

***Heating, Ventilation and Air Conditioning in
Smart Energy-Efficient Buildings
A State-of-the-Art***

**A report within the research program
Smart Energy-Efficient Buildings
at NTNU and SINTEF
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RESULT (summary)

This report summarises the State-of-the art within Heating, Ventilation and Air conditioning (HVAC) and related areas. This report marks the start of subtask 3.1 "Heating, Ventilation and Air conditioning" within the project "Smart Energy Efficient buildings" ("SmartBuild"). The aim of the SmartBuild project is to develop new knowledge, integrated solutions, and technologies that will make it possible to cover our buildings-related energy needs with substantially less harmful environmental emissions, while still satisfying the whole range of end-user needs such as comfort, aesthetics, costs, operability, reliability, and functionality.

Future buildings will need very little thermal energy, because of well-insulated envelopes, high-performance windows, and energy-efficient ventilation. It is a wish to use more central heating with water as energy carrier at the sacrifice of direct electric heating. To succeed with this it is necessary to develop systems with lower cost and control units that work well together with other processes in the building. In well insulated buildings it is also necessary with a ventilation system and some kind of cooling to control the temperature.

Within the SmartBuild Project it is of special interest to emphasize:

- Improve the integration with other installations in the building and utilization of weather forecasts and previous events and use of the building
- Accumulation in buildings' structures and surfaces and/or separate storages
- Energy efficient distribution of air
- Cost and energy effective solutions for central heating with water as energy carrier

KEYWORDS

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1 Introduction

This report marks the start of subtask 3.1 “Heating, Ventilation and Air conditioning (HVAC)” within the project “Smart Energy Efficient buildings” (“SmartBuild”). The aim of the SmartBuild project is to develop new knowledge, integrated solutions, and technologies that will make it possible to cover our buildings-related energy needs with substantially less harmful environmental emissions, while still satisfying the whole range of end-user needs such as comfort, aesthetics, costs, operability, reliability, and functionality. To accomplish this, a 5-year multi-disciplinary project has been initiated in 2002, combining the knowledge of a wide range of experts in the field of energy use in buildings at NTNU and SINTEF, as well as the expertise of related Norwegian industry.

The aim of this report is to form the basis for further work within the SmartBuild project, and to provide information that may be used by the other project participants in order to see the possibilities for effective integration of our different fields of expertise.

HVAC covers a wide technical sphere and involves many professions at several levels. This report therefore only manages to give a superficial presentation of the field.

To make the presentation clearer some of the subchapters differs between heating, ventilation and cooling. In addition to HVAC also domestic hot water is mentioned in some chapters.

2 Central Concepts

HVAC covers a wide technical sphere. This chapter only gives a superficial presentation of the area. The presentation in this chapter divides between heating, ventilation and cooling.

2.1 Heating

The purpose of the heating system is to cover the net heat loss from the building. The heat balance for the building can be shown in Figure 1.

The heat loss from a building consist of three parts:

- Transmition
- Infiltration
- Ventilation

The heat gain consist of:

- Equipment
- Lighting
- Persons
- Solar radiation

Heat can also be released or transferred to the structure. The heating system should cover the difference between losses and gain and corrected for heat transferred to or from the storage.

Heat balance for the room

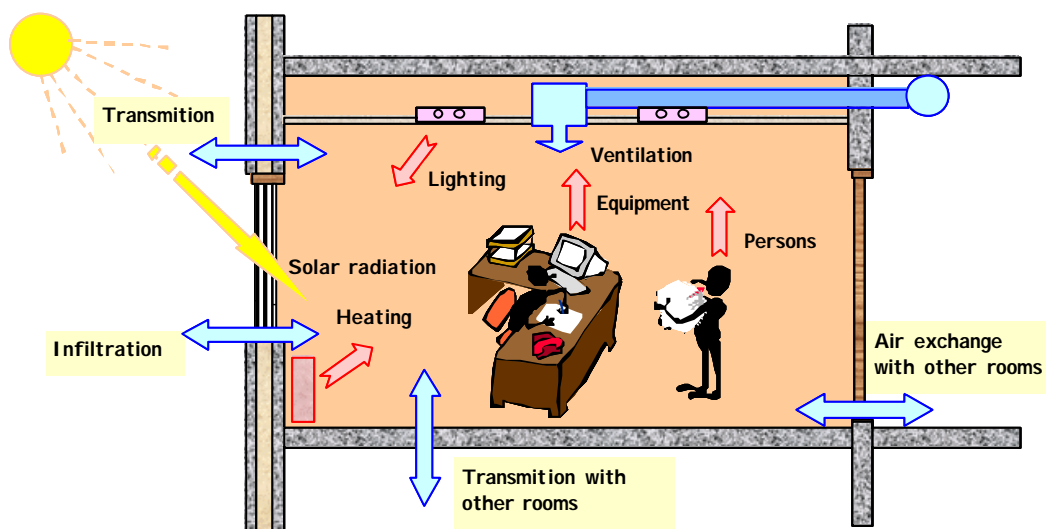


Figure 1. Heat balance

The heating system is classified as local heating or central heating.

In a central heating system the heat is first transferred to a carrier who transports the heat to the different rooms. Typical heat carriers are:

- Water
- Steam
- Air

Steam is not used in ordinary applications. And there are many reports on problems with air systems. In Norway today central systems uses water as heat carrier. Heat is usually transferred the water to the conditioned space by underfloor heating systems or radiators. Underfloor heating use low temperature water that circulates through a series of continuous pipe loops laid under the floor.

In a local heating system the energy is transferred to heat locally in the room. Typical examples are:

- Open fireplace
- Stove

Actual fuels are oil, gas, biomass or electricity.

Heat from electricity is usually transferred to the room as underfloor heating or convectors placed under windows.

The status in Norway today is a discussion about direct electrical heating vs. central heating systems with water as energy carrier. The main point is the low heat load vs. the higher cost for the central heating system.

2.2 Ventilation

Ventilation is used to: Remove pollutions and odours from the room, control the temperature, replace oxygen and in some rooms to supply air to an oven. Usually the airflow rate necessary to remove excess heat becomes the design value. Replacement of oxygen requires very little air.

To have outdoor air to flow into the building and used air to flow out there must be some kind of driving forces. In natural ventilation wind or thermal buoyancy is used while mechanical ventilation use fans.

2.2.1 Natural and hybrid ventilation

Natural ventilation uses to different driving forces; wind and buoyancy, see Figure 2:

- Wind could be used for cross ventilation where the air flows mostly horizontally through the building through windows and other openings in the facades. It could also be combined with towers and ducts arranged to force the air through the building in a more controlled way.
- The buoyancy force is often referred to as the stack effect. Warm air has lower density than colder air and flows upward when allowed. This is utilized in ventilation by making openings in the bottom and the top of the building. One disadvantage of this ventilation is that it becomes weaker the warmer it is outdoors.

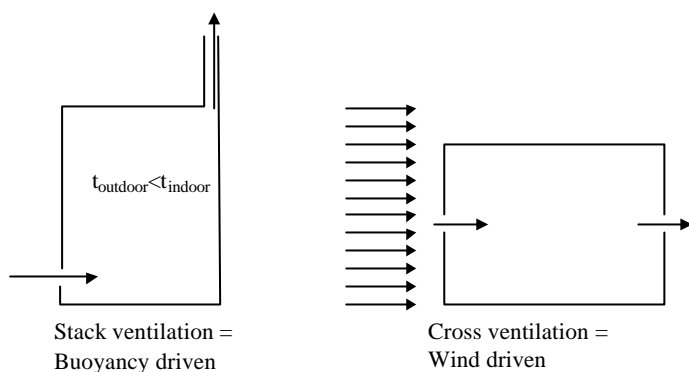


Figure 2. Principles of natural ventilation

The driving forces in natural ventilation are very small. It means that it is almost impossible to combine it with heat recovery and filtering of air.

To counteract some of the disadvantages of the natural ventilation, but still benefit from some of the advantages one could use so called hybrid ventilation. In hybrid ventilation, fans are used to transport the air when the natural forces are not strong enough. This also gives a possibility for heat recovery and filtering of the air.

2.2.2 Mechanical

Mechanical ventilation occurs mainly in two main alternatives; Exhaust and balanced ventilation. In exhaust ventilation untreated air is usually supplied to the ventilated rooms through openings in walls, see Figure 3. The used air is sucked out trough ductwork by mean of fans.

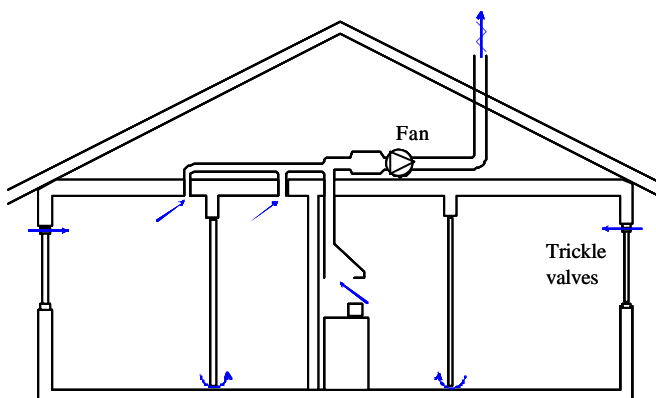


Figure 3. Exhaust ventilation

In balanced ventilation fans are used both to supply and exhaust air, see Figure 4. Usually the air is treated before it is supplied to the rooms. In a ventilation plant it is possible to heat, cool, humidify, dehumidify and clean the air. Downstream the ventilation plant the air is distributed through a ductwork to the different rooms and inlet openings.

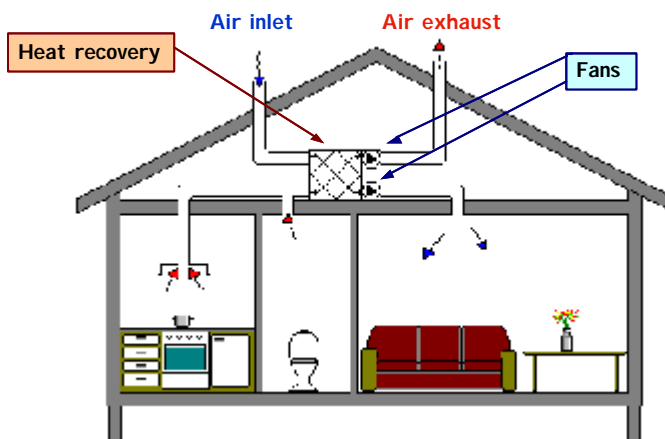


Figure 4. *Balanced ventilation*

In constant air volume (CAV) ventilation the airflow rate is kept constant independent of the requirement of the room. Eventually the ventilation could be reduced or turned off by a timer in periods.

In variable air volume (VAV) ventilation, the airflow rate is adapted to the room's requirement for air. This is often referred to as demand controlled ventilation.

2.2.3 Air distribution in building

Air could be distributed from the air intake to the rooms and to the outdoor again either by ducts, usually made of steel, or in building integrated conduits. Building integrated distribution could be culverts, or corridors and stairways.

Air distribution in room

The most usual way of supplying air to a room is by mixing ventilation. In mixing ventilation air is supplied with high velocity. The air is mixed with room air before it enters the occupied space. In that way air can be supplied at low temperatures without causing draught or unpleasant temperature differences. Pollutions are diluted down to acceptable concentrations.

In displacement ventilation air is supplied to the room with low velocity in the occupied space or close to this. The temperature is kept just below the room air temperature and the air distributes along the floor. The exhaust is placed close to the ceiling. Heat sources in the room generate convective plumes. Air from the room is entrained into these plumes. Pollutions that occur together with heat sources flows against the upper part of the room. In this way it is generated an upper polluted zone above the occupied space. The advantage of displacement is that the air quality in the occupied space is better than for complete mixing. On the other hand it is difficult to remove large amounts of excess heat without draught (max 50 W/m^2).

2.2.4 Treatment ventilation air

In our climate, it is often necessary to heat the air before it is blown into the room. Air handling units contains these units to treat the air:

- Filter for cleaning the air for particles
- Heat recovery unit
- Heating coils to heat the air if the heating in the heat recovery unit is not enough
- Cooling coils

- Humidification, but this is seldom used due to indoor environmental problems

2.2.5 Heat recovery

To recover energy from the exhaust air different types of heat recovery units are used. :

- Recuperative. The energy is transferred continuously from the warm exhaust air to the colder air entering from outdoor.
- Regenerative. By heat transfer a surface is loaded with heat from the warm exhaust air. Later in the cycle the heat is transferred from the same surface to the colder outdoor air.

2.3 Cooling

By cooling we think of ways to prevent the temperature to rise above certain limits in occupied rooms. In Norway we can use outdoor air most of the year to replace the warm room air, but during summer time other means becomes necessary. Removal of excess heat could be done by a mechanical cooling plant or by absorbing heat in heat accumulating surfaces.

2.3.1 Passive

All kind of surfaces in a building is able to absorb heat, but only heavy materials with high heat capacity is able to contribute substantially to the temperature control. That means that walls, floors and ceiling should expose concrete, stone and bricks.

In addition it could be added elements to the building to increase the heat absorbing surfaces. Ventilation ducts could be made of concrete culverts buried under the building or in the ground or it could be added thermal elements that absorbs latent heat. (Phase shifting elements)

2.3.2 Mechanical

Mechanical cooling usually consists of an electric driven refrigeration unit with an evaporator. The heat transfer from the room to the evaporator can be done in several ways as explained below.

Indirectly systems

In the evaporator heat is exchanged with water or a glycol mixture. The water is distributed to heat exchangers either placed in the room or in the ventilation air handling unit.

Water distribution:

- This is a suitable solution for rooms where large amounts of heat should be removed.
- Ceiling panels shaped as a suspended ceiling has been much used
- Chilled beams for free convection and radiative heat transfer are increasing in popularity.
- Chilled beams with ventilation air are a combination of an air terminal device and a chilled beam. In this solution the heat transfer is forced.
- Fan coils are units where a fan is used recirculate air from the room at blowing it through a heat exchanger before it is blown back to the room. These are not much use in Norway, but can be seen (and heard) in hotels.
- One reason to use water is that water is a much more efficient transport media than air.

Air distribution:

- Supply of chilled air from the air handling unit is able to remove up to 70-100 W/m². Air should be let into the room through air terminal devices that give good mixing with the room air. If displacement ventilation is used the temperature should be kept just below the room air temperature. Displacement is able to remove less heat than complete mixing.
- Chilled air could be supplied in water chilled beams to increase the cooling ability.

Combined

There are also other solutions like induction units placed below windows. Due to among other things indoor environmental problems, this solution it is not much used today.

Direct Expansion

In stead of the indirect process described above the evaporator could exchange heat directly with ventilation air or room air. Several options exist.

Window units are small complete cooling plants placed either in the window or on the façade with the condenser outdoor and the evaporator in the indoor air.

In *split units* the evaporator is placed away from rest of the plant. The evaporator could be a part of the ventilation plant cooling the air. Another alternative is *fan coil units* where the evaporator is placed together with a fan in the room.

Free cooling

Free cooling could be used when the outdoor temperature is below the conditioned space temperature. Heat is transported to the outdoor without running the compressor.

3 Technology and market

3.1 Heating

The status in Norway today is a discussion about direct electrical heating vs. central heating systems with water as energy carrier. The main point is the low heat load vs. the higher cost for the central heating system.

For local and central heating systems a numerous of components and solutions are available. The cost is about 2000 kr/kW-installed power for a central system and 1000 kr/kW-installed for a direct electric heating system.

Gas stoves with catalytic combustion are available for 200 kr/kW-installed

Wood fuel fired stoves are available for around 1000 kr/kW-installed. Biomass fired stoves for pellets and semi continuous operation costs around 2000 kr/kW-installed.

The strategy that leads to direct electrically heated houses is the low installation cost and historical low cost for electrical energy.

3.1.1 Challenges

Conversion of houses with direct electrical heating

It is a political and environmentally wish that we shall reduce the use of direct electrical heating. It is very costly to install a central heating system in an existing house. The challenge is therefore to come up with cost-effective solutions for alternative heating systems.

Low energy houses

Arguments that are for direct electrical heating in new houses are the low heat load. In super isolated houses this will reduce the heat load further. In the case of super isolated houses it could be possible to look in to central systems with air as a heat carrier. This is traditionally not a good solution but the low heat load and the need for a good ventilation system with higher airflow due to the cooling load in summer can make it possible to use air as a heat carrier.

Development in heat gain

During the last two decades there have been a tremendous development in heat gain from equipment, especially in office buildings. This is a contributing factor to the low heat load in new buildings.

3.2 Cooling

Better insulated buildings and more windows together with more use of computers and other electronic equipment has increased the heat loads in modern buildings. Together with that, it seems like the occupants of today want more comfort. Because of this use of mechanical cooling seems to be growing. Research by Wyon (1979) supports the viewpoint that cooling could be beneficial. He has shown that discrepancy from optimum temperatures strongly affects the productivity and mental performance.

3.2.1 Mechanical

Widespread solutions are central units for cooling where the ventilation air and/or water distributes cooling to rooms. Earlier chilled suspended ceilings were popular, but during the last years chilled beams has gained in popularity. These chilled beams could either be passive (with purely convective and radiant heat transfer), or active (forced convection), in combination with supply of ventilation air.

In buildings with a water as carrier of cooling, so called free cooling with water distribution is used in periods where the outdoor temperature is sufficiently lower than the room temperature.

3.2.2 Passive

By passive cooling we mean ways to control the temperature without a mechanical cooling unit. Passive cooling is more related to design and programming of the Building Energy Management System than technological products. To utilize passive cooling the building must be planned for this from an early design stage.

By using this technique both energy and costs can be saved.

3.3 Ventilation

3.3.1 Common products and solutions

In most buildings, the chosen solution for ventilation is balanced mechanical, with constant air-flow rates. Timers changing the airflow rate between to levels or on/off perform a simple demand control. Variable Air Volume (VAV) has existed for many years and is used in some buildings.

To simplify the balancing of the airflows between different ducts/rooms the pressure drops in the ventilation systems are usually relatively high giving high energy use for running fans.

3.3.2 Some newer solutions

To reduce the energy use for running fans solutions with lower specific fan power (SFP) have been developed. In Denmark regulations for maximum allowed SFP have been introduced. The investment cost for low SFP will be higher than for conventional ventilation, but running costs will be reduced.

Hybrid ventilation is a concept where natural ventilation is combined with mechanical ventilation. Natural driving forces are used when available. This solution has an extremely low SFP.

Demand controlled VAV is integrated with BUS to give an airflow rate both as a function of presence, air quality, and room air temperature.

Some years ago it was developed solutions for heat recovery from exhaust air and heating of air to reduce the number of components in the air-handling unit and to reduce the return water temperature in district heating systems. This system is called Thermonet and was developed by Fläkt Woods (previous ABB)

Displacement ventilation was developed for use in different types of non-residential buildings during the 1980's. Due to its low pressure drop it is now used for hybrid ventilation.

Klimatak is a supply air outlet for cooling and ventilation that was developed by ABB during the last years, and has gained quite high popularity.

Many of the new solutions have lower life cycle costs than the traditional ones, but one of the problems for some of these more advanced new products is that they are competing with traditional solutions that have low installation costs. Another problem is that new products that have no similar competitors cannot be described without violating regulations for competitive tendering.

The HVAC industry is quite big:

- Consists of consulting engineers, manufacturers of HVAC products, installers and service companies.
- The total turnover for the technical installations in buildings is about 33 000 MNOK. Of this 38% comes from HVAC.
- The HVAC industry employment was 13 000 persons in 2001 in 2900 companies.

4 *Interaction with other Smart Building strategies and technologies*

4.1 HVAC and User Needs

Architects

Air handling units, ducts and terminals devices are space consuming and might reduce the design freedom, and therefore give rise to problems for the architects. On the other hand some architects seems to be positive to hybrid ventilation, even if this also needs a lot of space and adds extra elements to the building, like culverts.

Natural ventilation might reduce the comfort and give higher energy bills and the same air quality level.

The architectural solutions have big influence on *cooling* loads. Both choice of windows design, direction etc and building materials will have substantial influence on the heat loads. Good solutions require a excellent teamwork between partners in the design process.

Engineers

Good knowledge about mechanical ventilation, lack of knowledge about natural and hybrid ventilation. Feed back from completed projects is lacking.

Contractors

Ventilation contractors have a bad reputation about poor quality of their installations and little or no education of the operators. Companies that have specialized on refrigeration seem to have somewhat better following up than ventilation companies, due the stronger regulations.

Operators

Modern technical installations can be rather complex and controlled by computers. The education of operators seems to be more or less absent, especially for smaller businesses and establishments. The technical installations and buildings suffer from this.

Building owners

Building owners usually have little or no knowledge about ventilation and cooling systems. When building they therefore has little consciousness about consequences of their choices.

Building occupants

The health and productivity of the building occupants relies on the quality of buildings and the buildings' technical installations.

Authorities

Several authorities supplies regulations and building codes and guidelines that impact the size and design of the HVAC solutions.

4.2 HVAC and Environmental Criteria

4.2.1 Heating

CO₂ from furnaces for heating is negative for the environment.

Negative impacts from electric heating depends how the energy is produced.

4.2.2 Ventilation

An investigation (Mysen 1999) show that in Norwegian 10 years old office buildings 15 to 20% of the energy consumption is used to run ventilation fans. This comes in addition to the energy used to heat the ventilation air.

A conventional ventilation system is mainly constructed of steel and contributes modestly to the total material use in building. In some buildings where hybrid ventilation culverts leads to an increased use of concrete.

Some challenges:

- Reduced energy use to run ventilation fans. For each building owner this does not contribute much to the total cost, but for the society this is a quite considerable amount of energy.
- Recycling. Used ventilation filters contain road dust, microorganisms and other pollutions. Most filters is mounted in a steel frame, that is deposited or burnt together with the filter. In addition most filters are made of glass fibres that are not deteriorated in deposits. New filters made of plastic with burnable frames are developed

4.2.3 Cooling

Negative environmental impacts from mechanical cooling in HVAC:

- Uses energy to remove heat
- Some working fluids have negative environmental impacts. Modern natural working fluids eliminates this problem.

Dry coolers are most common for cooling the condenser, but on some plants cooling towers are used. These are possible places for growing Legionella.

4.3 HVAC and Indoor Environment

HVAC exist mainly to generate good indoor environment for people. Sometimes the purpose of the ventilation is for instance to make good conditions for a industrial process or computer equipment, storage of food or preservation of art. Here we mainly discuss the human needs for a good quality environment.

Through heating it is possible to control the room air temperature during the cold season. It is also possible to counteract draft from windows and other cold surfaces be placing heat sources below the surfaces. By placing the heat source in the floor, it is possible to maintain good comfort with reduced room air temperature. Heating from ceiling, that was quite popular some decades ago, proved to give discomfort.

A fast change in internal heat loads requires a quick response from the heating system to keep the room temperature constant. Floor heating systems have a noticeable tendency to be slower than radiators.

In the warmer season, heat must be removed to keep the temperature at wished level. If the outdoor temperature at least is somewhat below the desired temperature, ventilation air can be used to remove excess heat. In other cases some kind of cooling might be used:

- If the temperature could be allowed increasing a few degrees thermal storage in the building construction could be used. During the day, heat is stored in the building construction and at nighttime the heat is transported out of the building by cooler air.
- If the heat load is too high, or the requirements for variations in the room temperature are too strong, then some kind of artificial cooling is needed. If the exhaust air is not too humid indirect evaporative cooling by cooling the exhaust air could be used. Otherwise, mechanical cooling of either of the ventilation air or heat exchangers in the room must be used. By this accurate temperature control can be obtained.

One must beware to avoid condensation with cooling system, i.e. surfaces in contact with room air must not be allowed to decrease the dew point temperature.

Air quality is obtained through ventilation. Usually the cooling load becomes the design value for the airflow rate. Some moments to take into consideration for ventilation and air quality:

- With high Contaminant Removal Effectiveness, the level of contaminants will be lower with the same airflow rate.
- With high Air Change Efficiency, the age of the air in the room will be lower, i.e. the transit time for the air through the room becomes lower for the same airflow rate.

The ventilation might also have some negative effect on the air quality if not designed and maintained well:

- If air intake, air handling unit and ducts are not kept clean odours can be the result
- If humidity occur in the air intake, filter or humidifying unit microorganisms might grow and impure the air quality
- Mechanical and hybrid ventilation can generate noise in the air-handling unit. Natural ventilation can transfer noise from outdoor.
- In rooms with high cooling loads draft can occur due to air “falling down” from the air terminals in the ceiling.
- Aesthetically the ventilation might aggravate the indoor environment.

4.4 HVAC and Implementation Strategies

We have interpreted this as implementation of new solutions within the field of HVAC. In general requirements that prerequisite HVAC installations in most buildings is given through laws, regulations and guidance.

The HVAC industry works with a mature technology and seems to be conservative. New innovations are not common and are to some extent confined by regulations for competitive tendering. New technologies cannot be directly described in tender invitations and this makes it difficult to introduce products that differs much from known technology. The manufacturing industry in Norway is relatively small making it further difficult to introduce new innovations.

The competition between companies is hard and profit margins are small. The investment in R&D is small, for example the two largest HVAC contractor companies has one person each working with development.

New innovation in other businesses has some influence. The increasing use of BUS-technology in buildings has increased the interest for, and generated new solutions. It seems for instance to be an growing interest for demand controlled ventilation and heating systems.

4.5 HVAC and Integrated Design

The HVAC solutions could be hidden as far as possible and/or viewed as a separate addition to the building. On the contrary they could be integrated in the building construction and also be used as architectural elements.

In general HVAC equipment is space consuming. Outdoor air intakes, air handling units, ducts, cooling machinery, furnaces and so on occupies space and reduces the flexibility of the building.

An integrated design process where all mutual influences between architectural solutions, requirements for flexibility in use of rooms, requirements for indoor environment, energy use for heating and cooling and space requirement for technical installations is very important.

Good examples of this integrated design process have been seen in some of the buildings with hybrid ventilation.

HVAC must be an integrated part of the building's energy system. In that way thermal storage and natural driving forces can contribute to reduce the buildings energy consumption.

Examples of integrated designs:

- Most solutions for hybrid ventilation are integrated with the building construction. In Norway several schools with hybrid ventilation has been built during the last years. Most of these has a culvert buried in ground and that continues into the building in the basement. This construction increases the total volume of the building and reduces the flexibility at reconstruction of the building.
- Even more than hybrid ventilation natural ventilation needs to be part of an integrated design if it is used in larger buildings. In domestic buildings natural ventilation needs less integration as windows and/or trickle ventilation are used as inlets.

4.6 HVAC and Building Integrated Energy Systems

We interpret this as a solution where the HVAC system interact directly with the building integrated energy system.

4.6.1 Heating

Solar energy could be used by solar panels for heating buildings. Either air or water could be used for energy transport. If water is used this could be integrated with a low temperature hydronic system and for instance floor heating. If air is used it could be heat exchanged with water or it could be used in combination with the ventilation.

Solar radiation through windows is available in large amounts, but is difficult to handle because it varies much with time and is most available when it is less needed. Thermal storage is necessary to utilize this.

The use of exhaust air in combination with heat pumps to produce warm tap water or water for a low temperature heat distribution is discussed in 4.8.

4.6.2 Ventilation

In double skin façades the cavity behind the outer glazing could be used for preheating of ventilation air. Usually the air enters the space at the bottom of the façade. In mechanical ventilation system the air is drawn from the cavity and into the air handling unit. For summer conditions this preheating of air is unwanted and another intake of air ought to be used. If the wall is supplied with photovoltaic elements the cooling effect from the circulation air is an wanted effect.

In buildings with natural or hybrid ventilation air could be drawn directly from the cavity and into the ventilated rooms.

A window that allows air to flow between glasses is another option. If outdoor air is drawn through the window transmission heat from the room preheats the air before it enters the room. In this way the transmission heat loss through the window is almost completely eliminated. If exhaust air from the room is drawn through the window the inner glass gets approximately room air temperature and the heat transfer between room air and glass is eliminated. This system works best with laminar flow.

In “dynamic walls” ventilation air is drawn through a porous insulation media. If outdoor air is drawn through the insulation the transmission heat preheats it and the transmission heat loss is eliminated. The flow could also be in the opposite direction eliminating the heat transfer between room air and wall.

4.6.3 Cooling

Heat accumulative surfaces in the building could be used to reduce the temperature inside the building in warm periods. During the night the colder ventilation air is used to cool down surfaces in rooms. As the room temperature increases the next day heat is absorbed by the surfaces. To work effectively it requires large areas of heavy materials like concrete. The surfaces must not be isolated from the room air by suspended ceilings or any other kind of thermal insulation. Using culverts for the supply of ventilation air could also increase the heat accumulating surfaces.

4.7 HVAC and Lighting Systems

4.7.1 Heating

Daylight also supplies heat, but at our high latitudes the supply of daylight is in antiphase with the demand for heating. During spring and autumn heat that is supplied from daylight can be stored in the surfaces of heavy materials and be utilised during the night.

Electric light supplies heat that is a direct contribution to the room heating during the heating season. In principle the electric lighting system could be designed as a part of the heating system, however, this means that the light should be let on during the night.

4.7.2 Ventilation

An example of a system where daylight and parts of the ventilation system is combined is found at Grong school. This school has a hybrid ventilation system. A large duct placed as a solar collector at the roof collects air from the classrooms. This sunspace has windows both to the outdoor and towards the classrooms so daylight can be transmitted to the classrooms. The idea is that heat

from the sun should be collected by the exhaust air in the sunspace and recovered in the heat recovery unit.

Some decades ago a system where fluorescent tube fixtures were combined with room air exhaust were popular. The idea was to collect heat from the electric light before it entered the room. This product seems to have disappeared from the market, probably due to problems with cleaning and maintenance and reduced flexibility.

4.7.3 Cooling

Heat from both natural and electric light has substantial influence on the heat load. Heat from window irradiated by the sun usually decides the design values both for cooling and/or ventilation airflow rates. It is therefore important to use effective solar shading systems.

4.8 HVAC and Heat Pumps

Heat pumps play an important role in HVAC and we can think of the HP as a component of this. In buildings we have a lot of low temperature energy like in exit air (Exhaust air that has passed through the heat recovery unit).

4.8.1 Heating

Modern buildings have relatively small heat losses. This means that the heat transferring surfaces could be either small or the temperature differences small. If we choose to use for instance floor heating the supply temperature could be 35 to 45 °C. For radiators the supply temperature could be about 50 to 55 °C. This means that building heating is well suited to use a heat pump as a heat source.

4.8.2 Ventilation

In connection with ventilation, we can use a heat pump for different purposes:

- The heat pump could be used for heat recovery. Heat is taken from the exhaust air and supplied to the supply air. However, usually the economy of using an ordinary heat recovery unit could be much better.
- In swimming pools the system described above in combination with recycling of air is used conventionally. The main purpose here is to dehumidify the air. Excess heat from the heat pump could be used to heat the water in the swimming pool.
- The energy in the exhaust air could be used to heat tap water or water for the heating of the building. Some systems combine these two functions. A challenge here is thermal storage to level out peaks in the need for heat or tap water.
- The ventilation air often needs some heating additional to the heating from the heat recovery. However, this appears for shorter periods and requires relatively high power, that is not beneficial for the heat pump solution.

4.8.3 Cooling

Heat pumps that are used for heating during the heating season could be use for cooling during the summer.

4.9 HVAC and Operation and Automation

HVAC was one of the first installations that started to use automation to control the temperature. HVAC was also the first fields where Computerized Diagnosis and Operation systems (CDO-systems) were implemented. The first CDO-systems were only a central interface against the HVAC systems with possibility to collect data. The controllers were analog and all the CPU-power was in the central computer. Today the CDO-systems can be integrated with all the technical installation down to the components in a single room and the CPU-power has moved out to all the components in the system.

The main goal of CDO-systems is to optimise the operation of all technical installations and HVAC systems represents a large part of the energy flows in the building. They are therefore closely connected.

The challenge now is to put to use all the possibilities that the system opens up for. But also keep the systems simple and robust.

There are many standard tasks in optimisation of operation that are implemented in the CDO-systems. Examples on this are optimum start and stop in systems with night setback of room temperature and Systems for monitoring the energy consumption etc.

There are still many possibilities to use the CDO-systems to optimise the use of the heating, cooling and ventilation systems to fulfil the user needs and at the same time reduce the energy consumption in the HVAC system.

Examples on new possibilities of optimised operation:

- Continuous monitoring of the indoor climate
- Night free cooling
- Optimum supply temperature for ventilation systems

4.10 HVAC and Storage

Here we interpret storage as storage of thermal energy.

In addition to seasonal variations, the demand for heating and cooling varies with the time of the day and from day to day. In domestic buildings the heat demand due to use of tap water and increasing the room temperature is big in the morning. In office buildings with nighttime setback of the temperature the heat load is also big in the morning. Later in the day, there might be excess heat due to energy supplied from sun, persons, and equipment.

During the summer season the highest cooling loads occur in the afternoon, while the outdoor temperature could be quite low during the night. Between days heating or cooling loads shift due to changes in the weather.

Maximum power loads could be reduced if some energy could be supplied from storage. In periods with excess heat energy could be put into the storage. This would reduce the total need for energy.

Some of this storage effect is naturally present in the building's materials, like concrete and surfaces. In addition external storages could be constructed, either included in the building or separate.

Since some of the variation in heat load is from hour to hour the storage should store and supply energy with high power. On the opposite, we have the seasonal variations where the storage should be able to conserve energy for month.

4.11 HVAC and Building integrated Photovoltaics

4.11.1 Heating

The energy contribution from PV is too limited to be used directly for space heating. However, PV might be combined with solar panels and double skin facades.

4.11.2 Ventilation

Ventilation can be combined with PV for cooling the elements. This is partly done in some double skin facades. At the same time this acts as a preheating for the ventilation air.

PV could be used to supply energy to fans for supplying air for cooling purposes.

4.11.3 Cooling

The maximum output from PV often occurs at the same time as the maximum demand for cooling. Therefore PV could be used to supply energy to run for instance dry cooler DC-motor fans that is often situated at the ceiling of buildings.

Another occurrence that appears together with high output from PV is the demand for solar shading. This means that PV-energy could be used directly to move blinds etc.

The PV-element could also be arranged to act as a shading themselves.

5 *HVAC and Smart Buildings*

5.1 **Demand controlled ventilation and room heating**

With a smart building system, demand controlled ventilation can be fully utilized. It can adjust the ventilation and temperature in the room to the instantaneous loads. It can foresee coming use of the room and prepare the HVAC system and the room for future loads. For instance:

- The ventilation starts some minutes before the user enters the room.
- The room temperature is reduced in no occupied periods and raised to required level again before the occupant enters the room.
- The system foresees changes in weather and prepares the building thermally for that. Using free cooling at night before warm days, heating at night before cold periods.

With smart buildings, the size of the installations might be reduced because peak loads is levelled out and simultaneity is taken into account in a more accurate way. Smaller size means smaller investment costs and lesser use of materials. Further, the energy consumption is reduced, both energy for heating and electric energy for fans.

To utilize the smart building concept entirely ventilation solutions that is more flexible is needed.

Systems that can operate without an uneven distribution of air at a wide range of airflow rates are needed. (Uneven distribution applies both between rooms and within rooms) This type of ventilation can benefit from natural driving forces.

Further, it is a need for sensors for different aspects of air quality that is more reliable

Smart building systems could be used for fault diagnosis of HVAC installations by analysing the energy use and building behaviour.

Choosing of energy source for heating could be done with regard to:

- Environmental criteria
- Energy prices
- Weather forecast

5.2 **Thermal storage**

Optimum use of thermal storages needs predictions about when loading and unloading is expected. This is due to both storing of thermal energy in building materials and in separate storages.

5.3 **Tap water**

The heating of tap water amounts to roughly one fourth of the energy use in domestic buildings. During the heat up the energy consumption and power is high and in the storing period there is some heat loss. With a smart building's system, the heating period could be better adapted to the user period and to the electric energy consumption in the building.

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6.2 Some central R&D institutions

Aalborg University, Department of Building Technology and Structural Engineering, Denmark

Department of Construction Management & Engineering, University of Reading

ETH Zürich, Air & Climate Group, (Interdisciplinary Research Group of Air Flow Simulation, Computational Fluid Dynamics for Buildings, and Indoor Climate)

Helsinki University of Technology, Laboratory of Heating, Ventilating and Air-Conditioning

Institut National de Recherche et de Securite (INRS)

Lawrence Berkley, Indoor Environment Department, Energy Performance of Buildings Group

Lawrence Berkley, Indoor Environment Department, Commercial Building Ventilation & Indoor Environmental Quality Group

Royal Institute of Technology (KTH), Byggd Miljö, Gävle

Royal Institute of Technology (KTH), Bygghälsa – Installationsteknik, Stockholm

Statens Provningsanstalt, Borås

Technical University of Denmark, International Centre for Indoor Environment and Energy

VTT Building Technology, Indoor Environment and Systems

VTT Building Technology, Energy and Sanitary Technology

6.3 Industry

ABB

Auranor

Bruvik

Carrier

CTc FerroFil

Danfoss

Dantherm

Fläkt Woods

Flexit

Gunnar Karlsen

Halton

Lindab

OSO Hotwater

Stifab Farex

Sulzer Infra Laboratory

Systemair

Tipro Nova

Wirsbo Norge