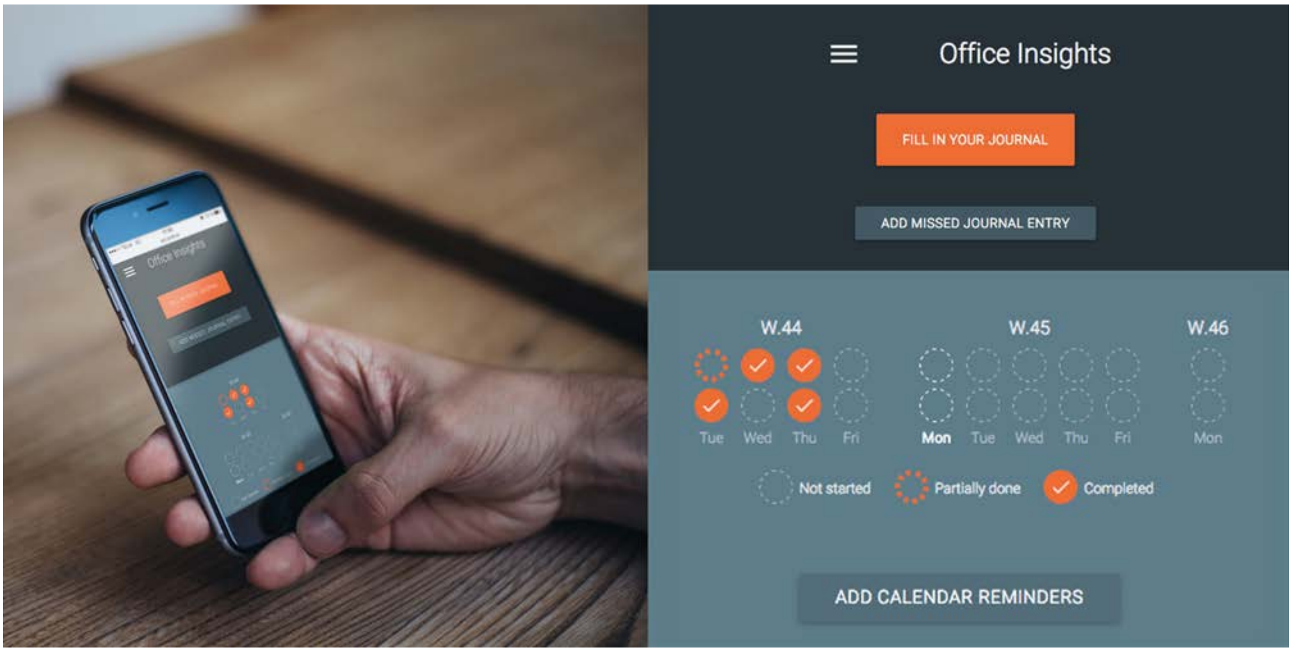

Figure 2. Web-based SSO User Insight Toolbox of Questionnaire and Diary Apps.

with perceived and measured results, and user behavioural and work pattern, and the third level consisting of recommendations for the (re-)building design of an innovative office environment. **Figure 3** shows the reported result of perceived stress in the indoor environment.

The Virtual Reality (VR) design tool is newly developed and based on the above described SSO User Insight Toolbox and is expected to further support interactive co-creation sessions with users and planners by creating a virtual office space based on the inside gained through the SSO mixed-method approach.

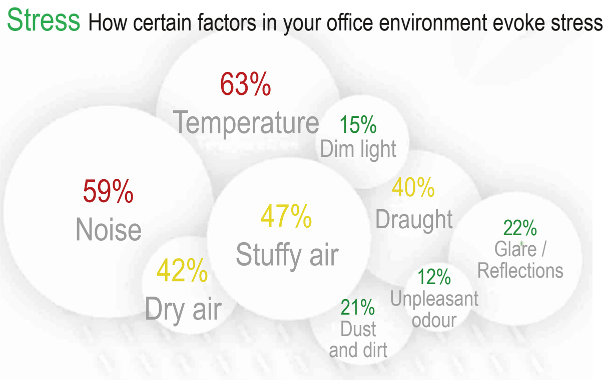

Figure 3. Illustration of the perceived stress for indoor environment reported by the Reporting Tool.

With the help of a created Virtual Reality, the occupants are enabled to make informed decisions and test and rate indoor environment according to their preferences.

Case example of User Insight Apps

A building has been extensively renovated in 2017 and was certified as *Miljöbyggnad* (the Swedish Environmental Building Certification) Silver, specifically addressing low energy consumption, comfortable indoor environment and creative workspaces. Energy-efficient features include sunshine shading, energy-efficient window, low U-value wall and mechanical VAV system. To examine the real performance of the building after the renovation, the SSO User Insight Apps were used to collect occupant responses of general experience indoors and also on a daily basis, for example filling in the Diary App in the morning and in afternoon during all workdays during the study period. **Figure 4** shows the user interface from the Questionnaire App for office indoor environment satisfaction of air quality, relative humidity and temperature. The distribution result of the responses on different perceived scale is also visualized in real-time from the SSO User Insight App's administrative side.

Figure 4. Illustration of user interface for voting office environment satisfaction on the Questionnaire App.

Case example of the VR tool

In the SSO approach, user feedback is key for each stage of the design process. During the co-creation sessions, employees will be wearing VR goggles while experiencing a fully immersive virtual environment. With a small hand controller, they can browse through each room in a first-person view. They are able to navigate through any selection or sequence of rooms, teleport, and even walk in the room virtually. The following case example shows the influence of daylight on users in the virtual office environment. By changing the location of the office and varying sky conditions and view directions, subjective perceptual ratings of daylight are collected and the satisfaction levels can be compared among different daylight conditions in different rooms. **Figure 5** shows the VR design result from daylight.

Discussion

Comparing to the existing post-occupancy evaluation methods, the SSO approach can in-depth observe user experience, preference and behaviour in the building by using the web-based Apps and implementing the surveys with different time resolution and location information. For example, the App can track users' experience for the indoor environment in different time-slot and different rooms during the day which gives the opportunity to identify the patterns of comfort, preference, behaviour and occupancy. Furthermore, an innovative added value is provided by deep insight studies that complement each level, building the scientific ground for an advanced and demand-oriented building design.

The SSO User Insight Apps and the VR tool provide an efficient platform to collect user feedback while using the buildings. This is of great value to various

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building stakeholders including the end-users and enables easy communication and interaction, based on validated findings. One of the challenges to achieving a user-centric building design is an efficient communication among project developer, designer, engineer, and building owner since we still lack a standardized way of sharing this type of information. Thus, the tools developed from the SSO project will be of help to integrate the needs from various stakeholders, and in particular emphasize user needs. In parallel, the tools deliver valuable occupant related assumptions for the building designer/architect to be able to better achieve a user-centric and sustainable design.

The mixed-method approach of the SSO User Insight Toolbox has the potential to be adapted to other types of commercial buildings beyond offices that contribute largely to the CO_2 eq contributions as e.g. hospitals where energy savings of up to 40% are estimated. To combine evidence on human factors from patients and staff with building service technologies, interior design and workflow optimization, can also in this area lay the ground for a new smart generation of low carbon hospitals unique insight for the adaptation of the SSO-method to the healthcare sector.

VR realisation: Tengbom

Figure 5. Illustration of user experience on daylight in the virtual office room by the VR design tool.

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Conclusion

The SSO approach and the SSO User Insight Toolbox provide in-depth information on occupant experiences indoors, and the way how users tend to use buildings. Therefore, office workers' comfort, health, well-being and productivity can be holistically addressed. Furthermore, the performance of indoor environmental quality can be evaluated by both qualified and quantified data collection methods which provide more empirical data to create a healthier and more productive indoor environment guided by a user-centric approach. It also enhances efficient communications among various building stakeholders and the interactions between the building and its users to achieve a productive office environment. With the reporting tool and the VR tool, the information collected by the web-based User Insight Apps from the user and building can be further transferred to BIM for future digitalization in the building design process. The tools are developed to be adapted to the standard industry practice in the future. ■

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Data-driven analysis of occupancy and lighting patterns in office building in Norway

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Energy usage in buildings

Both commercial and residential buildings are major energy users. Together, they are responsible for 36% of global final energy use and 40% of the CO_2 emission [1]. In buildings, the energy is used for a variety of purposes, including space heating/cooling, ventilation, lighting, cooking, working, entertainment etc. For better energy efficiency in buildings, it is important to understand the characteristics of energy use by different sub-sectors. This is typically conducted via building energy performance modelling.

However, the energy usage is affected by a large number of factors, including building envelope, outdoor temperature, occupant behaviour, etc. Among all them, although the impact of some factors could be expressed by physical models, it is impossible to model the impact of the other factors, like the occupant behaviour. However, it has been shown that occupant behaviour has significant affections on the energy consumption of buildings [2,3]. As a result, it is important to investigate the patterns of these factors, for which data-driven analysis is an efficient solution.

Smart building enables data-driven analysis

With the rapid development, smart building facilitates data-driven solutions to understand the characteristics of energy use patterns. Utilizing sensors and internet-of-things (IoT), a large number of factors affecting energy usage pattern could be monitored and investigated in smart buildings. As a result, huge amount of data is generated, which promotes data-driven analysis for better energy-efficient management of buildings and for better energy performance modelling.

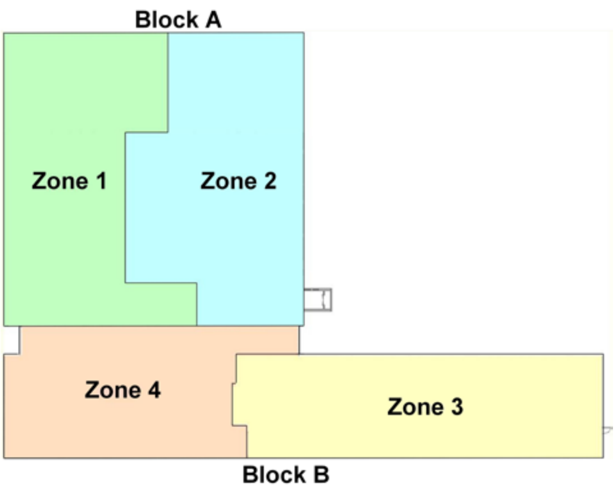
To demonstrate the advantages of data-driven analysis in building environment, this study analysed the occupancy and lighting patterns of an office building in Trondheim, Norway, based on yearly data collected from occupancy and lighting sensors. Through analysing these data, several interesting findings are summarized. On the one hand, these findings can be used to improve the control strategy of the building system for better energy efficiency. On the other, the occupancy and lighting level could be directly used as inputs of the building energy performance model for better accuracy.

Office building in Trondheim

Figure 1 (a) shows our study object with an example floor plan given in **Figure 1 (b)**. This is an office building with five floors. The building is composed of two blocks (Block A and B), which are further divided into different zones (Zones 1 to 4), where each zone shares same utility facilities. In this building, two monitoring platforms were developed. One with a large number of sensors at each office to monitor indoor environment. The second platform was installed to monitor the building services and supply system. The second platform may be treated as building energy monitoring platform.

In each office, occupancy and lighting sensors are installed to capture the characteristics of occupants and the lighting system. The sensors are configured to sense and upload data periodically with the time interval set to 15 minutes. This leads to 4 packets/hour, 96 packets/day, and 35 040 packets/year for each sensor.

(a) Appearance



(b) Floor plan

Figure 1. The smart building at Trondheim, Norway.

In this study, the yearly monitoring data from occupancy and lighting sensors installed in nine sample offices of three different zones were analysed to capture their characteristics and correlations. This helped us to analyse the impact of occupancy on energy usage, to understand the energy use pattern of lighting systems, and to improve the energy management strategies accordingly.

Data-driven analysis of the occupancy and lighting patterns

To conduct data-driven analysis, we considered three cases to analyze the occupancy and lighting patterns for selected sample offices.

- Case 1: investigated the daily occupancy and lighting patterns. For a specific day, the occupancy and lighting data from the same sample office were analysed to find the correlations and to identify potential energy-saving opportunities.
- Case 2: studied the stochastic pattern from Monday to Sunday. With yearly data collected from sample offices, the stochastic pattern was examined to understand the occupancy and lighting characteristics of each day.
- Case 3: compared the average patterns for weekdays between summer and winter. With monthly data collected from sample offices, the stochastic pattern was studied to compare the differences of occupancy and lighting patterns between summer and winter.

Daily occupancy and lighting patterns

The results of Case 1 are shown in **Figure 2**, illustrating the data collected by occupancy and lighting sensors for two selected days, namely July 25th and August 6th, 2018. Here, the occupancy data were represented by the solid blue line and the lighting data are plotted with the red dashed line. For both occupancy and lighting sensors, the value '1' indicated that a human was detected / the lights was on in the office; the value '0' indicated that nobody is in the office and the lights are off.

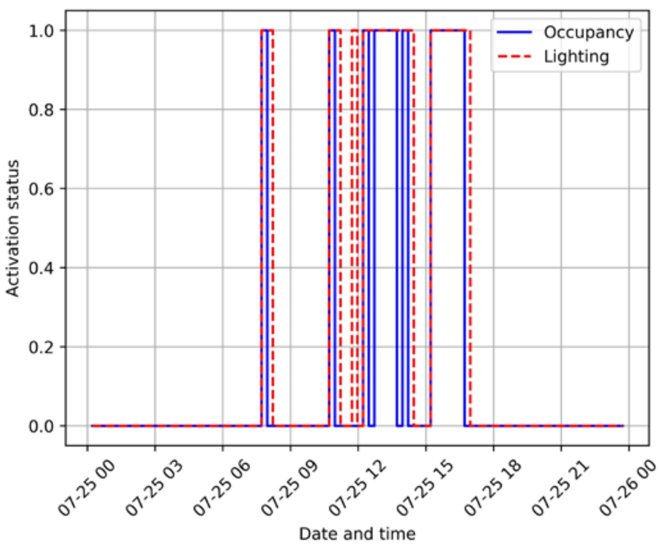
Comparing **Figure 2 (a)** and **(b)**, it was found that both the occupancy and lighting show significantly different patterns from one day to another, even for the same office. The random variations of occupancy and lighting were the main reasons why they cannot be modelled with physical models. Analysing **Figure 2 (a)** and **(b)** in detail, it was found that the occupancy and lighting were highly correlated. The presence of occupants simultaneously triggers the lights to turn on. It was even more interesting to find that the absence of occupants did not trigger the lights to turn off immediately, which was beyond our expectation. Actually, the lights turned off 15 minutes later than the occupant left the office. This unnecessary delay could be further shortened for energy-saving purpose. The third finding was that the lights occasionally turn on but the occupancy sensor did not detect any occupant. To find out what occurs during these periods, it is necessary to reduce the measuring period of the occupancy sensor for further investigation.

Comparison from Monday to Sunday

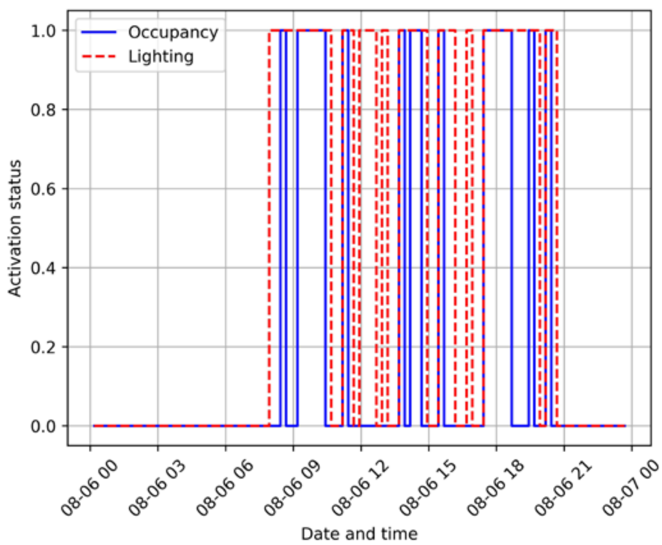
The results of Case 2 are given in **Figure 3**, showing the averaged value of each time interval from Monday to Sunday. After data cleaning process, the collected data from August 6th 2018 (Monday) to May 26th 2019 (Sunday) were used to capture the characteristics of occupancy and lighting from Monday to Sunday. Data from different zones were analyzed separately as shown in **Figure 3 (a)-(c)** for the occupancy and **Figure 3 (d)-(f)** for the lighting in Zones 1-3, respectively.

Looking into **Figure 3 (a)–(b)**, it is found that occupants could be detected stochastically from 6 a.m. on weekdays and the average occupancy rate gradually increases to the maximum value until 8 a.m. for all the three zones. After that, the occupancy rate fluctuated around the maximum value until 4 p.m. when occupants started to leave the offices. As for the decreasing of the occupancy rate, Monday and Friday are special weekdays showing different patterns than the others. On Monday, occupants tended to stay in the office longer and the decreasing speed was much slower than that of the other weekdays. Whereas, the occupants tended to leave the office early on Friday. This phenomenon implied higher energy demand on Monday and lower energy demand on Friday, which should be taken into consideration for energy management in this building. On Saturday and Sunday, the influence of the occupancy and the lighting might be neglected compared to weekdays.

Interestingly, it is found that the lighting rate was stochastically 10% higher than that of the occupancy by comparing the graphs for each zone, e.g. **Figure 3 (a)** and **(d)**. The main reasons were that the lights remain on for an additional time interval after occupants left the office and the light occasionally turned on for unknown reasons. Due to these reasons, we could conclude that there were huge potential for energy-savings in the lighting system. This cannot be neglected when improving the energy control strategies for this building.

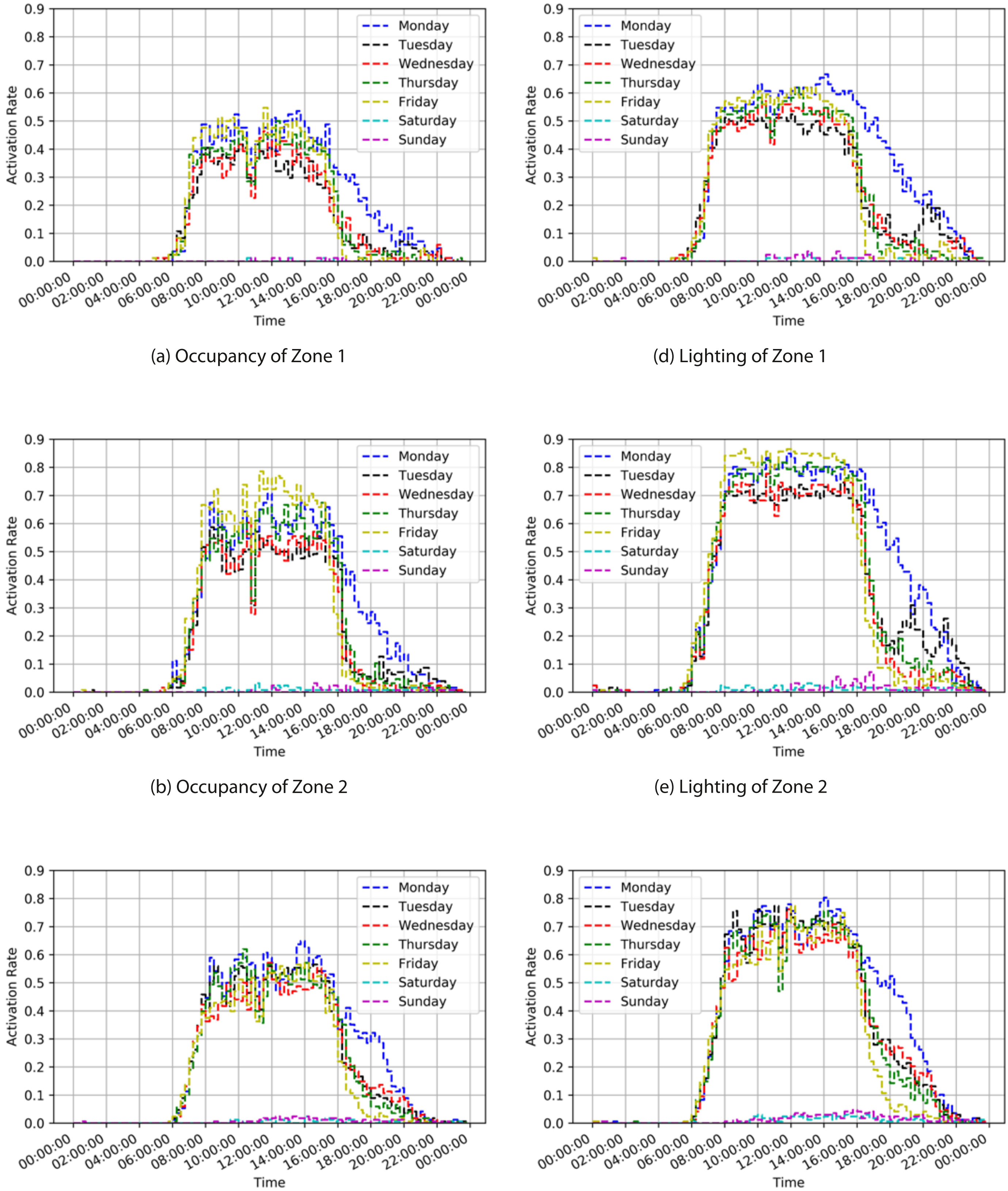


(a) Data for 25 July, 2018



(b) Data for 06 August, 2018

Figure 2. Daily occupancy and lighting patterns for an office in Zone 1.



(a) Occupancy of Zone 1

(d) Lighting of Zone 1

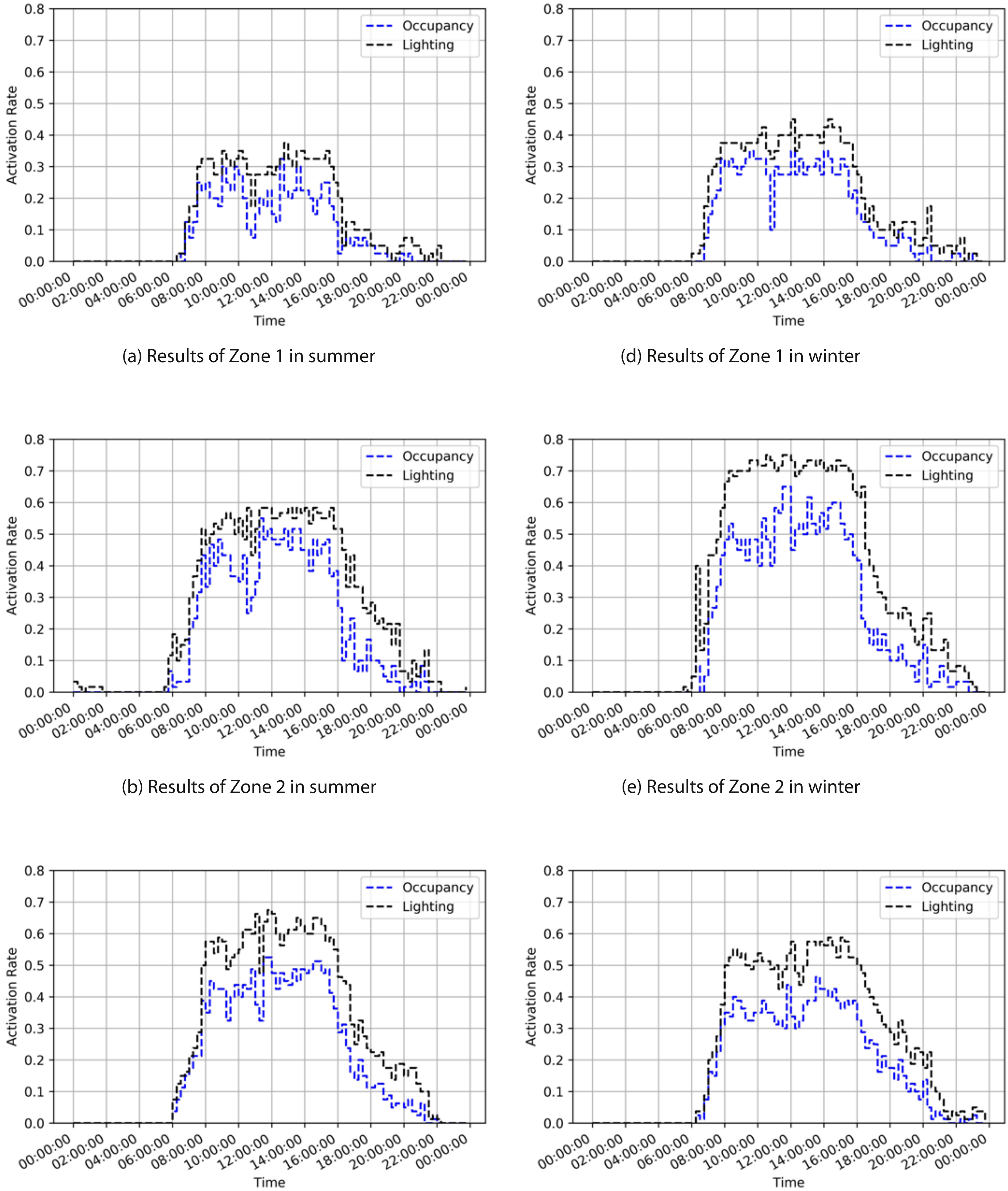
(b) Occupancy of Zone 2

(e) Lighting of Zone 2

(c) Occupancy of Zone 3

(f) Lighting of Zone 3

Figure 3. Comparison of patterns from Monday to Sunday..



(a) Results of Zone 1 in summer

(d) Results of Zone 1 in winter

(b) Results of Zone 2 in summer

(e) Results of Zone 2 in winter

(c) Results of Zone 3 in summer

(f) Results of Zone 3 in winter

Figure 4 . Comparison of patterns between summer and winter.

Comparison between summer and winter

The results of Case 3 are illustrated in **Figure 4** showing the averaged value of weekdays in summer and winter. The data used for summer were collected from August 6th to September 2nd and those for winter were collected from November 26th to December 23rd, 2018. Similar to Case 2, the averaged value of the occupancy and the lighting rate were compared between the winter and the summer for different zones.

By investigating the data from **Figure 4 (a)-(b)** in comparison with those from **Figure 4 (d)-(f)**, it is found that the occupancy and the lighting patterns were highly correlated both in the summer and the winter. Moreover, it is surprising that no obvious difference could be identified for the lighting patterns between the summer and the winter, especially when we take the daytime length into consideration. In Trondheim, Norway, the daytime was longer than 17 hours in July and less than 5 hours in December and the light intensity was much stronger in the summer than in the winter. A possible reason that there was no difference between the summer and the winter light patterns may be due to shading devices. The shading devices are covering the windows whenever the sun irradiation was above a certain level, which may not be so high. The shading devices induce the need for automatic turning on the light. For better energy performance of this building, the control strategy for the lighting system and the operation of the shading devices in the summer should be improved to fully utilize the natural light for illumination purpose and decrease the cooling need at the same time. Please note that the observed building has no cooling devices.

Conclusions and future work

With the office building at Norway, this study conducted data-driven analysis to identify the occupancy and lighting patterns as well as the correlations between them. Through analysing the data collected by occupancy and lighting sensors, several interesting conclusions were drawn:

i) The occupancy and lighting patterns were highly correlated with each other for our study case;
ii) The occupancy and lighting showed different patterns on Monday and Friday in comparison with Tuesday to Friday;
iii) Further opportunities still exist to improve the energy efficiency of the lighting system, such as reducing the delayed time interval after occupants leave the office and utilizing nature light for illumination purpose in summer without increasing the cooling needs.

The analytical results of occupancy and lighting could also be used to build accurate building energy performance models.

For the future, it is necessary to use data-driven analysis to identify the energy usage patterns of the other subsectors, such as ventilation and space heating system. It is also important to investigate further energy-saving opportunities for this office building to improve the energy management strategies accordingly, and to verify the analytical results with practical experiments. ■

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Comparison of laminar and mixing airflow pattern in operating rooms of a Norwegian hospital

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Abstract

At present, laminar airflow (LAF) systems and mixing ventilation (MV) systems are two commonly used ventilation solutions for operating rooms (ORs) to ensure the required indoor air quality. Recent studies have shown that there is little difference in the prevalence of surgical site infection (SSI) between LAF systems and MV systems. The objective of this study was to compare the performance of a LAF system and a MV system in ORs at St. Olavs hospital, Norway. In this study, all experimental measurements were conducted in real ORs at St. Olavs hospital in Trondheim, Norway. The results showed a wide range of air distribution patterns in the surgical microenvironment with both systems. Under operating conditions, the thermal plume from a lying patient and surgical staff may change the local airflow distribution in the surgical microenvironment in the OR with LAF. This indicates that MV may be a robust way to deliver airflow under disturbed conditions. This study suggests that the performance of LAF and MV needs to be evaluated regularly under real surgical procedures in Norwegian hospitals.

Introduction

Surgical site infection (SSI), which are the most common hospital-acquired infections, leads to a big burden for the patient and an increased cost for the society. Among other factors, the air quality of operating rooms (ORs), especially the surgical microenvironment (see **Figure 1**), plays an important role to prevent the development of surgical site infections (SSIs). One previous study shows that an improved indoor environment of a hospital building can reduce costs associated with airborne illnesses by 9% – 20% [1]. At present, both laminar airflow (LAF) systems and mixing ventilation (MV) systems are commonly used in ORs to ensure the required indoor air quality. **Figure 1** shows sketches of an operating theatre with a mixing system and a laminar airflow system.

Recent studies have shown that there is little difference in the prevalence of SSI between the designs of an LAF system and an MV system. The recently published WHO guideline suggests that LAF systems should not be used to reduce the risk of SSI for patients undergoing total arthroplasty surgery, but the conclusion is disputed and based on conditional recommendation, low to very low quality of evidence [3]. In fact, ORs contains numerous transient phenomena that may cause significant changes to the time resolved indoor air distribution patterns. Multiple studies have investigated how different factors affect the efficiency of the two different ventilation systems. **Table 1** summarizes these findings.

The reason for these controversial results and conflicting guidance is the lack of scientific understanding of the dynamic distribution in the surgical microenvironment (see **Figure 1**) in ORs under operating conditions. The objective of this study was to compare the performance of LAF systems and MV systems in terms of airflow distribution in the surgical microenvironment in ORs at St. Olavs hospital.

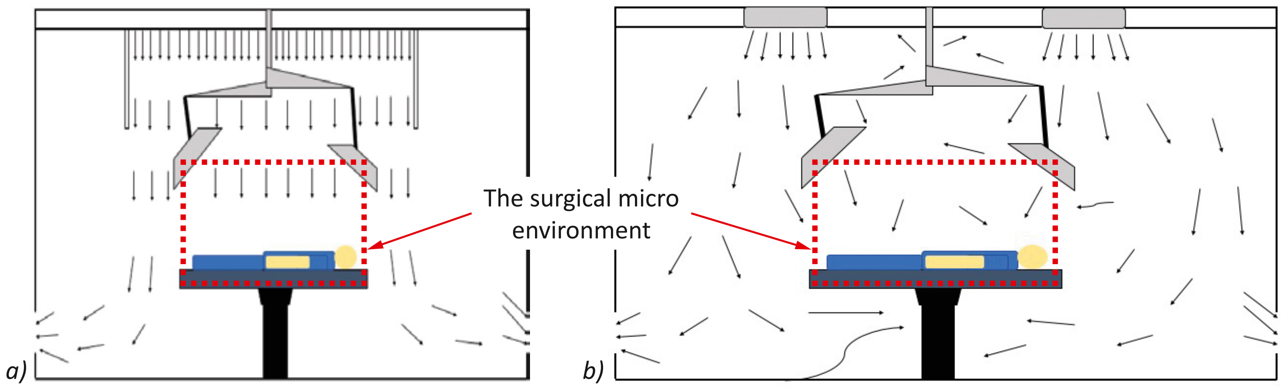


Figure 1. Principle of ventilation systems in operating rooms: a) a vertical laminar system, b) a mixing ventilation system. [2]

Table 1. *A comparison of LAF and MV. [4]*

Aspects	LAF	MV
Position of the operation table and the sterile operating team	Very important. Has specific borders between the sterile zone and the surroundings.	Not so important. Designed to provide equal conditions in the entire room.
Type and position of the lamps	Very important [5]. It was identified that the positioning of lamps is crucial to the airflow distribution near the patient.	Less important. Mixing airflow will dilute the contamination concentration in the whole operating room.
Operating staff clothing system	Very important. To great extent determines staff source strength.	Very important. To great extent determines staff source strength [6].

Methods

Experimental setup

In this study, all measurements were conducted in two ORs at St. Olavs hospital in Trondheim, Norway. The OR with an LAF has an area of 56 m² with 11 m² of laminar airflow zone, which is surrounded by 1.1 m long partial walls (see **Figure 2**). During the experimental measurements, the ventilation system was operated with full load, and the room temperature was commonly set to 22°C. During the experiments, the supply air temperature was 20 ±1°C. The designed supply air in the orthopedic OR with LAF was 10 580 m³/h: comprising 4 280 m³/h of outdoor air and 6 300 m³/h of recirculated air. A male thermal manikin was used to simulate a patient in an operating room. The detailed description of the thermal manikin can be found in Cao et al. (2018) [7].

The OR with an MV system was equipped with four ceiling-mounted diffusers. For the exhaust, there were two wall-mounted exhaust outlets and one near the ceiling. The OR with MV had an area of 59.7 m². The set-point temperature of the theatre was 22.0°C in all scenarios. The supply airflow rate was 3 700 m³/h, and the exhaust airflow was 3 600 m³/h. During measurement, an adjustable stand was used to carry the anemometers. Five anemometers were aligned on the stand with a separation of 10 cm. The stand was placed at three different positions above the operating table: pelvis, waist and chest. At each cross-section, measurements were performed at six heights: 5, 10, 15, 20, 25, and 30 cm above the surface of the location.

The heights of the measurement point were selected to present relative to the human body, which does not have equal heights at each part of the body surface.

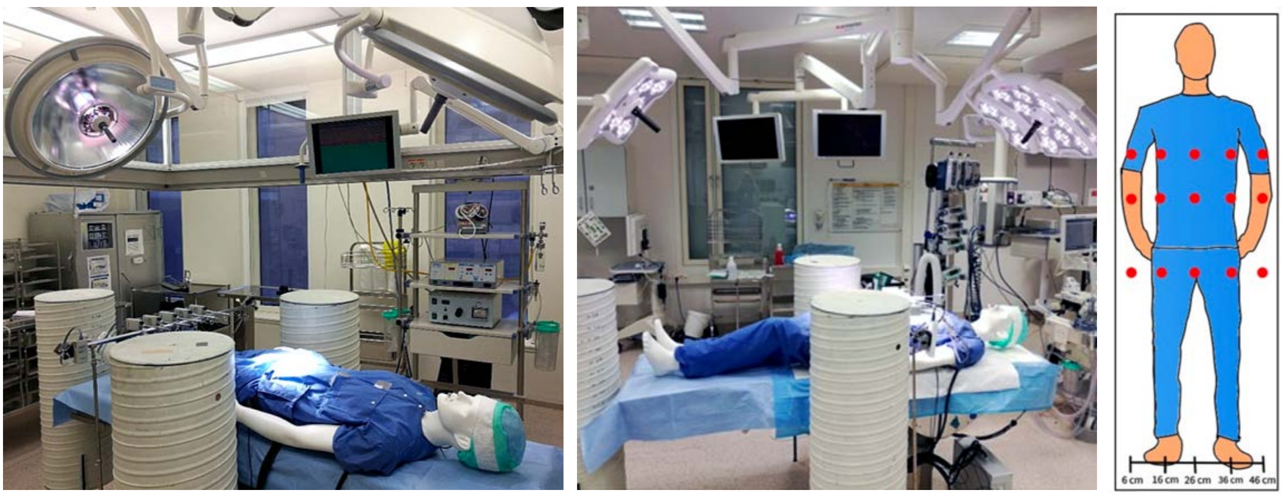
In this study, two scenarios (see **Table 2**) that include four different cases, were investigated. Scenario 1 (cases 1-2) measured the airflow distribution in these ORs with only an operating table as a reference case. Scenario 2 (cases 3-4) measured the airflow distribution in the ORs with a lying patient. Operating lamps were put away from the measurement zone.

Table 2. *Scenarios of the experimental measurements.*

Scenarios	Cases	Number of patients	Ventilation mode
S1	case 1	0	LAF
	case 2	0	MV
S2	case 3	1	LAF
	case 4	1	MV

Instruments

The AirDistSys 5000 system with five omnidirectional anemometers was used to measure the velocity and temperature of the airflow near the operating table. The velocity range of the SensoAnemo 5100 LSF omnidirectional anemometers is 0.05 – 5.00 m/s with an accuracy of ±0.02 m/s ±1.5% of readings. The recording time for each measurement row was set to 3 minutes.



a) b) c)

Figure 2. Experimental setup: a) photo of the operating room with a LAF; b) photo of the operating room with an MV; c) location of measurements. [4]

Results

Measured air velocity distribution over an empty operating table - Scenario S1

Figures 3 a-d show the velocity distribution above an empty operating table in ORs with LAF and MV. **Figures 3a** and **3b** show the velocity contours above the chest of the patient in ORs with LAF and MV, respectively. With the LAF system, the velocity above the chest position is 0.15 – 0.26 m/s, which is similar to the velocity distribution with the MV. The velocity contours in the LAF system show a downward airflow pattern, and the velocity contours in the OR with MV shows a side-blow (from left to right) airflow pattern. **Figures 3c** and **3d** show the velocity above the waist position in two ORs with the LAF and the MV, respectively. In the OR with LAF, the minimum value is 0.18 m/s, and the maximum is 0.32 m/s. The results show that the velocity distribution varies in these two systems. The airflow distribution in the OR with LAF resembles a stratified airflow with decreasing velocity when it approaches the operating table. The velocity distribution in the MV system is more similar at different positions.

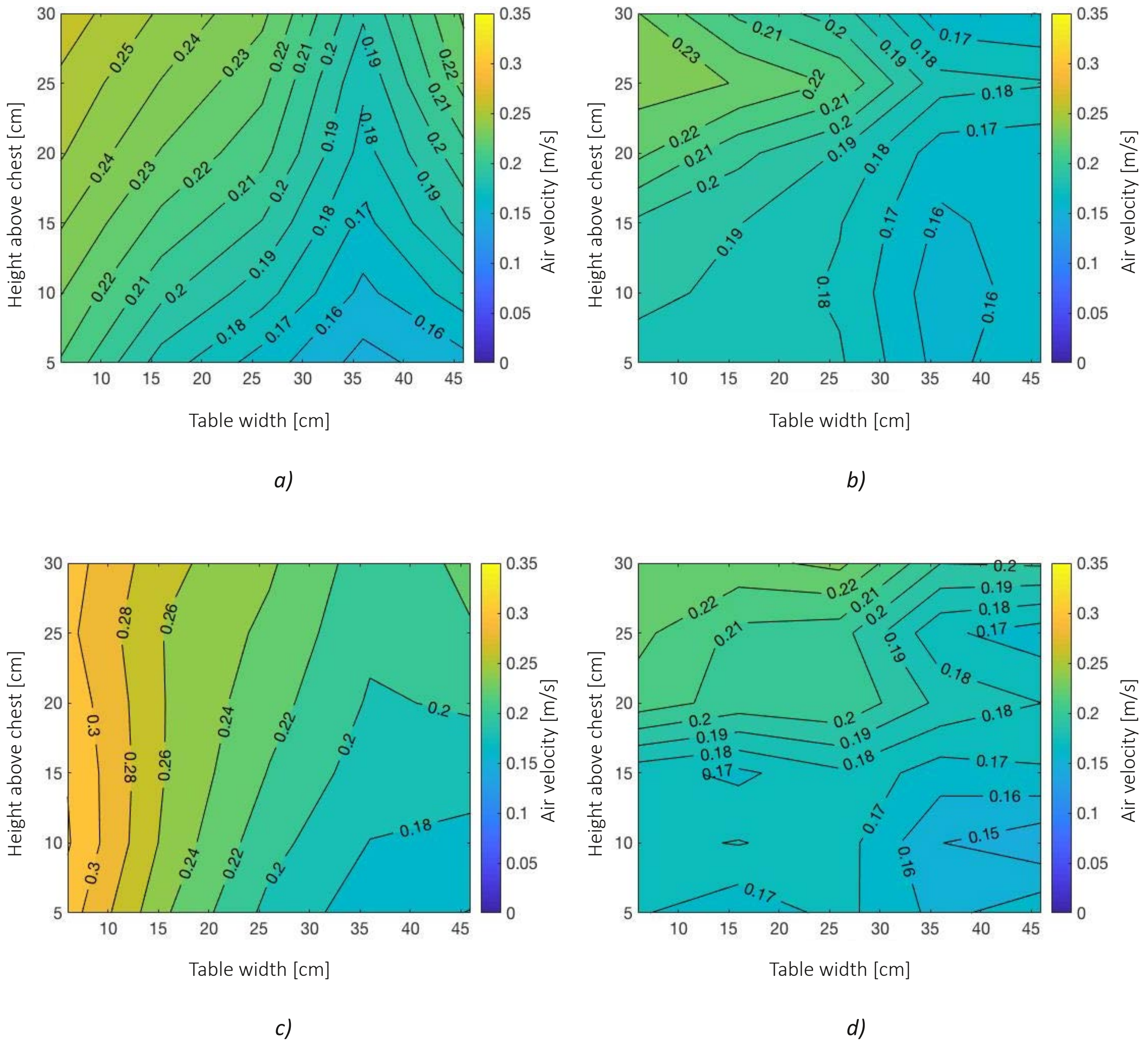


Figure 3. Measured velocity contours above operating table in ORs with LAF and MV – scenario S1 including case 1 and case 2: a) above the chest position with an LAF system; b) above the chest position with an MV system; c) above the waist position with an LAF system; d) above the waist position with an MV system.

Measured air velocity distribution over one patient - Scenario S2

Figures 4 a-d show the velocity distribution above a lying patient in ORs with LAF and MV. **Figure 4a** and **4b** show the velocity contours above the chest of the patient in ORs with LAF and MV, respectively. With the LAF system in **Figure 4a**, the velocity above the chest position was 0.12 – 0.24 m/s. The velocity near the patient was notably low (0.12 m/s) because of the thermal plume generated by the patient. **Figure 4b** shows a similar distribution with the MV system, which generated a slightly higher velocity zone (0.16 m/s) notably near the chest. **Figure 4c** shows the velocity distribution above the waist in the OR with LAF. It shows that the velocity near the patient became even lower above the waist, 0.08 m/s. The plume-like airflow distribution may be caused by the rising thermal plume from the patient. As **Figure 4d** shows, the velocity measured above the waist varies between 0.14 – 0.20 m/s, which is similar to that in **Figure 4b**, which was measured above the chest.

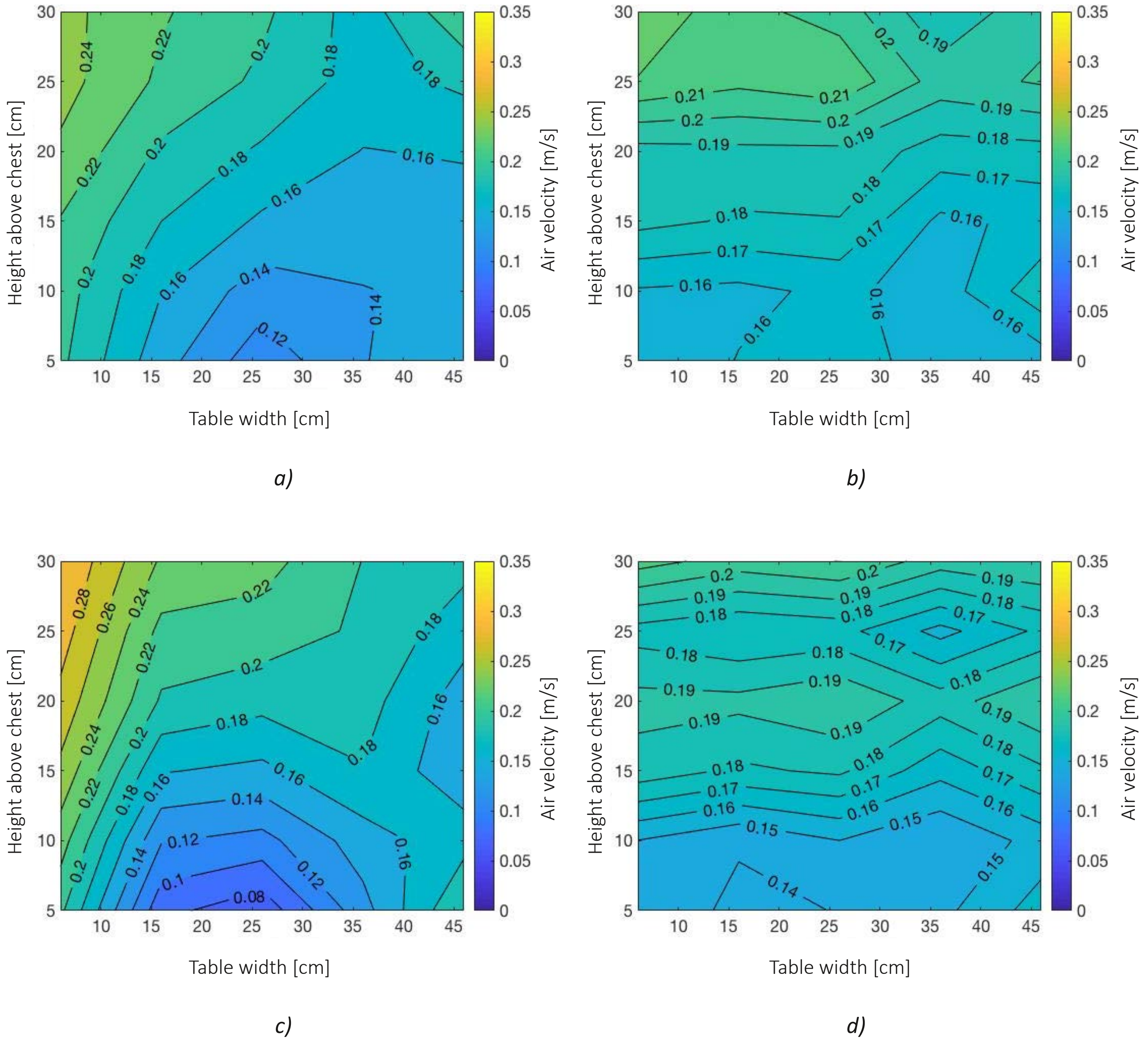


Figure 4. Velocity contours above a lying patient in ORs with LAF and MV – scenario S2 including cases 3 and 4: a) above the chest position with an LAF system; b) above the chest position with an MV system; c) above the waist position with an LAF system; d) above the waist position with an MV system.

Discussions

Effects of surgical lamps on airflow distribution

This study only presents the measurement results in ORs without the use of surgical lamps, which may affect the airflow pattern significantly. One earlier study reported the measured air velocity profiles formed under the surgical lights and without lights for different heights [7] (shown in **Figure 5**). The edges of lights are highlighted with dashed lines of the same matching color that is used for the velocity profiles. The turbulent airflow formed behind lights is illustrated by the gap formed between the yellow marked points representing velocities measured without lights and the points measured under different surgical lights – marked by blue, red and green colors. The mean value of the velocities measured under surgical lights were 0.07 m/s under light mo. 1 (blue), 0.07 m/s for light mo. 2 (red) and 0.06 m/s for light mo. 3 (green). The measured air velocity was over 0.25 m/s without the effect of surgical lamps.

Turbulence intensity in the surgical microenvironment with MV and LAF

In addition to airflow distribution, another previous study investigated the turbulence intensity in the surgical microenvironment with an MV and an LAF [4]. **Figure 6 a-b** show the measured air turbulence

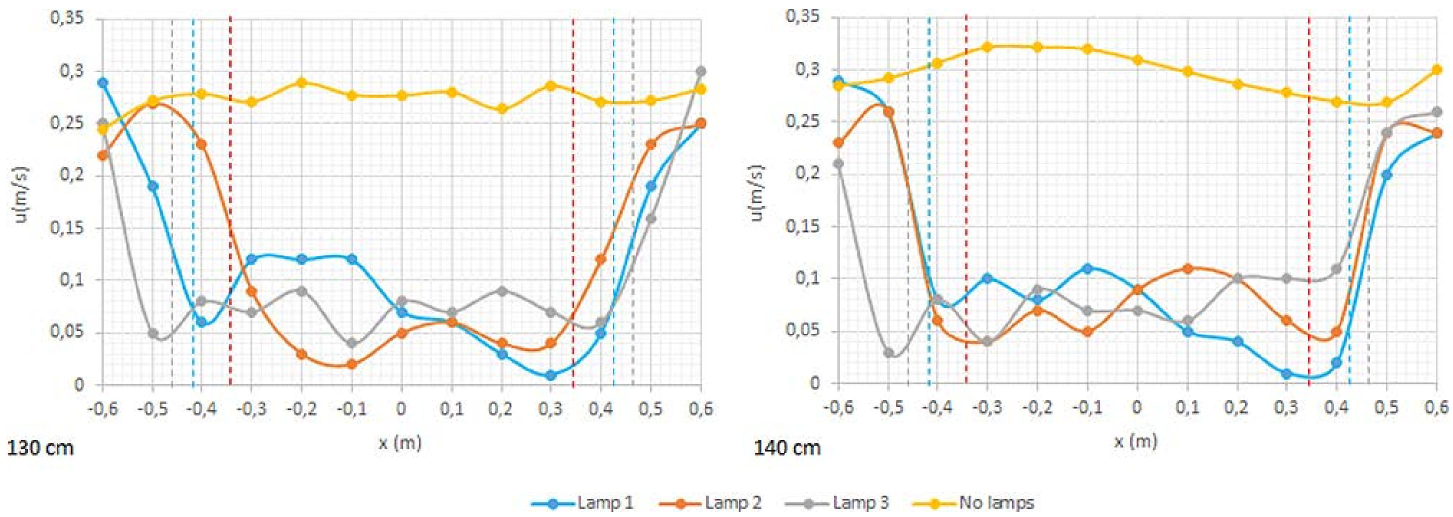


Figure 5. Measured mean velocity profiles with and without the effect of surgical lamps at different heights in ORs. [8]

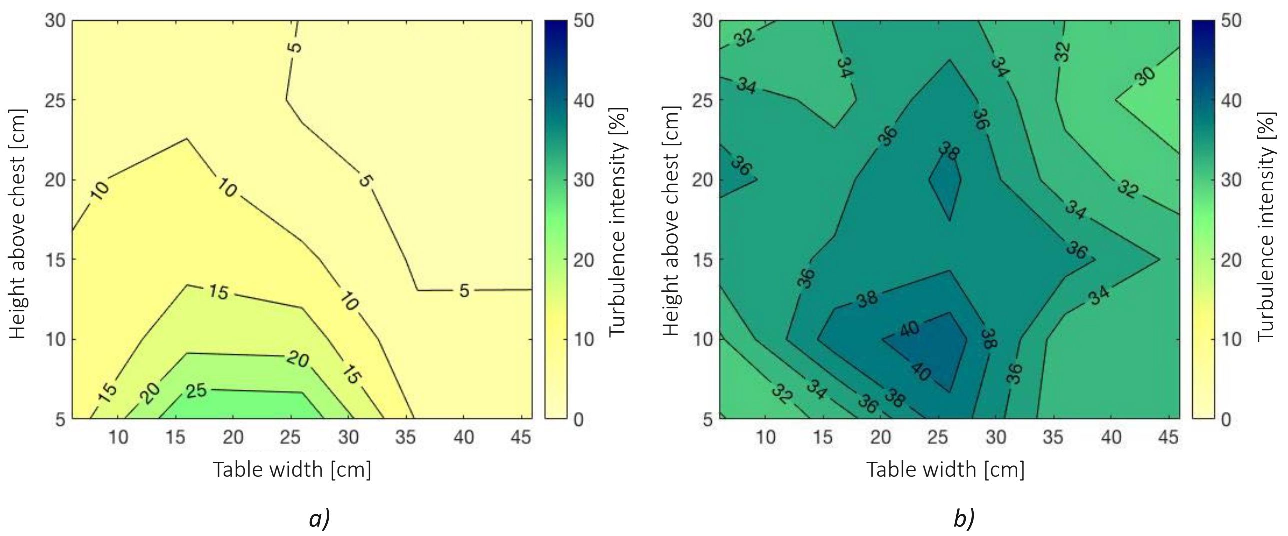


Figure 6. Air turbulence intensity contours above a lying patient surrounded by three surgical staff with the use of two surgical lamps: a) above the waist position with an LAF system; b) above the waist position with an MV system. [4]

intensity distributions above a lying patient surrounded by three surgical staff with the use of two surgical lamps. **Figure 6a** shows measured turbulence intensity in an OR with an LAF. The values range from 5 to 20% at 15 cm above the body surface. While the highest values, 20 to 25% are encountered within 10 cm from the body surface. **Figure 6b** shows the measured contours of air turbulence intensity in the operating room with MV, which varies from 30% to 40% above the waist of the simulated patient. These results indicate that air turbulence intensity level of supply airflow from LAF is much lower than from MV. This was caused by the mixing processed of supply air and ambient air in operating rooms in the surgical microenvironment.

Conclusion

The air distribution in operating rooms may significantly change under real operation conditions with various disturbance, including surgical facilities, internal heat sources, patients, surgical staff and various monitors. A common feature of the airflow pattern in ORs with either LAF or MV is that the velocity contours are drastically changed from each cross-section, which indicates the combined effect of surgical facilities and the thermal plume of the patient and surgical staff. However, the surgical lamps appear to have a greater effect on the velocity with an LAF system than with an MV system. This study provides evidence that the airflow velocity in the surgical microenvironment shows a wide range of patterns with an LAF system and an MV. The thermal plume from a lying patient may change the airflow distribution in the surgical microenvironment more in the OR with an LAF than with an MV system. This study suggests that the performance of LAF and MV need to be evaluated under different surgical procedures in Norwegian hospitals. Further studies are needed to clarify how these different airflow patterns will influence the development of SSIs. More experiments using tracer gas need to be performed to investigate the effect of MV and LAF on the heat and mass transfer in the surgical microenvironment. ■

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Diffuse ceiling ventilation

Diffuse ceiling ventilation is a novel ventilation concept where the fresh air is supplied into occupied zone through perforations or slots in the suspended ceiling panels. The large opening area of diffuse ceiling inlet enables the system to supply low temperature air without causing draught. This system has a great potential to make full use of the natural cooling resource of outdoor air, especially in cold and dry climates, such as in Central or Northern Europe. Even though the interest in applying diffuse ceiling ventilation has been growing rapidly, the technical experience in designing the system is still very limited. This article aims to provide an overview of this novel ventilation system in terms of ventilation principle and system characteristics, benefit and limitation, critical design parameters and their impact. Recommendations on designing a diffuse ceiling ventilation system are given at the end.

Keywords: Diffuse ceiling ventilation, Design guide, Thermal comfort, Energy saving

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Ventilation is one of the most important approaches to control the indoor environment. Besides the basic requirement on ensuring acceptable indoor air quality, more and more attention is paid to design of the ventilation systems to be more energy efficient and with a high level of thermal comfort. Diffuse ceiling ventilation is a very promising system, showing superior performance on both of these aspects (energy and thermal comfort) compared to conventional ventilation systems.

The principle of diffuse ceiling ventilation is to supply fresh air to the occupied zone from perforations or slots in the suspended ceiling panels, see **Figure 1** [1]. Due to the large opening area of the supply inlet, the air enters the occupied zone with very low velocity and no fixed direction, therefore given the name of 'diffuse'. Due to the low momentum supply, the system can directly supply air with very low temperature without causing draught. It has a great potential to make full use of the natural cooling resource of outdoor air, especially in cold and dry climates, such as in Central or Northern Europe.

Even though the interest in applying diffuse ceiling ventilation has been growing rapidly, the technical experience in designing the system is still very limited. This article aims to provide an overview of this novel ventilation system in terms of ventilation principle and system characteristics, benefit and limitation, critical design parameters and their impact.

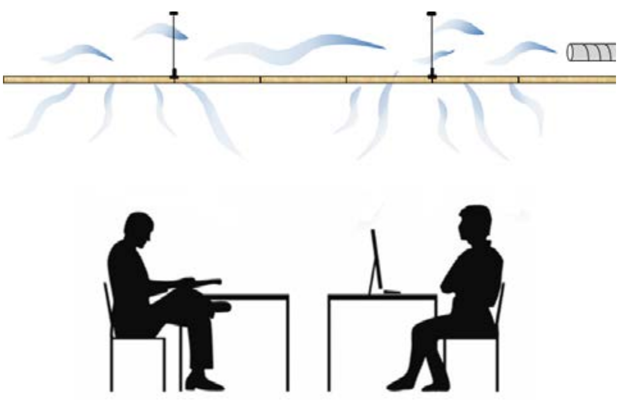

Figure 1. Illustration of the diffuse ceiling ventilation system. [1]

Air distribution principle and different types of diffuse ceiling inlet and their characteristics

Depending on air change rate the air distribution patterns in rooms with diffuse ceiling inlet can either be controlled by buoyancy force from heat sources or by momentum force from the air supply. To control the air distribution pattern by momentum force, a high air change rate is needed (50 – 100 h^{-1}), where a piston-flow takes place in the room. This air distribution principle is often applied in clean rooms, where very high ventilation effectiveness is expected. Low return openings are required in this case. When the air change rate is lower than 10 h^{-1}, air distribution will be controlled by buoyancy forces, and the ventilation effectiveness will be close to 1, which can be regarded as similar to a mixing flow. There is no strict requirement for the location of the return opening in this case.

In this article, special attention is paid to systems with a buoyancy-controlled air distribution pattern. This diffuse ceiling air distribution principle is suitable for buildings with a high cooling load and with high requirements to thermal comfort, like in offices or classrooms.

The supply inlet of diffuse ceiling ventilation can generally be divided into three types based on their airflow path through the ceiling [3]. As shown in **Figure 2**, Type A is made of ceiling panels which are impenetrable to air. The supply air enters the room through the slots between the panels and with relatively high velocity. These micro-jets below the slots generate high local entrainment and might cause draught problems at the occupant head level in the room with low floor to ceiling height. Type B is made of perforated ceiling panels, the air is supplied through both ceiling panels and the slots in between. Type C is made of porous materials instead of composed by ceiling panels. Compared with the first two types, this type of inlet has a relatively large pressure drop. **Figure 3** illustrates the pressure drop across different types of diffuse ceiling inlets, as a function of the airflow rate.

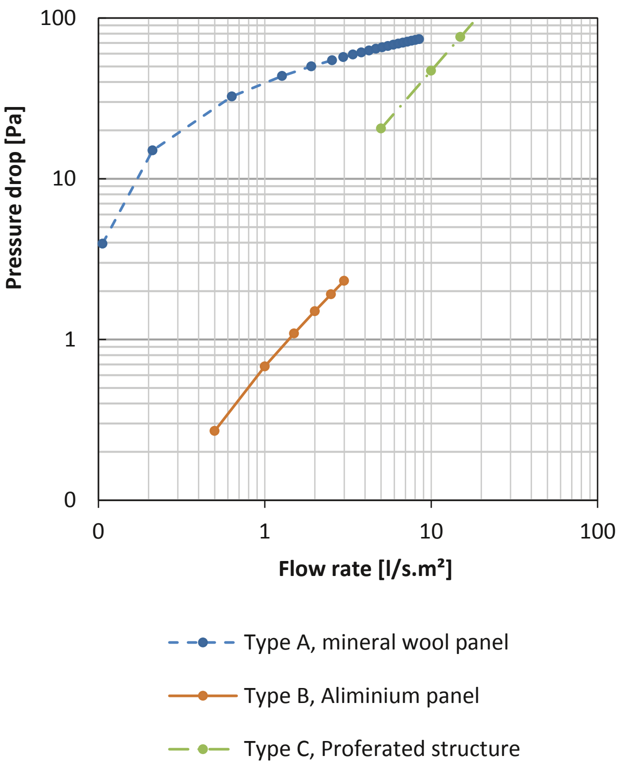

Figure 3. Pressure drop across the diffuse ceiling as function of airflow rate. [1]

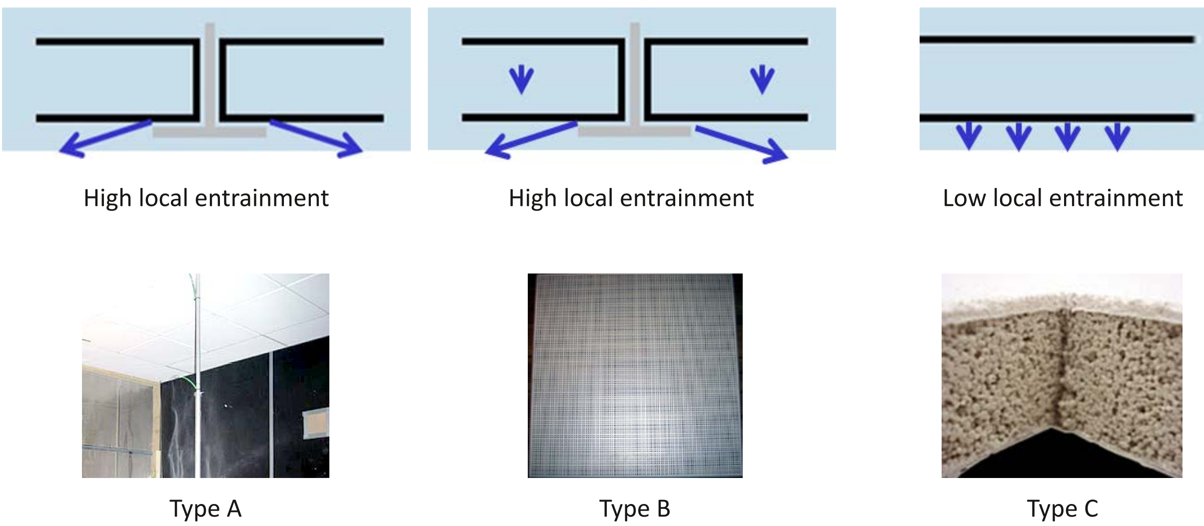

Figure 2. Three types of diffuse ceiling inlet based on air path and related product examples. [3]

Thermal comfort and indoor air quality

One of the most important features of diffuse ceiling ventilation is the high thermal comfort level. The low momentum supply enables the system to provide a draught free environment, even without preheating the cold outdoor air in the winter season. Experimental results indicate that no significant draught is experienced even with supply air temperatures down to 0°C [4]. In addition, diffuse ceiling ventilation creates a uniform temperature distribution in the occupied zone and a vertical temperature gradient less than 1 K/m can be expected under cooling conditions. A temperature stratification may occur if the system is used to warm up spaces. However, heating by ventilation is normally only required during unoccupied hours to preheat the space before occupants show up.

The airflow pattern in the room with diffuse ceiling ventilation is comparable to mixing ventilation, even though the driven force is different for these two ventilation principles. The ventilation effectiveness by diffuse ceiling ventilation is close to 1 (one meaning perfect mixing). The previous studies also indicate that no stagnant zones or shortcut of air circulation occurs in the room [5].

System capacity

In **Figure 4**, the system capacity of diffuse ceiling ventilation is compared with five other ventilation systems use a design chart method. The design chart can be expressed as a $q_0 - \Delta T_0$ chart, which encloses an area that supplies sufficient fresh air and ensures draught-free air movement in the occupied zone. This method makes it possible to compare different systems under the same boundary conditions (same room geometry and heat loads) [6]. The five other ventilation systems include the most commonly applied systems in office buildings or classrooms, they are mixing ventilation from a wall-mounted terminal, mixing ventilation from a ceiling-mounted diffuser, mixing ventilation from a ceiling-mounted diffuser with a swirling flow, displacement ventilation from a wall-mounted low-velocity diffuser and vertical ventilation from a ceiling-mounted textile inlet. It is shown in **Figure 4**, that the diffuse ceiling inlet is able to handle the highest heat load of 72 W/m² without compromising thermal comfort, while the cooling capacity of the other ventilation systems is between 36 ~ 53 W/m². The system does not have clear limits on the ventilation rate and temperature difference between supply and return. However, the limit of cooling capacity is caused by the air velocities created by convection flows generated by the heat

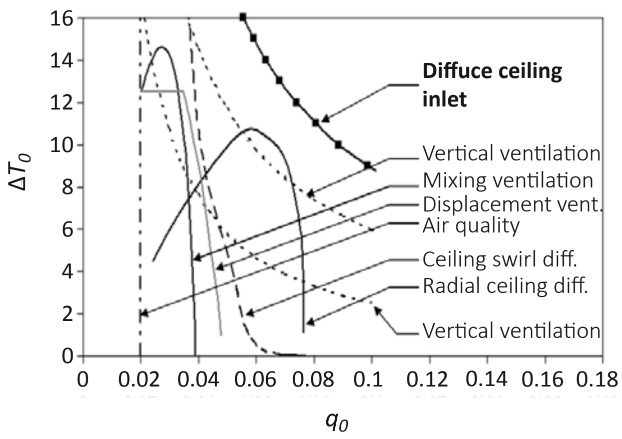

Figure 4. Design chart for diffuse ceiling inlet and five other air supply systems, q_0 is airflow rate [m³/s] and ΔT_0 is temperature difference between supply and exhaust air [°C]. **Note:** Design chart can only be applied under certain boundary conditions. [6]

sources in the room. The diffuse ceiling inlet could supply cold outdoor air (down to 0°C) to the room without creating draught. This means that preheating will often not be required and a high cooling capacity of the air can be maintained. Diffuse ceiling ventilation is especially preferable in the climate like Northern Europe or Central Europe, where a large natural cooling resource is available almost all year.

Energy saving potential

Diffuse ceiling ventilation presents large potentials for energy saving. First of all, the low-pressure drop of the system, associated with diffuse ceiling inlets and air distribution by a plenum (instead of ducts) as well as low ventilation rate demand (no preheating for supply air), allows a reduction in fan power and even allows the system to be driven by natural ventilation. Secondly, diffuse ceiling ventilation presents a high possibility to work together with night cooling. Because the ceiling slabs are typically exposed to the supply air pathways in the plenum, it increases the efficiency of the thermal storage and improves the pre-cooling effect.

Design parameters

It is important to emphasize that system capacity of diffuse ceiling ventilation is determined by several design parameters, such as diffuse ceiling type, opening area size and location, room geometry and plenum configuration, heat load magnitude and distribution, and that system capacity will be depended on the given conditions. The effects of different design parameters are discussed in the following.

Heat load magnitude and distribution

Buoyancy force is the dominant driven force for the air distribution in the room with diffuse ceiling ventilation. Therefore, heat sources play an important role and the magnitude and location of heat sources influence the system performance significantly. An evenly distributed heat load result in much lower air velocity and turbulence levels than a concentrated heat load at one end of the room, as shown in **Figure 5** [4][7][8]. At the same time, the system is more efficient in removing heat loads from sources with a high location, for example, light bulbs. Different heat load locations generate different flow patterns with resulting in variations in the maximum allowed heat load [1].

Room geometry and plenum design

Room geometry is another parameter that influences the performance of diffuse ceiling ventilation. In rooms with a high floor to ceiling height air velocity levels increase relatively and reduces the cooling capacity [4][7]. As mentioned earlier, the space above the suspended ceiling serves as a plenum to distribute air and the dimension of the plenum influence the supply airflow. If the maximum distance to the plenum inlet is larger than 10 m or if the plenum height is below 20 cm [1][9], it cannot be guaranteed that the supply air will be acceptably distributed in the room and which will cause draught issue in the occupied zone. In order to overcome this issue, it is recommended to install ducts in the plenum and help to uniform the air distribution throughout the ceiling area, if the plenum dimensions cannot be fulfilled [1].

Diffuse ceiling inlet properties

The inlet area of diffuse ceiling ventilation is rather flexible. The inlet can either occupy the whole ceiling area or a part of the ceiling. The relative location of heat sources and the diffuse ceiling opening areas plays an important role. The results from the previous studies indicate that air supply just above heat sources give the highest cooling capacity because the cold downward supply air meets the upward thermal plume and reaches a good mixing.

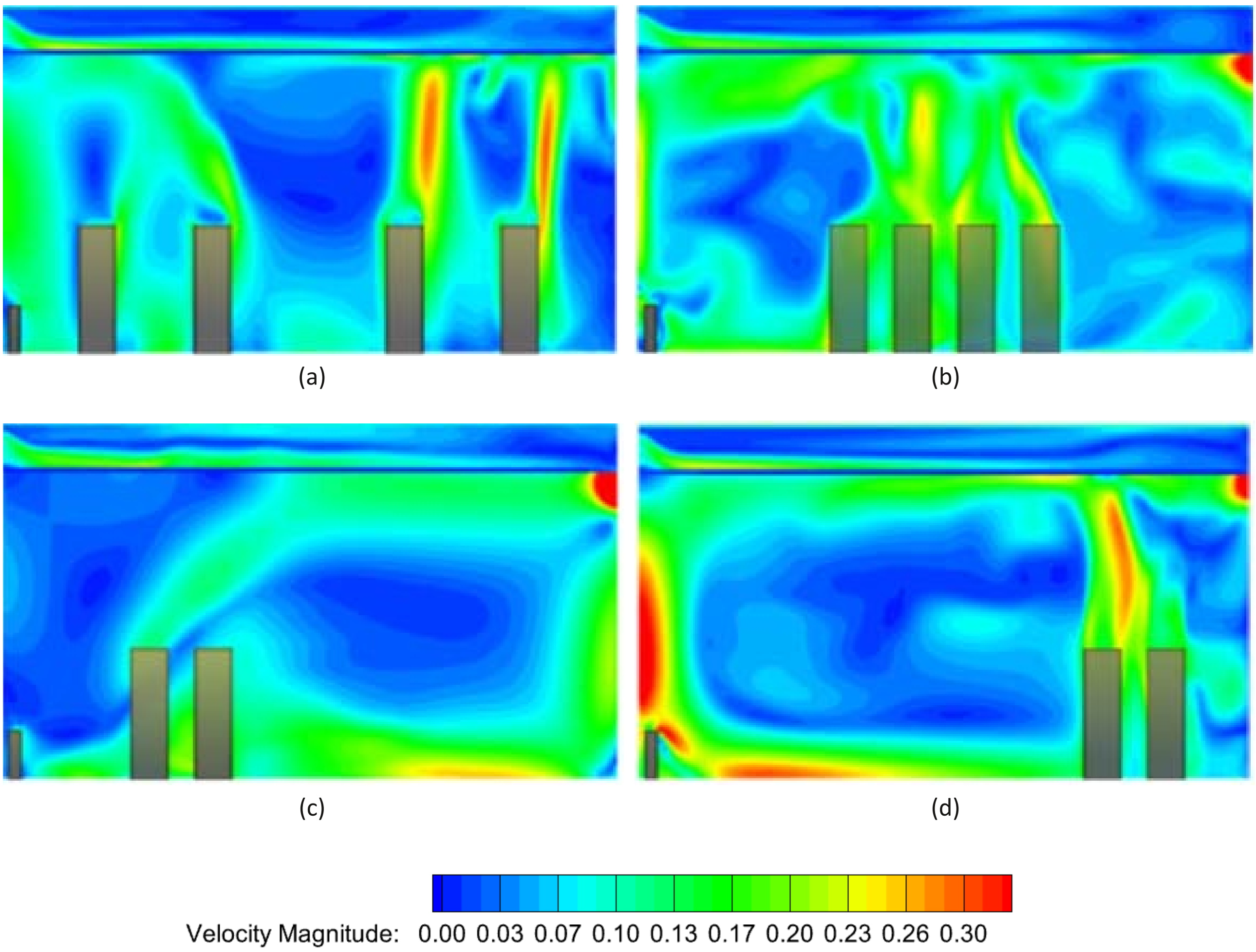

Figure 5. Velocity distribution with different heat load layouts (a) evenly distributed, (b) centered, (c) front side and (d) backside. [4]

Different from the other air distribution devices, diffuse ceiling inlet has a radiant cooling potential due to its large inlet area and low surface temperature. Instead of removing the entire heat load by convection, a part of the sensible heat load can be removed by radiation heat exchange. The surface temperature of the suspended ceiling is determined by the supply air temperature and the ceiling panel material. Ceiling panels with high thermal conductivity have a high radiant effect, for example, aluminium [9]. However, the surface temperature needs to be controlled carefully to be above the dew-point temperature of the space, in order to avoid condensation on the ceiling panels.

Condensation is a risk needs to be addressed when uses this ventilation system. Condensation on diffuse ceiling panels will affect visual perception, ventilation function and cause early failure of ceiling panels. The risk can be minimized by choosing proper diffuse ceiling panel and suspension profile. The ceiling panels with high absorptive capacity could serve as humidity buffers and give substantial stability to the indoor relative humidity, for example wood-wool cement panel with moisture capacity up to 3 kg/m². In addition, the suspension profile with high air tightness could avoid high-temperature, high-humidity room air travelling back to the plenum.

Conclusion

Recommendations on designing a diffuse ceiling ventilation system include:

- The diffuse ceiling ventilation system is primarily used for cooling. Stratification might occur when the system is used for heating. However, the system could be applied to preheat the space before occupants show up.
- The heat load distribution strongly affects the indoor thermal comfort. Avoid a concentrated location of the heat load at one side of the room.
- Avoid applying diffuse ceiling ventilation in rooms with large floor to ceiling heights. It is recommended to be applied in rooms with a room height less than 3 m and with a room width less than 10 m.
- If the plenum height is less than 20 cm or the room geometry cannot fulfil the recommendation above, it is recommended to install ducts in the plenum to uniform the air distribution.
- The diffuse ceiling inlet can either occupy the whole ceiling area or a part of the ceiling. It is more efficient to place inlet above the heat sources.
- Diffuse ceiling surface temperature needs to be carefully controlled to avoid condensation risk.

A diffuse ceiling ventilation design guide [1] has been published, which includes design procedure and case studies. Please refer to [10]. ■

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Research possibilities in the Norwegian ZEB Laboratory

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Introduction

This article presents the ZEB Laboratory and describes its research possibilities. ZEB Laboratory is an experimental facility located at the Norwegian University of Science and Technology (NTNU) campus in Trondheim, Norway. The laboratory will become four stories high, totally 1 800 m² floor area. The building is intended to be an office, an education, and a laboratory building. Regarding the environmental targets, the idea is that the building should achieve the Zero Emission Building (ZEB) level with compensation for emissions from construction, operation and production of building materials over 60 years. This means that the building must have a local renewable energy production that can compensate for greenhouse gas emissions from construction, operation and production of building materials over 60 years. This definition is called ZEB-COM. The definition was developed by the Research Centre on Zero Emission Buildings (www.zeb.no).

The vision is that the ZEB Laboratory will contribute to building knowledge on ZEB and be an arena for experimental investigation of the interaction between users and building and as a benchmark to test new technologies.

ZEB Laboratory is a joint effort between NTNU University and SINTEF Research organization with funding from the Norwegian Research Council.

Regarding the building's energy supply systems and building service systems, the building is equipped with flexible solutions so that the components can be operated in different ways, adjusted or maybe be changed. The ZEB laboratory has its own energy supply system and it is connected to the public electricity and the district heating grid of campus. An innovative ventilation system combining mechanical and natural ventilation are installed. For example, on the first floor, two identical rooms are equipped as test cells with dedicated HVAC systems. For the monitoring purpose, a larger number of sensors are installed, and they are connected to a flexible control and monitoring system. The vision for the control and monitoring system is to enable interoperability and to allow communication between different sensors and meters for energy, occupancy, and any other measurement.

This article describes the characteristics of the ZEB Laboratory and some of the possibilities for research.

ZEB laboratory description

The vision of the Norwegian ZEB Laboratory is to be an arena where new and innovative components and solutions are developed, investigated, tested, and demonstrated in mutual interaction with building occupants.

ZEB Laboratory shall be:

- a basis for knowledge development at an international level,
- a basis for international competitive industrial development,
- an example for new and retrofitted zero emission buildings,
- a research arena for the development of zero emission buildings,
- an arena for risk reduction before new zero-emission technologies are implemented by the building sector;
- a national and international resource for research and
- a tool for NTNU and SINTEF for institutionalizing the post ZEB Centre [1].

The ZEB Laboratory, shown in **Figure 1**, is a living office laboratory. It will be used for everyday office work, education and research at the same time. ZEB Laboratory will be a full-scale office building where building façades, components and technical systems can be modified and replaced. The building will form a *living laboratory*, i.e. a laboratory used by people as an ordinary office building or for educational purposes which becomes a source of continuous experimental data. The ZEB Laboratory focuses on making the initial building a relevant research case, both regarding occupant interaction and energy performance in a Nordic climate.

Figure 1. The ZEB Lab is a living office laboratory. (Source: LINK Arkitektur) (Preliminary drawing)

The number of building users will be about 80, besides comes about 40 places for students in the auditorium. The building is positioned at 63° 24′ north and 10° 24′ east.

The design process started in 2016, the construction work started May 7th, 2019. The taking-over commissioning process will start in August 2020 and is planned for 6 months. As for all buildings, the testing and commissioning phase is important, but especially for this building as it has an advanced solution for building energy management system and more comprehensive instrumentation than regular office buildings. The adaptability of the building/laboratory will make it possible to investigate different building configurations, technologies and usages.

Ambitions for the ZEB Laboratory

NTNU and SINTEF have a set of ambitions for the ZEB Laboratory [2]. These ambitions are related to building performance and the possibility to use and learn from the building use. The ambitions are, in prioritized order:

1. The building should be a role model project and achieve the ZEB-COM level (simulated over a 60-year perspective) [5]. See the introduction the Norwegian definition for the ZEB-COM.

2. The operation of the building and measurements must be made independently of each other, i.e. research data can be obtained without interfering with the operation of the building. On the other hand, the operation of the building should be capable of being put into "research mode" so that different models and algorithms of operation can be tested for all or part of the building.
3. Flexibility in use of energy and HVAC systems
4. Flexibility in use of working space
5. Advanced selection and use of materials and enabling rebuilding parts of the facades
6. Adaptation of the building to climate change [4]

Even though the building is ambitious regarding the energy and monitoring requirements, the building should be simple and practical in use with a good indoor environment.

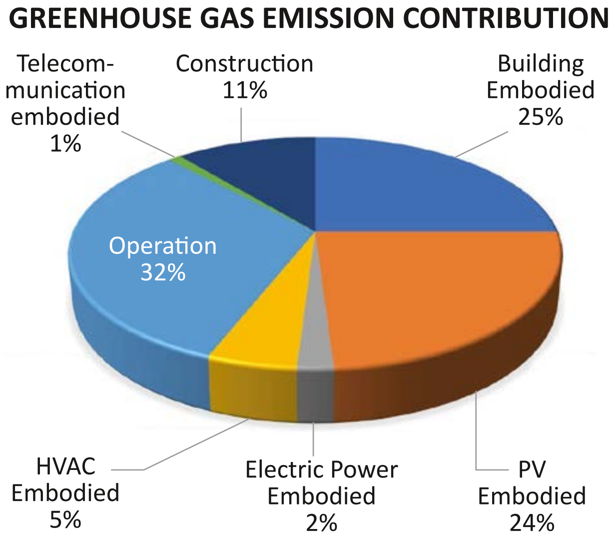

Figure 2. Evaluation (budget) of greenhouse gas emission of the ZEB Laboratory. (Source: LINK Arkitektur AS)

The procurement and development of the ZEB Laboratory

Design and solutions to best fulfil the high ambitions for the building were not determined in advance but developed as part of a design process. The building owners NTNU and SINTEF developed the new laboratory together with a selected group consisting of a leading contractor with a team of architects, consultants, subcontractors, and other professionals. Experienced researchers from the Norwegian research centres Zero Emission Buildings (ZEB) [1], Zero Emission Neighbourhoods (ZEN) [3] and Klima 2050 [4] were included with their specialist expertise.

Development of ZEB-COM

As mentioned in the Introduction the ZEB Centre definition of a zero-emission building [1] focuses on greenhouse gas emissions rather than on energy use. The emissions due to all the phases of construction and operation need to be compensated for by onsite production of renewable energy. [5].

Figure 2 shows the emission contribution of material, construction and operation of the ZEB Laboratory. The emission contribution is evaluated in kg $CO_{2eq}/m^2/y$ for a period of 60 years. For the evaluation of the emissions associated with the construction, the adopted value per square meter comes from a previous Norwegian project, Campus Evenstad [6].

Building Materials and Envelope Technologies

ZEB Lab is built with a loadbearing system made from wood. Glue laminated timber columns and cross-laminated timber elements in floors, elevator shafts and some elements for stiffening the building. Outer walls are wooden frames insulated with glass wool. This is to keep the embodied emissions low and to make the achievement of ZEB-COM possible. The building is cladded with PV-cells located on the roof, the whole southern façade and part of the other facades. Elsewhere burnt wooden panels are used to achieve a homogenous appearance and to keep embodied emissions low. The south façade of the first floor, including the twin rooms (see later), is made so that the façade or window elements can be replaced. New products, components and technologies can therefore be applied to investigate and optimize the building envelope and building performance. This allows investigations of the performance and the effect of products and envelope properties (e.g. insulation levels, façade configurations including solar shading and natural ventilation strategies) on energy use and user comfort.

A part of the air cavity below the PV panels is separated from the rest of the roof. This is to prepare for future experiments which can make use of heat below the PV panels in the heating of the building. Experiments can investigate the potential for improving the efficiency of PV panels, coefficient of performance for the heat pump for the building, and directly charging of the buildings thermal PCM storage. Temperature, relative humidity, and air pressure differences will also be measured behind the PV and wooden claddings and on the wind barrier on the vertical facades to characterize long term climate conditions for tapes and barriers.

Twin Rooms test facility

The identical twin rooms on the first floor (i.e. second level), see **Figure 3**, each represent a 66 m² office room with independent HVAC systems, a dedicated control room and a much larger number of sensors than the other spaces in the laboratory. All the parameters which influence the occupants' comfort are monitored (temperature, relative humidity, carbon dioxide, air change rates, illuminance, etc.). The data acquisition and control system is provided by Siemens. The twin rooms of the ZEB Laboratory allow both comparative and close to calorimetric studies. The material of façades and components can be replaced.

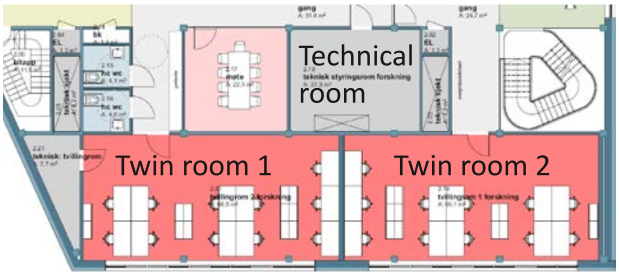

Figure 3. Plan for the twin rooms (areas in red, each room 66,5 m^2) on the first floor with separate technical rooms (27,3 m^2 area in grey) (Preliminary).

Building energy supply systems

The laboratory is equipped with building integrated photovoltaic (BIPV) panels and a heat pump that can make use of different heat sources (i.e. heat recovery from service and outdoor air). This makes it possible to investigate possible combinations between available local renewable energy production and the electricity grid that matches the zero emission building requirements. A phase change material (PCM) heat storage will be installed in the building and is used to recover thermal energy and as a thermal energy buffer to ensure more efficient use of the heat pump. The PCM heat storage infrastructure is made flexible, so different operation modes can be tested [7]. **Figure 4** illustrates the energy supply system of the ZEB Laboratory.

Grid integration makes it possible to implement experiments on the interface between buildings (ZEBs) and grids, especially smart power grids, but also district heating and cooling grids. This enables, for example, the study of the performance of optimal predictive control strategies, load shifting, and energy storage.

Building services - HVAC

The building is facilitated to explore different ventilation strategies together with monitoring of user satisfaction and energy use. The whole building is prepared for operation and research with natural ventilation, mechanical balanced ventilation or a combination of both (hybrid ventilation/mixed mode ventilation).

Natural ventilation

Some windows in the building can be opened manually while others are motorized. The windows' positions are designed to facilitate cross and buoyancy driven ventilation. The main staircase (**Figure 5**) is designed to work as an extract for both mechanical and natural ventilation air. Windows in the north façade close to the ridge of the roof are designed as an outlet for natural ventilation. The twin rooms can be ventilated naturally by windows and a separate exhaust duct.

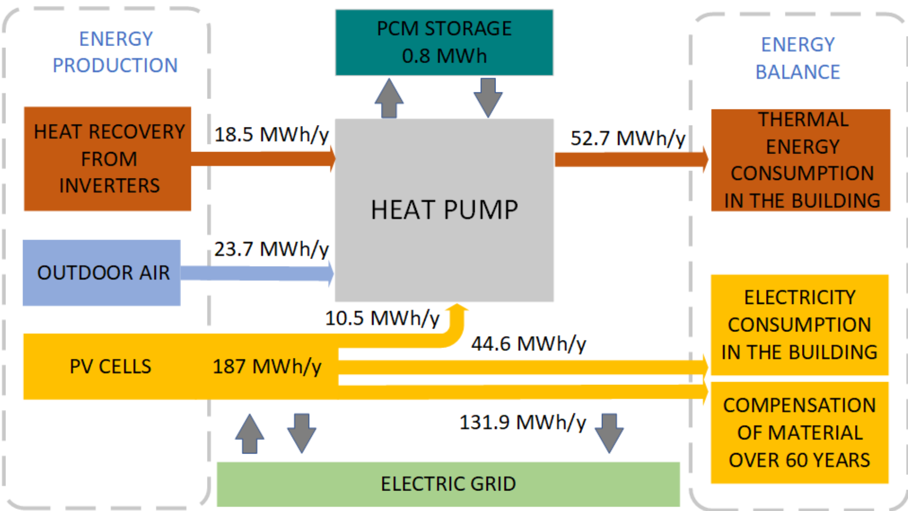

Figure 4. Schematic view of energy supply and use for the ZEB Laboratory (modified from [8] - preliminary).

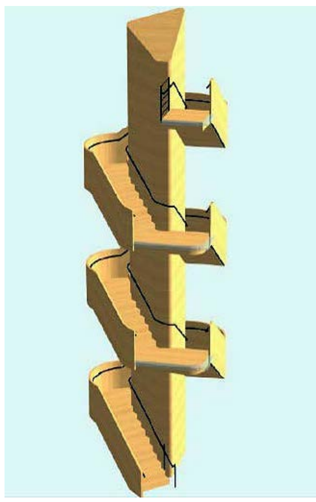

Figure 5. Preliminary design of the main staircase. (Source LINK Arkitektur)

Mechanical ventilation

The building is equipped with a central mechanical ventilation system. Different air distribution systems were designed for each of the four floors, but they all rely on the principle of displacement ventilation. At the ground floor air is supplied through inlet devices mounted in the floor, on the first floor through porous ceiling boards in the suspended ceiling, in the second floor through slots in the suspended ceiling and on the third floor through wall air terminals placed at floor level. The volume above the suspended ceiling is used as a plenary chamber. The air handling units are fitted with heat wheels. The heating is achieved using a heat pump with possibilities for PCM accumulation. No mechanical cooling system is installed. The twin rooms are specially equipped both with their technical rooms and independent HVAC systems, see **Figure 3**. The twin rooms can apply both heating and cooling via heating/cooling coils connected to the central hydronic system. Furthermore, the twin rooms are more densely equipped with sensors for monitoring and control systems for indoor climate, energy supply, ventilation strategies, cooling, space heating, lighting and window shading.

Indoor positioning system, monitoring and control

The building is designed with an indoor positioning system delivered by Siemens that detects the occupants' position. The solution establishes a communication network that interacts with the occupants' smartphone using wireless sensors. User position is calculated using triangulation algorithms and the results are sent in real-time to a cloud solution. Data concerning occupancy and position are valuable data for investigation and are stored to the SINTEF API server.

The same data can be used to provide services and information which the user can visualize using a browser or a mobile app. Using these apps users can, for example, locate colleagues, equipment, be guided to meeting rooms or exits. Each portable device can be selected to be visible or not, i.e. possible or impossible to locate. The system is designed to have enough flexibility to be modified to address changes both due to building management and experimental necessities.

The building, or part of it, can be "overtaken" by researchers and operated by a research simulation server. In this way, researchers can control the building by own algorithms.

Research possibilities

The focus on adaptability and flexibility in the construction of the ZEB Laboratory allows the investigation of large-scale building envelopes and the effect of the envelope materials and properties on the whole energy balance of a building and on the user comfort. As described, the building integrates several systems such as heat storage in PCM and BIPV on the roof. This, together with the modularity of these systems, allows the ZEB Laboratory to be a valid benchmark to investigate the optimal combination of building characteristics with local renewable energy production. The interaction between a building with this kind of equipment and the grids, especially smart power grids and district heating grids is another area of interest with the possibility to conduct accurate measurements at the building-grid interface.

Measurement and control of energy supply, air supply, lighting, windows shading, occupancy etc. are performed via a dedicated Building Control Systems. The ZEB Laboratory gives the possibility to test for example:

- Integration of building energy simulation tools for studies of new methods for the user-centred design of buildings and building technologies.
- Test of wireless technologies for analysis of occupant behaviour.
- Investigation of building operation considering active user interactions with building energy management systems
- Impact of lighting systems on user health and well-being.
- User perception of different natural and mechanical, natural and mixed-mode ventilation strategies
- Optimal and advanced use of natural and mechanical ventilation against climate and user data
- Connection between external parameters (smart grid, weather data, and forecast) and the thermal energy storage efficiency
- Use of AI to interpret connections between indoor positioning data and indoor climate data
- Peak load and load shifting strategies for building design

The experience that NTNU/SINTEF accumulated with living laboratories has clearly shown that the research opportunities for a laboratory of this kind go farther than what the laboratory is specifically designed for, ranging from deeper modifications of systems and structures to the use of the laboratory as a controlled environment.

Conclusions

The ZEB Laboratory is the result of the cooperation between NTNU/SINTEF, the contractor, architects, consultants, and subcontractors. The building is an example of a zero-emission building constructed following a ZEB-COM ambition, and an arena for the evaluation of large-scale material, systems and solutions. Testing large-scale technologies on this building will be a substantial scientific contribution and it contributes to reducing the entrepreneurial risk for those companies which are willing to invest in new technologies.

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The large amount of data collected will be an important contribution to specific studies on human-building interaction, on the impact this has on the energy balance and the interface between the building as a system and the smart power grids (electric, district heating, etc.).

The research opportunities are increased by the presence of the twin room, which allows an easy replacement of façade components and allows researchers to run specific comparative tests in a controlled environment. ■

Acknowledgements

The authors want to thank the Research Council of Norway and the extended ZEB Laboratory project team for contributions, help and support.

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Sino-Nordic Research Center for Indoor Environment and Energy

Sino-Nordic Research Center for Indoor Environment and Energy (SNRCIEE) was launched by Xi'an University of Architecture and Technology (XAUAT), Technical University of Denmark (DTU), Aalto University (Aalto), Umeå University (UMU) and The Arctic University of Norway (UiT).

XAUAT has long tradition and high reputation in international HVAC field especially for ventilation and air distribution research. Under policy supports from national and local governments, SNRCIEE was launched to push forward international research collaborations.

DTU, Aalto, UMU and UiT are all top Nordic Universities, especially in HVAC and indoor environment fields. The four Nordic Universities have long history research collaborations with XAUAT. Apart from these four Universities, professors from other Nordic Universities including Royal Institute of Technology (KTH), Luleå University of Technology, Dalarna University, Aalborg University, Norwegian University of Science and Technology are center members. Here we'd like to emphasize the research collaborations between XAUAT and KTH can be retrospect to 1980s.

The center will focus on strengthening internationalization and research collaborations between China and Nordic countries, developing internationally high-level experimental platform, establishing international level research team, serving research and engineering needs for both China and Nordic countries. ■

Directors of Sino-Nordic Research Center for Indoor Environment and Energy (SNRCIEE):

Angui Li
Director of Center,
Xi'an University,
China

Arsen Melikov
Vice-Director
Denmark

Risto Kosonen
Vice-Director
Finland

Thomas Olofsson
Vice-Director
Sweden

Bjørn Sørensen
Vice-Director
Norway

Bin Yang
Vice-Director
China

Elphi Nellissen receives REHVA professional award at TVVL's annual event

Every year, REHVA dedicates special awards to one person for their strong contribution and dedication to the HVAC sector. The REHVA professional award in Education was granted to **Elphi Nelissen**, a professor at Eindhoven University of Technology. TVVL and REHVA are extremely proud of Elphi being granted this award.

Elphi Nelissen is a Full Professor and Chair of Building Sustainability at Eindhoven University of Technology (TU/e). She is specialised in renewable energy and the built environment, circular building economy, sustainable building, building services, building physics, building acoustics and girls and technology. She also led the development of a true smart district in the Brainport region, to be established in 2021. This initiative gives the university the opportunity to research, to develop and to experiment new building methods. Unfortunately, Elphi Nelissen was unable to attend The REHVA Annual Meeting and CLIMA 2019, which was held in Bucharest, Therefore, the official hand over of the award took place during TVVL's annual event 'TVVL Techniekdag' on November 13th at Putten, The Netherlands.

During the TVVL Techniekdag on Wednesday, November 13, 2019 in the Vanenburg in Putten, the Expert Groups and communities examine parallel ongoing projects through parallel sessions and make an in-depth study of results, techniques and innovations. With over 200 visitors last year, the TVVL Techniekdag proved once again to be successful in this connection of disciplines and knowledge sharing within the association. ■

REHVA Brussels Summit Highlights

On Monday the 4th of November, and Tuesday 5th of November, REHVA hosted and organised its third edition of the REHVA Brussels Summit 2019. First day being dedicated to REHVA committee members and stakeholders, and the second day being a conference. In the second edition of the conference, REHVA had 13 different speakers from various backgrounds of the HVAC sector.

REHVA Committee Meetings

The first day of the Brussels summit was dedicated for REHVA committee members to come together, and to discuss their activities and next steps. The committees involved in the meetings were the REHVA Cooperation group (COP), and The REHVA standing committees on Education and training (EC), Publishing and Marketing (PMC), Supporters (SC), and Technology and Research (TRC).

The meetings discussed a range of decisions, future activities, and ideas to increase the visibility of REHVA. During the Publishing and Marketing Committee meeting, ideas were delivered to improve the usage of the REHVA Dictionary app, as well as visualising our new website better. A new REHVA guidebook was also announced and launched at the Summit: REHVA Guidebook 30. Hygiene in Potable Water Installations.

CENCE Stakeholders meeting

CEN-CE team organized under the leadership of REHVA the 2nd CEN-CE Stakeholders' Workshop on 4 November (10:00–12:30) during REHVA Brussels Summit (4–5 November) for enquiring, engaging and exploring synergies with key stakeholders across Europe about the CEN-CE training and certification scheme for identifying the best solution for the buildings sector in terms of EU-wide roll out strategy.

It was an interactive event with live polling sessions and open discussions. The participants received in advance preparatory material for facilitating a more effective workshop during which the focus was predominantly on having an inclusive, constructive and fruitful discussion.

Over 50 participants covering two main target groups i.e. building professionals (mostly national level REHVA experts) and EU level stakeholders (Brussels based organisations) joined the workshop for initiating together the exploration process of possible strategic partnerships [1] with the ultimate goal of maximising market usefulness and ensuring an effective and tailored EU-wide market uptake of the CEN-CE training and certification scheme [2].

CENCE STAKEHOLDERS MEETING.

This 2nd interactive working session opened the synergies exploration dialogues in terms of reaping full benefits of CEN-CE scheme in cooperation with other EU level activities on construction skills and national level training organisations (e.g. REHVA Member Associations).

Lastly, CEN-CE team, launched the CEN-CE pilot training and certification organised on the protected area of CEN-CE website. ■

[1] https://www.cen-ce.eu/for-strategic-partners.html
[2] https://www.cen-ce.eu/cen-ce-project/cen-ce-in-a-nutshell.html

REHVA Conference on Delivering healthy, zero-carbon buildings by 2050?

On the Second day of the REHVA Brussels Summit, the REHVA conference was held on the 11th November 2019. The conference was split into three sessions with over 12 speakers bringing their contribution forward to the summit:

SESSION 1 – EU policies for healthy, zero-carbon and sustainable buildings by 2050

A presentation on Energy and buildings on the policy agenda for the new Commission was led by **Paula Ray Garcia**, who focussed on the policy framework for 2030. The framework dived into the vision for 2050 which is achieving net-zep GHG emissions, including highly efficient and decarbonized EU building stocks.

This presentation was then followed by **Stijn Verbeke**, who delivered a presentation on *Second Technical Study to support the establishment of a common European scheme for rating the Smart Readiness of buildings* where the revised EPBD. The indicator is intended to raise awareness about the benefits of smart technologies and ICT in buildings (from an energy perspective in particular) and to motivate consumers to accelerate investments in smart building technologies and support the uptake of technology innovation in the building sector.

The session then ended with an ALDREN presentation on TAIL-a pragmatic IEQ indicator for building certification (ALDREN project) by **Pawel Wargocki**, DTU. TAIL, which stands for the four components "Thermal environment, Acoustic environment, Indoor air quality, Light – Luminous (visual) environment". The index is used to document IEQ in a building before and after renovation and provides information on the quality of each of the components. GREEN standing for high quality, YELLOW for medium quality, ORANGE for moderate quality and RED representing low quality.

SESSION 2 – Building performance certification to bridge the finance gap

This session brought engineers, building certification organisation and investors to share perspectives, followed by a moderated panel discussion.

Frank Hovorka led this session with a key question "What triggers investors to invest in sustainable construction and energy retrofit projects?" which was then followed by Johann ZIRNGIBL, coordinator of ALDREN project who described the ALDREN certification in his presentation, highlighting their European Voluntary Certification Scheme.

Stefan Plesser from synavision, GmbH and also QUEST/QUANTUM coordinator presented a brand-new project- QUEST in his presentation "Quality Management to De-Risk Real Estate Investments" where he tackled the issue that "technical risks turn into financial risks for real estate investments" in which the solution would be that Quality Management can reduce these financial risks and how the QUEST Missions objectives is to "Identify & score the risk profile of investments", "Translate the risk profile into asset value", and to "Develop a toolkit to evaluate investments regarding technical and financial risks". The presentation concluded to the ways in which QUEST can help to reduce these risks. **Christine Lemaitre** also presented DNGBs certification for sustainable buildings. Her goals addressed new architectural environments such as ecological colours, open spaces and visual comfort.

Jessica Stromback, from Joule assets was last to present in this session on the topic: *Aggregating sustainable investments / LAUNCH results* where a case study was presented on Hybrid Home Challenges Public Housing, as well as The LAUNCH h2020 project. The session ended with a panel discussion from all 5 speakers, moderated by **Anita Derjanecz**, REHVA Managing Director.

SESSION 3 – Sustainability, product efficiency & drinking water systems

The last session of the day was Moderated by **Jarek Kurnitski**, REHVA TRC chair. This session mainly dived into HVAC products, which must comply with new EU regulatory requirements and systems tackling climate goals. It presented these from the perspective of leading HVAC manufacturers, the first being led by **Josefina Lindblom**, Policy officer from the European Commission who investigated the topic of *Policy Developments on Circular Economy and an Introduction to Level (s).* She presented the goals for priorities of the new European Commission that dived into the new framework for the future of environmental policy which listed three points:

- Climate-Neutral Continent
- Sustainable Europe Investment Plan & Just Transition Fund
- Preserving Europe's Environment

The session then continued to **Angsar Theimen**, from DAIKIN who delivered information on Resource efficiency in the HVAC sector presenting their Refrigerant Policy. Daikin strives to become the lowest CO_2 equivalent manufacturer in which four factors were mentioned in the talk to make the best-balanced refrigerant choice for each application: Safety, Environmental Impact, Energy Efficiency and Cost- Effectiveness.

Eco-design updates were also presented by **Rene Kemna**, Director of VHK in which Space heaters and Water heaters were reviewed. The session then ended with two speakers, **Ilari Aho**, Vice President for UPONOR and a REHVA fellow who reviewed the EU Drinking Water Directive in his presentation. The EU drinking water (EDW) is an alliance of 30 European Trade associations who represent industries supplying materials and products in contact with drinking water. EDW also acts to safeguard equal drinking water quality for the consumers across Europe.

This presentation was then followed by Dr **Christian Schauer**, head of the drinking water department, Viega, who presented the scope of the latest REHVA guidebook 30, *Hygiene in potable water installations in buildings* that looked into the interrelationships between water quality, health and the well-being of users require that all parties involved have a specific responsibility for aspects of hygiene in specifying the requirements for potable water installations in buildings. The guidebook also gives an overview about the fundamentals of hygiene and water quality and contains main information's on the design, installation, start-up, use, operation and maintenance of potable water installations in buildings. It also opens suggestions for the practical work (maintenance, effects on microbiology, potential causes and measures in practical work, checklists).

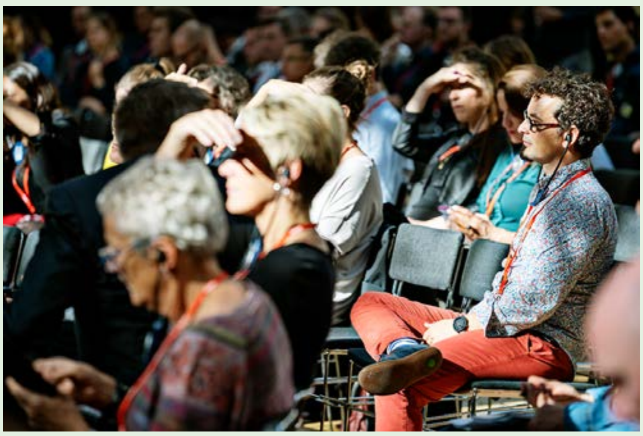
The session ended with closing remarks and open questions. ■

Highlights from the Velux Days in Paris, 9-10 October, Paris, 2019

Report by **ANITA DERJANECZ**, REHVA Managing Director
Photos: velux.com

Velux organised a 2-days event combining for the first time the Daylight Symposium and the Healthy Buildings Day. The venue, "Le Carreau du Temple", was a 19th century listed market hall building, a steel and glass structure in Paris, recently renovated and turned into an event venue from an abandoned building. A symbolic venue reflecting the focus of the event: the transformation of the existing building stock. The Velux Days joined over 600 researchers and professionals discussing building design options for comfort and health.

THE **DAYLIGHT SYMPOSIUM** focused on the merits of daylight for human well-being, health and visual delight, aspects that are more and more recognised in the building industry, highlighting architects' perspective on new designs for daylight and fresh air showcasing renovation projects of existing buildings. Key academics presented research studies on the impact of daylight on human health,



Bringing light to life

sleep and indoor comfort, and good examples for high quality daylighting solutions with energy saving.

The afternoon outbreak session "*Tools & metrics*" presented the main features, tested its application and impact of the new European Daylighting Standard EN17037. The standard considers four key daylighting qualities, each one ensuring important aspects of human well-being. In addition to the daylight levels and distribution of daylight in each space, these include views out of windows, the extent and duration of direct sunlight exposure, and visual comfort conditions. **Max Tillberg**, member of the CEN/TC WG that developed the standard, assessed in his presentation existing simulation tools if they are compliant with the requirements of the new standard. He pointed out the urgent need that design tools support the cooperation between architects and engineers to ensure high indoor climate quality.

Werner Osterhaus, Professor at Aarhus University, presented the outcomes of a case study applying the standard in dense urban environments. They found that in densely built-up areas (obstruction angle ≥ ca. 10°), it is impossible to reach daylight factor targets for the medium or high-performance levels. This was confirmed also by **Bernard Paule**, Director at ESTIA in his presentation assessing the impact of the standard on building design. Beside the extremely demanding requirements and non-suitability in urban environments, he pointed out that the standard encourages the realization of entirely glazed facades which may cause problems to be tackled by the system design, like overheating.


Max Tillberg


Werner Osterhaus


Bernard Paule

THE HEALTHY BUILDINGS DAY gave a platform for architects, engineers and researchers to tackle key question of building design for healthy indoor climate and user-centric design.

The session breakout session "*Catalysing scale*" presented the RenovActive project on healthy housing with Danish and Belgian study cases of energy renovation of social housing buildings. The project contained a very interesting component of sociological research studying user behaviour, indoor comfort perception and the use of control devices from the point of view of the tenants. The presentations are available online.

Velux launched the latest edition of The Healthy Homes Barometer 2019 studying problems with today's building stock with serious effect on health and comfort. This year's edition turns its attention towards one of the most vulnerable groups of society and investigates how unhealthy buildings affect the health, wellbeing and learning abilities of our children. Every third child in Europe live in what the research institute RAND Europe labels as an unhealthy building, characterized by dampness, darkness, excess noise and cold temperatures. ■

Send information of your event to Ms Giulia Marenghi gm@rehva.eu

Exhibitions, Conferences and seminars in 2019-2020

Exhibitions 2019

4-6 December 2019	50th International HVAC&R Congress and Exhibition	Belgrade, Serbia	https://www.rehva.eu/news/article/kghs-silver-anniversary-hcacr-and-exhibition-congress

Exhibitions 2020

27-29 February 2020	ACREX	New Delhi, India	http://acrex.in/home
8-3 March 2020	Light+Building 2020	Frankfurt, Germany	https://light-building.messefrankfurt.com/frankfurt/en.html
10-13 March 2020	SHK Essen	Essen,Germany	https://www.shkessen.de/branchentreff/
17-20 March 2020	MCE - Mostra Convegno Expocomfort	Milan, Italy	https://www.mcexpocomfort.it/

Conferences and seminars 2020

1-5 Feb 2020	2020 ASHRAE Winter Conference and AHR Expo	Orlando, Florida	https://www.ashrae.org/conferences/2020-winter-conference-orlando
4-6 March 2020	World Sustainable Energy Days	Wels, Austria	https://www.wsed.at/en/world-sustainable-energy-days.html
1-3 April 2020	14th TTMD Symposium	Istanbul, Turkey	http://www.ttmd.org.tr/en/activities/international-symposium-on-installation-in-construction
12-14 May 2020	13th IEA Heat Pump Conference	Jeju, Korea	http://hpc2020.org/
14-17 June 2020	NSB 2020 Building Physics Conference	Tallinn, Estonia	www.nsb2020.org/
20-24 July 2020	Indoor Air 2020	Seoul, Korea	www.indoorair2020.org
14-16 Sept 2020	Roomvent 2020	Torino, Italy	http://roomvent2020.org/
14-16 Sept 2020	AIVC Conference	Athens, Greece	https://www.aivc.org/event/14-16-september-2020-conference-athens-41st-aivc-conference
13-14 October 2020	BuildSim Nordic 2020	Oslo, Norway	https://buildsimnordic2020.ibpsa-nordic.org/our-travels/

Rakennusten energiaseminaari 2019

Logo of the FINVAC conference on energy efficiency of buildings

FINVAC conference on energy efficiency of buildings

Conference venue Finlandia hall.

Invited guest speakers Mr Dimitrios Athanasiou (left), from DG Energy and Mr Frank Hovorka (right), president of REHVA, with the chair of seminar programme committee, prof **Olli Seppänen**, FINVAC.

5th FINVAC* conference on energy efficiency of buildings in October attracted close to 500 top experts in Finland. The audience was a mixture of business and public sector people. The focus of the seminar was on implementation of EPBD and EED in Finland including also the strategies for new energy systems when the country will stop using coal in power plants and heat production by 2035.

The opening speech in the seminar was delivered by the State Secretary, Ms **Lehtonen** from Ministry of the Environment. She stressed the importance of the construction sector in the Finnish energy policy, and summarized the government energy policy.

The foreign invited speakers came from the DG Energy in Brussels and from France. Policy officer Mr **Dimitrios Athanasiou** from the Commission presented an overview of current and future energy policy in EU, and stressed the role of building sector in it. Mr **Frank Hovorka**, president of REHVA, explained in his presentation how important it is to the building owners and investors to have reliable data on the quality of buildings regarding the indoor environment and energy.

The Finnish speakers updated the participants regarding the implementation of the EU directives in Finland, and presented interesting cases such as the Energy Efficiency Action plan of City of Helsinki and Aalto University campus.

FINVAC organised also an exhibition at the conference venue with about 40 exhibitors. The seminar and the exhibition were very well received by the participants.

Due to great success of the conference the board of FINVAC decided to organize the 6th annual conference and exhibition on November 2020 at the Finlandia Hall. ■

* FINVAC is the Finnish member of REHVA, representing over 5 000 HVAC professionals in Finland. Its president is Professor Olli Seppänen and secretary general Ms **Siru Lönnqvist**.

https://danvak.dk/produkt/installationskonferencen-2019-for-praktikere/

"Installationskonferencen 2019"

– a conference about the technical installations in buildings arranged by Danvak

Every year in the fall, Danvak arranges a conference about the technical installations in buildings. The conference is aimed at the entire value chain in the building sector from building owners, consultants, entrepreneurs, manufacturers, operation & maintenance and not to forget the university sector.

The focus of the conference is to address and discuss issues about the technical installations in building, and to inform the sector about new regulations and standards in Denmark. This year we had a special focus on the new fire ventilation regulation in Denmark and the general situation on the piping for drinking water installations in buildings.

As the EPBD 2018 was approved during spring 2018, we brought in Professor **Risto Kosonen** from Aalto University as a guest speaker to inform the participants on the work being performed on the Smart Readiness Indicator (SRI), which might be implemented in Europe in the near future.

Project Director **Casper Kasting** from NCC, presenting their renovation project "Falkoner Center".

The opening speak was made by one of Denmark's largest construction companies NCC, that presented their renovation project "Falkoner Center" which was nominated for the Danish Building Award 2019 in the Building Process category.

Moreover, subjects such as energy behaviour, energy distribution, electrification in Denmark seen in the light of facing out fossil energy, economy in operation of ventilation systems, indoor climate and cooling situation in the Danish schools and other relevant subjects within technical installations in buildings were presented.

"Installationskonferencen 2019" is made in close cooperation with The Danish Society of Engineers – HVAC Section (https://english.ida.dk/what-is-ida) and The Innovation Network Smart Energy that is partly financed by the Ministry of Higher Education and Science of Denmark (https://inno-se.dk/english/).

The conference is also meant to be a day where all involved take a day away from their work, meet with colleagues, network and absorb new thinking and ideas for handling their challenges in a better and more efficient way and thereby creating better buildings in Denmark.

Danvak is an association for professionals within the areas of HVAC, energy and indoor climate. Our aim is to form the basis for better buildings in Denmark. In Denmark, we have members from more than 550 companies and counting approx. 2,000 professional members. The Chairman of Danvak is Mrs. **Christina B. Daél** and the Secretary General is Mr. **Claus Andreasson**. ■

World Sustainable Energy Days 2020

4 - 6 March 2020 Wels/Austria

The World Sustainable Energy Days

Clean. Competitive. Connected.

The World Sustainable Energy Days (WSED), one of Europe's largest annual conferences on energy efficiency and renewable energy, takes place from 4 – 6 March 2020 in Wels/Austria.

The clean energy transition is taking on a new dynamic in Europe and worldwide. "Energy efficiency first" and "global leadership in renewables" are at the centre of this transformation process. This requires strong policies, competitive businesses, technology innovation, investments and the involvement of the citizens. By addressing these topics and more, the annual WSED conference attracts over 660 participants from over 60 countries each year.

Value for your time!

In just 3 days, you can benefit from a comprehensive package:

- up-to-date information on markets, policies, technologies, financing, business models, research and case studies
- hands-on experience through technical site visits
- a major tradeshow on building efficiency and renewable energy, new business opportunities, valuable networking and Austrian hospitality!

Conferences and events:

- European Energy Efficiency Conference
- European Pellet Conference
- Young Energy Researchers Conference
- Energy Efficiency Policy Conference
- Smart E-Mobility Conference
- Innovation Workshops Energy and Buildings
- Industrial Energy Efficiency Conference
- a major tradeshow

Upper Austria – a leader in the clean energy transition

The WSED are organised by the OÖ Energiesparverband, the energy agency of Upper Austria. Upper Austria, one of Austria's 9 regions, is well on its way in the clean energy transition. Through significant increases in energy efficiency and renewable energy, greenhouse gas emissions from buildings have been reduced by 41% in 10 years. 58% of all space heating and 31% of the primary energy come from renewables. Over 2 billion Euro are invested annually in the region for the energy transition. ■

Mark your calendar for 4 – 6 March 2020 and come join REHVA and the worldwide energy efficiency community in Wels/Austria at the World Sustainable Energy Days!

4 - 6 March 2020 Wels/Austria

MCE – MOSTRA CONVEGNO EXPOCOMFORT 2020

Almost everything ready for the next edition of the world's leading exhibition dedicated to residential and industrial installations, air-conditioning and renewable energies, scheduled for 17 – 20 March 2020 at Fiera Milano.

Milan, December 2019 – The organisation of MCE – MOSTRA CONVEGNO EXPOCOMFORT, the world's leading biennial exhibition dedicated to residential and industrial installations, HVAC&R and renewable energy scheduled for 17 – 20 March 2020 at Fiera Milano, is now moving into top gear. Technological innovation in terms of products, systems and solutions for comfortable living and strong internationalism, reign once again as the undisputed protagonists of MCE 2020, running alongside the second edition of BIE - BIOMASS INNOVATION EXPO, dedicated to biomass heating products and solutions, reaffirming the event leading position in an even more global context. Right now, MCE - MOSTRA CONVEGNO EXPOCOMFORT 2020 has registered over 1,800 exhibitors.

MCE 2020 will, once again, be an ideal showcase that will take visitors on a journey through the most innovative technologies to understand the evolution of HVAC&R industry, where the new horizons for comfort increasingly pass through the digital dimension of management and control, and the efficiency is bound, more and more, by the intelligent use of Information Technology for the optimisation of energy resources of buildings.

An evolution that will find its ideal stage in the new exhibition layout of MCE 2020, capable of creating homogeneity and continuity into the several industry sectors, giving value to the conceptual areas in a "unicum", different and one-of-its-kind, carefully studied to meet the needs of exhibitors and professionals alike always on the hunt for technological novelties. The entirely new layout will better tell the present and future trends of the market: in this context, **heating, ventilation, air-conditioning and refrigeration** areas will take up not only halls 13/15 and 22/24 as usual, **but also hall 9/11 together with THAT'S SMART space,** joining link between the heat and power environment. **The whole components sector** will be located **in hall 2/4,** adjacent to the entrance gate of the underground, and very close to the areas dedicated to heating, renewable energy, and plant design services (halls 1/3, 5/7 and 10), synergistic and complementary sectors.

As it is now customary, MCE 2020, will be supplemented by a busy programme of conferences organised in collaboration with the leading trade associations, once again coordinated by the chair of the Scientific Committee Professor Vittorio Chiesa of Energy & Strategy Group, Polytechnic University of Milan.

Indeed, many initiatives will be on offer livening up MCE 2020 throughout the course of the four days. From Partner Country with Turkey as the special guest of the next edition to **Percorso Efficienza & Innovazione**, a short-list of the most cutting-edge products and solutions in terms of efficiency and energy savings made by the Polytechnic University of Milan, on show at MCE, to lead visitors on a journey into the future of HVAC&R. A particular focus on MEP BIM, a unique area located in Hall 10 at Fiera Milano, where booths and desks of specialised companies will offer presentations and live demonstrations aimed at thoroughly investigating all the technical and regulatory aspects as well as standardisation and planning features, for the BIM model, to help trade operators seizing the best market opportunities.

Amongst the new features in store for this edition, a unique space dedicated to **Intelligent Water** stands out. On display, the most advanced technologies for the bathroom environment to good living together with special initiatives aimed at energy efficiency in the industry with the intention of bringing a number of new categories of professionals to the trade show.

All the latest updates on MCE - MOSTRA CONVEGNO EXPOCOMFORT 2020 will be available online on www.mcexpocomfort.it, Facebook.com, Twitter.com and Instagram MCE's pages. ■

Light + Building 2020

– All set for success with the latest topics and 2,700 exhibitors

'Connecting. Pioneering. Fascinating'. Such is the tagline of the upcoming Light + Building in Frankfurt am Main, providing the central theme that runs through this leading world trade fair, to be launched from 08 to 13 March 2020. All the market leaders have signed up and we are currently expecting some 2,700 exhibitors, who will be presenting their world firsts in the fields of lighting, electrical and electronic engineering, home and building automation and security technology.

Centre stage at Light + Building will be some of the major drivers in the sector: topics such as 'Smart Urban' and 'Functional Aesthetics in Lighting and Luminaire Design'. 'Smart Urban' encompasses topics relating to intelligent infrastructure in urban districts. At the same time, a key element in this headline theme is the interlinking of home and work, as the smallest unit of space that people inhabit in their private and working lives, on the one hand, and the city as the largest unit on the other. This includes things like the location of production sites, digital charging infrastructure to provide for e-mobility and dynamic street lighting, as well as surveillance networks and intelligent parking systems.

A key area in the 'Lighting' product group is the presentation of the latest trends in design and technology on the lighting market. Digitalisation in the lighting sector continues to throw the focus ever more closely on human beings themselves and their individual needs. For that reason, too, 'Functional Aesthetics' is one of the beacon issues of the current season. This is all about the deliberate avoidance of ornamental design features and a focus on the specific requirements for lighting in each individual case. Subtly designed lamps, which emit variable light spectra for various, different scenarios – controlled, in part, by the smart building itself, are increasingly being employed in educational, work and leisure contexts. Thus, for example, windowless rooms are transformed into spaces that are flooded with light. Adaptive light wavelengths serve to excite or dampen natural biorhythms - depending on requirements.

At this, the world's largest trade fair for lighting and building services engineering, the industry will be showcasing its intelligent and networked solutions, ground-breaking technologies and up-to-the-minute design trends, which all contribute to improving both the economic efficiency of buildings and the comfort, convenience and security requirements of the users. Light + Building is a trade fair of innovation and encompasses all the electronically controlled building services; with the unique breadth and depth of its product spectrum, it promotes integrated building planning – from the 'smart home' to the 'smart building' and the 'smart city'.

Electrical engineering, together with disciplines relating to home and building automation, all have a key role to play in the construction and operation of the intelligent, networked building. The crucial factor is the interoperability of the systems involved. So that, at Light + Building, you find electro-technical solutions in the context of other fields such as lighting, home and building automation and security technology. Here, the industry will be exhibiting solutions and technologies aimed as much at low energy usage and modern safety and security requirements as at opportunities for individual design and high levels of convenience and comfort.

In addition to the broad range of exhibitors' products on offer, Light + Building scores highly with its varied complementary programme, which is grouped under the headings of 'Emotion', 'Skills', 'Career' and 'Selection'. There are specific topics on offer for the entire spectrum of trade visitors, including architects, engineers, planners, interior architects, designers, tradespeople, retailers and representatives from industry – ranging from special exhibitions and demonstrations to specialist lectures and trend presentations.

Further up-to-date information relating to Light + Building and its complementary programme, as well as travel arrangements and tickets can be found at: www.light-building.com. ■

Visit Light + Building on the following social networks, too:

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Svanvac RoomVent Conference 2020

– 14-17 June 2020 in Torino, Italy

Conference Venue in Torino, at campus of Politecnico di Torino

The 15th Scanvac International RoomVent Conference will be organized in Torino, Italy, 14-17 June 2020, according to the agenda on the right.

The ROOMVENT 2020 Conference offers scientists and academics, business professionals and policymakers a forum for disseminating technical information, new ideas, and discuss the latest developments and future direction in the fields of natural and mechanical ventilation. In addition to presentations of technical papers, RoomVent 2020 will also include expert keynote talks, workshops, special sessions for research projects and doctoral student seminars.

Roomvent 2020 will be focused on the theme "*Energy efficient ventilation for healthy future buildings*". This complex issue will be undisclosed in various themes, including:

- new technologies and ventilation strategies for low energy, passive houses and zero emission buildings
- indoor environment control for thermal comfort and IAQ
- effective natural, hybrid, and mechanical ventilation
- research, modelling and experimental methods for air flow characterization and visualization
- air distribution & ventilation effectiveness
- Special topics are: urban ventilation, ventilation for means of transport, fire and smoke control, ventilation of Underground Spaces, infections control by ventilation in hospitals and health facilities

Sunday, 14 June
Welcome Reception

Monday, 15 June
Conference day 1
Chairs dinner

Tuesday, 16 June
Conference day 2
Social dinner

Wednesday, 17 June
Conference day 3

The president of RoomVent 2020 Conference professor **Gian Vincenzo Fracastoro**

This Scanvac conference is organised by the Energy Department of Politecnico di Torino (Polito), together with ATI, the Italian Association of Heating and Ventilation Engineers, and Scanvac, the Scandinavian Federation of Heating, Ventilation and Sanitary Engineering Associations.

Call for abstracts has been launched in July 2019 and the deadline is October 31, 2019. First round of manuscript submission will end on February 29, 2020. ■

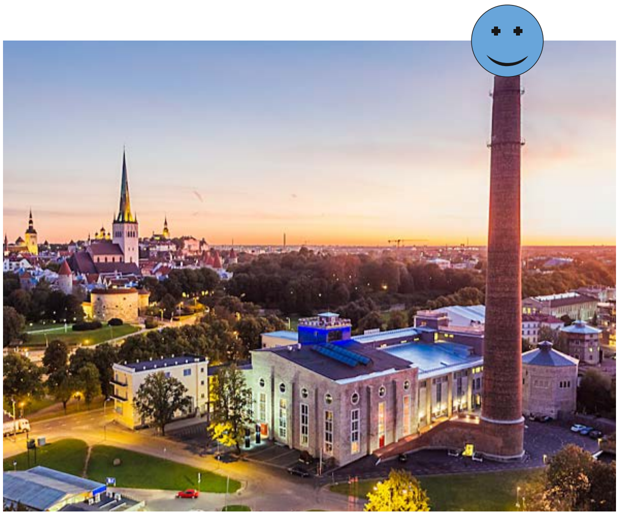
More information: http://roomvent2020.org/

Cold Climate HVAC & Energy 2021 and REHVA AM 17-21 April 2021 in Tallinn

10th International Scanvac Cold Climate Conference will be organized in Tallinn, Estonia 18-21 April 2021. The conference is combined with REHVA Annual Meeting & General Assembly, which takes place 17–19 April. In this way, REHVA delegates can attend the conference. REHVA workshops, as well as Technology and Research Committee and Supporters Committee meeting will be organised in parallel with the conference, on Monday 19 April.

It is planned to extend the scope of the conference to HVAC and energy and to make conference attractive for PhD students by offering an open access scientific conference papers indexed in Scopus. For practitioners, another, technical paper category is offered. Therefore, the conference is not only focusing to HVAC systems performance, but also more widely to energy performance and management of buildings.

Organisation is shared in between Tallinn University of Technology, and EKVÜ, an Estonian Society of Heating and Ventilation Engineers. Call for the abstracts will be launched in February 2020. ■



Conference center is located in the city center of Tallinn (Chimney in the picture is a land mark, not used for decades).

Tentative themes of the conference are:

- Modern ventilation and air conditioning technology
- Energy efficient heating and cooling systems
- Nearly zero energy and carbon buildings
- Healthy and productive indoor environment
- Intelligent building management

SCANVAC Conference		Sunday, 18 April Welcome Reception	Monday, 19 April Conference day 1 PhD-student event Chairs dinner	Tuesday, 20 April Conference day 2 SCANVAC WS Conference dinner	Wednesday, 21 April Conference day 3 SCANVAC WS
REHVA AM	Saturday 17 April General Assembly Gala Dinner	Committee and other meetings	Committee meetings and REHVA workshops in parallel with the conference		

The president of the conference is professor **Jarek Kurnitski**, former member of REHVA board of directors and chair of the REHVA Technical Committee.

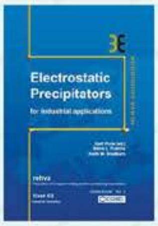
REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

EUROPEAN GUIDEBOOKS

No.01: DISPLACEMENT VENTILATION IN NON-INDUSTRIAL PREMISES

No.02: VENTILATION EFFECTIVENESS



No.03: ELECTROSTATIC PRECIPITATORS FOR INDUSTRIAL APPLICATIONS

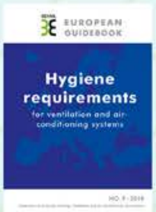
No.04: VENTILATION AND SMOKING

No.05: CHILLED BEAM APPLICATION GUIDEBOOK

No.06: INDOOR CLIMATE AND PRODUCTIVITY IN OFFICES

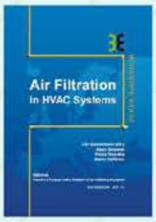
No.07: LOW TEMPERATURE HEATING AND HIGH TEMPERATURE COOLING

No.08: CLEANLINESS OF VENTILATION SYSTEM



No.09: HYGIENE REQUIREMENTS FOR VENTILATION AND AIR-CONDITIONING SYSTEMS

No.10: COMPUTATIONAL FLUID DYNAMICS IN VENTILATION DESIGN



No.11: AIR FILTRATION IN HVAC SYSTEMS

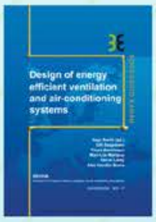
No.12: SOLAR SHADING

No.13: INDOOR ENVIRONMENT AND ENERGY EFFICIENCY IN SCHOOLS - PART 1

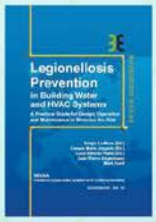
No.14: INDOOR CLIMATE QUALITY ASSESSMENT

No.15: ENERGY EFFICIENT HEATING AND VENTILATION OF LARGE HALLS

No.16: HVAC IN SUSTAINABLE OFFICE BUILDINGS



No.17: DESIGN OF ENERGY EFFICIENT VENTILATION AND AIR-CONDITIONING SYSTEMS



No.18: LEGIONELLOSIS PREVENTION IN BUILDING WATER AND HVAC SYSTEMS

No.19: MIXING VENTILATION

No.20: ADVANCED SYSTEM DESIGN AND OPERATION OF GEOTABS BUILDINGS

No.21: ACTIVE AND PASSIVE BEAM APPLICATION DESIGN GUIDE

No.22: INTRODUCTION TO BUILDING AUTOMATION, CONTROLS AND TECHNICAL BUILDING MANAGEMENT

No.23: DISPLACEMENT VENTILATION

No.24: FIRE SAFETY IN BUILDINGS

No.25: RESIDENTIAL HEAT RECOVERY VENTILATION

No.26: ENERGY EFFICIENCY IN HISTORIC BUILDINGS

No.27: HVAC COMMISSIONING PROCESS (REHVA-ISHRAE)

No.28: NZEB DESIGN STRATEGIES FOR RESIDENTIAL BUILDINGS IN MEDITERRANEAN REGIONS

No.29: QUALITY MANAGEMENT FOR BUILDINGS