Heating and cooling challenge in nZEB

Experiences from built houses and detailed building simulations calls for a careful and integrated approach when designing heating and cooling systems for nearly zero energy buildings

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Introduction

Building codes are presently moving towards new low energy standards with annual primary energy rates gradually approaching net zero energy levels. One can rightly ask what implications this has for the design and layout of heating and cooling systems. There is clearly a need to adapt our current systems in such a way that they optimise both energy use and comfort requirements in low energy construction. Even nearly zero energy buildings require some energy input to maintain an acceptable indoor climate, and the task is to ensure that the supplied energy is utilised for an optimal indoor environment.

Legislation and building labelling

The EPBD recast of May 2010 introduced nearly zero energy buildings (nZEBs) requiring that all new buildings in member states shall be nZEB from 31 December 2020 – and that public buildings shall lead the way and be nZEB from 31 December 2018. A zero energy building is most often defined as a building with zero net energy use on annual basis or zero

"Trelleborg huse" in Denmark. An example of newly designed mass produced low energy houses specified with radiant under floor heating and cooling controlled by a dynamic energy management principle. The house has mechanically-balanced ventilation with heat recovery, a double heat pump (ground heat and hot water with solar connection). Active summertime floor cooling is applied using the ground heat loops. (Source: Trelleborg and Uponor).

net carbon emissions, but different definitions exist and different approaches will be taken and adapted in national building codes. Very low energy demand buildings or even positive energy buildings are already being constructed in significant numbers throughout Europe.

In addition to the official national building regulations, a number of voluntary labelling schemes exist in the European markets, such as MINERGIE® and passive house standards. The passive house concept has proven successful in providing single family houses with very low net energy need for space and ventilation heating meeting a threshold typically around 15 kWh/m², but with remaining issues to be resolved for user comfort, indoor climate and energy optimisation. Meanwhile, the concept is being challenged by different active house concepts that aim at optimising the balance between indoor climate, energy and environment, with the most known example of MINERGIE®. Some active houses even produce more energy than they use and therefore become net energy suppliers to the public electricity grid and possibly also heating networks.

As the overall energy use is lowered, it is evident that the overall energy efficiency becomes a more important issue. We need a more integrated building design and more attention should be given to the integration of the building in its environment. In other words, the engineering focus is shifting from energy savings to energy optimisation.

This article describes heating and cooling needs in typical low energy houses which are built to adhere to the climatic conditions in Nordic countries. In particular we have simulated the performance of low energy houses build in accordance with the current definition of low energy buildings in the Danish building code (BR 2010).

The Danish building code operates with maximum primary energy use for space, ventilation and hot water heating as well as HVAC-electricity based on a fixed element plus a variable element depending on the heated space. The Standard Regulation 2010 stipulates a maximum primary energy use of $(52.5 + 1650/A)$ kWh/m² per year and the Low Energy Class 2015 stipulates a maximum primary energy use of $(30 + 1000/A)$ kWh/m² per year, where A is the heated space in m²-gross.

The Danish Low Energy Class for 2020 is in preparation and is expected to be ready in spring 2011. The final requirements have not be settled and decided on yet, but the working definition stipulates a primary energy frame defined as $(15+500/A)$ kWh/m² per year in 2020.

Engineering challenges – for all seasons

Designing for a proper indoor climate in nZEBs implies a number of challenges. There is a great need to adapt building services to low energy standards as even passive buildings need a small amount of energy to remain inhabitable with an adequate indoor environment year round. Ventilation, heating and cooling strategies need to be planned in order to maximise the use of renewable sources and thus limit the environmental impact. The required energy must be supplied utilising the lowest cost and most environmentally-friendly energy sources possible.

The heating system must meet the heat need with the lowest possible use of primary energy. In well-insulated buildings equipped with heat recovery, the heating system must operate on the basis of a very low average heat need while remaining reliable and energy efficient during peak load periods. The improved thermal envelope will shorten the annual operation time, but peak load situations need to be designed very carefully in order to ensure adequate system capacity.

Another challenge is to optimise the thermal envelope and architecture in such way that the summer cooling loads are minimised. In principle the energy use for heating and cooling should be optimised during building design. Clearly passive measures like solar shading, geometry and building orientation should of course always be exploited to a maximum, but much evidence still points to severe overheating problems in well insulated buildings. Often overheating is not even limited to the hot summer months.

Typically large heat gains from the sun can start to heat up a building already in March and April, with a similar pattern in autumn. The heat gains entering the house as solar radiation through the windows can be several hundred W/m², largely exceeding the dimensioning heat power. The heat gains from the sun combined with the internal heat gains create a need for cooling, even in the colder seasons.

End user experiences

Experiences from low energy houses that have already been built show that several issues regarding comfort and energy performance remain unsolved. According to the indoor climate comfort criteria, thermal comfort for inhabitants requires an indoor temperature of

between 20 and 26°C when occupied, but there is often a significant difference between what is calculated in the design phase and what is really experienced by the end user.

Residents typically suffer discomfort from overheating in the summer and cold due to low temperatures outside the comfort range in the winter. This often translates into missed heating and cooling capacity and an expressed wish to have more direct user influence on the technical heating and cooling systems.

In addition, people with heat pump installations often experience their electricity bills being much higher than the design expectations. This is most likely a result of heat pump installations running at none-optimal supply levels and in none-optimal operating schemes.

Case studies

In order to adapt heating, cooling and ventilation system design to low energy standards, Uponor has carried out extensive simulations of low energy buildings located in different locations throughout Europe. The simulations were made for annual net energy need for space and ventilation heating within the range of 10 to 25 kWh/m² per year with heating power needs within the range of 20 to 40 W/m². The building simulations were carried out using the building simulation software IDA-ICE Indoor climate and Energy 4.0.

The simulations were made for building geometries corresponding to the current national building codes based on real buildings currently being constructed by local house builders.

Table 1 specifies input data for a Danish case study. Weather data from a Danish reference year is used, and most findings would be applicable in similar climatic conditions in Northern Europe. All employed data such as U-values, loads, ventilation and infiltration rates were specified according to the Danish building regulation BR2010. Internal heat gains with a total maximum of 5 W/m² (persons 1.5 W/m² and equipment and lights 3.5W/m²) were specified according to a detailed occupancy schedule. The "standard" input data corresponds to the minimum requirements in the current building codes, whereas the "low energy" input data corresponds to the insulation and tightness requirement stipulated in the Low Energy Class 2015.

Heating season and peak loads

Exposing the test house to the Danish reference year shows that the heating season for the standard house

Table 1. Input data for building envelope, ventilation and infiltration for a Danish low energy case study.

	U-values [W/m²K]	
	Standard	**Low energy**
External walls	0.23	0.18
Roof	0.13	0.10
Ground floor	0.10	0.09
Windows	1.56	1.09
Doors	1.56	1.09
Ventilation max efficiency	85%	85%
Infiltration	0.13 l/(s m²)	0.06 l/(s m²)

adds up to about 4500 hours while the low energy insulation and tightness measures reduce the heating season to about 4000 hours. The low energy building standards typically reduced the annual net energy need by 30% or more while the peak loads only typically reduced by 15%.

The heating peak loads have been calculated excluding the internal heat gains and solar heat gains. Transmission loss, infiltration and ventilation losses are calculated when the outdoor temperature is -12°C and room the temperature is 20°C. The peaks for the space heating power need are calculated for an air change rate at 0.5 ach supplied at temperature of minimum 18°C.

For the low energy house, average peak loads above 14 W/m² (total 2000 W) only occur for a very limited time period of about 70 hours per year. It is nevertheless crucial to take the extreme peak into consideration when designing the capacity of the heating system, in order to meet the indoor comfort requirements. There is a large peak load variation between rooms and peak loads of up to 22 W/m² (south facing rooms) and 32 W/m² (north facing rooms) can be observed during the standard Danish reference year. Relying on average values for capacity design will most certainly lead to discomfort.

The large variation in heating power needs between rooms supports the need for individual room controls. Furthermore, it is of course important that central heating systems are properly commissioned and controlled in order to prevent improperly balanced water flows in the system.

A typical design misconception is that the free heat contributions from solar and internal heat gains are equally distributed over time. As seen in **Figure 1** this is far from being the case. Nevertheless, capacity dimensioning is in many cases done with average values, assuming an average contribution from the sun and an internal heat gains based on a standard number of people using the house. This is a simple explanation for many insufficient heating problems in practice.

Need for Cooling

Several tendencies indicate that the need for cooling in residential buildings is generally increasing. This is partly because we experience more extreme weather types with warmer summers, because people's requirements for indoor comfort are rising and last but not least because of low energy building codes with stricter requirements for tightness and insulation have brought about significant cooling loads during the warmer seasons.

This trend is confirmed by the building simulation, which identifies significant cooling loads that of course depend on applied solar shading. Peak loads of more than 60 W/m² are identified, in particular in rooms exposed to the south and south-west. In addition, for the

cooling loads a very high variation occurs, mainly due to the room orientation, so one has to be careful when using average building values for design purposes. Direct sunshine has the most significant influence on the cooling loads and therefore the cooling peak loads don't necessarily occur on the "warmest day". Instead they are dependent on the building geometry and its orientation.

If there is no cooling at all in the building, the temperature will be outside the comfort range (20-26°C) for about 20% of the time for a standard house and about 30% of the time in a low energy house.

As can be seen in **Figure 2**, shadings can reduce the cooling loads to some extent, but not fully eliminate them. The applied external shadings have an 86% shading factor and the in-between shadings have a 50% shading factor. The shadings are applied in the period from 1 March to 30 September and only during the daytime between 8am and 5pm, when it is assumed that the house is not going to be occupied. Weekend occupancy patterns are assumed to be similar to weekdays.

The calculated cooling loads excluded the part being covered by the ventilation system. The inlet air of the
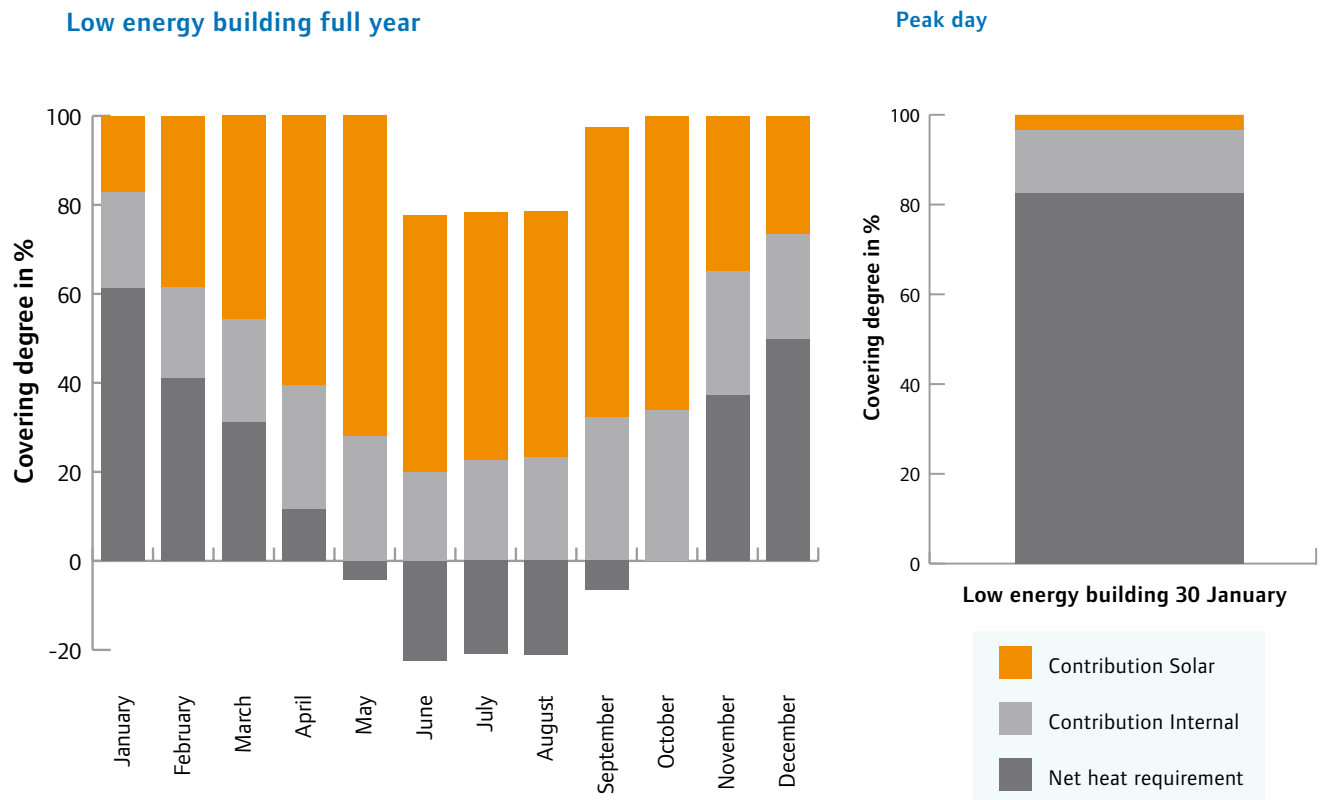
Low energy building full year

Peak day

Figure 1. During the coldest month (January) solar gains and internal heat gains nearly cover 40% of the heat power need on an average basis. On the coldest day, however, the free contribution is less than 20%.
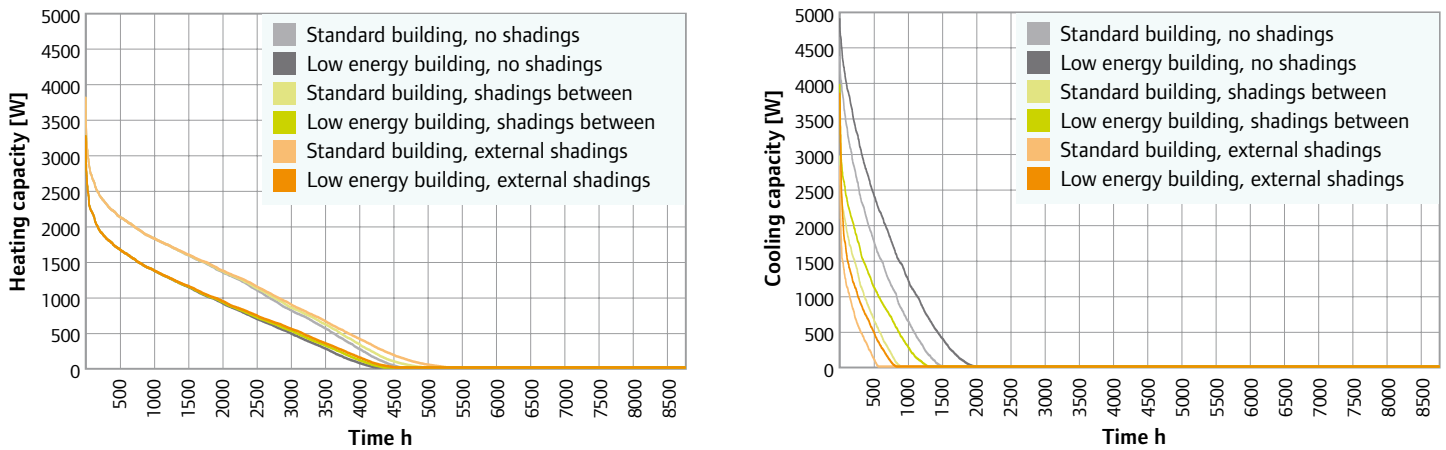
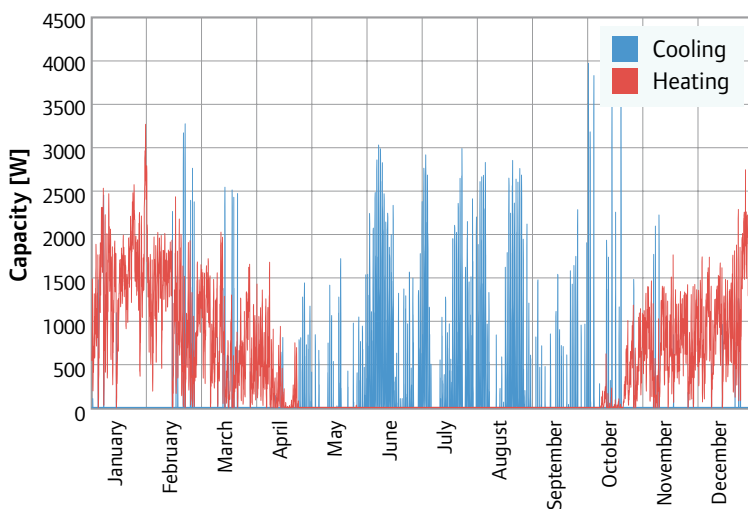**Figure 2.** Duration curves for heating and cooling needs (Danish test house).

Figure 3. Cooling loads are present in summertime as well as throughout the intermediate seasons. Applying shadings can reduce the building average cooling peak loads to around 25 W/m².
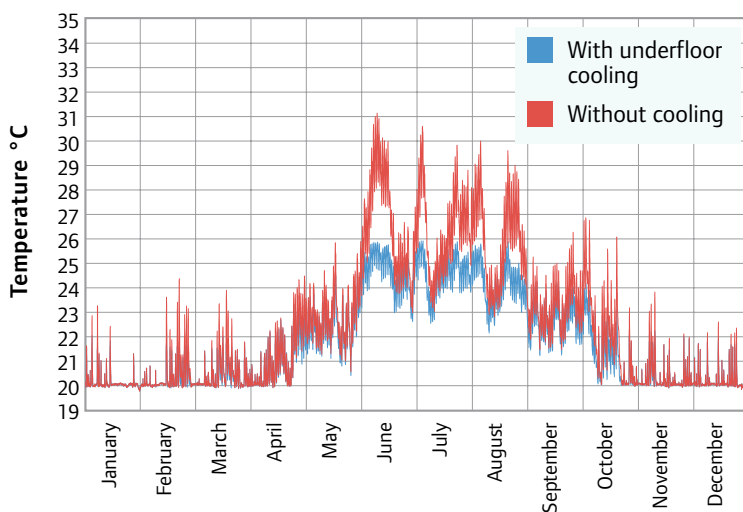

Figure 4. An under floor cooling system designed with supply water temperature at 14°C, return temperature 17°C and thermostat set point at 24°C yields a cooling output of 30 W/m², sufficient to maintain the room temperature at levels below 26°C.

ventilation system was supplied with a temperature of 18°C at an applied air change rate of 0.5 ach for the total volume of the building. During the summer period there was a by-pass for the HRV unit when the outdoor temperature exceeded 18°C. As long as the outdoor temperature is lower than the indoor temperature it is possible to allow the cooler outdoor air to enter the room and reduce any overheating effect.

Proper use of shading of the windows from direct sun radiation and other passive measures should always be the first steps taken to reduce cooling loads. In the simulated case this can reduce cooling peak loads to 25 W/m². The remaining part of the cooling loads need to be removed by active or passive cooling. Using electricity (compressor cooling) for active cooling by the ventilation system, will in most cases not be possible within the nZEB energy frames. Instead, by using a combined under floor heating and cooling system, the cooling need can be met by using floor cooling with a flow temperature relatively close to room temperature, typically at 15-17°C. With this favourable temperature level the cooling needs can be covered with minimal energy use, for example via free cooling from the ground or with a ground coupled heat pump.

Primary energy use

Heat pump technology is widely used in low energy houses and is an important way to reduce the primary energy use. The overall efficiency of heat pumps strongly depends on the supply temperature in the heating system. The lower the supply temperature, the higher the efficiency. A rule of thumb suggests that lowering the supply temperature in the heating system by 1°C will yield a reduction in annual heat pump electricity use up to approximately 2%.
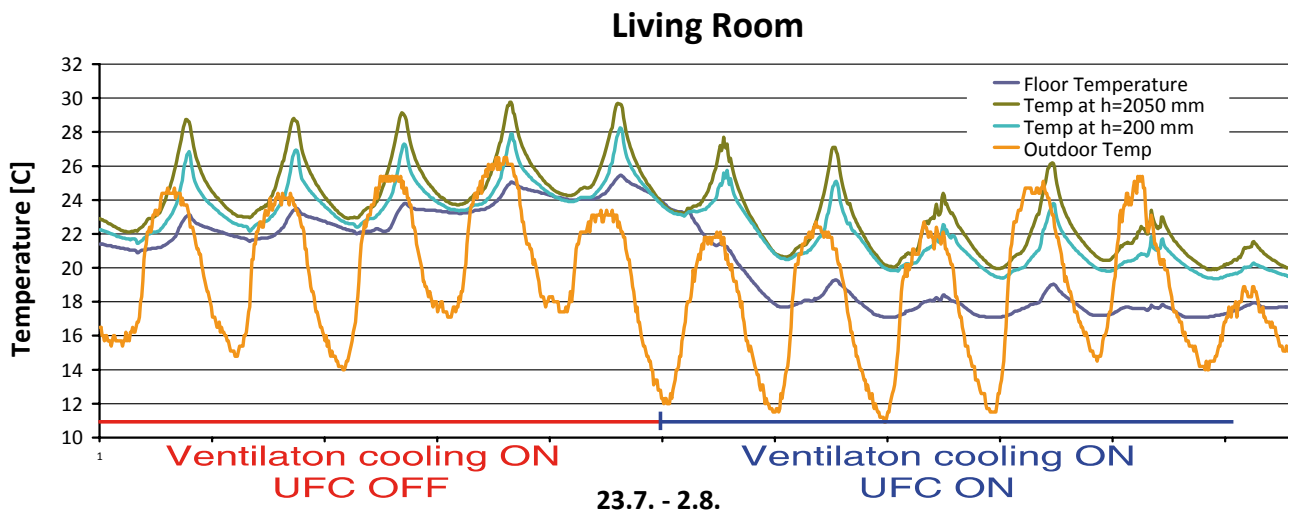
Living Room

Figure 5. Example of applied radiant under floor cooling in a Finnish single family house (source: Uponor).

A low supply water temperature requires that the heat transmission takes place over relatively large surfaces as applied in under floor heating systems, for example. The favourable temperature levels make it possible to operate heat pumps at a favourable seasonal performance factor.

As an example, when using a brine water heat pump, if the heating system is designed with low temperature heating operating at a supply temperature of 30°C instead of a conventional system with a supply temperature of 50°C, this will yield an annual saving of about 20% to the electricity bill, depending of course on the heat pump type and other parameters (see **Figure 6**).
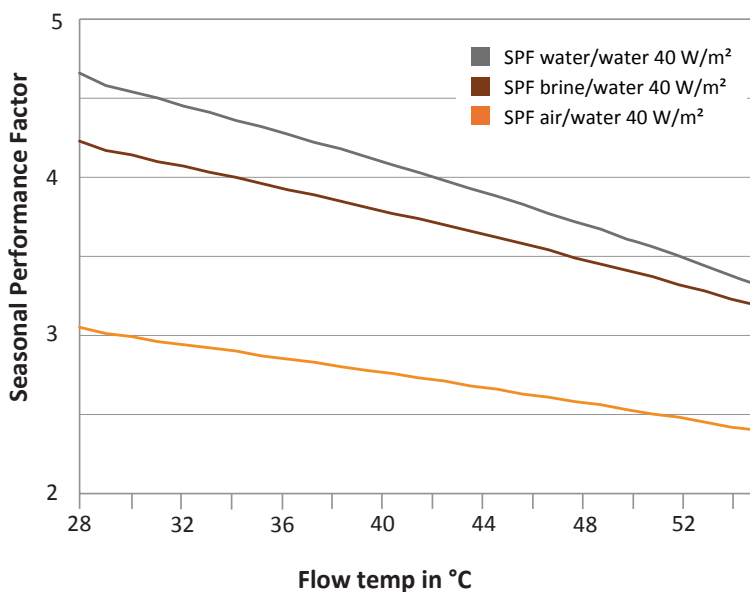

Figure 6. The influence of the supply temperature on the seasonal performance factor (SPF) for different types of heat pumps installed in a low energy single-family house. The SPF is calculated based on a 6 kW heat pump model using VDI4650.

Summary and perspectives

Nearly zero energy buildings are already being constructed and inhabited in significant numbers throughout Europe. Reducing the net energy need for space heating has proven to be successful, when applying passive measures such as improved insulation and building tightness. Various aspects of comfort, energy efficiency and optimised use of primary energy calls for an integrated design approach for building architecture and building services.

If the focus is only on the reduction of the required heating energy, there is a risk that the comfort of the occupants is neglected. It is important to design the building geometry in such a way that periods with temperatures outside the thermal comfort criteria are minimised. It is equally important to design the heating, cooling and ventilation systems in such a way that the cooling loads can be removed efficiently with minimum extra energy consumption, preferably using free or renewable cooling sources.

In order to utilise our energy resources in an optimal way, it is suggested that integrated low temperature water-based systems are a key element in the future construction design practice and energy system design.

At the end of the day, marketable solutions which potential house owners are actually likely to be willing to invest in are the joint responsibility of the different parties involved in the design and construction of nearly zero energy buildings. **3C**