Review of building services solution fitted for a low emission building stock in urban areas

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ABSTRACT

The purpose of this paper is to summarize the status of promising low carbon building services solutions fitted for a low emission building stock in urban areas.

It is believed that well-performing building envelopes with low thermal losses or low solar heat gains, enables simplified building services solutions. This paper compiles promising building services solutions studied in other research projects and fitted for highly insulated buildings for the most common building categories within a neighbourhood.
The common building categories include new and renovated offices, educational buildings, residential buildings, grocery stores and shopping centres. Some of the following building services solutions are still relevant for single buildings, but for utilizing surplus energy sources in particular, it is better to look at multiple buildings in a neighbourhood. Especially the following topics are presented and evaluated:

- Demand-controlled ventilation
- Ventilation-based heating and cooling
- Simplified hydronic heating
- Smart energy control
- Responsive lighting equipment
- Utilizing surplus energy sources

Each technical solution is discussed and its suitability for other building types is evaluated. Technical installations are moving towards low-temperature heating and high-temperature cooling, in order to better utilize renewable energy sources and surplus energy, and to reduce heat loss from the systems. Future buildings and renovated existing buildings should aim for an optimization between energy, power and indoor environment, and reasonable economy. Although power demand and peak loads have not been significantly discussed in this report, it is currently undergoing a lot of research to reduce costs of upgrading the electricity grid and will continue to receive substantial focus in the coming years. When assessing energy performance, comfort quality and economic feasibility of low energy building services, a comprehensive approach is needed.

KEYWORDS

Demand-controlled ventilation, ventilation-based heating and cooling, simplified hydronic heating, smart energy control, responsive lighting equipment, utilizing surplus energy sources.

1 INTRODUCTION

It is believed that well-performing building envelopes with low thermal losses or low solar heat gains, enables simplified building services solutions.
The original definition of the passive house is a building where thermal comfort can be achieved by preheating and precooling of the ventilation air, with no larger ventilation rates than are necessary for achieving satisfactory air quality. Under this definition, separate heating and cooling systems are unnecessary. Heating and cooling by ventilation may not be the ideal solution for all buildings in a zero emission neighbourhood (ZEN), but in general, building services solutions can be simplified or downsized in buildings with little thermal transport through envelope and low solar heat gains when there is no heating demand.

2 OBJECTIVE

The purpose of this paper is to summarize the status of promising low carbon building services solutions fitted for a low emission building stock in urban areas. The suitability of the solutions was assessed according to the building categories characteristic usage profile, heating, cooling and el-specific power profile, demand for different thermal zones, floor-plan flexibility and availability of excess heat. The solutions are relevant for use by researchers and practitioners for further research. It is not a state-of-the-art research paper covering all the details, but rather a foundation for further work in the area of low carbon solutions fitted for low emission buildings and neighbourhoods.

3 METHOD

The present study is based on a systematic mapping study designed to carry out an objective selection of literature sources relevant to the topic in question. The methodology adhered to in the present study is described (Petersen, Vakkalanka, & Kuzniarz, 2015).
In the present study, the Scopus abstract and citation databases of peer-reviewed literature was considered for the past 10 years (2008 – 2019). The search string was structured using Boolean operators to refine the search process in terms of action description ("how") and object ("what") and corresponds to the keywords set out in Table 1.

Table 1: Keywords and Boolean operators used for the initial search.

HOW?	AND WHAT?	AND NOT to exclude
zero emission buildings	Building services	food medical

The search produced 1014 publications for (zero emission buildings) and this was restricted to 244 publications when adding "AND (building services). Fig. 1 illustrates the recent marked increase in publication numbers. The screening of publications was performed on the basis of the following inclusion and exclusion criteria with the aim of excluding publications that are not relevant to the research questions. The qualitative inclusion criterion was as follows:
- English language

The scientific inclusion criteria were as follows:
- The technology under study should correspond to the definition of objectives provided in Section 2, and
- The object to which the study in question is applied should correspond to cold climate. This excludes publications related to warm climates where technical solutions might look different.

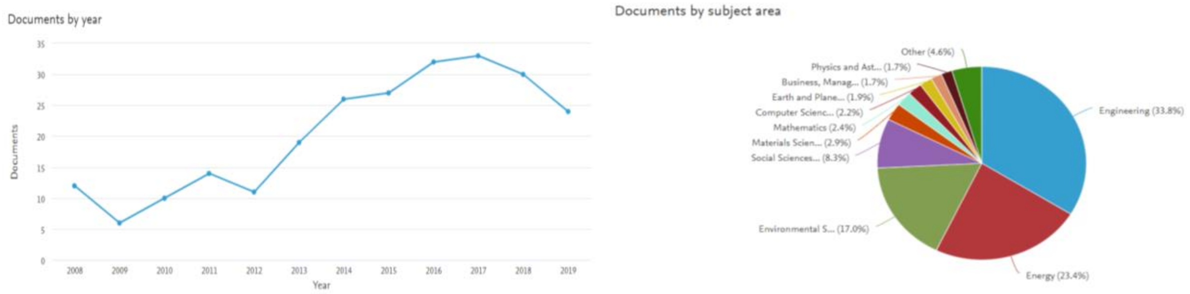

Figure 1: Results of screening exercise in scopus database; development of publications per year on the left and documents by subject area on the right

This resulted in 32 publications. In addition, 106 project reports (ZEB, EBLE, BestVent, Svalvent) and 55 project reports in the EU project Commonenergy were screened. After a screening process based on titles and abstracts, a total of 92 publications were deemed to be relevant to the research questions.

List of relevant publications for this study:
(Aaberg, 2018; Alfstad, 2018; Ampenberger, 2017; Antolin et al., 2017; Antolin et al., 2015; Avantaggiato et al., 2017; Belleri & Avantaggiato, 2017; Belleri, Haase, Papantoniou, & Lollini, 2017; Berge, 2016; Berge, Georges, & Mathisen, 2016; Berge & Mathisen, 2016; Berge, Thomsen, & Mathisen, 2016; Bluyssen & Fanger, 1991; Bointner et al., 2014; Bukat, Niewczas, Kozioł, Łazowski, & de Ferrari, 2015; Bøhn, Søreng, Holljen, Dehlin, & Grini, 2014; Daldosso, Gentile, Mangili, & Papantoniou, 2017; Dipasquale, Belleri, & Lollini, 2016; Edvardsen, 2014; Emerson Climate Technologies, 2014; *Enovarapport*, 2003; Federico Visconti, Maurizio Orlandi, & Saro, 2015; Feist, Schnieders, Dorer, & Haas, 2005; Foster & Quarini, 2001; Fricke & Becker, 2010; Froehlich & Ampenberger, 2017; Galvin, 2016; L. Georges et al., 2017; L. Georges, Berner, & Mathisen, 2014; Laurent Georges, Håheim, & Alonso, 2017; L. Georges & Skreiberg, 2016; L. Georges, Skreiberg, & Novakovic, 2013; L. Georges, Skreiberg, & Novakovic, 2014; L. Georges, Thalfeldt, Skreiberg, & Fornari, 2019; L. Georges, Wen, Alonso, Berge, & Thomsen, 2016; L. Georges, Wen, Alonso, Berge, Thomsen, et al., 2016; Gram-Hanssen, 2010; Haase, 2016; Haase & Ampenberger, 2017a, 2017b; Haase, Antolin, & Belleri, 2016; Haase & Skeie, 2013, 2015; Haase, Skeie, et al., 2016; Haase, Skeie, Belleri, & Dipasquale, 2015; Haase, Skeie, & Woods, 2015; Haase, Woods, & Skeie, 2014; Halvarsson, 2012; Haukås, 2016; Heiselberg, 2017; Holand, Yang, Holøs, Thunshelle, & Mysen, 2019; Jones, 2018; Karmakar, Das, & Ghosh, 2016; KIWI, 2017; Kragh, 2016; Larsen et al., 2010; Lekang Sørensen, Jiang, Nybakk Torsæter, & Völler, 2018; Madsen & Gabrielsen, 2016; Mattilsynet, 2018; Micro Matic, 2016; Midttømme, 2018; Mysen, Berntsen, Nafstad, & Schild, 2005; Mysen & Schild, 2013, 2014; Mysen, Schild, & Cablé, 2014; Mæhlen, 2017; NVE, 2016, 2018; Olsen, 2018; Rozanska et al., 2017; Rønneseth, 2018; Schieldrop, 2019; Selvnes, 2017; Seppänen, Brelih, Goeders, & Litiu, 2012; Skeie, Lien, Svensson, & Andresen, 2016; Solt et al., 2017; Staggl, Reiter, & Ampenberger, 2017; Standard Norge, 2017; Stene, 2017; Stene, Justo Alonso, Rønneseth, & Georges, 2018; Stiller, 2012; Sundlisæter et al., 2015; Sweco, 2016; Thomsen, 2017; Thomsen, Gullbrekken, Grynning, & Holme, 2017; Thunshelle, 2016; Vázquez et al., 2017; Venås, Harsem, & Børresen, 2014; Walnum & Fredriksen, 2018; Wargocki, Fanger, Krupicz, & Szczecinski, 2004; Weschler, 2011; Woods, Mellegård, Schlanbusch, Skeie, & Haase, 2015)

4 RESULTS

The common building categories include new and renovated offices, educational buildings, residential buildings, grocery stores and shopping centres. Some of the following building services solutions are still relevant for single buildings, but for utilizing surplus energy sources in particular, it is better to look at multiple buildings in a neighbourhood. Especially the following topics are presented and evaluated:

- Demand-controlled ventilation
- Ventilation-based heating and cooling
- Simplified hydronic heating
- Smart energy control
- Responsive lighting equipment
- Utilizing surplus energy sources

Each technical solution is discussed and its suitability for other building types is evaluated. Some of the technologies were tested in specific building types. Some assumptions and prerequisites are explained that will make these technologies also suitable for other building types. Table 2 provides an overview of the different technologies and their suitability in the different building types.

4.1 Demand-controlled ventilation

Demand-control of mechanical ventilation systems has a significant impact on the demand for heating, cooling and electrical power in all buildings where the need for mechanical ventilation varies in time, and there are dependable ways of detecting these variations. In spaces where humans are the predominating pollution source and occupancy varies over time, e.g. classrooms, meeting rooms, congregation halls and open-plan offices, demand-control using CO_2-sensors or presence detector for determining the ventilation need is a cost-efficient way of reducing the energy use.

In situations where indoor and outdoor sources not directly linked to human presence is important for the air quality, and especially if indoor chemical reactions are important, the control issue becomes more complex. Further development of control algorithms taking enthalpy and a wider range of chemical and in particular pollutants into account may expand the cost-effective potential use of DCV further.

4.2 Ventilation-based heating and cooling

With well-insulated and energy efficient buildings, premises are suitable for ventilation-based heating. Only isotherm or slightly over-tempered supply air is necessary during workhours, which is proven to give satisfied users and acceptable physical conditions upon certain premises. The solution is documented for energy efficient office buildings but is a relevant solution also for office-related areas in other buildings and well insulated existing buildings. Key premises are heating demand and documented characteristics of the inlet valve.

Ventilation-based heating for residential buildings are closely studied for European conditions, but still need further research in cold climates. Low ventilation rates together with low relative humidity in winter, makes this solution more challenging for this kind of buildings. With a standard one-ventilation using a single air supply temperature, the temperature in bedrooms would be higher and could further increase the risk of window opening.

Ventilation-based cooling is very promising for offices and shopping centres, as these typically have high cooling demands. For the other building categories, it is evaluated to only have a minor impact. The use of ventilation-based cooling is expected to both improve energy efficiency and thermal comfort for the users. User satisfaction is also expected to increase through products enabling individual demand-control. Full-scale field measurements are however required to verify that the concept for commercial use.

4.3 Simplified hydronic heating

Simplified space-heating distribution has been investigated in the context of highly-insulated residential buildings. The configuration of the heating and ventilation considered in these researches is the most representative of Norwegian passive houses: a centralized balanced mechanical ventilation with a single air supply temperature for all the rooms (so-called one-zone ventilation) and using a cascade flow while, in the case of radiator heating, one heat emitter is placed for each floor. Previous research works have documented and explained the temperature distribution inside the building generated by the simplified space-heating distribution, both in terms of temperature differences between rooms but also in the temperature distribution inside the room equipped with the heat emitter. The main conclusions from these studies show that indoor thermal environment of living areas is experienced as comfortable by occupants. The most critical part is related to the thermal comfort in bedrooms. Many Norwegians would like cold bedrooms, at least during night-time (in the range of 14-18°C), and it has been shown that a large fraction of the occupants in such highly-insulated buildings opens the bedroom window during several hours per day (in winter time) to control the bedroom temperature.

It has been argued that water-borne heat in floors gives a slow-reacting heating system and is therefore difficult to regulate, especially if the heating pipes are cast in concrete. A "slower" system can more easily cause problems with over/under temperature. Various heating solutions have been chosen. On average, the two projects with water-borne heat in the floor have 1.7 ° C higher indoor temperature than the other houses.

4.4 Smart energy control

A smart Building Energy Management System (BEMS) has typically different functionalities, providing integrated solutions that includes monitoring and management of differing systems of the building to other correlated services, like heating and lighting. A smart BEMS facilitates the integration of sensors, systems and subsystems that are able to collect complete information and make it available to the management team and to all the participants involved in the construction, restructuring and maintenance of the building.

The smart BEMS enables communication between different systems to improve the performance, while an ICT system facilitates the process and allows this interaction, in addition to the collecting of completed data. The architecture of a smart BEMS allows to centralize and put into communication all the systems and subsystems, in particular: lighting and management of natural light; heat and air-conditioning; solar panels; food refrigeration; hydrogen and electric batteries and if needed the recharging of electric cars.

4.5 Responsive lighting equipment

Lighting equipment uses electricity and provides internal heat gain. The efficiency of the lighting equipment describes the amounts of illuminance, electricity use and internal heat gains. New equipment for lighting is, therefore, an important component as it determines the responsiveness. The exploitation of daylight to cover portions of illuminance should be the first step. The responsive control of the lighting equipment can then be used to provide the additional illuminance to the indoor spaces. The use of lighting equipment includes the light source and the luminaire that distributes the illuminance. The use of electricity needs to be monitored and provides input to dynamic energy balance calculations at each timestep and thus determine the need for heating and cooling. This is important for all building types but more prominent in buildings with high required or wanted illuminance levels.

LED is developing and provides now efficacies comparable to T5 lamps. Appropriate luminaires are needed that distribute light in the indoor space according to a specific use. LED provide opportunities to not only control the electricity use (on/off) and dimming, but also light quality (e.g. light colour). This should be used to plan and size the lighting equipment according to specific needs before heating and cooling equipment is dimensioned.

4.6 Utilizing surplus energy sources

There are already multiple buildings in Norway utilizing surplus heat from various cooling processes. Examples of heat sources are refrigeration systems in grocery stores as presented in chapter 5 and cooling of computer servers, which is expected to be an increasingly relevant source of surplus energy. Available surplus thermal energy (heat) should always be utilized, either directly through heat recovery or as a heat source for heat pump systems. It is important to identify the thermal needs, as well as temperature requirements, for space heating and cooling, heating of ventilation air, heating of DHW and process cooling. This should be taken into account before sizing heating and cooling systems. The surplus energy can either be used within the same building or at neighbouring buildings. The principle of utilizing surplus energy is transferable to all building categories, either through export or import of heat. A good match between the source of surplus energy and the heat load is however important. Duration curves is a good tool for designing heating and cooling systems and to visualize the potential of utilizing surplus heat sources.

Storage of surplus energy is also an option if there is poor matching between the thermal loads. Short term storage through water accumulation tanks, the thermal mass of the building and phase-changing materials (PCM) as well as borehole systems for seasonal storage may all be relevant. Such solutions will also moderate heating and cooling power demands but may increase the energy use through additional heat loss.

Loads for cooling and freezing food, process cooling and computer/telecom cooling are relatively constant throughout the year and are thus considered to be very good and reliable sources for surplus heat. Process cooling is typically found in industrial buildings, while computer/telecom cooling may be relevant for office buildings or educational buildings with server rooms etc. As space cooling of buildings usually is only necessary for short periods of the year, it is not a suitable source for heat recovery, except for "charging" boreholes for ground source heat pumps through free cooling. Recovered heat should also be used for a load that is relatively stable throughout the year, such as preheating of domestic hot water.

Zero emission neighbourhoods will have better conditions for utilizing surplus heat than single buildings, as a neighbourhood have a larger variety of loads (through different building categories) and thus more possibilities for exchange of thermal and electric energy.

Table 2: Overview of technical solutions and their suitability for different building categories.

Building category / Technical solution		***New offices***	***Renovated offices***	***Educational buildings***	***Kinder-gartens***	***Residential buildings***	***Grocery stores***	***Shopping centres***
Demand-controlled ventilation		+++	+++	+++	+++	++	0	0
Simplified hydronic heating		+++	0	0	0	+++	0	0
Ventilation-based heating		+++	++	0	0	+	0	0
Ventilation-based cooling		+++	+++	+	+	+	+	+++
Responsive lighting equipment (LED)		++	+++	+++	+++	++	+++	+++
Smart energy control (BEMS)		+++	+++	+++	+++	++	++	++
*Utilizing surplus energy sources**	*import*	+++	+++	+++	+++	+++	+++	+++
	export	++	++	++	+	+	+++	++

Technologies are considered to be a promising solution (+++), possibly promising solution (++) or just might have a minor impact (+). Building categories where the technical solutions have not been evaluated are marked (0). This provides an overview of the different technologies and their suitability in the different building types.

5 CONCLUSIONS

For successful implementation of *demand-controlled ventilation*, it is important to focus on planning with the correct air volumes and the appropriate ventilation strategies. The technology is most suitable for offices, educational buildings and kindergartens, but could also be considered for other building categories with variable ventilation demands.

Regarding *simplified hydronic heating*, the main conclusions from studies on residential buildings show that the indoor thermal environment of living areas is experienced as comfortable by occupants. It is therefore recommended for residential buildings, while further research is required for other building types.

Ventilation-based heating is very promising for highly insulated buildings, but it has currently only been evaluated for office buildings. For residential buildings, however, if a traditional one-zone ventilation strategy is applied, air heating using ventilation is not a robust option as it will generate relatively higher bedroom temperatures. This may further increase the risk of window opening during wintertime. If the configuration of the ventilation system is not adapted, this approach is unlikely to be a good option, either for the building occupants or the building industry. Dry air during the heating season and periodically low relative humidity in indoor air is a general problem occurring in all new buildings with balanced mechanical ventilation system. This problem occurs independent on whether ventilation-based heating is used, but the problem increases for residential buildings, as they require higher supply air temperature due to low airflow rates. One possible solution for increasing the relative humidity in indoor air is to lower the air exchange during particularly cold periods. Such a reduction of the air exchange can also reduce energy consumption for heating ventilation air during cold periods.

Ventilation-based cooling is gaining more importance in buildings with high internal gains, such as offices and shopping centres. The potential for energy savings is very high in Nordic countries due to favourable climatic conditions. More focus should be put on utilizing this technology in educational buildings, kindergartens, dwellings and grocery stores.

Responsive lighting equipment (LED) is an important part of low energy buildings. New technology developments of luminaires and control strategies can minimize energy use and maximize IEQ by full exploitation of the daylight availability (responsiveness).

Smart energy control (BEMS) play an important role in making use of the promising potential of many technologies. Integrated control of IEQ parameters can fully exploit this potential. Some building types have less focus on advanced control systems and further cost reductions are needed.

Available *surplus energy* should always be *utilized*, and the principle of utilizing surplus heat is transferable to all building categories, either through export or import of heat. While all building categories are suitable for importing surplus heat, the potential for export depends on the specific heat loads of both the building and the neighbouring buildings. Residential buildings and kindergartens usually do not have process cooling or other loads suitable for export.

When assessing energy performance, comfort quality and economic feasibility of low energy building services, a comprehensive approach is needed.

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