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SINTEF NOTES 33

ZEB Laboratory – Research Possibilities

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Preface

This report describes challenges and research possibility within the new ZEB Laboratory (www.zeblab.no) under construction at the Gløshaugen Campus in Trondheim, Norway. The project is funded by the Norwegian Research Council (NFR) in cooperation with Sintef and NTNU.

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Trondheim, August 2019

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Abstract

The ZEB Laboratory is an experimental facility located in NTNU Gløshaugen campus in Trondheim. The building is designed as 4 storeys high and 1800 m^2 area office space and should achieve the ZEB-COM ambition level over 60 years. The laboratory will contribute to build knowledge for zero-emission buildings, it will be an arena for experimental investigation of user-building interaction, and a laboratory to test new technologies on a large scale. Innovative ventilation and energy technologies are included. At the first floor two identical rooms are equipped as test cells with dedicated HVAC systems, a larger number of sensors and with a higher flexibility for control. This paper reports some characteristics of the ZEB Laboratory and some of the research possibilities.

Contents

Introduction

The vision of the Norwegian Zero Emission Building Laboratory (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's 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 developing zero emission buildings
- an arena for risk reduction when implementing zero emission building technologies
- an international resource within the research area

The ZEB Laboratory, see Figure 1, is a living office laboratory 4 storeys high and 1800 m^2 located in Trondheim at the NTNU Gløshaugen campus, close to the existing laboratory facilities of SINTEF Community and NTNU Department of Civil and Environmental Engineering. The design process started in 2016, the construction work started 7th of May 2019 and the laboratory will be ready for test operation in August 2020. The test operation period is planned for 6 months.

ZEB Lab 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.

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

Furthermore, to investigate and demonstrate new technologies in a full-scale office building is important to reduce risk for the first movers willing to start implementing zero emission building levels in their designs and constructions. The adaptability of the building/laboratory will make it possible to investigate different building configurations, technologies and usages.

The Ambitions

NTNU and SINTEF have a set of ambitions for the ZEB Laboratory [2]. These are, in prioritized order:

1. The building should be a model project and achieve ZEB-COM level (simulated over a 60 years perspective) [5]
2. Separate control and measurement systems
3. Flexibility in design and use of energy and climatisation systems
4. Flexibility in design of working space
5. Continuous selection of new materials and improvements by rebuilding parts of the facades
6. Adaptation of the building to climate change [4]

The procurement and development of the ZEB Laboratory

The building has been developed in a collaborative project with a leading contractor and its consultants and subcontractors.

Design and solutions to best fulfil the high ambitions for the building were not determined in advance, but selected as part of the design process. NTNU and SINTEF developed the new laboratory together with a very skilled group of architects, designers and contractors. Professionals from the Norwegian research centres Zero Emission Buildings (ZEB) [1], Zero Emission Neighbourhoods (ZEN) [3] and Klima 2050 [4] are included with specialist expertise. The implementation model was described in detail in the announcement. A novel project delivery model, a collaborative contract, was asked for in the bid.

Development of ZEB-COM

The ZEB Centre definition of a zero-emission building [1] focuses on greenhouse gases emissions rather than on energy use during the design. The emissions due to all the phases of construction and operation need to be compensated for by onsite production of renewable energy. Several levels of ambition are fixed [5]. The ambition goal of the ZEB Laboratory was set to ZEB-COM. This means that the renewable energy production technologies installed in or on the building should compensate for the emissions due to:

- Energy use for operation and equipment
- Embodied material emissions
- Construction process

Figure 2 shows the emission contribution of material, construction and operation of the ZEB Laboratory. The emission contribution is evaluated in $kgCO_{2eq}/m^2/y$. For the evaluation of the emissions associated with the construction phase, the adopted value per square meter comes from data acquired during the realisation of the ZEB pilot building Campus Evenstad [6].

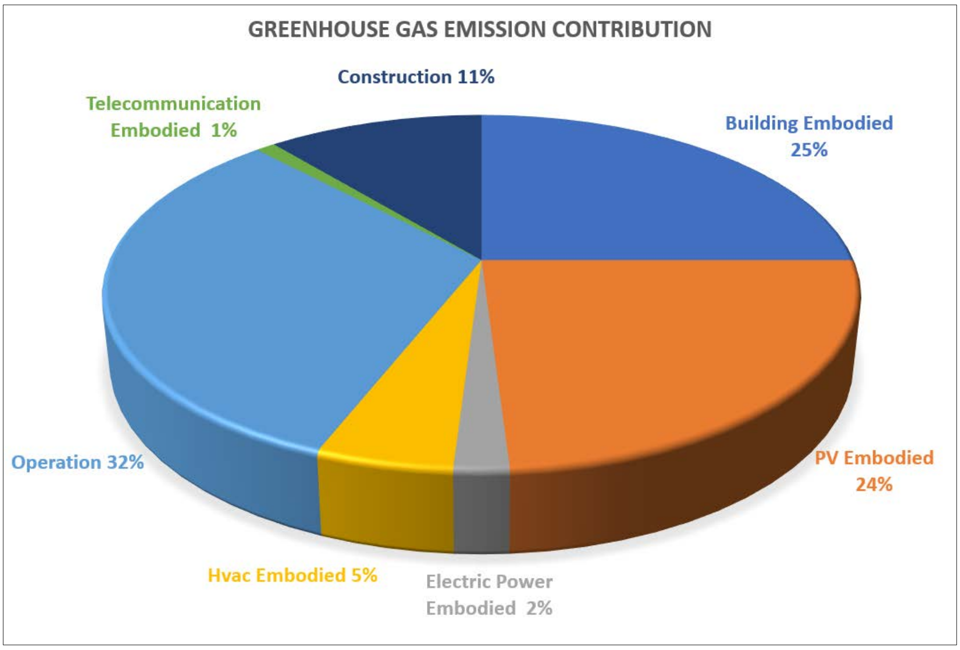

Figure 2 Evaluation (budget) of greenhouse gas emission of the ZEB Laboratory (Source: LINK arkitektur AS)

Building Materials and Envelope Technologies

ZEB Lab will be built with a loadbearing system made from wood. Glulam (Glue Laminated Timber) columns and CLT (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 make the achievement of ZEB-COM applicable. The building is cladded with dark 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 chapter 3.3), is made so that the whole façade or the window elements can be replaced and rebuilt. New products, components and technologies can therefore be applied in order 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 facilitate studies on temperature, relative humidity and air pressure underneath the PV-roofing and prepare for future experiments which can make use of heat below the PV panels in the climatization of the building. Additionally, the cavity will function as at solar roof, and experiments can investigate potential for improving the efficiency of PV panels, efficiency of performance for the heat pump for the building, and directly charging of the buildings thermal PCM storage. Temperature, relative humidity and air pressure will also be measured behind the PV and wooden claddings and on the wind barrier on the vertical facades to characterise long term climate conditions for tapes and barriers.

Twin Rooms Test Facility

NTNU/SINTEF expertise on living laboratories has been recently growing with the realisation of the ZEB Test Cell Laboratory [7] and the ZEB Living Lab [8]. These two represent a test environment for research on, respectively, an office room and a residential building. The ZEB

Laboratory is a much larger facility that makes it possible to solve one of the limitations of the existing two laboratories. In fact, some of the most attractive solutions to be used in passive buildings, require a larger scale to be implemented and tested under realistic conditions. This option to test solutions at different scales represents a valuable increase in the experimental possibilities of NTNU/SINTEF. The twin rooms at the first floor (i.e. second level) of the ZEB laboratory are designed including the expertise gained with the ZEB Test Cell. They each represent a 66 m^2 office room (where Test Cell rooms are designed as single person office), 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 concentration, air change rates, illuminance, etc.). The data acquisition and control system are provided by Siemens. The system is more robust but less flexible than the system realized in the ZEB Test Cell. This makes the two laboratories complementary facilities: solutions can be implemented in the ZEB Test Cell and tested on larger scale in the ZEB Laboratory. As in the ZEB Test Cell, the twin rooms of the ZEB Laboratory allow both comparative and close to calorimetric studies. The facades material and components can be replaced.

Building Service – Energy Supply

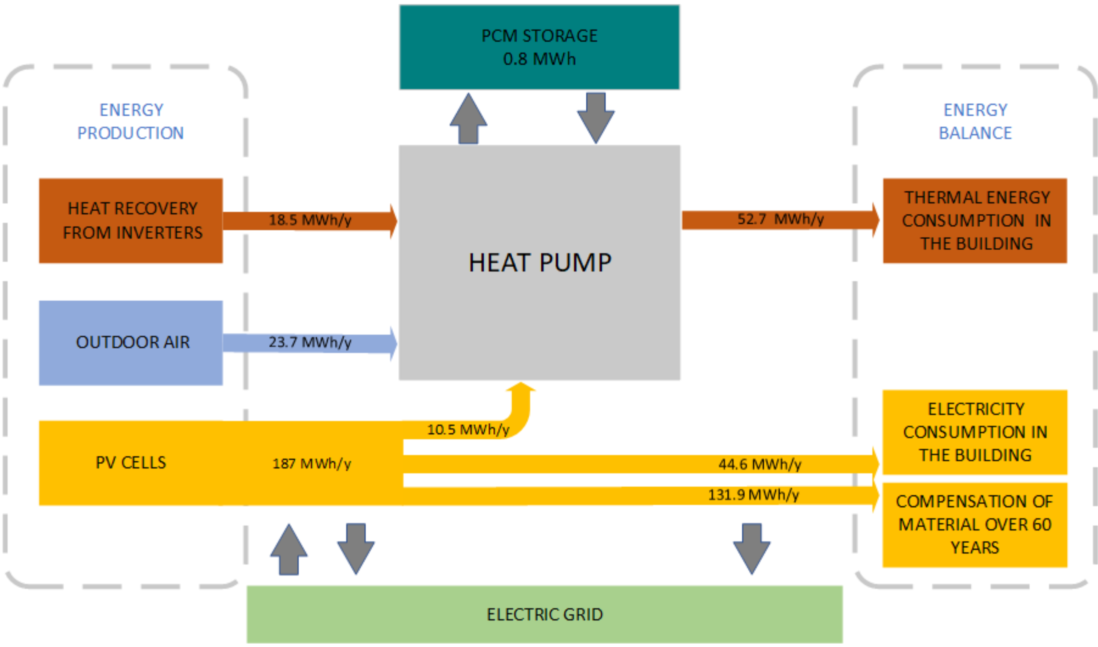

Figure 3 Schematic view of energy supply and use for the ZEB Laboratory (modified from [10] - preliminary)

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 outside air). This makes it possible to investigate possible combinations between available local renewable energy production and centralised electricity grid that matches the zero emission building requirements. A twin phase change material (PCM) heat storage will be installed in the building and it is used to recover thermal energy from the building-integrated photovoltaic (BIPV) roof and as a thermal energy buffer to ensure more efficient use of the heat pump. The PCM heat storage infrastructure is made flexible so that research and development of such systems can take place in the future. A more detailed description of the PCM-based heat storage can be found in [9]. Figure 3 reports the energy balance of the whole system.
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 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 ventilation or a combination of both (hybrid ventilation or mixed mode ventilation).

Natural Ventilation

Some windows in the building can be opened manually while some other are equipped with an automatic opening system. The windows are designed to assure cross ventilation when opened. The main staircase (Fig. 4) is designed to work as an extract for both mechanical and natural ventilation air. A fire hatch on the top of the stairs is designed as an outlet for natural ventilation that is driven by the chimney effect (thermal buoyancy). The twin rooms can be ventilated naturally by windows and by extracting air via ducts in different configurations.

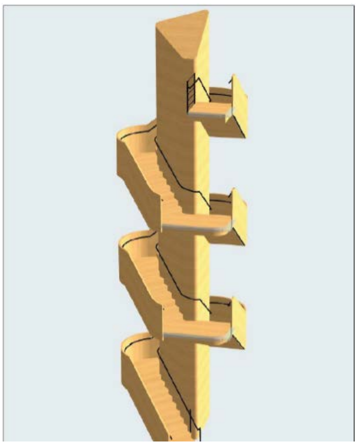

Figure 4 Preliminary design of the main staircase (Source LINK Arkitekter)

Mechanical Ventilation

The building is also 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 the air is supplied through inlet devices in the floor, in the first floor through porous ceiling boards in the suspended ceiling, in the second floor through slots and in the third floor through wall air terminals places at floor level. A heat recovery unit (annual average efficiency > 80 %) is installed in the exhaust. The heating is achieved using the central heat pump with possibilities for PCM accumulation. No mechanical cooling system is installed. The twin rooms are specially equipped both with own technical rooms and independent HVAC systems. Dedicated AHU (Air Handling Units) can pre-process the air before entering the room, see Figure 5. The twin rooms have the possibility to apply both heating and cooling to the internal environment via heating/cooling batteries connected to the central water-based system and additional electric heating batteries. 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.

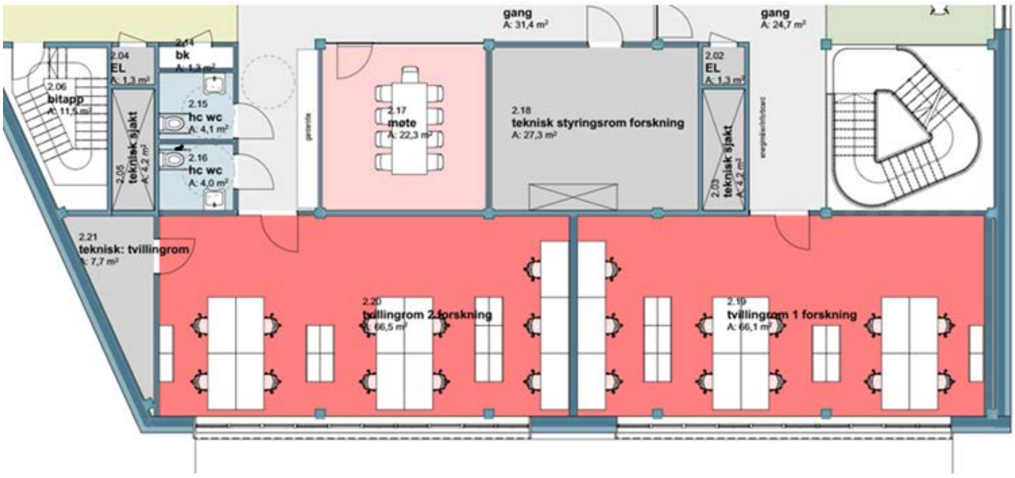

Figure 5 Plan for the twin rooms on the fourth floor with separate technical rooms (preliminary)

Indoor Positioning System

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 data communication with the occupants' smart phone using wireless sensors mounted on the ceiling. 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 SINTEF API server.

The same data can be used to provide services and information which the user can visualise 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.

Monitoring and Control

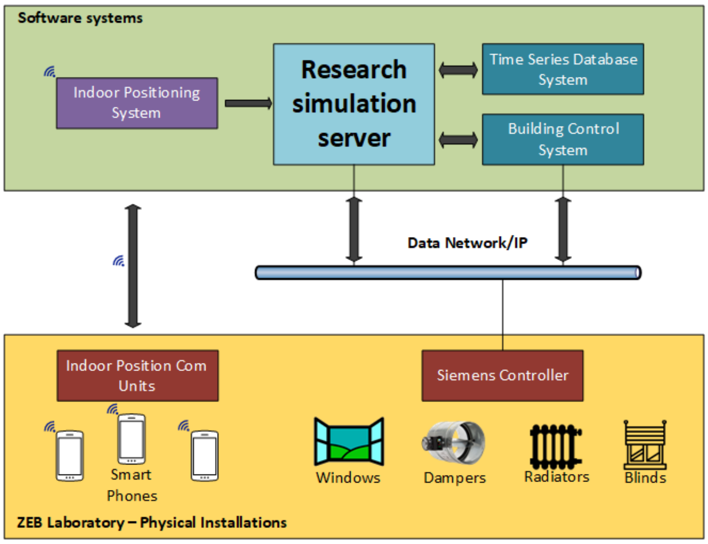

Figure 6 A schematic view of the monitoring and control system (Source: Siemens) (preliminary)

The building is equipped with a common platform including a Building Energy Management System (BEMS) and a time series database system provided by Siemens. The physical installations in the building and in the twin rooms are controlled by the same technology. For both rooms, a system consisting of Siemens room controllers (Siemens Total Room Control) that makes research and normal operation possible will be installed. The building will mainly be operated by NTNU Campus Service, which requires connection to the campus' central building energy management system that Campus service operations already uses. However, the building, or part of it, can be "overtaken" by researchers and operated by a research simulation server. This is how researchers can control the building by own algorithms. A schematic view of the control system is shown in Figure 6.

Stormwater Management

The building and close surroundings must tackle climate change and enhanced precipitation. The areas that needs drainage capacity (roof and near surrounding) are divided into different zones. 1)The parking space, 2) permeable surfaces and rain beds and 3) the roof. They are separate zones and the water from each is lead to a new innovative water storage tank (Alma Smart Tank [11]) designed to store and detain water. There is also a functionality in the tank for "water for utilization". Further instrumentation and measurements are made possible.

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 characteristic 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.

The laboratory reserves ample space for air handling units (AHU), heating and cooling systems and other equipment. Measurement and control of energy supply, air supply, lighting, windows shading, occupancy etc. is performed via a dedicated Building Control Systems. This will allow integration of a building energy simulation program for studies of e.g. the impact of an eco-visualization system on building energy use and test of wireless personal interface technologies for informed occupant behaviour. The indoor environment quality (IEQ) including users' well-being and productivity can be evaluated. The interaction between advanced ZEBs and human occupants is a performance index for this kind of constructions. This gives the ZEB Laboratory the possibility to test:

- New methods for user centred design of zero emission building technologies
- User interfaces of building technologies in general (end users)
- Synergy effects of user interaction and building response
- User interfaces of building energy management systems (building operators)
- The building as an ecosystem - Systemic interfaces
- 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
- Thermal energy storage efficiency in relation with external parameters (smart grid, weather data and forecast)
- 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 showed that the research opportunities for a laboratory of this kind go farther than what the laboratory is specifically designed for, spacing from deeper modifications of systems and structures to the use of the laboratory as a controlled environment: i.e. testing of systems not integrated in buildings that makes use of the sensor capacity to investigate the physics of general phenomena.

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 zero-emission building constructed following a ZEB-COM ambition, and an arena for the evaluation of large-scale material, systems and solution. Testing large-scale technologies on this building will be a substantial scientific contribution and it contribute to reduce the entrepreneurial risk for those companies which are willing to invest in passive buildings.

The large amount of data collected will be an important contribution to specific studies on human-building interaction, on the impact this have on the energy balance and on 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, that allows an easy replacement of facade materials and components and allows to run specific (calorimetric, comparative, etc) tests in a controlled environment.

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ZEB LABORATORY – RESEARCH POSSIBILITIES

This report describes challenges and research possibilities within the new ZEB Laboratory under construction at the Gløshaugen campus in Trondheim, Norway. The project is funded by the Norwegian research Council (NFR) in cooperation with SINTEF and NTNU.

The laboratory will contribute to build knowledge for zero-emission buildings, it will be an arena for experimental investigation of user-building interaction, and will serve as a laboratory to test new technologies in large scale.

SINTEF