Future Positive Energy Building by design

The EXCESS team defines Positive Energy Buildings (PEBs) as "an energy efficient building that produces more energy than it uses via renewable sources, with high self-consumption rate and high energy flexibility, over a time span of one year. A high-quality indoor environment is an essential element in the PEB, maintaining the comfort and well-being of the building occupants. The PEB is also able to integrate the future technologies like electric vehicles with the motivation to maximise the on-site consumption and also share the surplus renewable energy."[1]

This replication case participated in the competition organised by the City of Helsinki in 2021. The purpose of the competition was to (1) produce an architecturally high-level, as low-carbon and highly energy-efficient green block as possible, from which a competitive proposal (plan) for the plots is created that is distinctive in terms of cityscape and can be implemented in lot 10656/1-2 as the basis for implementation, (2) meet the ambitious Carbon Neutral Helsinki 2035 goal and (3) choose an implementer or implementer group and a designer or design group for residential apartment building plots in the competition area. The competition was decided, and the mutual comparison of the competition proposals was carried out anonymously based on the qualitative evaluation criteria given in the competition programme, including the goals set in terms of architecture and cityscape as well as low carbon and environmental values. Both lots were reserved for the contractor or group of contractors who presented the best-evaluated competition proposal. This document describes one of the proposals suggesting technology solutions similar to the one developed in the EXCESS project. This proposal did not win the competition, so it did not proceed to the implementation phase, but lessons can be learnt from it.

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[1] PEB as enabler for consumer centred clean energy transition: shared definition and concept (EXCESS D1.1)

1 Baseline assessment of the implementation environment

1.1 Building description

The central block of Verkkosaari, known as “Mitte,” will be a prominent addition to the maritime urban landscape. Its distinctive roof shapes, equipped with solar panels, create a recognizable landmark. The courtyard features natural vegetation for storm water absorption, while unglazed green balconies serve as railings and climbing support for vines. A maritime rooftop garden at the top of the block provides sunnier green space and sea views for multiple apartments. Residents can cultivate fruit trees, maintain a vegetable garden, and work remotely.

The block also offers versatile community spaces, including saunas and shared areas. The proposal not only explores the versatility of housing types and their adaptability but also introduces new forms of urban living. This innovative approach to urban development is evident in the structural design, which includes lightweight walls between apartments, allowing for adaptability so smaller units can easily be combined into larger ones.

1.2 Regulatory aspects and public support schemes

In Finland, the legal system operates under a framework of national law that is the primary source of legal authority. However, local and regional regulations also play important roles, complementing and specifying national laws to address local needs and circumstances. While energy performance and fire safety provisions are regulated at a national level, specific construction provisions and soil drilling fall under the jurisdiction of the City of Helsinki. Here, the most relevant aspects of the regulations for the VERKKO case are presented[2]

Energy Performance

In Finland, energy performance[3] regulations for buildings play a crucial role in ensuring sustainability, minimizing energy consumption, and mitigating environmental impact. This overview presents key regulations governing energy performance in buildings within the Finnish context.

Minimum Requirements for Building Energy Performance: Designers must ensure new buildings comply with stringent energy performance standards. These standards include minimizing energy loss and achieving efficiency in room temperature, energy consumption, and ventilation systems.

Calculated Consumption of Delivered Energy of Buildings: Energy consumption encompasses heating, ventilation, cooling systems, auxiliary units, consumer equipment, and lighting, minus any energy from environmental sources used within the building.

[2] All pieces of information cited come from translated sources and are only legally binding in Finnish and Swedish.

[3] Decree of the Ministry of the Environment on the Energy Performance of New Buildings.

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Net Heating Energy Demand: The net heating energy demand for building spaces is calculated considering conduction loss, leakage air heat loss, and internal thermal loads.

Various other provisions address specific aspects of building energy performance, including building airtightness, ground frost insulation, calculated room temperature for the summer season, specific fan power of mechanical ventilation systems, and the building's heating capacity and electrical power demand.

Fire Safety Regulations

Fire safety regulations[4] are critical to ensuring the safety of buildings and their occupants.

Structural Integrity in Fire: A building and the elements therein must not cause danger through collapse due to the effect of fire within a specified period after the start of fire. If necessary for the safety of persons, the building shall sustain the combustion of the entire fire load and the cooling phase without collapse.

Fire-Separating Elements: Along with any attached installations and equipment, fire-separating building elements shall be constructed to prevent the spread of fire from one compartment to another for a specified period. Doors, windows, ducts, pipes, ventilation systems, and similar components must be built with materials and in a manner that does not significantly increase the hazard of fire ignition or the spreading of fire and smoke.

Fire Extinguishing and Rescue: The prerequisites for extinguishing fires and rescuing people must be ensured in a building and its vicinity. Adequate access must be provided for fire and rescue service equipment, and water supply facilities must be accessible through designated fire lanes.

[4] E1 THE NATIONAL BUILDING CODE OF FINLAND. Fire safety of buildings Regulations and guidelines 2002.

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Environmental Regulations

Deep Geothermal Drilling: All construction projects and changes to them that are likely to have significant environmental impacts must comply with the provisions under the Act on the Environmental Impact Assessment Procedure.[5]

In addition to the latter and the Land Use and Building Act, the provisions stated in the City of Helsinki building regulations must be complied with. While constructing underground, it must be ensured that construction will not impact the safety of the existing above- and underground structures. Drilling a hole for a geothermal heat pump must not damage underground district heating, water, sewage, and other tunnels, pipes, or cables, nor any rock-covered facilities, such as cable tunnels, air-raid shelters, or parking garages.[6]

Construction Regulations

The construction regulations[7] in the City of Helsinki ensure that buildings harmonize with their surroundings, preserve environmental integrity, and adhere to legal requirements.

Harmonizing with Surroundings: The surrounding environment and historical layers of the built environment must be considered to ensure that buildings form a harmonious ensemble with the urban image and natural values of the area.

Surface Level Maps: Building permits require a surface-level map to show existing height relationships. Lighting must enhance safety without disturbing residents.

Shoreline Regulations: Buildings must be at least 20 meters from shorelines, preserving vegetation, topography, and cultural values, with particular attention to external noise mitigation.

Building Permits: According to Section 125 of the Land Use and Building Act, a building permit is required to construct a building. This permit ensures compliance with all relevant regulations, including those related to energy performance, fire safety, and construction standards.[8]

EU Level

At the EU level, new constructions must ensure the building meets high energy performance standards in accordance with the EPBD. The directive also mandates optimizing health, indoor air quality, and comfort levels in building energy calculations. This emphasis on indoor environmental quality not only ensures compliance but also significantly enhances the health, productivity, and overall well-being of building occupants.

1.3 Social Dimension

[5] Act on the Environmental Impact Assessment Procedure, Section 3.

[6] Building regulations in Helsinki, Section 58 < https://www.hel.fi/en/urban-environment-and-traffic/plots-and-building-permits/rakennusluvan-hakeminen/building-regulations-in-helsinki#chapter-9--environmental-and-health-protection>

[7] BUILDING ORDER OF THE CITY OF HELSINKI Approved by the city council on May 24, 2023 <https://www.hel.fi/static/rakvv/Rakennusjarjestys.pdf>

[8] Land Use and Building Act, Section 125.

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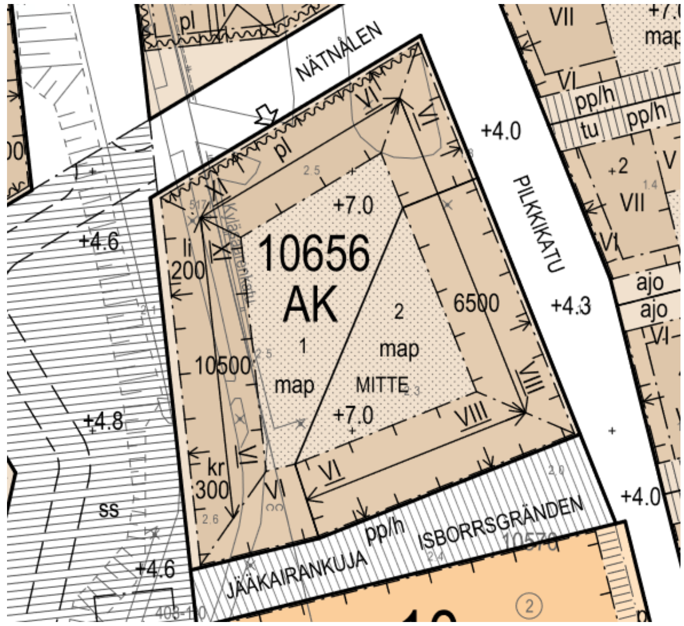

Situated in the Kalasatama district, the replication case is located at the core of energy-efficient innovation, as the "Smart Kalasatama" project sets ambitious targets for an innovative remodelling of the area. The project foresees saving one hour for residents by improving traffic flow, logistics access, and multi-functional facilities open to the public[9].

Residents of the district, therefore, take an active role in shaping it, which is bound to install an intelligent energy grid, showing the willingness of the City of Helsinki to give residents a more active role in shaping the renewable energy transition. The proximity of this replication case to the bright city environment and pilot sites in Kalasatama shows a positive outlook for energy-efficient neighbourhood management, with residents being able to profit from many smart city district projects, such as the Kalasatama Innovators Club that brings together stakeholders from the area to shape the district cooperatively. The agile piloting program, which ran from 2016-2018, taught residents about new energy technologies and helped them take part in the urban development of the area, resulting in solutions, e.g., related to health and well-being in urban environments, scaled up to district and city level.[10]

The central goal of the block has been to design an inviting, human-scale residential environment. An arcade surrounds the entire building. Beneath the arcade, there is a weather-protected outdoor terrace for the restaurant. Under the arcade and the balconies on the courtyard sides, bicycles can be stored safely from rain.

The block has many community-supporting spaces for residents, such as a rooftop garden, saunas with club facilities, and flexible shared spaces for various activities. The courtyard within the efficient block contrasts with the urban street environment, and nature is strongly present. In the north-west corner of the courtyard is a shared multi-purpose room for the entire block. The space has washing machines, kitchen fixtures, and a dining set. The multi-purpose room provides a good view of the playground area. The space extends to a covered terrace under the green balconies. A shared floor-specific balcony terrace is in the north-west corner of the green balconies. All common areas are versatile, allowing remote work indoors and in the covered outdoor space.

[9] Smart Kalasatama, Forum Virium (2015). https://fiksukalasatama.fi/en/smart-city/

[10] Cook Book: Recipes for Agile Pilots, Veera Mustonen, Kaisa Spilling and Maija Bergström (2018).

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1.4 Assessing strengths, weaknesses, opportunities and threats in relation to a PEB compared to a BAU scenario

The PEB solution developed for the Finnish demonstration in EXCESS and replicated in VERKKO is based on a highly energy-efficient building combined with a hybrid energy system. The hybrid energy system represents an innovative approach to modern energy challenges, offering numerous strengths and opportunities that set it apart from traditional systems. This system boasts lower energy consumption, reduced life cycle costs, and decreased carbon emissions while harnessing various energy sources through advanced digital controls. However, its complexity and the necessity for extensive expertise present notable weaknesses and potential threats, such as unpredictable electricity prices and maintenance availability.

The potential and challenges of implementing hybrid energy systems are present in the following SWOT analysis:

Strengths

- Lower yearly energy consumption of a hybrid system compared to a traditional one
- Lower life cycle total costs
- Lower carbon emissions
- Hybrid system enables the use of various sources: excess heat from ventilation cooling, excess heat of PVTs, and geothermal heat from energy wells
- Intelligent control system: the digital system enables modifications later when a new system version is developed
- Self-production by PVs

Weaknesses

- Complex hydronic system; the entire system requires high expertise
- Massive amount of sensors and possibilities of sensor failures
- A lot of initial/basic adjustments of the hydronic heating network
- Long hydronic lines cause uncontrolled heat losses

Opportunities

- Having access to the cheapest possible energy source
- Possibilities for new control strategies implemented later: version management/updates for software
- Service fee for the service provider

Threats

- Availability of maintenance and service; Lack of service provider
- Uncontrolled/unpredictable electricity prices

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2 Technical information / design specifications

Overview of structural solutions

The material with the best properties for each purpose has been selected. Carbon footprints are essential but only one of the criteria when making material choices. The building has become a hybrid frame whose primary materials are wood and reinforced concrete. The load-bearing frame consists of reinforced concrete partitions and hollow slabs. Further, the basement structures are watertight, cast-in-place concrete structures. Between the apartments, the non-load-bearing partition walls are rigid plaster walls. Green concrete is used at the destination. Each façade has solid wooden elements, and the solid wood structure is visible inside the apartment. Since the frame is non-combustible, more wood can be left visible than in the same size class in an entirely wooden building. The façade material is wood-treated with fire protection. Balcony tiles, pillars, and beams are solid wooden tiles. It also has a water roof, an inverted roof structure containing water and heat insulation, and either green spaces or solar panels. The load-bearing frame of the parking garage consists of reinforced concrete columns and pre-stressed reinforced concrete beams.

The hall's intermediate level is realized as a pre-stressed joint structure consisting of shell tiles and surface casting. Its roof consists of tensioned jaw beams and hollow slabs. On top of the load-bearing structure are waterproofing and layers required by green structures. The suitable material for the right place has been purposefully selected at "VERKKO."

Overview of the energy system

In the project's energy system, deep boreholes, heat pumps, solar panels, ventilation heat recovery, ventilation cooling, and an intelligent hybrid energy control system form one entity that works together. This innovative system collects data from different parts of the energy system and monitors the building's current and predicted consumption data. It considers, among other things, the spot price of electricity and weather forecasts when optimizing the system proactively and as needed. With numerous circulation pumps and valves, heat or coolness can be used and circulated in several ways in boreholes and ventilation machines. Through the help of an intelligent control system, energy production and consumption are optimized, and energy is stored in boreholes, which are used both as long-term energy stores and for short-term storage within a day. Residents can monitor the entire energy system in real-time and see how energy is produced, consumed, and recycled at any given time. Boreholes are 600-800m deep, and the number of boreholes is dimensioned in such a way that the temperature of the bedrock does not decrease even during an extended review period. The heat pumps have step-by-step hot water heating, which achieves high efficiency. Heat pumps' energy efficiency is improved by using low-temperature floor heating in all warm rooms instead of radiators.

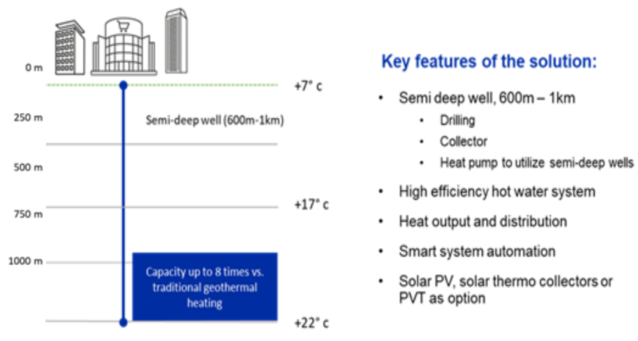

Figure. The key features of semi-deep geothermal system[11]

The ventilation machines are significantly larger than typical and have cooling, which can be used very cheaply with the free circulation of heat wells. In the summer, the cooling can be enhanced by using the system via heat pumps, especially when solar electricity is available in excess. Ventilation machines have a large heating radiator, which can use low-temperature floor heating water produced by heat pumps with high efficiency.

In addition to ventilation cooling, the ventilation system has a variable air volume (VAV) system that improves indoor air quality and saves energy.

[11] Saku Pitkänen, HYBGEO project report, 30.6.2021, 47 pages, unpublished

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The planned performance

Heated net area: **13000 m^2**

Calculated purchased energy, not including appliance electricity: **194,445 MWh/a**

Energy certificate, A-class: **45 kWh/m^2,a** (limit for A-class in apartment buildings is **75 kWh/m^2,a**)

Carbon footprint during life cycle (50 years): **7176 tCO_2e**

Carbon footprint per heated net area in a year (A-C): **10,99 kgCO_2e/m^{2}netto /a**

3 Business model details & possible financing arrangements

The EXCESS demonstration and replication case buildings have high insulation and energy efficiency standards combined with renewable energy sources (RES) and a hybrid geothermal energy system with deep boreholes. The high thermal insulation standard and energy efficiency lead to deficient heat energy demand. The building uses high-area heat dissipation systems (floor heating) with a low required temperature level for space heating, enabling low operating temperatures. These low supply temperatures can be provided at high conversion efficiencies from the geothermal energy system, which further reduces the electricity consumption of the heat pump and, therefore, the cost of heating. RES production with PV panels further reduces the building's electricity costs. Surplus PV production could be fed into the grid, leading to an additional revenue stream.

Additionally, the hybrid geothermal energy system, combined with the high insulation standard, a high thermal mass, and a smart building management system, leads to a remarkably high flexibility potential of the building. This adaptability could be an additional revenue stream, reducing payback times and increasing the overall profitability of the replication. It represents an essential aspect of the business model, reassuring stakeholders about the system's adaptability to changing needs.

The high complexity of the thermal system requires specialized developers and integrators. The company Tom Allen Senera offers the development, integration, and realization of such systems. Additionally, they want to provide an additional service contract for the regular monitoring, maintenance, and adjustment of the energy system.

Furthermore, a high indoor environmental quality is another essential element in the replication case, maintaining the comfort and well-being of the building occupants. Indoor Environmental Quality addresses indoor air quality and thermal, visual, and acoustic comfort. This comfort has been shown to enhance productivity, decrease absenteeism, and improve the building's value.

The innovative hybrid energy system combined with high comfort and low energy consumption leads to a high property value of the replication which represents a central aspect of the business model. Due to these advantages, the property value is much higher than that of conventional buildings, which could partially compensate for the higher initial investment costs.

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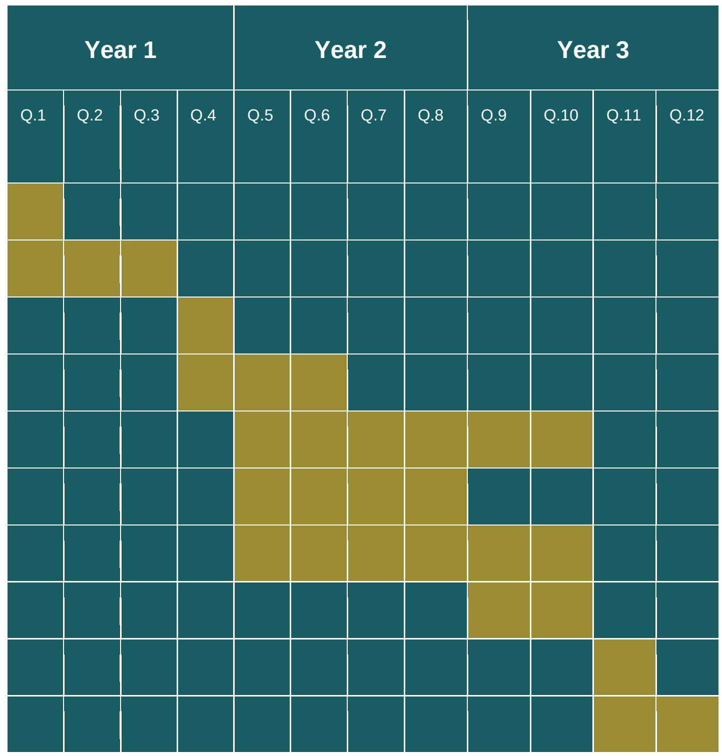
4 Possible PEB timeline

The general timeline for the PEB's design, construction, and operation is presented in the table below. There is a previous phase to the final decision of construction, which usually takes around one year but can vary depending on the market situation. The suggestions for the new plot construct are the following: a draft figure of the building(s), a draft of calculations/market price level, and pre-design and pre-marketing. In case of appeals, the building permit can take longer than 8 to 12 months. Depending on the technical solution, the energy system installation Q5 and Q10 may be shorter. The boreholes can be drilled before construction starts or when the building envelope is constructed.

PEB Activities in the 3 years after the construction contract

- Contract of plot
- Building permit (can take longer)
- Non-appealed permit & setting the guarantees*
- Contracts with clients
- Construction (~18 months)
- Detailed designs during the construction
- Energy systems installation
- Commissioning
- Inhabitants moving in
- Operation phase (M30=>...)

* 1,5-2 months to get final approval
1-2 months for setting the guarantees



5 Local Government Recommendations

To accelerate energy efficiency, RES integration, and PEB roll-out, as well as financial incentives such as subsidies and grants, local governments could make PEBs more attractive in various ways:

Due to the high complexity and lack of expertise required, lighthouse projects or programs should be created for the private sector to develop expertise and gain skills in the practice of complex hydronic systems. Local governments could strengthen those by offering tender projects on public buildings, such as libraries and public schools.

In addition to regional and national grant or subsidy schemes, local governments could consider establishing a special fund for PEB support and acting as guarantors for banks to offer low-interest loans for PEB projects. Furthermore, LGs should establish support mechanisms to facilitate energy efficiency access to the market via energy communities.

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