DESIGN STRATEGIES FOR NON-RESIDENTIAL ZERO - ENERGY BUILDINGS
Lessons learned from Task 40/Annex 52
"Towards Net Zero - Energy Solar Buildings"

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Abstract

Net zero-energy buildings (Net ZEBs) have been the object of various studies in recent years as various countries have set this performance as long-term goal of their energy policies. Designing successful Net ZEBs represents a challenge since the definitions are yet generic, the assessment method and monitoring approach are under development and the literature is relatively scarce about the best sets of solutions for different typologies and climates likely to deliver an actual and reliable performance in terms of energy balance (used consumed vs. generated) on a cost-effective basis. The International collaborative research initiative between the Solar Heating and Cooling (SHC) and the Energy Conservation in Buildings and Community Systems (ECBCS) through Task 40/Annex 52 - Towards Net-Zero Energy Solar Buildings-, summarises most of the recent developments in this field. The authors of this article, who are participants in this task, are providing insights from on-going research work on some best practice leading projects which have been the object of an exploratory cross-case analysis in order to facilitate identification of the set of relevant design strategies. The close inspection of the strategies and indicators of the relative performance of the projects revealed interesting features about the combination of design challenges with techniques and technologies responsible for delivering the Zero Energy performance.

Keywords – net zero energy; non-residential buildings; design strategies

1. Introduction

Energy efficiency has become a priority as a consequence of increasing buildings energy consumption in the recent years. With the publication of EPBD recast in 2010 which require all buildings to become "nearly zero-energy" by 2020, it is expected all new buildings to meet higher levels of performance than before [1]. Since a "nearly zero-energy building" refers to a high energy performance building of which annual primary energy consumption is covered to a very significant extent by energy from renewable sources, it also expected the buildings to explore more the alternative energy supply systems available locally on a cost-efficiency basis and without compromising the comfort. Since the Directive does not specify minimum or maximum harmonized requirements as well as details of energy performance calculation framework, it is up to the Member States to define the exact meaning of "high energy performance" and "amount of energy from renewable sources" as well as the metric used to calculate the energy balance (primary/final energy, carbon emissions, etc.) according to their own local conditions and strategic interests. Nearly zero-energy performance derives from net zero-energy concept which in case of buildings is usually defined as a high energy performance building that over a year is energy neutral (i.e. net balance of primary energy is 0 kWh/(m². y)). Therefore, a possible way to assess the nearly zero-energy performance is by first analyzing the annual energy balance in Net Zero-Energy Buildings. Net Zero-Energy Buildings have been the object of various studies in recent years as various countries have set this performance as long-term goal of their energy policies [2, 3, 4]. The International collaborative research initiative SHC ECBCS Task 40/Annex 52 - "Towards Net-Zero Energy Solar Buildings", summarizes most of the recent developments in the field [5]. The approximate 55 National Experts, among which can be found the authors of this work, together with other 25 regular participants and contributors, are currently researching net zero-energy, plus energy and nearly zero-energy buildings in order to develop a common understanding, a harmonized international definitions framework, tools, innovative solutions and industry guidelines for Net ZEBs.

Unlike residential buildings, where net zero energy performance depends greatly on passive approach strategies adopted to minimize the buildings energy demand, in non-residential buildings the net zero energy performance is more closely related to energy efficiency of systems (HVAC, lighting and others). To find out the main design strategies used for achieving the desired zero-energy performance in non-residential buildings, a number of 8 projects were selected and analyzed in a systematic and target oriented way in the present article. However, in order to facilitate identification of the set of relevant design strategies, rather than performing a detailed analysis of each individual project, an exploratory cross-case analysis was employed instead. This procedure, which has been applied

successfully elsewhere for the analysis of net zero residential buildings [6], allows the identification of the set of relevant Net ZEB design strategies (combination of passive approaches (PA), energy efficient systems (EES) and renewable energy systems (RES)) which are more likely to succeed in reaching the desired net zero-energy performance.

2. Net Zero Energy Performance

In the international context, Net ZEB concept can be addressed in four main approaches: Net Zero Site Energy, Net Zero Source Energy, Net Zero Energy Cost and Net Zero Energy Emissions. Net Zero Site Energy means that the annual balance is based on the grid interaction at the boundary of the building site, i.e. the overall energy delivered to the building from the utility grid has to be offset by the overall energy feed in to the grid. In the Net Zero Source Energy approach, which is the one currently used by EPBD recast in the nearly zero-energy context, the energy (delivered from and feed into the grid) has to take into account primary energy conversion or weighting factors. Net Zero Energy Cost buildings approach is based on an economic balance (the energy bills of a building are equivalent the amount of money the utility pays the owner for renewable energy the building feeds to the grid) whereas in the Net Zero Energy Emissions case, buildings produce and export at least as much emissions-free renewable energy as they import and use from emission-producing sources on an annual basis [7]. Although there is no standard approach for designing and realizing a Net Zero Energy Building (there are many different possible combinations of building envelope, utility equipment and on-site energy production equipment able to deliver a net-zero energy performance) there is some consensus [8] that zero energy buildings design should start from passive sustainable design as this level of performance is achieved as a result of executing three distinct steps: reduce building energy demand by adopting passive measures, use energy efficient systems and technologies and adopt renewable energy systems (RES) to generate electricity or other energy carriers to get enough credits to achieve the desired energy balance.

3. Case Studies

Table 1 presents a summary of the main features of the 8 projects selected from the IEA Task 40 project data base for analysis [9, 10]. As it can be seen from Table 1, buildings are characterized according to location, type, net floor area and primary energy performance (demand versus supply). One can also note that 4 buildings are office and 4 are educational (with the exception of Die Sprösslinge, which is a nursery school, all educational buildings are primary schools). Concerning energy balance, which takes lighting, heating, cooling and appliances into account, the Net Zero Source Energy approach applies to all cases.

Table 1. Main features of the 8 projects under investigation

Building/ Country	Building Use	Net Floor Area (m^2)	Annual primary energy demand (kWh/m^2. year)	Annual primary energy generation (kWh/m^2. year)	Annual primary energy balance (kWh/m^2. year)
SolarXXI *Portugal*	Office	1200	87.00	84.00	-3.00
Circe *Spain*	Office	1743	87.20	31.00	-56.20
Kemptthal *Switzerland*	Office	1550	97.00	80.93	-16.07
AEE-Villach *Austria*	Office	292	111.01	181.90	70.89
Die Sprösslinge *Germany*	Educational	969	116.61	113.62	2.99
Schule Niederheide *Germany*	Educational	6563	44.00	39.00	-5.00
Laion school *Italy*	Educational	625	11.00	27.00	16.00
Volksschule Mähdle *Austria*	Educational	3367	29.27	12.14	-17.13

4. Net ZEB Design Features

Although the main principles applied in passive sustainable design are well known, the fundamental issue is to find if the same applies in Net ZEB design as well. To find out the answer, the analysis of the 8 projects was performed according to the scheme shown in Figure 1. In this approach, which has been successfully applied elsewhere for the analysis of residential buildings [6], the three main steps required to achieve the Net ZEB performance represented by the concentric circles of the chart are related to specific challenges in terms of lighting, heating and/or cooling and power generation. This procedure has the advantage of facilitating the identification of the set of relevant Net ZEB design issues (combination of passive approaches (PA), energy efficient systems (EES) and renewable energy systems (RES)) which are more likely to succeed in reaching the desired energy performance.
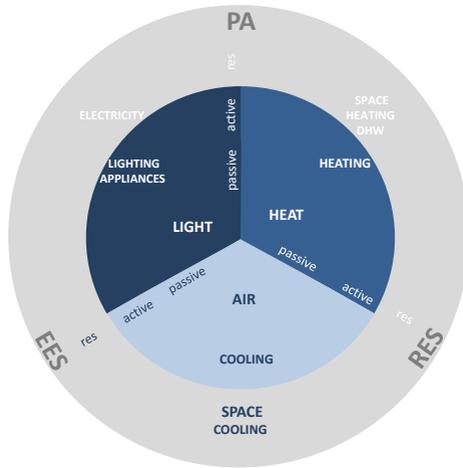
Fig. 1 Net ZEB design approach [6]

In the following, and in order to understand better the key components that affect Net ZEB energy performance of the 8 projects, a second set of features is presented in Table 2, namely climate challenge, U-value of walls, g-value of windows, building compactness (ratio of area per volume), heating and/or cooling systems and installed PV capacity. At this point, it is known that passive approaches play a key role in Net ZEB design of residential buildings, as they directly affect the loads put on the buildings mechanical and electrical systems, and indirectly, the strive for renewable energy generation. In the context of non-residential, even though the buildings were designed to meet different energy performance levels (according to building use and national specific strategic needs), it is believed that it is still useful to obtain information on the envelope thermo-physical characteristics and compactness. From this point of view, it is known that buildings that are dealing with heating challenges should adopt passive strategies which are oriented towards solar heating maximization and prevention of heat loss strategies. If one analyses the "U-values" in Table 2, one can see that, with the exception of corresponding values of Solar XXI, Circe and Laion buildings, all values are very low. This, however, is no surprise given the fact that all these buildings are heating dominated (HD) and were all designed according to Passive House concept. Contrary to the rest of the buildings, Solar XXI, Circe and Laion are heating and cooling dominated (HCD) and it is interesting to observe that they are characterized by "U-values" greater than the indicated by the Passive House Standard as a consequence of this. One should mention the fact that Passive House Standard is not appropriate for Southern Europe [11].

Table 2. Characterization of 8 projects under investigation according to U-value, g-value, compactness, Heating/cooling system and PV system

Building	Climate challenge	U-value wall [W/m^2.K]	g - value	Surface to volume [m^2/m^3]	Heating/ cooling system	PV system [kWP]
SolarXXI *Portugal*	HCD	0.45	0.75	0.40	SWH; BIPV; earth-tube	30.0
Circe *Spain*	HCD	0.57	0.40	0.52	GHP	5.5
Kemtthal *Switzerland*	HD	0.12	0.40	0.41	GHP	44.6
AEE-Villach *Austria*	HD	0.10	0.51	0.46	CHP; SHW	3.60
Die Sprösslinge *Germany*	HD	0.14	0.51	0.56	GHP; SHW	49.0
Schule Niederheide *Germany*	HD	0.15	0.45	0.39	CHP	55.0
Laion school Italy	HCD	0.22	0.34	0.89	GHP	17.70
Volksschule Mähdle Austria	HD	0.13	0.50	0.36	GHP	26.00

Concerning the "g-values", with the exception of Solar XXI and Laion, all buildings are characterized by values close to 50% that is the reference of Passive House concept. With consideration of "U-values" and "g-values", it is well known that they must be balanced according with the climate building challenge and that low "U-values" in conjunction with high "g-values" are appropriate for a cold climate given that in this way is promoted heating performance. Bearing this in mind, it is no surprise that "g-value" of Laion school is lower than the rest. Regarding thermal heat loss surface area of envelope (A) - heated volume (V) ratio (compactness) is well known that a high compactness (A/V ≤ 0.7 m^2/m^3) is recommended for heating dominated climates in order to limit the heat losses, whereas medium-high compactness is more adequate for heating and cooling dominated climates because the cooling demand will be reduced [12]. According to values shown in Table 2,

with the exception of Laion building, which has an A/V ratio value equal to 0.89 m^2/m^3, all buildings have high compactness.

However, as referred above, unlike residential buildings, of which energy usage and consumption depends mainly on climate challenges (the so called skin-load dominated), in educational and office buildings energy demands are largely driven by the internal loads of the building (so called internal-load dominated). As one can deduce, in internal-load dominated buildings, in addition of passive design adopted in order to reduce solar gains, buildings should also rely on improving energy efficiency of systems (HVAC, lighting and other equipment). Regarding the energy efficient systems for ambient heating and cooling, the investigated projects make use of low exergy systems in the form of radiant heating and cooling (Laion, Die Sprösslinge, Schule Niederheide and Circe) and efficient mechanical ventilation through air heat recovery (all with the exception of Solar XXI, Villach and Circe). At the same time, low power lighting as a strategy is common to all buildings, whereas energy efficient electrical equipment (Solar XXI, Villach and Kemptthal) and load management system (Mähdle, Schule Niederheide and Die Sprösslinge) are also used, despite of the fact that their clear advantages are yet to be proved [13].

After having performed all necessary steps towards lowering building´s energy demand, the last step to be carried out is the integration of renewable systems for energy generation. Since the objective is to reach a net zero energy performance, the lower the energy demand the lower the strive for energy generation. Given the buildings specific energy needs, renewable energy systems should either provide the heating and cooling or the fuel necessary to run the space heating and cooling systems together with lighting and other occupant's related uses. With this respect, and as it can be seen from Table 2, the most common strategies make use of photovoltaic systems (PV) for electricity generation (all cases) and ground source heat pumps (GHP) for both space heating and cooling (all with the exception of Solar XXI, Villach and Schule Niederheide). For space heating, Solar XXI uses a solar water heating system (SWH) coupled with a conventional gas-fired boiler and a façade mounted building integrated photovoltaic system (BIPV) which is able to pre-heat the incoming ventilation make-up air developed through the heating of the modules. For cooling, Solar XXI uses an earth-tube system. A combined heating and power plant (CHP) fired by wood pellets is used by Villach and Schule Niederheide buildings.

5. Cross-Case Analysis

The main design strategies used in Net ZEB design have been addressed in the preceding sections in a systematic and target oriented way. Based on the information above one can deduce that passive approaches are likely to play an important role in Net ZEB performance of non-residential buildings, and that together with energy efficient systems may successfully address the

required reduction of energy demand. In order to demonstrate the role played by PA, EES and RES, one can think of the energy performance associated to each individual category as a consequence of executing the steps shown in Figure 2. The value of point B represents the energy demand as a result of adopting passive measures from point A which is the equivalent of the minimum energy performance as indicated by corresponding national energy code for buildings. Further adoption of energy efficient systems, results in a reduction of energy demand to point C, where from further adoption of renewable energy systems leads to net zero energy balance (point D).
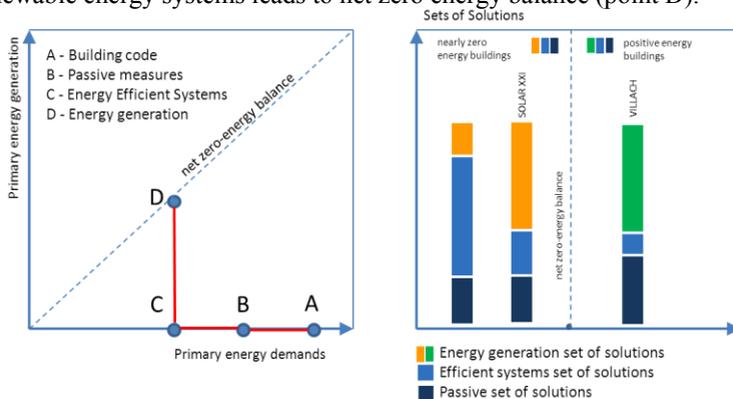

Fig. 2 Methodology for cross-case analysis of PA, EES and RES contributions

Since these 8 cases of buildings are well documented in terms of simulated energy performance (in addition of physical characteristics and monitored energy performance data), the illustration of each step is possible and offers an integrated perspective with several advantages, as it can be seen from right-hand panel of Figure 2. In the stack columns (shown as illustrative examples here), one for each building, is possible to identify the percentage each category (PA, EES and RES) contributes to the final result. Sets of solutions of PA, EES and RES are identified with distinctive colors, with a second differentiation being made between the buildings exhibiting a positive energy balance (green colored RES) and the rest of the buildings, where RES is identified by orange. Note that the blue bars (PA and EES) show energy savings (A-B, B-C) rather than energy use. Therefore, the relative length of the blue bars compared to RES generation does not inform on the Net ZEB performance (i.e., whether the building meets the net zero balance).

The application of this methodology for cross-case analysis of the 8 buildings results in the representation shown in Figure 3. As it can be seen, for each building under analysis it is possible to identify which set of sets solutions contributes more to the final energy performance.
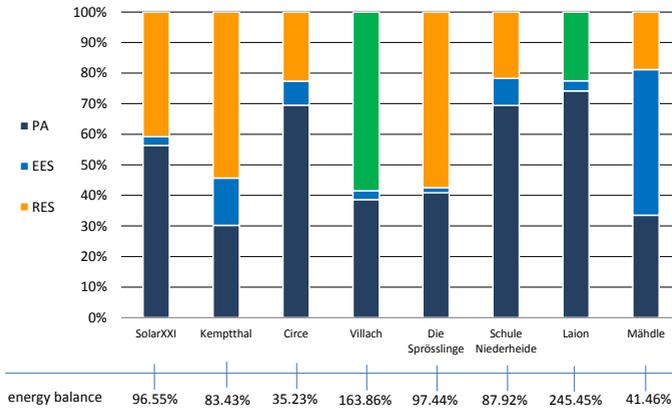
Fig. 3 Cross-case analysis of PA, EES and RES contributions of 8 buildings under investigation

Taking Solar XXI as example, one can observe that the 96% of energy performance (ratio of energy generation to energy demand) is a result of a reduction of energy demand as a result of implementing PA and EES equivalent to 56% and 3%, respectively, the remaining percentage being associated to RES equivalent required to compensate the energy demand, which in this case is approximately equal to 40%. In the perspective of lowering buildings energy demand through the implementation of PA and EES, the inspection of 8 buildings reveals, with only one exception, and regardless of building use, that the major percentage is due to implementation of PA. The Mähdle case (which is a renovation project) is the exception to this rule, though one needs to be aware of the fact that this building exhibits a low Net ZEB performance (only 41% of energy demand is covered with renewable energy). Concerning the role of EES, one can also note that buildings with largest net floor area exhibit the large percentages of reduction of energy demand, 47% in the case of Mähdle, 15% in the case of Kemptthal, 9% in the case of Schule Niederheide and 8% in the case of Circe. It should also be noted that in some cases EES results in relatively small savings of primary energy use due to fuel switching from (e.g.,) natural gas (in the reference building) to electricity (to run a heat pump in the actual building), which usually has a much higher final to primary energy conversion factor.

6. Conclusions

In order to present and discuss the design strategies used in Net ZEB design of non-residential buildings, a number of 8 projects have been selected from IEA Task 40/Annex 52 - "Towards Net Zero Energy Solar Buildings" project database. The cross-case analysis employed has shown

that there is no standard approach for designing a Net ZEB as that there are different possible combinations of PA, EES and RES able to achieve a desired Net ZEB performance. However, a close inspection of the strategies and indicators of the relative performance of the 8 case studies revealed that is possible to achieve a Net ZEB performance using well known strategies and that zero-energy buildings design is a progression of passive sustainable design.

7. Acknowledgement

8. References

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