TOPIC & PROGRAM   WORKSHOPS   KEYNOTE SPEAKERS   PANEL DISCUSSION   CONFERENCE PAPERS   SITE VISITS   APPENDIX

Distributed Energy Systems and Infrastructure

Zurich, June 15-17 2016
Sustainable Built Environment (SBE) Regional Conference

Expanding Boundaries:
Systems Thinking for the Built Environment

DYNAMIC ENERGY WEIGHTING FACTORS TO PROMOTE THE INTEGRATION OF RENEWABLES INTO BUILDINGS

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Abstract

One of the major challenges for the future of our energy systems is the integration of renewables and the continuous replacement of fossil and nuclear fuels in energy generation. Buildings play a very important role in this respect because of their large share in global energy usage and GHG emissions but as well because of their potential for integrating energy harvesting devices such as PV, wind turbines or solar thermal collectors.

On EU-level (Energy Performance of Buildings Directive 2010/31/EU) the target for nearly zero energy buildings (NZEB) was formulated without giving a clear definition for its implementation. The net zero energy requirement does make a statement regarding energy efficiency and the usage of renewable energy in buildings but it does not address the requirement of a proper integration of renewables into buildings to avoid peak loads on the grid. Typical performance evaluation of buildings as suggested by European Standards (e.g. EN 15603:2008) is based on the use of static weighting factors such as annually averaged primary energy factors or CO_2 intensities per energy carrier.

This paper suggests using dynamic weighting factors instead to judge the building performance and to set incentives for a better integration of renewables into buildings. A specific weighting scheme is suggested and has been applied to the research and innovation platform NEST on the Campus of Empa - Swiss Federal Laboratories for Materials Science and Technology. First results indicate that for the cases considered, static weighting of energy use is overestimating the energy performance of the building by 10 to 15%.

Keywords:

energy weighting; dynamic weighting factors; energy performance; net zero energy building

1 INTRODUCTION

An increase of efficiency and integration of renewables at a building or district level is a key issue of the energy transition aimed at by the Swiss energy strategy 2050. Similar goals are envisaged at a European and international scale. According to the Energy Performance of Buildings Directive (EPBD 2010/31/EU), all buildings realized after 2020 within Europe shall be implemented as so called nearly zero energy buildings (NZEB) showing a net zero energy balance over the year. European countries are requested to define their building codes accordingly in order to achieve the formulated goal across Europe. Although there is a binding goal being formulated, a clear definition of the NZEB is lacking. There are many different attempts for consistent yet different definitions of NZEB as presented e.g. by [1], [2], [3] as well as several critical reviews [4], [5]. Coming out of a task force of the Federation of European Heating, Ventilation and Air Conditioning Associations (RHEVA), [2] presents a technical definition of NZEB closest possible to the EPB Directive. This definition shall serve as a basis for European countries to establish their proper definition framework within national building codes. The definition of NZEB suggests the application of an

export/import energy balance leading to the net delivered energy. Weighting of the energy flows per energy carrier happens with national primary energy factors to achieve a net zero yearly balance. While there is no discussion on the shortcomings of a static energy balance discussed in [2] other authors like [3], [6] address the importance of dynamic effects for grid loading and suggest additional metrics to be used along with the basic static NZEB definition. One major critique using dynamic measures for load matching between the source and the sink is the increased complexity during the design phase and the need for more advanced and dynamic simulation methods with high temporal resolution.

The method presented in this paper replaces the static definition as typically found for NZEB by introducing dynamic weighting factors. With this dynamic nature it encourages the implementation of building's energy systems such that peak loads in wintertime are minimized and partly shifted to the summertime when more electricity from renewable sources is available.

The dynamic weighting scheme leading to a weighted net energy performance figure for a building has been developed in the context of the research and innovation platform NEST on the Campus of Empa - Swiss Federal Laboratories for Materials Science and Technology. This platform is hosting a large number of experimental buildings (called units) that are hooked up to a central energy network that allows for studying the energy performance of individual units or of a compound as found within districts. The NEST-specific performance figure was created with the idea in mind to set a standard which is more advanced compared to existing ones as well as providing the possibility to control the implementation of renewables on the level of the individual units. NEST is hence the first example where this energy performance metric has been applied and it is the place where it will be further developed to hopefully be applied to buildings outside of the research domain in the near future.

2   METHODS

A dynamic weighting scheme has been defined for the energy use in buildings. Key in this weighting scheme is the consideration of differences between seasons and weekdays/weekends. The differences between weekdays and weekends are reflected in the energy prices of the electricity spot market which again reflects the demand pattern (see figure 1a and 1b).
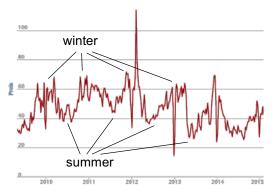

Fig. 1a: Spot market prices for electricity reflecting seasonal fluctuations.

Fig. 1b: Spot market prices for electricity reflecting weekly fluctuations.

Electricity prices are highest in wintertime and on weekdays when demand is highest. This price signals are used for weighting of electricity use in NEST after a normalization and smoothing procedure has been applied. Six different prices or weights result for the three seasons (winter, summer, spring/autumn) and the weekdays or weekends.

2.1   Exergy-based weighting of energy use

Thermal energy prices depend on the temperature of a respective heat source as well as on a reference temperature and can be quantified applying the concept of exergy. The exergy of a heat stream can be calculated by multiplying it with the Carnot factor as shown in equation (1)

$$\dot{Ex} = (1 - \frac{T_0}{T})\dot{Q} \tag{1}$$

If the temperature of the heat stream is below the reference temperature the exergy supplied can be considered "cold exergy" as supplied by an ideal cooling machine. In this case the exergy calculation of a heat stream needs to follow the definition given in equation (2).

$$\dot{Ex} = (\frac{T_0}{T} - 1)\dot{Q} \tag{2}$$

Relevant for the judgement of the thermal energy price for a unit is the net exergy demand which is defined by the exergy supplied minus the exergy returned. The exergy demand of a system can be seen as the electricity equivalent of the thermal energy demand and again be weighted using

electricity prices. The relation between the thermal energy demand and its respective exergy demand is represented in figure 2 for an exemplary building.
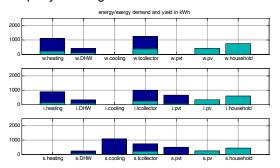

Fig. 2: Energy and exergy demands for an exemplary building using typical parameters.

2.2 System-based weighting of energy use

Departing from a pure exergy-based weighting of thermal energy finally, a more heuristic approach has been chosen. The latter is based on assumptions regarding efficiencies of heat pumps as well as heat and pumping losses of the systems found within NEST. The electrical equivalent of a thermal load is then calculated using equation (3), where COP is the efficiency of the heat pump, gamma and epsilon are the heat and pump losses expressed as a percentage of the unit's heat demand and the heat pump's electricity demand respectively.

$$\frac{P_{electric}}{Q_{thermal}} = \frac{1}{(1-\varepsilon)(1-\gamma)COP} \tag{3}$$

For the final weighting of the energy demand the electrical equivalent of formula (3) is multiplied with the electricity price of the respective season and day in the week. In the case of NEST where three thermal networks are available a price list as represented in table 1 results.

thermal winter			thermal inter.			thermal summer			electr. winter		electr. inter		electr. summer	
H	M	L	H	M	N	H	M	N	wd	we	wd	we	wd	we
0.432	0.240	0.034	0.306	0.107	0.029	0.137	-0.025	-0.123	1.222	0.838	1.045	0.623	0.868	0.408
-0.345	-0.228	-0.034	-0.244	-0.101	0.029	-0.137	0.022	0.123	-1.222	-0.838	-1.045	-0.623	-0.868	-0.408

Table 1: Combined weighting factors (electrical and thermal) for energy use differentiated by seasons and weekdays/weekends.

Based on the values presented in table 1 a weighted net energy performance figure as represented in equation (4) has been defined for NEST. The equation presents a weighted sum of individual energy demands such as heating,

cooling, domestic hot water, ventilation, appliances, etc. In contrast to comparable approaches electricity demand for the household is also taken into account. Energy demand of units is weighted using positive weights while energy supply is weighted using negative weights.

$$NEPF = w_i Q_{heating} + w_j Q_{DHW} + w_k Q_{cooling} + w_l Q_{PV} + ... \tag{4}$$

3 RESULTS

3.1 Definition of a NEST design limit

Based on the defined energy weights and assumptions made for the individual energy demands a design limit for the NEST specific net energy performance figure has been derived. Assumptions regarding energy demands are all based on Swiss energy standards (SIA 380/1:2009 and 380/4:2009). For the heating demand a more restrictive limit corresponding to 60% of the values defined in Swiss standards has been used. Energy demands were distributed over the different seasons according to the actual use pattern, e.g. of heating in winter and cooling in summer and according to the duration of each season. Taking the following definition for the seasons:

- winter: Ta,24h <= 10 °C
- intermediate: 10 °C < Ta,24h < 16 °C
- summer: Ta,24h >= 16 °C

a distribution of days of the year of 181, 93, 91 between summer, intermediate and winter results using weather data for a design reference year delivered by Meteonorm (V7.1.3.28617) for the location of Empa Duebendorf.

Finally, for the NEST specific net energy performance figure a limit of 136.8 MJ/(m2*a) corresponding to 38 kWh/(m2*a) for apartments and 190.8 MJ/(m2*a) corresponding to 53 kWh/(m2*a) for offices results. This limit has to be reached by the design of respective units built within NEST.

3.2 Comparison to static evaluation of design limit

For the comparison to a static weighting approach the dynamic weighting factors were averaged over the entire year and as such transformed to static weighting factors. Evaluation of the same energy demand with a static weighting yields a net energy performance figure for apartments of 124.3 MJ/(m2*a) corresponding to 34.5 kWh/(m2*a) and for offices of 170.3 MJ/(m2*a) corresponding to 47.3 kWh/(m2*a). This is 9.6% less for the apartment and 10.5% less for the office in comparison to the NEST-specific net energy performance figure.

3.3 Comparison for simulated office case within NEST

The NEST-specific net energy performance figure was also evaluated for an office unit implemented within NEST using simulation results provided by the unit's research partner (Lucerne University of Applied Sciences and Arts). A comparison of the net energy performance figure using dynamic NEST-specific weighting and the static weighting respectively identifies 12.7% lower values for the latter case. In case of dynamic and static weighting energy performance take values of 171.2 MJ/(m2*a) corresponding to 47.5 kWh/(m2*a) and 149.5 MJ/(m2*a) corresponding to 41.5 kWh/(m2*a) respectively.

4 DISCUSSION

An important strength of the energy weighting method presented is the flexibility it offers to the designers. Because of the performance requirement being formulated as a weighted sum the designer is free to make choices regarding individual summands. The designer could for example tune his energy concept towards a maximization of solar electricity generation while making moderate efforts on the level of the building envelope or vice versa.

A major goal of the energy weighting method discussed is to facilitate and incentivize the integration of renewables on a building level while accounting for the limitations given by the electrical grid. Assuming a high market penetration of NZEBs the load on the electrical grid and the need for regulating power capacity will increase unless there is any local storage installed. Using a dynamic weighting scheme and a performance goal based upon, it is possible to incentivize the implementation of energy concepts with low electricity peaks in wintertime and/or the installation of local energy storage.

The NEST-specific weighting method was applied along with a comparison to static weighting for two cases. Both cases revealed the significance of the dynamic weighting as the static weighting consistently led to lower values of the specific energy use of the building. The reason for the more optimistic judgment of the energy performance taking a static perspective is mostly due to the fact that high energy demands stemming from heating and domestic hot water applications in wintertime are not penalized.

The method presented essentially captures dynamic effects on different time-scales (seasonal and weekly). Fluctuations due to seasonal variations can be easily captured even when an analysis with low temporal resolution such as a month is applied. As such it can also be applied in an early design phase to guide systems design accordingly. Higher resolution of the method of course requires again higher temporal resolution on the simulation side typically in the range of an hour.

An important benefit of the presented method to be mentioned is its flexibility. While the method can remain unchanged the pricing scheme can be easily adapted to actual goals formulated by environmental policies.

The NEST-specific performance criterion is formulated as a net energy balance accounting for various energy supplies and demands. The deduction of the design limit was based on the demand side. As a consequence, the actual formulation allows units within NEST to fulfil the energy performance requirement without any energy harvesting implemented. For units on the roof-top of the NEST platform being highly exposed to the sun an additional requirement for the solar fraction of the energy demand is formulated. With a view on the definition of NZEB it is now straight-forward to change the design limit of the NEST-specific net performance figure to zero asking the roof-top units for a substantial amount of renewables to be integrated by design.

5 CONCLUSIONS AND OUTLOOK

This paper presented a dynamic weighting method to assess energy performance of buildings. For its application in the innovation and research platform NEST a design limit for a weighted net energy performance figure has been defined. The method presented is guiding the design of building's energy systems towards a better integration of renewables in terms of grid compatibility. Two cases studied, delivered first indications that a static method is overestimating the energy performance, leaving out the aspect of grid compatibility. The lack of accounting for this requirement in many todays' methods such as NZEB is seen as one of the major shortcomings that need to be addressed in the implementation of tomorrows building codes.

In future, more experience with the application of the dynamic method in the design phase as well as more results from simulation and actual operation need to be collected for upcoming NEST units. A major goal is also to find out about how strongly technology choices can be influenced by different pricing schemes and how those schemes need to be adapted to further instigate integration of renewables and installation of local energy storage. Finally, a link of the energy use to CO2 emissions and eventual embodied emissions of building materials used shall be studied.

6 ACKNOWLEDGMENTS

TOPIC & PROGRAM

WORKSHOPS

KEYNOTE SPEAKERS

PANEL DISCUSSION

CONFERENCE PAPERS

SITE VISITS

APPENDIX

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