Role of Building Automation related to Renewable Energy in nZEB's

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Summary

The Energy Performance of Buildings Directive (EPBD) requires all new buildings as from 1.1.2021 to be built as nearly zero energy buildings (nZEB's) that combine a nearly zero or at least very low energy use with a significant share of renewable energy. This ambitious aim will lead to significant changes of the actual buildings standards in all European countries.

Compared to actual new building practice, nearly zero energy buildings require well a mastered equilibrium between minimized energy losses, internal gains and the remaining energy needs. In most cases control systems will be necessary to reach this equilibrium, especially in non-residential buildings.

Therefore, the role and potentials of building automation in the context of future nearly zero energy non-residential buildings were examined in this project.

In a first step of this examination the relevant background concerning the common practice of building automation in non-residential buildings are discussed. Then the demand characteristics of different buildings types at different climate conditions as well as the supply characteristics of on-site renewable energy and the possibilities of energy storage are described.

This analysis resulted in the identification of the following most relevant building automation functions:

1. **Central, concerted control of all energy related components**
to tap all "internal" potentials and to insure that the whole system can work with highest efficiency
While sophisticated central systems with producer-independent compatibility are commonly available, they need to be developed and supported further to arrive at a necessary standard requirement for nearly zero energy buildings.

2. **Monitoring and providing feedback**
a) to insure that the demanded and calculated (low) energy demand of the nearly zero energy is met
This will be one of the key aspects to help to meet climate goals.
b) to encourage the users to save energy
The expected saving potential of this indirect efficiency measure are estimated to be up to 30 %, for example in nearly zero energy hotels or offices.

3. **Load shifting and storage management**

   a) to increase the coverage rates of by renewable energy on site (PV)
   The expected increase of total coverage rate by building automation without additional storage is estimated to be up to 5 % in southern European regions
   b) to increase free cooling potentials in central and southern European regions
   Free cooling potentials are often still untapped, but necessary to reduce cooling demand significantly
   c) *to increase grid stability.*
   The challenge to maintain grid stability will become larger with increasing penetration of renewable energies.

4. **Ensuring the thermal comfort**

   Especially important at highly efficient but slow reacting systems, like concrete activation or floor heating.
   Industry needs to develop /improve control mechanisms, which are specialized to control slow reacting systems in nearly zero energy buildings (e.g. by using weather forecasts)

Summarizing it can be stated that building automation will have to play a key role for the successful implementation of nearly zero energy buildings. Building automation is needed as the connector of all the single requirements for nearly zero energy buildings, such as a well-insulated and airtight building shell, efficient HVAC system and a high share of renewable energy.

Building automation will be needed to reduce the primary energy consumption, especially by automatic-optimisation- functions, to increase the amount of (directly usable) renewable energy, on- and offsite and to monitor the success of the building concept in real operation.

Not at least building automation will also be necessary to provide a good thermal comfort in nearly zero energy buildings.

An important precondition for a successful application of building automation in nearly zero energy buildings is a very low energy consumption by the building automation itself.

To ensure that the indicated potentials of building automation are achieved different actions from different stakeholders will be necessary. As indicated in chapter 6 some of those need to originate from policies, e.g. to develop an adequate regulatory basis or to create awareness. Others need to come from industry to provide suitable products.

Finally, many aspects of building automation will need to be further investigated before their full benefits can be reaped. Testing and monitoring of realized nearly zero energy buildings with integrated building automation systems will be key for optimising their potential.

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1 Introduction

Buildings consume about 40% of total final energy requirements in Europe in 2010. It is the largest end-use sector. The tertiary sector in the EU shows a small decrease in energy use per employee (-3%) but a strong growth in *electricity* consumption per employee (16%) due to economic growth in eastern European countries and ICT (earlier these decades). Countries with a high level of economic welfare show stable or even decreasing electricity consumption per employee.[1]

Over the last 20 years in Europe electricity consumption in European non-residential buildings has increased by a remarkable 74%. This is caused by technological advances over the decades where an increasing penetration of IT equipment, air-conditioning systems etc. means that electricity demand within this sector is on a continuously increasing trajectory.[2]

The European Union is heading towards regulation for nearly Zero Energy Buildings (nZEB).

As from 31.12.2020 the recast of the EPBD - Energy Performance of Buildings Directive (COM 2010/31/EU) on it requires all new buildings to be "nearly zero energy buildings".

The EPBD defines a nearly zero energy building as follows:

[A nearly zero energy building is a:]

"Building that has a very high energy performance… [ ]. The nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby."

Although the expression "nearly zero or very low amount of energy required" is not specified and also a cost efficiency needs to be considered it is obvious that nearly zero energy buildings will have a significantly reduced energy demand, compared to the requirements of actual national regulations. In addition also the share renewable energy supply will be increased significantly[3] [4].

The requirement of a significant share of renewable energy on-site could be a challenge, also depending on the choices member states make for the period of balance in the NZEB calculation and for metering schemes.

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[1] ADEME, Energy Efficiency Trends in Buildings in the EU, September 2012

[2] B. Atanasiu et al, Europe's buildings under the microscope - A country-by-country review of the energy performance of buildings, BPIE, 2011

[3] Boermans, Thomsen et al., Principles for nearly-zero energy buildings, Buildings Performance Institute Europe (BPIE), 2011

[4] Hermelink, Pagliano, Voss et al. 2013. Towards nearly zero-energy buildings - Definition of common principles under the EPBD. Ecofys Germany GmbH. 2013

The main questions, which should be solved within this study are:

Which types of buildings offer the best chances to benefit from automation?
Which type of energy demand and/or which types of renewable energy are most suited to control?
Which indications or conclusions can be found that help direct policy towards meaningful and feasible regulations regarding building automation to reduce the energy demand of future non-residential buildings significantly and to optimise the use of renewable energy?

Energy consumption in buildings can be divided into energy use related to the indoor climate and energy use related to production processes (e.g. IT equipment in offices) . The first category is strongly related to the building (design) and the second category is strongly related to the use of the building and its occupant(s). Both categories overlap to certain extent: Energy consumption for business processes adds heat to the building which affects the indoor climate.

Energy consumption for indoor climate in central Europe originally mainly concerns heat, although also electricity consumption is involved (fans, compressors, pumps, controls). With regard to expected requirements for nearly Zero Energy Buildings the heat demand will be reduced significantly. Energy consumption for business processes mainly concerns electricity, although some production processes require (also) heat (or cold).

1.1 Building automation

One of the main goals of building automation is to help improve indoor climate by taking over related *actions* from occupants without taking over *control*. Successful application of building automation can be found in cases where changes in circumstances strongly affect indoor climate and/or changes are unpredictable and/or operands are mutual dependable which results in a complex behaviour, too complex for occupants to deal with themselves.

Another important goal is to minimize the energy demand. Energy prices in the future will depend strongly on availability of energy.

The spot market of electricity already shows extreme price variations (see Figure 1). Traditionally consumers tariffs are calculated on a comparably fix. Usually they are dependent on the total energy demand and the peak load (mostly: the higher the demand, the lower the tariff). More and more companies offer reduced off peak tariffs e.g. for heat pumps. In the near future with increased implementation of smart grids it can be expected that the flexibility of tariffs will increase.

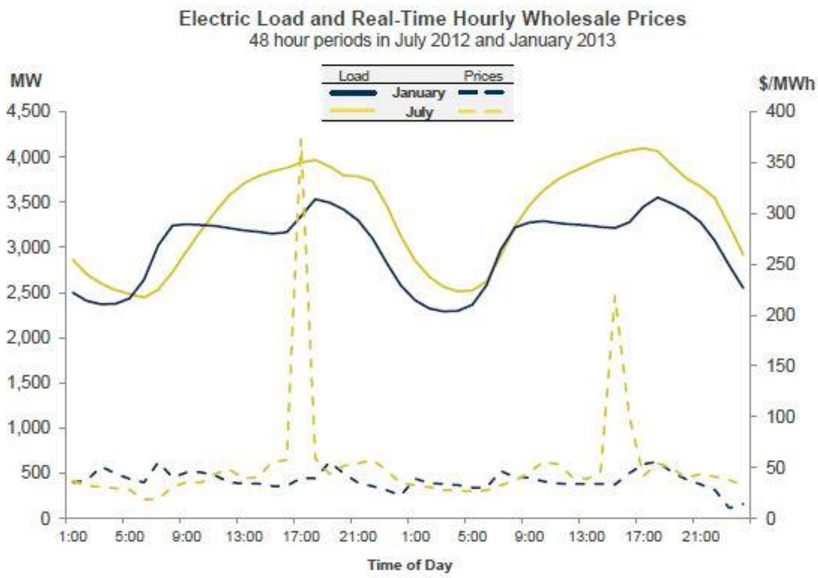

Figure 1 Typical power demand curve on a regional level and corresponding fluctuation of pricing.

Buying energy when needed without any consideration will still be possible but will surely result in a higher price. Buying energy at the right moment requires continuous monitoring of volatile prices, which can easily differ by a factor of 10. Consumers will leave decisions about when to buy and when to sell own produced energy to the building automation, only specifying priorities and boundary conditions for buying and selling energy. Communication and information-exchange with the rest of the grid is crucial. Without building automation the instrument of energy pricing to shift towards a sustainable situation will be less effective.

1.1.1 Energy performance of buildings – Impact of Building Automation, Control and Building Management (EN 15232:2012)

The standard EN15232 "Energy performance of buildings – Impact of Building Automation, Control and Building Management" provides guidance for taking BACS and TBM functions as far as possible into account in the relevant standards. This standard specifies:

- A structured list of control, building automation and technical building management functions which have an impact on the energy performance of buildings;
- A method to define minimum requirements regarding the control, building automation and technical building management functions to be implemented in buildings of different complexities;

- Detailed methods to assess the impact of these functions on the energy performance of a given building. These methods enable to introduce the impact of these functions in the calculations of energy performance ratings and indicators calculated by the relevant standards;
- A simplified method to get a first estimation of the impact of these functions on the energy performance of typical buildings.

A structured list of functions relates to 4 classes of building automation. In general terms these classes can be described as:

Class	Description
A	High energy performance BACS and TBM (including renewable energy optimization)
B	Advanced BACS and some specific TBM functions
C	Standard BACS
D	Non-energy efficient BACS

Classification is based on various functions of BA. Description of the functions depends on the working area (HVAC, DHW, auxiliary energy). In general terms these functions can be described as:

Function-level	Description
0	No automatic control
1	Central automatic control
2	Individual control
3	Individual control with communication
4	Individual control with communication and other feedback

The standard provides also an assessment or calculation of (detailed) BA efficiency factors for heating & cooling, DHW and auxiliary energy. Since BA interacts strongly with the realm of user behaviour, assessment of these efficiency factors include a large uncertainty, at least on the level of an individual building.

EN 15232 standard offers two different procedures for calculating the energy efficiency of automation, control and supervision systems:

- Detailed calculation
- Calculation based on efficiency factors (BAC factors).

The detailed calculation is applicable only when a system is completely known. The method of efficiency factors, which is based on measurements and calculations performed on a large number of different types of buildings, in rooms with different boundary conditions, is useful for estimation in the initial phase of building project.[5]

The detailed calculations are very complex. Furthermore the procedure has to be kept up to date by almost continuously implementing changes in the construction and/or the use of the building.

The efficiency factors method is valid for large numbers of similar buildings on average. But it does not have any validity for individual buildings with specific design and/or use.

Energy efficiency classification of building automation originates from the wish to give an energy label to building automation products. However, a fundamental problem is that their performance strongly depends on the way the product is applied. Classification of energy performance of building automation is therefore dangerous and could easily backfire on building automation itself.

Successful combinations of building design and building automation products will surface in due time. Providing an energy label for building automation itself *without* a strong direct relation with the final performance will only lead to confusion and suspicion. Investigation and description of good practice examples of combinations of design and automation can speed up the familiarisation and introduction of good practices of building automation.

1.1.2 Demarcation of building automation and intelligence in energy consuming equipment

Products or equipment can have some kind of intelligent power control of their own in order to save energy. Most computers have power options for this purpose.

Building automation can also help to reduce energy demand of equipment but sometimes or already often the equipment itself can do this too. This is especially the case for ICT-equipment. Programs like Energy Star are motivating product manufacturers to develop products that use less energy. This can be done by design but also by adding intelligence that can (partly) take over control of the user to minimise energy consumption without or hardly affecting performance of the product.

In principle, building automation should refrain from interfering with the autonomous energy intelligence of equipment. Instead it should focus on the type of energy supplied to this equipment: From own (on site) generation, from storage or from the grid (green or grey) depending on the i.e. pricing. However, communication and even negotiation between equipment and building automation can be beneficial for both and thus for the owner.

[5] ECD, Application note on EN 15232, 16-jan-2011 (Confidential)

1.1.3 Future building automation

Initiatives in Europe and in America aim at developing technology known as demand response (DR). Smart grid policy is organized in Europe as Smart Grid European Technology Platform. Open Automated Demand Response (OpenADR) is a research and standards development effort for energy management led by North American research labs and companies. OpenHAN is a similar initiative specifically for homes. Demand response focusses at peak levelling and time of use pricing as well as greater penetration of sustainable energy, with or without storage.[6] An ADR should be able to handle several power suppliers at the same time in order to be able to switch between energy produced on-site as well as energy delivered by one or more utilities via the grid. This allows to choose the best (financial or sustainable) option from the point of view of the consumer. Exclusive contracts with a single energy supplier will become a thing of the past.

Web2Energy was a project within the 7th Framework of the European Commission running from 2009 to 2012 with the objectives to make consumers (end-users) part of the energy market, to cluster small power producers into an organised virtual power plant and to increase the reliability of energy supply by reacting faster to disturbing events. Results are that energy tariffs should be variable (based on availability and/or grid restrictions), a large number of small power producers with various technologies (both conventional as well as renewable) can be operated in a virtual power plant as if it was a large traditional power plant and (fast) automated on/off switching in case off disturbances with supply.[7] Communication between the grid and the building will be necessary. Communication between the building and equipment in the building will be necessary too or at least helpful to this end.

Demand response is all about using (financial) information from the energy supplier to adjust energy demand. Supply response would be all about using information from the energy consumer to adjust energy supply. Future supply is traded with future demand. Building automation can do this within boundary conditions provided by the building owner (and energy supplier).

Demand response is also beneficial for energy suppliers because it can take away the need for investing in extra power to cope with fluctuations in demand. Power stations that are able to deal with fluctuations rely on gas as fuel and are relatively expensive.

1.1.4 Limitations by usage, design of the construction and mechanical systems

With building automation energy demands can either be prevented, e.g. by an intelligent sun protection control or shifted to a point of time with better supply conditions. The potential to prevent energy demand by building automation strongly depends on the building design and the building use. The higher the glazing fraction of the facades the higher the prevention potential by a sophisticated

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[6] http://en.wikipedia.org/wiki/Smart_grid, http://www.smartgrids.eu/

[7] https://www.web2energy.com/about-the-project/

sun protection. Furthermore also the more heterogeneous the usage structure, like in conference rooms, shops, or cinemas the higher the saving potential.

The energy shifting potentials, without using additional energy storages, depend on:

1. the allowed comfort tolerances and
2. the thermal mass of the building.

While the total amount of moveable heat demand is nearly independent from thermal quality of the building, the possible shifting periods increase with improved thermal quality. In highly insulated nearly zero energy buildings the heating demand can be shifted by several hours, even when the allowed comfort tolerances are small. Although the total energy shifting potential is nearly independent from the thermal building quality, the relative shifting potential strongly increasing with increasing thermal quality.

1.2 Equipment in buildings

1.2.1 Occupant-related equipment

The variation in occupant-related equipment is large. Some occupant-related equipment can be found in almost all buildings (i.e. PC's & monitors, copiers/printers/scanners), while other equipment is strongly related to the production or service performed in the specific building (i.e. indoor transport). PC's (desktop), monitors, copiers, printers and scanners dominate the total electricity consumption of office and telecommunications equipment in commercial Buildings. The remaining part is covered by computers (servers), data-storage, telephony and other.[8]

The recent Trend in office-equipment is to replace current, less efficient equipment with more efficient multi-functional equipment. This reduces the number of equipment and hence reduces standby losses

Indoor transport

Escalators and elevators are the main equipment to handle indoor transport of people. Indoor transport of objects also occurs. Especially in warehouses that use indoor transport to move stock. Most indoor transport is electrically powered, from fork lift trucks to automated order picking. Larger libraries often have some kind of transport system to take in returned books and transport them to a central point from which they are returned to the bookshelves.

[8] Arthur D. Little, K.W. Roth et al, *Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings - Volume I: Energy Consumption Baseline*, January 2002, Cambridge MA

1.2.2 Building related equipment

Building related equipment can be categorized in the following groups.

Heating, ventilation and air-conditioning (HVAC)

The interaction between exterior climate, building envelope, building use and indoor climate is managed by (intelligent) controls of HVAC-equipment. HVAC controls use set-points and feedback of various parameters of the indoor climate (temperature, humidity, CO_2). Set-points are used to control actuators based on feedback from sensors to provide the desired indoor climate.

Lighting

Lighting is important in non-residential buildings. Fluorescent lighting is the most common applied lighting technology. It is expected that gradually, fluorescent lighting will be taken over by more efficient and flexible LED-technology. Energy savings related to lighting can also come from reduction of background lighting levels in favour of improved work-spot lighting and from smart operation. To prevent lighting been unnecessary turned on, when sufficient daylight is available and/or no one is present daylight- and/or attendance-sensors are used. Control sensors also need energy. Therefore the potential benefits strongly depend on the size and usage structure of the controlled zone as well as on the efficiency of installed lighting technology.

Fans, valves and pumps

Energy demand of fans, and pumps is mainly limited by laws of physics related to resistance. The relation between flow volume and related energy demand for pumps and fans is quadratic: A flow volume reduction by a factor of two results in an energy saving of a factor of 4. Therefore an adequate flow volume adaptation by intelligent controls can reduce the auxiliary energy demand significantly.

1.2.3 Smart building envelopes

Smart building envelopes are defined as building envelopes that are able to save fossil energy by changing a property of the building envelope, i.e. solar or light transmittance, outside air penetration and/or heat resistance

Most technologies that are able to change the property of the building envelope require energy, for example lowering or raising sunscreens or automatic opening or closing windows. Smart building envelopes do have the capacity to save multiples of their own energy consumption elsewhere, in particular in heating, ventilation and cooling. That makes smart building envelopes an interesting subject for building automation.

1.3 Energy consumption in buildings

The ultimate purpose of a building is to provide a comfortable shelter for people and/or animals. Next to creating a building envelope, this is done by adding heating, ventilation and cooling when needed.

Energy demand in buildings is related to the construction of the building, to the preferred indoor climate, to the use of the building as well as to the demolishment of the building. Currently, energy demand for the indoor climate is the largest share in energy demand in buildings. The energy demand for heating, cooling, (de-) humidification and ventilation is strongly dependant on the desired comfort level and the tolerances. Especially in the case of cooling an allowance of a maximum temperature of 26 °C instead of 24 °C can half the cooling demand[9]. Insulation and heat recovery are able to reduce the need for heating and cooling. Improved energy-efficiency further reduces fuel need. Although various measures and technologies aim at reducing energy demand for indoor climate in buildings, this becomes harder and harder for the remaining part of the energy demand. Energy consumption in buildings varies strongly.

The demand depends on the purpose of the building as well as on the geographical location of the building. Some buildings (e.g. shopping malls) tend to have a large share of electricity demand due to lighting and/or equipment and consequently a lower heating but also a higher cooling demand. Buildings at latitudes close to the equator require less heating than those closer to the artic.

Building automation deals with the energy demand in buildings. Building automation takes over the control of equipment in buildings in order to improve indoor climate as well as to reduce the energy consumption.

1.3.1 Autonomous and heteronomous equipment

Some equipment is autonomous, meaning that changing its operation doesn't affect other energy demands, at least not directly and/or significantly. An example of an autonomous piece of equipment is a copier. Assuming that the use pattern of the copier would change, while total use would not change –the effect on the energy demand for heating will be negligible.

Other equipment is heteronomous, meaning that changing its operation does affect other energy demand(s). An example of this kind of equipment is a sunscreen. Operating a sunscreen based on the availability of renewable energy directly influences the energy demand for heating or cooling. This group of equipment is of special interest for building automation.

[9] Bettgenhäuser et al., Klimaschutz durch Reduzierung des Energiebedarfs für Gebäudekühlung, Umweltbundesamt (UBA), 2011

1.3.2 Critical or non-critical demand, intermittent and continuous use of equipment: time-flexibility

Some demand has to be met without delay in order to function or to maintain productivity while other demand doesn't suffer at all from a delayed supply. Demand is critical when serious consequences for the indoor climate and/or the work process occur in case the demand isn't met. Most demand related to the work process is critical. Most demand related to the indoor climate is non-critical due to the heat storage in thermal mass. Non-critical demand can use both delay and storage to match demand e.g. with supply of renewable energy. Critical demand requires storage.

Some equipment will be used intermittently while other equipment will be used (more or less) continuously. Since supply of renewable energy also has a highly intermittent nature, it can be both harder and easier to match intermittent demand with renewable energy supply. This depends on the time-flexibility of the demand. Matching intermittent energy demand with (intermittent) renewable energy supply can be possible when demand is time-flexible.

Shifting demand in case of a time-flexible demand can improve the use of renewable energy. Automation is needed to make this happen because humans can only very roughly assess the supply of renewable energy and constant attention is needed to seize opportunities and/or to tune demands. Automation is capable of monitoring continuously all demands as well as the exact supply of renewable energy. Shifting demand is a general strategy for optimizing renewable energy. However, shifting demand has its limitations. It depends on the consequences of the delay how much delay is accepted.

Most equipment related to production processes isn't time-flexible. Equipment related to HVAC-processes is more time-flexible due to the storage of heat in thermal mass.

1.3.3 Predictable and unpredictable use, contradictory and coinciding use with renewable energy resources: patterns

Although most demands seem quite unpredictable on their own, they do show clear demand patterns on an aggregated level: in time, in scale and/or in similar objects. This is especially the case for demand which only depends on the work process. Most buildings show a similar average weekly pattern, many buildings together show a clearer pattern than a single building. Energy demand depending on the weather often shows a less clear pattern. However, daily and yearly cycles can be distinguished quite easy. Automation should focus on demand and supply patterns and try to match demand and supply patterns using forecasting.

1.4 Non-residential buildings

1.4.1 Building types and characteristics

Variation in non-residential building design, applied materials as well as building use is quite big. Figure 2 shows the shares of energy consumption different non-residential buildings in different European countries. The highest share can be observed for Offices, including Administration and Trade.

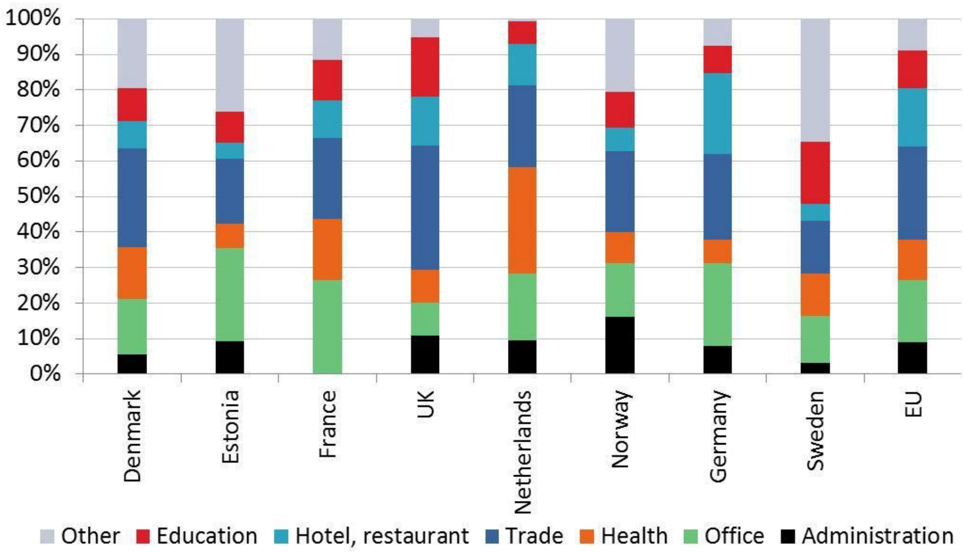

Figure 2 Energy consumption by subsector in services (2008). Source: Bosseboeuf, 2012, p.55.

Variation in energy demand in buildings is big because amongst other reasons variation in design and construction is big. Renewable energy in the built environment focusses strongly on solar energy. At the moment, wind energy is hardly economically feasible in an urban environment. Solar energy can be collected on the roof and on the façade. However, due to unfavourable irradiation angles and shading of trees and/or other buildings on façades, only the roof is of interest for solar energy.

A high roof/floor ratio (e.g. at single story building like typically supermarkets) indicates a high potential for solar supply and hence a good potential for building automation to optimize the direct use the solar supply.

1.5 Climatic conditions

Heating and cooling degree days can be used to for a comparison of the expected heating and cooling demand in buildings at different locations. Distribution of heating degree days in low-energy buildings is even more unequally distributed over a year due to the relatively big contribution of passive solar.[10] Heating and cooling degree days are defined relative to a base temperature, which reflects the average daily ambient temperature above which a building needs no heating or rather below which a building needs no cooling. For nearly-zero energy buildings base temperatures of 12°C for Heating Degree Days ($HDD_{base=12}$)[11] and 18°C for Cooling Degree Days ($CDD_{base=18}$) can be considered.

Table 1 Heating and cooling degree days in a normal year for 4 locations.

Parameter	**Stockholm, SW - Scandinavia -**	**Amsterdam, NL - Western Europe** (Sea) -	**Budapest, HU - Eastern Europe** (Land) -	**Catania, IT - Mediterranean -**
Heating Degree Days ($HDD_{base=12}$)	2.100	1.042	1.476	517
Cooling Degree Days ($CDD_{base=18}$)	91	74	411	953
Ratio HDD/CDD	23:1	14:1	4:1	1:2

Theoretically heating demand in northern Europe is four times bigger than in southern Europe. Influence of large water surfaces (like the North Sea and East Sea) are reflected in cooling demand rather than in heating demand. Cooling demand is virtual non-existing in northern and western Europe.

[10] A.G. van de Bree et al, Monitoring and research report demonstration Almere (EU Concerto Initiative, cRRescendo-proposal), July 2012, Ecofys

[11] Exception for the Mediterranean region: Heating Degree Days based on a heating limit temperature of 15°C ($HDD_{base=15}$)

2 Demand characteristics

This chapter provides an overview of the main demand characteristics (heating, DHW, electricity demand) in the building types regarded in this study. The aim is identify consumers with a high potential for using renewable energy resources which and/or are most suited to be controlled via building automation systems.

In Figure 3 the shares of electricity and fuel consumptions of four common non-residential building types are illustrated followed by further breakdown of both (Figure 4, Figure 5).

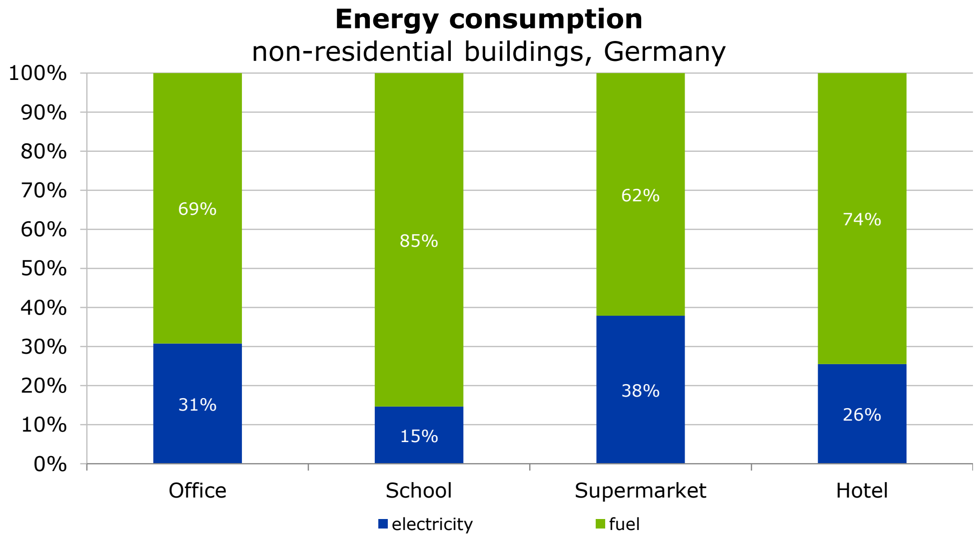

Figure 3 Electricity and fuel consumption in Germany for four non-residential building types. Source: Schlomann, Kleeberger et al, 2011.

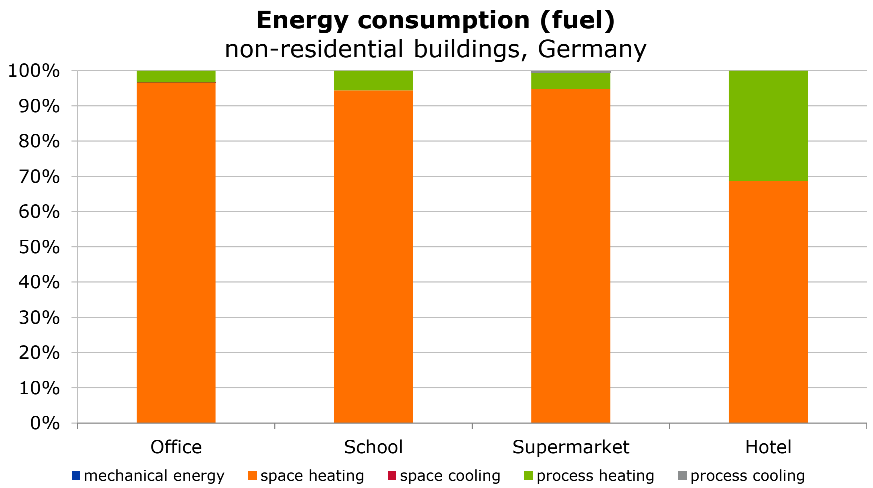

Figure 4 Puropses of fuel consumption in Germany for four non-residential building types. Source: Schlomann, Kleeberger et al, 2011.

For the most building types fuel consumption shares are significantly above 60%. The fuel consumption originates over 90% from space heating. Only in hotels does process heat (especially domestic hot water demand) also consume about 1/3 of the fuel consumption.

Four different types of heat generation can be distinguished:

- Boiler – typically fuelled by coal, oil or natural gas but also has an option of biomass and is only capable of producing heat;
- Heat pump – fuelled by electricity using a sustainable heat source and some kind of storage, and is also capable of cooling;
- Combined heat and power (including fuel cells) – fuelled by natural gas or biogas, capable of producing heat and electricity simultaneously;
- Solar – fuelled by some electricity for distribution or storage of solar energy (pumps, fans) and for control of the components of the heat balance of a building (automatic shading).

The nearly zero energy buildings of the future are expected to have dramatically reduced heating (fuel) demand, typically in a range between 5 kWh/m²a and 30 kWh/m²a (see Chapter 2.3.) Compared to the electricity demand for appliances, lighting and auxiliary energy, the shares of heating demand will reduce by half or more. Considering all electrical building solutions (heating by heat pumps) the share of heating demand in nearly zero energy non-residential buildings will be about 10 % of the total energy demand.

To optimize nearly zero energy buildings the focus will not be as it traditionally was on heating, but instead the whole system has to be considered.

In schools and supermarkets especially, lighting represents a large share of the electricity consumption. Communication (telephones, laptops, personal computers, copiers) follows in offices and schools, while process cooling (refrigerators) is next in supermarkets. Hotels are quite different from the other three building types. Mechanical energy (e.g. fans, elevators, pumps, motors, washing machines) represents the highest share, followed by lighting and process cooling.

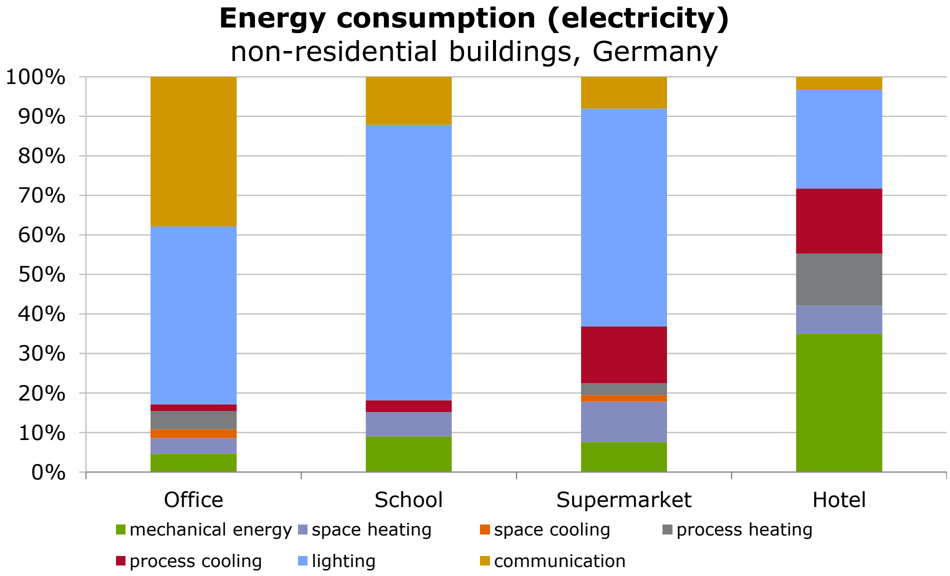

Figure 5 Electricity consumption (Germany) for the four non-residential building types. Source: Schlomann, Kleeberger et al, 2011.

2.1.1 Occupants of buildings

Providing shelter is the main purpose of a building. Modern society does have the technology to create optimal indoor conditions. Providing shelter within a range of indoor conditions should suffice. This comfort-range can be used by building automation to increase the share of renewable energy, especially solar energy. Postponing auxiliary heating at the time when some solar energy is expected may cause the indoor temperature to drop down to the minimum set-point. Adding solar energy to the building when soon a heat demand is anticipated may cause the indoor temperature to rise closely to the maximum air temperature set-point.

Indoor conditions are mainly the result of air temperature, radiant temperature and humidity, however, air velocity, clothing and metabolism also influence comfort

2.2 General trends in (fossil) energy demand in buildings

2.2.1 Heating

Heating technologies like CHP, fuel cells and heat pumps have an improved energy efficiency compared to (high efficiency) gas boilers and, before this, coal and wood furnaces, but the majority of energy saving in buildings has to come from insulation.

Heating (or cooling) can be considered an auxiliary heat (or cold) source to compensate for the net effect of transmission & ventilation losses, solar irradiation and internal loads. Together they compose the heat balance of a building. Heating (or cooling) is auxiliary as it "closes" the heat balance. A reduced heat demand increases instability of the heat balance, causing the other, uncontrollable components of the heat balance to gain more weight. This also depends on the heating capacity as well: a relatively big heating capacity would be able to cope with relatively large distortions.

In current installation practice, operation of HVAC-equipment is based on feedback. However, the distortion itself is neither noted nor monitored, only its consequence (e.g. lower/higher temperature, lower/higher CO_2-concentration) is reviewed. So, feedback is indirect and HVAC-equipment responds with a delay by definition. Until now HVAC-equipment got away with this due to its relatively large capacity, however, with a reduced role for HVAC in the heat balance in low-energy buildings, this delay can become an issue for maintaining the right indoor climate. The thermal mass and air buffers still help to absorb the first effects of the distortion but HVAC may prove incapable of restoring the indoor climate in time.

Current solutions or paradigms for indoor climate control strongly focus on HVAC-equipment. In the future, HVAC-equipment may prove to be incapable of doing the job on its own. Active control of other parts of the heat balance of a building will be required too, in order to provide sufficient control of the indoor climate. This requires new solutions and maybe even new technologies. A key factor in this new approach for indoor climate control is the need to know the (dynamic) behaviour of a building and the co-operation between all control opportunities. The link between all controls is some central intelligence of the building. Building automation can become the central brain that understands the behaviour of the building and knows the indoor climate capabilities of various equipment or products.

Dynamic behaviour of a building can be derived from neural networks. The crucial difference between a neural network and classical (i.e., first principles) model is that the neural network operates somewhat like regressions: it can readily map between input and output data without detailed knowledge of the physics involved. The advantage of neural networks over linear regressions is that neural networks inherently model non-linear processes without upfront data manipulation. This is desirable when modelling building HVAC processes and overall energy consumption because often the values of interest vary non-linearly with the driving variables.[12] However, linear regression, based on some main parameters of the building and its uses, is able to explain the majority of the energy consumption (see also 5.2). This could be improved when parameters are monitored more closely.

2.2.2 Ventilation

Ventilation will become one of the most important components of HVAC-installation in buildings. While fossil heat demand can be reduced by insulation and/or by using passive solar, and by using shading-devices and/or insulation to prevent cooling, there is no possibility to reduce the need for fresh air. Balanced ventilation systems with heat recovery help to reduce the involved heat consumption with ventilation. The question then is how to control all ventilation in such a way that reduction of energy consumption is achieved as well as securing a healthy indoor climate?

Modern technology for communication and sharing data turns many services to becoming independent of a specific location. Employees can choose to do their work wherever they want to. By consequence, the level of occupancy in buildings will vary much more and become less predictable. Ventilation-systems must be able to cope with this.

2.2.3 Electricity

Electrification in final energy demand continues to be a dominant trend with the share of electricity in final energy demand reaching 25% in 2030. Average electricity growth rates in the residential and tertiary sector will be about 3% annually. Heat use almost doesn't show any growth. The share of renewable power generation is believed to increase from 19% in 2010 to 32% in 2030. Electrification could further intensify if electricity also penetrated in heating and transportation. The increase in renewable energy supply requires a higher amount of gas-fired power plants to cope with the higher amount of intermittent energy resources.[13]

Equipment

Production, internal transport and/or office equipment will become continually more automated. Automation allows better capabilities to tune demand to renewable supply. Automation also improves capabilities to exchange information between various systems on various levels.

[12] Margaret B. Bailey, *Neural Network Modeling and Control Applications in Building Mechanical Systems*, 2002, United States Military Academy

[13] EC, DG-Energy, *EU energy trends to 2030 — Update 2009*, Brussels

Lighting

In contrast to heat, light does not have a natural buffer in buildings. Next to a higher efficiency, light savings are possible by reducing general lighting and focus on dedicated lighting (application-driven). Even the trend to adapt the luminance levels depending on outdoor conditions and circadian rhythm can save energy and create more healthy work environments at the same time.[14]

Lighting for dwellings and offices develops from incandescent light bulbs (15-20 lm/W) via fluorescent lighting (55-60 lm/W) to LED-lighting (60-100 lm/W).[15] The energy demand for lighting in new buildings is estimated to drop because of efficiency improvements by up to 30% in the comings years. At the same time, the effect on the cooling load becomes less important.

2.3 Nearly zero energy buildings (nZEB)

Nearly zero energy buildings (nZEB) are designed to have almost no energy demand for indoor climate and installations.

The nZEB will be supplied by a mix of (renewable) electricity and other renewable heat resources like biomass and solar. Not least because of the heating demand decreasing significantly, the share of electricity within the energy consumption will certainly increase at nZEBs.

The final definition of an nZEB has not yet been established. Several aspects are important in the definition: the metric system (end-use energy, primary energy, CO_2 equivalent emissions, costs, etc.), the balancing period (lifetime of the building, annual, monthly, etc.), the type of energy demand (dependent of the occupant or independent of the occupant), the type of balance (energy use/generation or energy delivered from/fed into the grid), the renewable energy supply (on-site or off-site), the connection with the energy infrastructure (on-grid or off-grid) and any requirements, especially indoor climate conditions, in order to allow comparison between calculation-methods.[16]

Some of these aspects are relevant for building automation while others are not. Some of these aspects align with the interest of the building owner/user (e.g. costs, delivered/fed in energy) whilst other aspects relate to general interests (e.g. CO_2 equivalent emissions). General interests can be made more applicable to the building owner/user through legislation (e.g. Energy Performance Building Directive).

Although the nZEB definition is still not fixed, some studies have already suggested and examined solutions for non-residential nZEB. Within the report "Principles for nearly Zero Energy Buildings (nZEBs)" (BPIE 2011) non-residential nZEB concepts for different European countries have been

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[14] http://ec.europa.eu/health/scientific_committees/opinions_layman/artificial-light/en/index.htm

[15] http://en.wikipedia.org/wiki/Luminous_efficacy, http://nl.wikipedia.org/wiki/Led

[16] A. J. Marszal et al., Zero Energy Building – A review of definitions and calculation methodologies, Energy and Buildings, Elsevier, 2011

specified and compared. The results of this examination can be used as a baseline for the estimation of the building automation potentials.

Table 2 Final energy demands of nearly zero energy office buildings in 3 climatic zones.[17]

Energy demand	Unit	Copenhagen, cold	Stuttgart, moderate	Madrid, warm
Heating (gas boiler)	kWh/m².a	11.7	9.7	5.0
Domestic hot water	kWh/m².a	2.1	2.0	1.8
Cooling	kWh/m².a	0.7	1.6	3.5
Ventilation	kWh/m².a	6.8	6.8	6.8
Lighting	kWh/m².a	8.2	7.3	6.3
Other auxiliary energy	kWh/m².a	0.2	0.2	0.1
Appliances	kWh/m².a	20.9	20.9	20.9
Sum	kWh/m².a	50.6	48.5	44.1

Although the BPIE Study indicates extremely low final energy demand for heating and cooling it is undoubted that the energy demands for heating and cooling will become less important, while the relative importance of the ventilation, lighting and other auxiliary energy will rise, independent from the climate. For the office building the most energy will be needed for appliances.

2.3.1 Balancing period

At the moment it isn't clear which balancing period will be chosen in standards for (nearly) Zero-Energy Buildings (nZEB's). A balancing period of one year is most common. This period means that the total supply of renewable energy matches the total demand of fossil energy over the course of one year. A different balancing period is possible. However, realizing (nearly) zero energy buildings becomes harder with shorter balancing periods. Especially heating, which strongly depends on the season, will be hard to be compensated for at a shorter balancing period. Seasonal thermal energy storages would be one option to overcome this issue.

[17] Boermans, Thomsen et al., Principles for nearly-zero energy buildings, Buildings Performance Institute Europe (BPIE), 2011

3 Supply characteristics

In general there are two possible renewable energy sources to produce energy on site: Wind and Solar Energy.

3.1 Wind Energy

The generation of wind energy on site (within an urban area) is not economically feasible. Urban areas strongly reduce wind speed due to the roughness of the local terrain, which is a consequence of the many building blocks at various heights, orientations, positions and shapes, all whilst existing in a compact area. With reduced wind speed, the potential energy in the wind also reduces. Only a high-rise building with a special design to increase the wind speed can theoretically make wind energy at building level economically feasible. But in urban areas there are also further items, like shadowing, noise or safety, which have to be considered, and so wind generators in urban areas will have to be an exception.

3.2 Solar Energy

Solar energy is the most relevant, completely renewable energy source that can be "produced" on site. The following two figures show a comparison of the global horizontal irradiation (hourly) in W/m² for two locations in Europe: Stockholm and Catania. Besides the fact that the total amount of solar radiation in northern Europe is only about half of that in southern regions, the most significant difference is the annual distribution: in northern regions the radiation significantly drops during the winter time, whilst the annual differences in the south are compatively low.

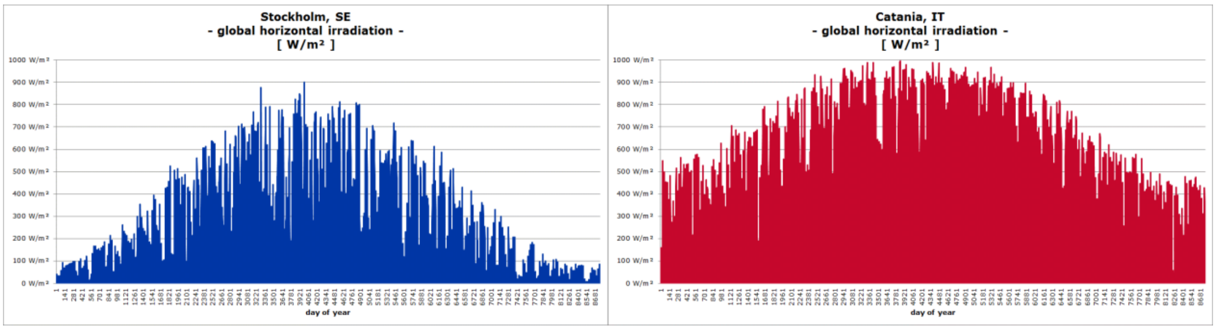


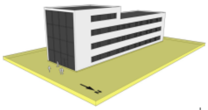
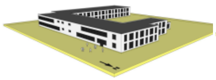
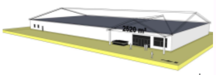
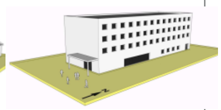
Figure 6 Annual global horizontal irradiation (hourly values) in W/m² for two location in Europe: Stockholm (left) and Catania (right). Source: meteonorm

In order to determine the overall possible solar energy supply, regardless of the simultaneity between demand and supply, the roof space is usually the crucial parameter.

Solar energy can either be converted into electricity by PV cells or into heat by solar collectors.

The following table shows the possible annual electricity yield for different typical non-residential buildings at different locations in Europe, assuming a potential 50 % coverage of the roofs.

Table 3 Average annual electricity yield of photovoltaic systems on 4 different non-residential buildings in 4 regions in Europe[18].

Parameter	Unit	Office	School	Supermarket	Hotel
View of building					
Roof type	-	flat	flat	pitched a)	flat
PV-power b)	W_P/m^2	22	35	77	18
Stockholm c)	kWh_a/m^2	15	24	53	12
Amsterd. d)	kWh_a/m^2	17	27	59	14
Budapest e)	kWh_a/m^2	19	31	68	16
Catania f)	kWh_a/m^2	27	44	97	22

a) Slope of roof is 30°
b) PV-power per m^2 usable floor area.
c) Stockholm (59°19'44" North, 18°3'53" East): 685 kWh_e/KW_P annual
d) Amsterdam (52°22'12" North, 4°53'42" East): 765 kWh_e/KW_P annual
e) Budapest (47°29'52" North, 19°2'24" East): 885 kWh_e/KW_P annual
f) Catania (37°30'28" North, 15°4'58" East): 1250 kWh_e/KW_P annual

Table 3 shows that the highest electricity production can be reached on the pitched roof of the supermarket in Catania while the lowest potential is available for the hotel in Stockholm.

As the yields in winter at northern European regions drop to almost zero (especialy when compared to the yields of the summer months), the typical use of solar thermal energy is for domestic hot water.

[18] Assuming a photovoltaic system with crystalline silicon cells (about 14% energy efficiency), a slope of 35° and orientation to the south.

Domestic hot water is not relevant in most non-residential buildings, except in hotels and aqua centres. Aqua centres do have large heat buffers (swimming pool), which can be exploited by the building automation in order to increase the share of renewable heat.

4 Energy storage

4.1 Energy storage

Energy storage is an important aspect of optimizing renewable energy in buildings. Both heat and electricity can be stored, but heat can be stored more easily than electricity. Heat can either be stored in a controlled way (in a vessel or in the ground) or an uncontrolled (passive) way, for example, in constructions and/or furniture, etc. Storage is a simple and elegant solution to match the demand with a cheap and/or renewable supply.

Controlled storage of heat involves some kind of pump or batteries and also leads to some energy losses. The idea, of course, is that the loss of energy is (far) less than the amount of a cheap or renewable energy that can and will be retrieved from the storage.

4.1.1 Heat

Heat in buildings is also stored in thermal mass, and this thermal mass can include walls, floors and constructions of other buildings. Inventories and stocks in buildings also represent thermal mass. The difficulty with this kind of storage of heat is to control it without lack of comfort. Storage and release of heat in constructions, inventories and stock follow the laws of physics. The autonomous storage and release of heat is known as the thermal response of the building. Building design is a key factor in optimizing the benefits of thermal response of a building; however, there are also controlled opportunities to exploit thermal mass in order to save energy and to improve indoor climate. A well-known opportunity is shading and another is so-called ‘concrete activation’, where water pipes or air ducts are positioned within the cores of the concrete ceiling, actively exploiting the thermal mass of a building. This is most effective to reduce the cooling loads.

Characteristic of stored heat in thermal mass is its low temperature, opposite to storage of heat in specially designed enclosures, which usually store at higher temperatures. For separate storage, water tanks were usually used. One can distinguish between the commonly-used short-term storages, on the one hand, and seasonal storages, which are at the moment only realised at research projects, on the other hand. Short term storages are typically used to improve the part load efficiency of the heat production systems or to bridge short interruptions in the energy supply. Such interruptions usually need to be considered in case a special heat tariff is applied. In some examples, the seasonal thermal energy storage have temperatures up to 65 °C.[19] The specific costs of storages [€/m³] range from 50 €/m³ for huge seasonal storages[20] with a size of about 10.000 m³ up to 1000 €/m³ for small short term storages. Although the costs of seasonal storage seem relatively low, the limited charge

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[19] Solar District Heating guidelines, Collection of factsheets (WP3 – D3.1 & D3.2), August 2012

[20] A good collection of background information concerning seasonal storages can be found at saisonalspeicher.de

and discharge frequencies (once per year) and the transmission energy losses add to the cost. Furthermore, active storage requires energy for pumps and control.

The role of building automation is to manage the storage and retrieval of heat, whether in passive or active storage. While the storage management by building automation is a "must" at active storages, the potentials of the passive storage by a sophisticated building automation are most often not tapped. As the thermal losses in nZEB will be reduced while the thermal masses will be more-or-less the same, the passive storage potentials are expected to be higher in those buildings than in conventional buildings.

4.1.2 Electricity

Electricity is usually stored in batteries. There are, however, serious limitations to storing electricity in this way. The costs per stored unit of net (usable) energy are still quite high (about 0,40 €/kWh), compared to energy production costs. In contrast to the transportation of heat, electricity can be transported easily. This partly overcomes the storage problem of electricity. The power grid is an ideal virtual battery and should be optimized for this purpose. The fear of blackouts due to fluctuations in renewable energy has recently been tempered by Fraunhofer-IWES. In a field test, Fraunhofer showed that sustainable energy plants are easier to control than current big power plants. Fluctuations in demand and supply can be handled without creating instability of the grid. Serious fluctuations in supply can be solved by temporarily storing the energy in another energy carrier. By continuous monitoring and weather forecasting, required capacities on a time scale of minutes or hours can be predicted very accurately, claims Fraunhofer. "A central control ensures that the disadvantages of the renewable energies are reduced, because the sun does not always shine, and nor does the wind blow continuously. However, when many small producers work together, then the regional differences regarding wind and sunshine can be balanced out by the power grid or controllable biogas facilities. In addition, surplus power can be stored or turned into thermal energy. A powerful network decentralized, can act as a larger entity. In order for this to work, the control room takes on two roles simultaneously: in its function as the "power plant facility manager", it monitors the facilities that are interconnected within the virtual power plant. And, acting as the "pool coordinator", "it simultaneously markets the energy that was produced."[21]

Buildings will be part of this decentralized network by providing information about short term demand, both quantitative and qualitative, and about on-site production of renewable energy. The building itself will receive its energy tariff information from the virtual power plant about day-ahead energy tariffs. A virtual agent on a regional, as well as on a building level will try to deal with both

[21] Fraunhofer-IWES, http://www.fraunhofer.de/en/press/research-news/2013/march/the-virtual-power-plant.html, http://www.kombikraftwerk.de/

flows of information: store or sell; retrieve or buy? All information is collected and dealt with in a virtual market. A crucial aspect of such a system is standardisation of information-exchange on various levels. From wind turbine to water heater, systems will need to be able to communicate with each other. All agents will try to optimize costs for individual objects on their own level. Such a market will be strongly-driven by economics. The challenge is, of course, to maintain the simplicity of the whole system, to allow for rules that deal with changing public regulations and to create an inherent, stable system.[22]

Demand side measures prove to be a good alternative for building a new power plant from the economic point of view. Demand side measures are cheaper on condition that transport of energy comes at a price (related to the actual costs of transport), especially in case an imbalance in demand and supply threatens to occur. An additional advantage of demand side measures is that they go together with a reduction of CO_2 emissions, while a new power plant increases CO_2-emissions.[23]

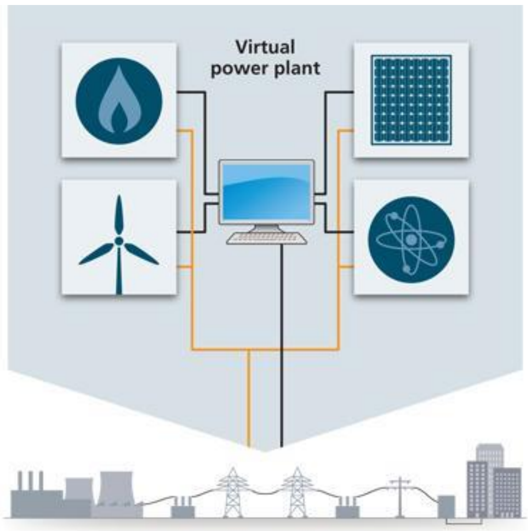

Figure 7 A Virtual Power Plant aggregates different types of energy generation and controls it as if it was one source. Source: Siemens.

Electricity demand on building level shows much stronger peaks than heat demand. These peaks become weaker when looking at a higher geographical level (regional, national, global).

Many research projects aim to improve batteries. The goals are lower costs, higher capacities and more rapid responses.

[22] http://www.renewableenergyworld.com/rea/news/article/2013/09/virtual-power-plants-a-new-model-for-renewables-integration

[23] M. Stadler, *The relevance of demand-side-measures and elastic demand curves to increase market performance in liberalized electricity markets: The case of Austria*, Dissertation, November 2003, TU Wien

Batteries can play a role, in particular, in short term storage (up to a number of weeks). The power grid can play a role in long term storage. Building automation should be able to deal with both: when to invoke batteries and when to invoke the grid to satisfy and optimize demand.

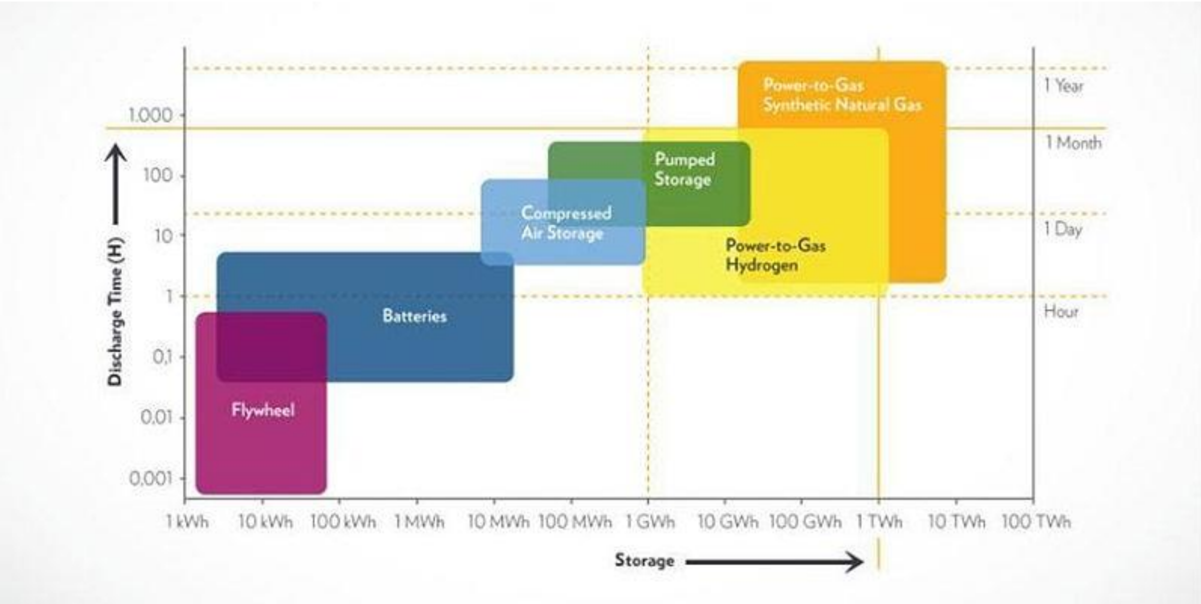

Figure 8 Energy storage technologies and their application. Source: ITM Power.

<u>Electric vehicles</u>

A promising storage of electricity can be found in electric vehicles (EV). This has to do with their almost-daily use, their electric storage capacity and their opportunity to connect frequently, and during most of their lifespan, with the power grid in an urban environment. Deregulation of the electric sector by unbundling generation and transmission and creating trans-national electricity markets provides greater opportunities for EV to provide valuable services to the electric grid. The typical battery size of European EV's is 20-40 kWh. EVs are well positioned to provide certain ancillary services because they can react much faster to grid-balance issues compared to "fast" power plants (on gas). Across the U.S., ancillary services account for 5 to 10% of electric costs.

EV's can operate in two ways: grid-to-vehicle and vehicle-to-grid. Variations on baseline charging behaviour can be brought about by tariff-based incentives and other policies. Implementing controlled charging requires information be sent to a vehicle through an internet connection, where advanced metering infrastructure is available or, more simply, through an on-board computer which is capable of interpreting conditions on the grid[24] [25]. An EV connected to the grid should be able to co-operate

[24] M.J. Bradley & Associates LLC, *Electric Vehicle Grid Integration in the U.S., Europe, and China - Challenges and Choices for Electricity and Transportation Policy*, International Council on Clean Transportation, July 2013

[25] Quiwei Wu (ed.), *Grid Integration of Electric Vehicles in Open Electricity Markets*, John Wiley & Sons Ltd, 2013

with the energy management system at the location of the connection in order to solve the load management issues, either in the grid or on-site, related to intermittent renewable energy resources, for which the management system is responsible. This connection could be at a public area or in a public building, a non-residential building or a residential building. Once again, the owner of the EV should be able to indicate the boundary conditions of the use of his EV's energy storage capacities by the connected energy management system. Energy pricing will be an important key for optimization. Similar to the control of the interior climate, the boundary condition should be expressed by or to the consumer as some kind of comfort level. The building automation should translate this comfort-level to more technical settings for the EV. Higher comfort (should) correspond(s) with higher cost and lower comfort (should) correspond(s) with less cost.

Forecast for the share of electric vehicles in the total number of vehicles in the near future in the European Union is still disappointing.

5 Prediction of energy supply and energy demand in buildings

5.1 Supply

Renewable energy supply has a highly intermittent character. Conventional approaches that try to match [on a regional level] the expected load by intermittent resources require expensive fast-start units in order to balance the high volatility of these intermittent resources. Alternatives propose to actively control the output of intermittent resources to follow the trend of time-varying loads. The technique for implementing this approach is called model predictive control (MPC). At each step, a finite-horizon optimal control problem is solved but only one step is implemented[26] [27].

Error! Reference source not found. Supply of solar and wind energy becomes harder to predict when looking further into the future. Solar irradiation can be predicted quite well up to 10 minutes ahead and reasonably up to several hours. Wind can be predicted quite well up to 1 hour ahead and reasonably up to a few days. Still a great deal of uncertainty is related to the predictions. To deal with these uncertainties requires mathematical techniques.

As wind power continues to gain popularity, it becomes a necessary ingredient in realistic power grid studies. Off-line storage, wind variability, supply, demand, pricing, and other factors can be modelled as a mathematical game. Here the goal is to develop a winning strategy. Markov processes have been used to model and study this type of system. One of the findings in the study is the need for efficient pricing mechanisms that intelligently tackles the ever-increasing uncertainties in the power system.[28]

5.2 Demand

Energy demand in buildings related to indoor climate is the interaction between outdoor climate, building envelope, a building’s use and auxiliary equipment. Prediction of the future state of such a complex system is very difficult. The problem lies with the prediction of the exterior climate and the use of the building as an accurate prediction of the exterior climate and the short-term use of the building is difficult. Prediction is a trade-off between accuracy and time horizon.

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[26] Le Xie, Marija D. Ilić, Model predictive dispatch in electric energy systems with intermittent resources, 2008, Carnegie Mellon University Pittsburgh.

[27] Maasoumy et al, Optimal control of building HVAC Systems in the presence of imperfect predictions. American Society of Mechanical Engineers (ASME). 2012

[28] Miao He; Sugumar Murugesan; Junshan Zhang (2010). "Multiple Timescale Dispatch and Scheduling for Stochastic Reliability in Smart Grids with Wind Generation Integration", arXiv:1008.3932 [cs.SY]

Collecting data and using a solid model can help to improve the accuracy of prediction of demand for a specific situation by looking for patterns and variations on those patterns.

Energy demand can often be characterised by patterns. The patterns differ depending on the type of appliance and their use. Due to a different use even individual appliances of the same type often have different patterns. While some appliances have a fairly constant energy demand, others have a highly intermittent demand. Some appliances follow roughly the pattern of supply of renewable energy (for example the need for cooling is related to the irradiation of solar energy), while other demands follow the opposite pattern from the renewable supply (for example heating or illumination). Both examples relate to indoor climate. Electrical equipment in buildings is distributed more evenly during the year.

Patterns can help us to visualize energy demand on a higher level. However, in reality energy demand can differ very much from the observed pattern at a certain moment. Future demand can be expressed as many different states with their own probabilities. Such an approach is more realistic and matches reality much better than the way forecasts of complex systems are made in general. Various studies have already addressed the issues of stochastic descriptions of building use and probabilistic performance of buildings.

Energy demand in buildings which are related to specific production processes is easier to predict since it depends less on unknown or complex external influences, at least not on the level of individual buildings. Energy demand related to production processes on the street, neighbourhood or city level is harder to predict on the basis of individual consumers, but reliable to model with statistical techniques.

Numerous characteristics of the individual buildings and its use can be related statistically to the observed energy consumption. A recent study in this field found that the distribution of energy consumption in buildings total energy consumption roughly follows a log-normal distribution. This means that energy consumption varies multiplicatively between different houses: a house in the 80th percentile of energy consumption uses about 3 times as much energy as a house in the 20th percentile. Furthermore, even the log-normal distribution, in fact, underestimates the spread of the data; the data is heavy-tailed, such that a log Student-t distribution fits the energy consumption even better. With the best algorithm, they were able to explain 75% of the variation (in the logarithmic scale). Furthermore, they found that simple linear regression performed marginally worse than the best, but more complex, methods. [29] Linear regression can be used to predict the energy consumption on the level of a street, neighbourhood or city. These predictions can be used to share generated renewable energy on site-level. Neural networks can also be used. Neural networks are better in dealing with non-linear processes (see also 2.2.1).

[29] J. Zico Kolter & Joseph Ferreira jr., *A Large-scale Study on Predicting and Contextualizing Building Energy Usage*, MIT, 2011

Sensors only look at the instantaneous measured state of the system. Sensors cannot predict the future state of the system and act on it, although this would help and maybe is even required to optimize the use of passive renewable energy.

6 Strategies for building automation

In the previous chapters, both energy demand and renewable energy supply have been characterised. Within this chapter these characteristics will be used to determine the role of building automation in increasing the energy efficiency and optimising the share of renewable energy in buildings, with regards to nearly zero energy buildings.

6.1 Overview of building automation by functions

Before addressing the general pathways for building automation, in the following an overview of the essential functions is given:

Providing a comfortable indoor climate

Building automation has to translate the needs and wishes of occupants to actions of (collaborating) indoor climate systems to provide a comfortable indoor climate. Occupants can remain in control by providing their boundary conditions to the building automation. Those boundary conditions can be related to measurable entities like indoor temperature, humidity and CO_2-level combined with time-schedules. Common practice in the newest non-residential buildings is the individual control of room (air) temperature. Other comfort parameters are usually set centrally.

As in nearly zero energy buildings, if the remaining heating and cooling loads are very small, the danger of overheating or undercooling increases. A sophisticated control is required, especially at nearly zero energy buildings with a small thermal mass and very slow reacting systems, like floor heating or concrete cooling. To overcome this control issue of nearly zero energy buildings' direct controls, responding to (predicted) external boundary conditions, like solar gains, ambient temperature, humidity and wind speeds, as well as on expected internal boundary conditions like occupancy, should be implemented.

Saving energy by controlling HVAC- and auxiliary-systems

Although nearly zero energy buildings will have a significantly reduced energy demand, a (central) control of the HVAC- and auxiliary-systems is necessary to ensure that in reality there is also a very low final energy consumption. Without a well optimized control, the final energy consumption can easily be doubled [30], even in buildings without extremely reduced energy demand. As indicated in Table 2, in Chapter 2.3, the energy needs for the (well optimized) illumination, fans and pumps are of the same requirements as energy needs for heating and cooling. Therefore, it is clear that nearly zero energy buildings require sophisticated central control systems, controlling all energy-related components simultaneously. An autonomous control, e.g. of the shading device without connection to the heating or illumination systems, causes wasted energy.

The building related energy costs at nearly zero energy buildings for most non-residential building types, like offices, hotels and schools, will be in a range of 5 €/m²a or less, independent from location within Europe. Therefore, the additional costs for a sophisticated building automation needs to be less than 50 €/m² to be able to achieve payback. With more efficient technologies, like LED, the payback times for building automation (e.g. daylight or attendance sensors) increase.

As the building automation systems also need energy, this needs to be considered for the calculation of the achievable benefits.

Besides the achievable energy cost savings the CO_2 reduction potential is also an argument for the implementation of central well-adjusted building automation systems in nearly zero energy buildings.

Feedback and communication

Building automation is suited to translate measured data about energy consumption and user behaviour into feedback and even into suggestions for adaptation of occupant behaviour.

Feedback on (desired) comfort-level or behaviour on the individual energy demand is currently very uncommon. Only in a very indirect way through the energy bill can a feedback be derived. However, a time span of a year or more is too big to affect daily behaviour of the building users. A feedback system is encouraging the occupants to save energy by adapting their behaviour or (comfort-)setting for indoor climate. The average saving potential of a feedback system in a nearly zero energy building is hard to predict. It is estimated to be significant, at least in a range of 5 to 30 % of the total demand. The cost and potential would need to be addressed in a separate study.

Feedback is also required for proof of whether the calculated low energy demand of realized nearly zero energy building are really achieved. As the energy demand and the related costs are comparably low, especially in nearly zero energy buildings, such a proof is seldom done.

A good energy performance of realised nearly zero energy buildings is indispensable to achieve climate protection goals of the European Union. Monitoring and feedback is the only way to ensure this.

[30] : see also http://energyindemand.com/2014/06/07/how-improved-controls-can-improve-energy-performance-of-commercial-buildings

Energy-load and energy-storage management

The thermal energy demands and energy fluxes are extremely low in nearly zero energy buildings. This creates good opportunities for shifting heating or cooling loads over longer periods, without installing separate storages. Presumption for achieving financial benefits by load shifting is a variable energy price. This can either be a flexible electricity tariff or electricity from different sources (PV produced on site and from the grid). Using the flexibility of electricity prices is interesting, especially for cooling, which is typically provided by a compression chiller or for heat pump system in case of heating.

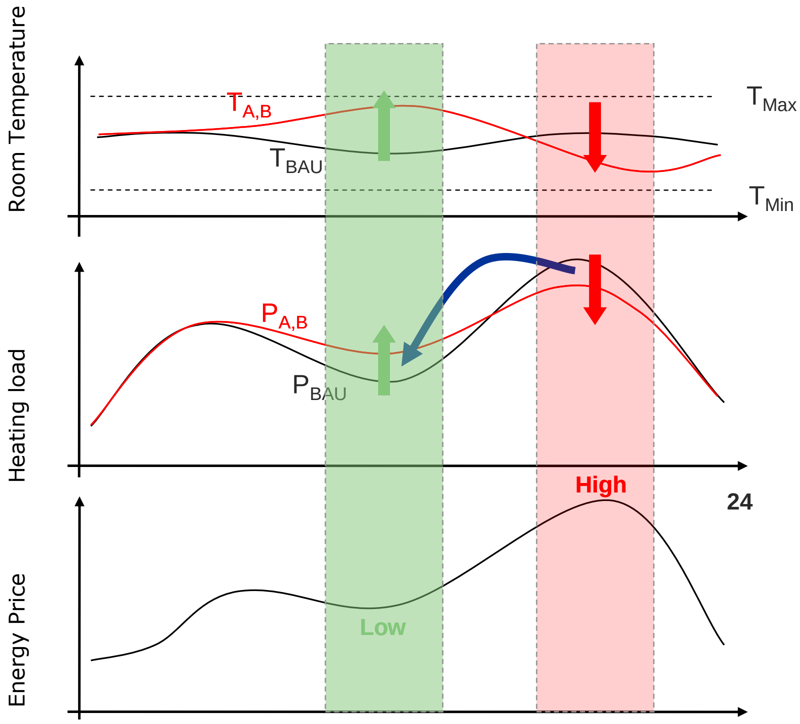

Figure 9 Price related load shifting at building heated by a heat pump:
Comparison of the two scenarios: Business at usual (BAU) and price optimized (A,B)

When the energy prices are low, the heating or cooling systems are activated until the setpoint boundary temperature is reached (see Figure 9: The room temperature rises close to T_{MAX}). When the energy prices are high, the heating or cooling systems are deactivated until the opposite setpoint boundary temperature is reached (see Figure 9: The room temperature drops close to T_{MIN}).

The achievable benefits by price related load shifting, with and without additional storages, strongly depend on the energy price variations. As the price variations are expected to increase in the future this offers good opportunities for by price related load shifting. For the use of flexible energy tariffs, an interface between the building system and the electricity provider is necessary. The baseline for this is already given by the increasing implementation smart meters. Flexible tariffs are still not commonly available.

Besides the price related load shifting, an energy related load shifting, to compensate expected heating with cooling demands (or other way around), can be economical as well. Self-learning systems can increase the energy load shifting potential.

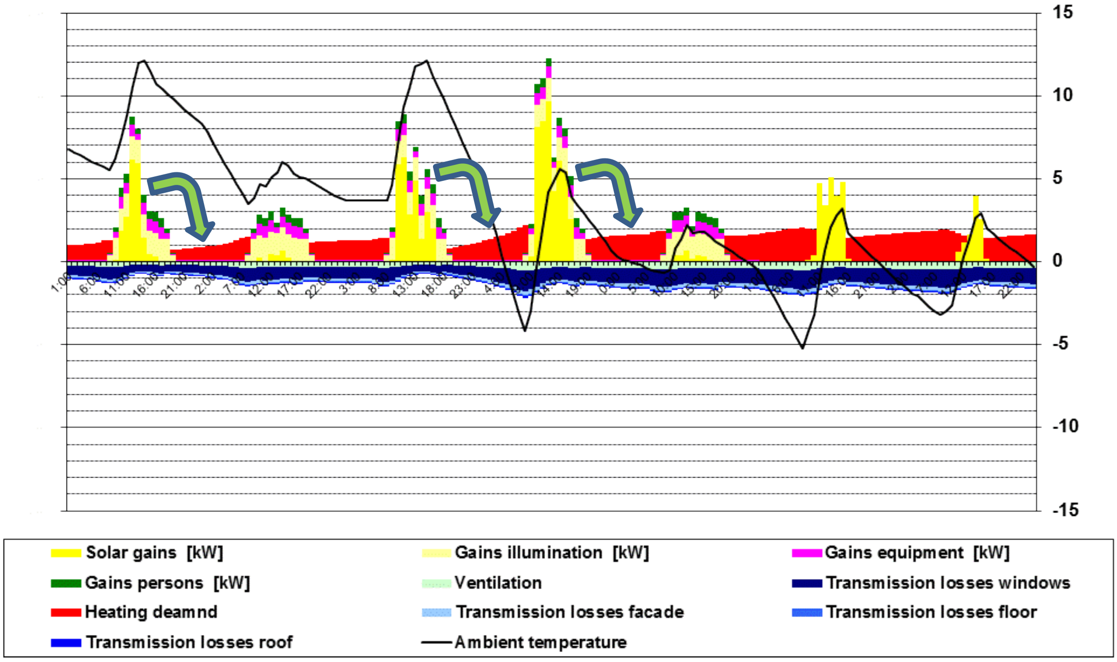

Figure 10 Thermal energy balance and load shifting potential (green arrows) of a nearly zero energy office building in Germany during one week in January. Source: Ecofys

In case of heating, a temporary excess of solar and internal loads can be used (see Figure 10), to slightly overheat the building in the evening, out of the usage hours. During the heating season, building automation could also help to reduce energy for heating by using short term weather forecasting. The heating system should be told to hold its action (maybe resulting temporarily in an air temperature below the set-point) in case a sufficient solar irradiation is expected on short notice. Because not all rooms within a building experience the same solar irradiation, this requires a control on at least zone-level and preferably on room-level. The highest potentials are expected for buildings in northern and central Europe. The higher the load differences and the higher the thermal masses, the higher are the expected potentials. Therefore, high energy related load shifting potentials can be expected in e.g. office buildings or schools.

In case of cooling, free (night) cooling can be used. Free (night) cooling with air can be done by opening windows or using the mechanical ventilation system. The highest energy savings by free (night) cooling for buildings can be expected in southern and central Europe. In northern regions an efficient night cooling can be able to substitute a mechanical cooling need when some comfort tolerances are accepted.

By using the thermal masses and the comfort tolerances a further reduction of the final energy demand can be expected: for cooling in a range of up to 20 %, for heating up to 10 %.

Increase the share of renewable energy

The definition of nearly zero energy building request for that the energy demand "should, to a very significant extent, be covered by energy from renewable sources, including renewable energy produced on-site or nearby".

Solar energy is the most relevant, fully renewable energy which can be "produced" on site. In the majority of European countries the costs of electricity-produced PV systems on top of the roofs are already lower than grid electricity prices. It is expected that these price differences will further increase in the future.

For increasing the share of renewable energy of buildings, load management, as already described in the previous section, is necessary.

The achievable shares of directly usable, renewable electricity produced by PV on site depend on solar radiation at the location and on the demand structure of the building. In southern European regions, the constantly high radiation in combination with the good load match for the cooling demand can lead to coverage rates at nearly zero energy buildings of more than 50% for the most non-residential building types. In Northern regions, the achievable coverage rates are expected to be significantly smaller (20% and less). In most non-residential buildings the thermal demand is often the only significantly flexible demand. As the thermal demand will be comparably small in nearly zero energy buildings, the expected increases of total coverage rates by load management are limited and expected to be below 5%.

Significantly higher coverage rates of the energy demand by PV estimated that up to 90% for most non-residential building types in southern European regions and up to 50% in northern European regions can be achieved by using batteries. As the prices for batteries storage are still very high, this option will not economically feasible in the near future.

6.2 Pathways of building automation with focus on nearly zero non-residential buildings

Many of the new non-residential buildings in Europe are being equipped with building automation systems to control the indoor climate and allow the HVAC systems to operate in an energy efficient way. However the capabilities of these are very different and range from basic functions to very sophisticated systems. Consequently, there is a potential to ensure that all new non-residential buildings are equipped with control systems that go beyond basic functions to ensure efficient operation.

At the same time, the EU Energy performance of buildings directive requires all new buildings as from 2021 on (public buildings as from 2019 on) to be built as nearly zero energy buildings that combine a nearly zero or at least very low energy use with a significant share of renewables. Different from buildings from the past that cover in worst case large energy needs with large energy supplies, the required balance between minimized energy losses, internal gains and the remaining energy need requires for nearly zero energy buildings a well mastered equilibrium.

Additionally, the integration of the significant share of renewable energy which is required for nearly zero energy buildings makes it important to manage the interaction of the produced energy with the buildings own consumption and the needs of the electricity grid.

Consequently, the realisation of nearly zero energy buildings will require building automation systems not for many but probably for all new non-residential buildings with these systems needing to be capable of and fine tuned to the specific needs of such buildings. Thus, building automation systems will play an important role for the realization of well performing nearly zero energy buildings.

Thereby building automation will be specifically relevant for the following aspects:

1. **Central control systems with concerted control of all energy related components** (opposite to independent component controls, as it is e.g. still common for the shading controls)
   Expected Impact: to be determined
   Proposed actions:
   Sophisticated central systems with producer-independent compatibility are available (e.g. BACnet), but need be further developed and supported to be standard requirement for nearly zero energy buildings
   More transparency concerning the energy demand of (sophisticated) building automation systems is required.

2. **Monitoring and providing feedback**
   a) to the realized energy consumption to ensure that the calculated (low) energy demand is met.
   A variety of examples show major differences between theoretical and real demand.
   Expected Impact: EU climate protection targets

Proposed actions:
Further research to specify the potential gap between paper and reality
By policies: Development of suitable regulations
By the industry: Development of suitable feedback systems

b) to the users to encourage them to save energy
Expected Impact: Reduction potentials of 5 % to 30 % of the energy consumption in buildings where individual control is possible (e.g. offices and hotels)
Proposed actions:
Further research to provide evidence of the potentials and costs
By the industry: Development of suitable feedback systems

3. Load shifting (storage management)

a) to increase the coverage rates of the energy demand by PV
This is economically interesting, especially in southern countries with high electricity prices and high solar potentials.
Expected Impact: Up to 5 % increase of total coverage rate
Proposed actions: Evaluation and publication of best practice examples could increase the market recognition

b) Energy related, to increase free cooling potentials
Expected Impact: to be determined
Proposed actions: Further research to specifying the potentials for different nearly zero energy building types in different regions is needed

c) Grid price related
Expected Impact: Increased grid stability, increased potential of renewable energies
Proposed actions: Electricity suppliers should offer (interesting) flexible electricity tariffs

4. Ensuring the thermal comfort
In nearly zero energy buildings with slow reacting systems, like concrete activation (common in office buildings in central Europe) or floor heating.
Expected Impact: Allowing the implementation of heating and (ground water) cooling systems with a high efficiency
Actions needed: Development of standardized control mechanisms, which are specialized to control slow reacting systems in nearly zero energy buildings (e.g. by using weather forecasts)

To grasp the full potential of building automation for nearly zero energy buildings, these aspects will be highly relevant and need further investigation. This can happen in further research, especially in connection with testing and monitoring of realized nearly zero energy buildings with integrated building automation systems.

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