Research possibilities in the Norwegian ZEB Laboratory

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Introduction

This article presents the ZEB Laboratory and describes its research possibilities. ZEB Laboratory is an experimental facility located at the Norwegian University of Science and Technology (NTNU) campus in Trondheim, Norway. The laboratory will become four stories high, totally 1 800 m² floor area. The building is intended to be an office, an education, and a laboratory building. Regarding the environmental targets, the idea is that the building should achieve the Zero Emission Building (ZEB) level with compensation for emissions from construction, operation and production of building materials over 60 years. This means that the building must have a local renewable energy production that can compensate for greenhouse gas emissions from construction, operation and production of building materials over 60 years. This definition is called ZEB-COM. The definition was developed by the Research Centre on Zero Emission Buildings (www.zeb.no).

The vision is that the ZEB Laboratory will contribute to building knowledge on ZEB and be an arena for experimental investigation of the interaction between users and building and as a benchmark to test new technologies.

ZEB Laboratory is a joint effort between NTNU University and SINTEF Research organization with funding from the Norwegian Research Council.

Regarding the building's energy supply systems and building service systems, the building is equipped with flexible solutions so that the components can be operated in different ways, adjusted or maybe be changed. The ZEB laboratory has its own energy supply system and it is connected to the public electricity and the district heating grid of campus. An innovative ventilation system combining mechanical and natural ventilation are installed. For example, on the first floor, two identical rooms are equipped as test cells with dedicated HVAC systems. For the monitoring purpose, a larger number of sensors are installed, and they are connected to a flexible control and monitoring system. The vision for the control and monitoring system is to enable interoperability and to allow communication between different sensors and meters for energy, occupancy, and any other measurement.

This article describes the characteristics of the ZEB Laboratory and some of the possibilities for research.

ZEB laboratory description

The vision of the Norwegian ZEB Laboratory is to be an arena where new and innovative components and solutions are developed, investigated, tested, and demonstrated in mutual interaction with building occupants.

ZEB Laboratory shall be:

- a basis for knowledge development at an international level,
- a basis for international competitive industrial development,
- an example for new and retrofitted zero emission buildings,
- a research arena for the development of zero emission buildings,
- an arena for risk reduction before new zero-emission technologies are implemented by the building sector;
- a national and international resource for research and
- a tool for NTNU and SINTEF for institutionalizing the post ZEB Centre [1].

The ZEB Laboratory, shown in **Figure 1**, is a living office laboratory. It will be used for everyday office work, education and research at the same time. ZEB Laboratory will be a full-scale office building where building façades, components and technical systems can be modified and replaced. The building will form a *living laboratory*, i.e. a laboratory used by people as an ordinary office building or for educational purposes which becomes a source of continuous experimental data. The ZEB Laboratory focuses on making the initial building a relevant research case, both regarding occupant interaction and energy performance in a Nordic climate.

Figure 1. The ZEB Lab is a living office laboratory. (Source: LINK Arkitektur) (Preliminary drawing)

The number of building users will be about 80, besides comes about 40 places for students in the auditorium. The building is positioned at 63° 24′ north and 10° 24′ east.

The design process started in 2016, the construction work started May 7th, 2019. The taking-over commissioning process will start in August 2020 and is planned for 6 months. As for all buildings, the testing and commissioning phase is important, but especially for this building as it has an advanced solution for building energy management system and more comprehensive instrumentation than regular office buildings. The adaptability of the building/laboratory will make it possible to investigate different building configurations, technologies and usages.

Ambitions for the ZEB Laboratory

NTNU and SINTEF have a set of ambitions for the ZEB Laboratory [2]. These ambitions are related to building performance and the possibility to use and learn from the building use. The ambitions are, in prioritized order:

1. The building should be a role model project and achieve the ZEB-COM level (simulated over a 60-year perspective) [5]. See the introduction the Norwegian definition for the ZEB-COM.

2. The operation of the building and measurements must be made independently of each other, i.e. research data can be obtained without interfering with the operation of the building. On the other hand, the operation of the building should be capable of being put into "research mode" so that different models and algorithms of operation can be tested for all or part of the building.
3. Flexibility in use of energy and HVAC systems
4. Flexibility in use of working space
5. Advanced selection and use of materials and enabling rebuilding parts of the facades
6. Adaptation of the building to climate change [4]

Even though the building is ambitious regarding the energy and monitoring requirements, the building should be simple and practical in use with a good indoor environment.

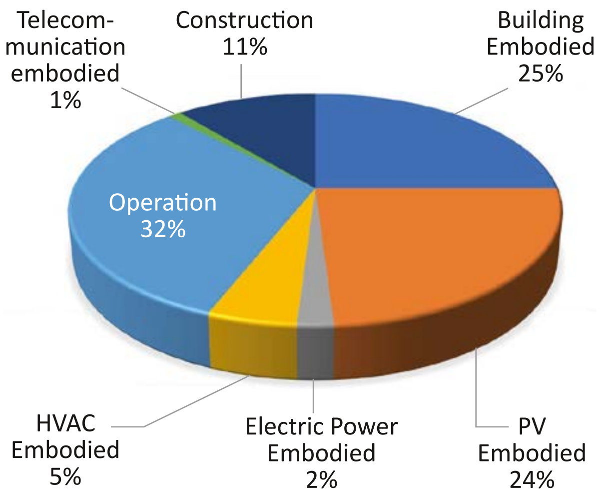

Figure 2. Evaluation (budget) of greenhouse gas emission of the ZEB Laboratory. (Source: LINK Arkitektur AS)

The procurement and development of the ZEB Laboratory

Design and solutions to best fulfil the high ambitions for the building were not determined in advance but developed as part of a design process. The building owners NTNU and SINTEF developed the new laboratory together with a selected group consisting of a leading contractor with a team of architects, consultants, subcontractors, and other professionals. Experienced researchers from the Norwegian research centres Zero Emission Buildings (ZEB) [1], Zero Emission Neighbourhoods (ZEN) [3] and Klima 2050 [4] were included with their specialist expertise.

Development of ZEB-COM

As mentioned in the Introduction the ZEB Centre definition of a zero-emission building [1] focuses on greenhouse gas emissions rather than on energy use. The emissions due to all the phases of construction and operation need to be compensated for by onsite production of renewable energy. [5].

Figure 2 shows the emission contribution of material, construction and operation of the ZEB Laboratory. The emission contribution is evaluated in kg $CO_{2eq}/m^2/y$ for a period of 60 years. For the evaluation of the emissions associated with the construction, the adopted value per square meter comes from a previous Norwegian project, Campus Evenstad [6].

Building Materials and Envelope Technologies

ZEB Lab is built with a loadbearing system made from wood. Glue laminated timber columns and cross-laminated timber elements in floors, elevator shafts and some elements for stiffening the building. Outer walls are wooden frames insulated with glass wool. This is to keep the embodied emissions low and to make the achievement of ZEB-COM possible. The building is cladded with PV-cells located on the roof, the whole southern façade and part of the other facades. Elsewhere burnt wooden panels are used to achieve a homogenous appearance and to keep embodied emissions low. The south façade of the first floor, including the twin rooms (see later), is made so that the façade or window elements can be replaced. New products, components and technologies can therefore be applied to investigate and optimize the building envelope and building performance. This allows investigations of the performance and the effect of products and envelope properties (e.g. insulation levels, façade configurations including solar shading and natural ventilation strategies) on energy use and user comfort.

A part of the air cavity below the PV panels is separated from the rest of the roof. This is to prepare for future experiments which can make use of heat below the PV panels in the heating of the building. Experiments can investigate the potential for improving the efficiency of PV panels, coefficient of performance for the heat pump for the building, and directly charging of the buildings thermal PCM storage. Temperature, relative humidity, and air pressure differences will also be measured behind the PV and wooden claddings and on the wind barrier on the vertical facades to characterize long term climate conditions for tapes and barriers.

Twin Rooms test facility

The identical twin rooms on the first floor (i.e. second level), see **Figure 3**, each represent a 66 m² office room with independent HVAC systems, a dedicated control room and a much larger number of sensors than the other spaces in the laboratory. All the parameters which influence the occupants' comfort are monitored (temperature, relative humidity, carbon dioxide, air change rates, illuminance, etc.). The data acquisition and control system is provided by Siemens. The twin rooms of the ZEB Laboratory allow both comparative and close to calorimetric studies. The material of façades and components can be replaced.

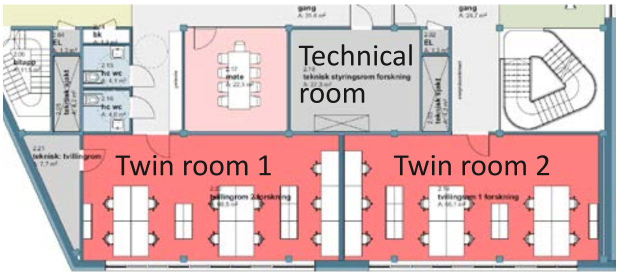

Figure 3. Plan for the twin rooms (areas in red, each room 66,5 m²) on the first floor with separate technical rooms (27,3 m² area in grey) (Preliminary).

Building energy supply systems

The laboratory is equipped with building integrated photovoltaic (BIPV) panels and a heat pump that can make use of different heat sources (i.e. heat recovery from service and outdoor air). This makes it possible to investigate possible combinations between available local renewable energy production and the electricity grid that matches the zero emission building requirements. A phase change material (PCM) heat storage will be installed in the building and is used to recover thermal energy and as a thermal energy buffer to ensure more efficient use of the heat pump. The PCM heat storage infrastructure is made flexible, so different operation modes can be tested [7]. **Figure 4** illustrates the energy supply system of the ZEB Laboratory.

Grid integration makes it possible to implement experiments on the interface between buildings (ZEBs) and grids, especially smart power grids, but also district heating and cooling grids. This enables, for example, the study of the performance of optimal predictive control strategies, load shifting, and energy storage.

Building services - HVAC

The building is facilitated to explore different ventilation strategies together with monitoring of user satisfaction and energy use. The whole building is prepared for operation and research with natural ventilation, mechanical balanced ventilation or a combination of both (hybrid ventilation/mixed mode ventilation).

Natural ventilation

Some windows in the building can be opened manually while others are motorized. The windows' positions are designed to facilitate cross and buoyancy driven ventilation. The main staircase (**Figure 5**) is designed to work as an extract for both mechanical and natural ventilation air. Windows in the north façade close to the ridge of the roof are designed as an outlet for natural ventilation. The twin rooms can be ventilated naturally by windows and a separate exhaust duct.

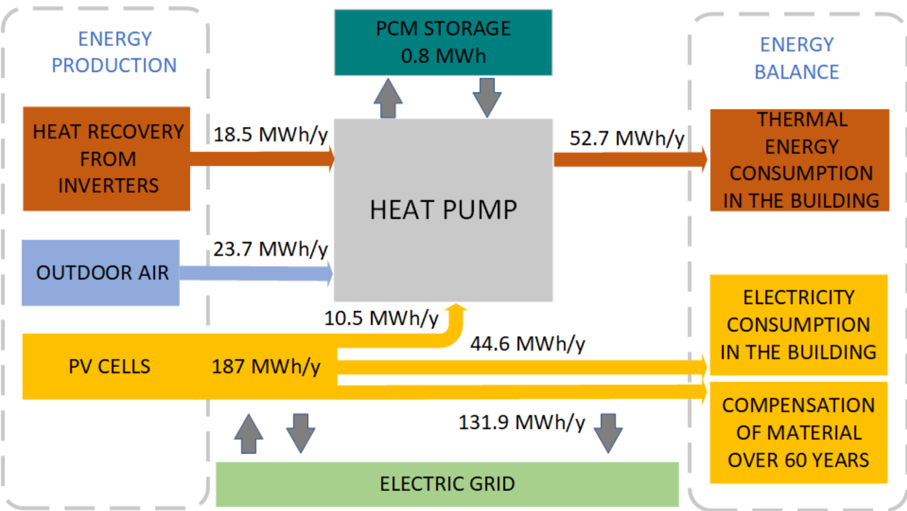

Figure 4. Schematic view of energy supply and use for the ZEB Laboratory (modified from [8] - preliminary).

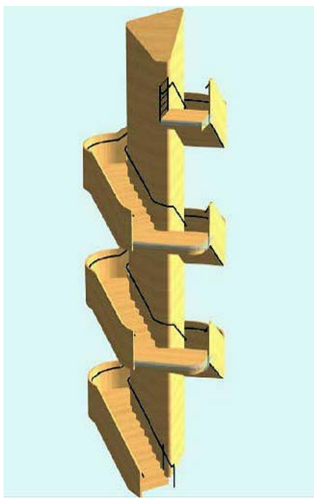

Figure 5. Preliminary design of the main staircase. (Source LINK Arkitektur)

Mechanical ventilation

The building is equipped with a central mechanical ventilation system. Different air distribution systems were designed for each of the four floors, but they all rely on the principle of displacement ventilation. At the ground floor air is supplied through inlet devices mounted in the floor, on the first floor through porous ceiling boards in the suspended ceiling, in the second floor through slots in the suspended ceiling and on the third floor through wall air terminals placed at floor level. The volume above the suspended ceiling is used as a plenary chamber. The air handling units are fitted with heat wheels. The heating is achieved using a heat pump with possibilities for PCM accumulation. No mechanical cooling system is installed. The twin rooms are specially equipped both with their technical rooms and independent HVAC systems, see **Figure 3**. The twin rooms can apply both heating and cooling via heating/cooling coils connected to the central hydronic system. Furthermore, the twin rooms are more densely equipped with sensors for monitoring and control systems for indoor climate, energy supply, ventilation strategies, cooling, space heating, lighting and window shading.

Indoor positioning system, monitoring and control

The building is designed with an indoor positioning system delivered by Siemens that detects the occupants' position. The solution establishes a communication network that interacts with the occupants' smartphone using wireless sensors. User position is calculated using triangulation algorithms and the results are sent in real-time to a cloud solution. Data concerning occupancy and position are valuable data for investigation and are stored to the SINTEF API server.

The same data can be used to provide services and information which the user can visualize using a browser or a mobile app. Using these apps users can, for example, locate colleagues, equipment, be guided to meeting rooms or exits. Each portable device can be selected to be visible or not, i.e. possible or impossible to locate. The system is designed to have enough flexibility to be modified to address changes both due to building management and experimental necessities.

The building, or part of it, can be "overtaken" by researchers and operated by a research simulation server. In this way, researchers can control the building by own algorithms.

Research possibilities

The focus on adaptability and flexibility in the construction of the ZEB Laboratory allows the investigation of large-scale building envelopes and the effect of the envelope materials and properties on the whole energy balance of a building and on the user comfort. As described, the building integrates several systems such as heat storage in PCM and BIPV on the roof. This, together with the modularity of these systems, allows the ZEB Laboratory to be a valid benchmark to investigate the optimal combination of building characteristics with local renewable energy production. The interaction between a building with this kind of equipment and the grids, especially smart power grids and district heating grids is another area of interest with the possibility to conduct accurate measurements at the building-grid interface.

Measurement and control of energy supply, air supply, lighting, windows shading, occupancy etc. are performed via a dedicated Building Control Systems. The ZEB Laboratory gives the possibility to test for example:

- Integration of building energy simulation tools for studies of new methods for the user-centred design of buildings and building technologies.
- Test of wireless technologies for analysis of occupant behaviour.
- Investigation of building operation considering active user interactions with building energy management systems
- Impact of lighting systems on user health and well-being.
- User perception of different natural and mechanical, natural and mixed-mode ventilation strategies
- Optimal and advanced use of natural and mechanical ventilation against climate and user data
- Connection between external parameters (smart grid, weather data, and forecast) and the thermal energy storage efficiency
- Use of AI to interpret connections between indoor positioning data and indoor climate data
- Peak load and load shifting strategies for building design

The experience that NTNU/SINTEF accumulated with living laboratories has clearly shown that the research opportunities for a laboratory of this kind go farther than what the laboratory is specifically designed for, ranging from deeper modifications of systems and structures to the use of the laboratory as a controlled environment.

Conclusions

The ZEB Laboratory is the result of the cooperation between NTNU/SINTEF, the contractor, architects, consultants, and subcontractors. The building is an example of a zero-emission building constructed following a ZEB-COM ambition, and an arena for the evaluation of large-scale material, systems and solutions. Testing large-scale technologies on this building will be a substantial scientific contribution and it contributes to reducing the entrepreneurial risk for those companies which are willing to invest in new technologies.

The large amount of data collected will be an important contribution to specific studies on human-building interaction, on the impact this has on the energy balance and the interface between the building as a system and the smart power grids (electric, district heating, etc.).

The research opportunities are increased by the presence of the twin room, which allows an easy replacement of façade components and allows researchers to run specific comparative tests in a controlled environment. ■

Acknowledgements

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