Model house F3 in Ljubljana – Nearly Zero-Energy Building

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Model house F3 in Ljubljana – Nearly Zero-Energy Building

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Abstract Building F3, Model House is a multi-apartment building, located in the new "Zeleni Gaj" residential development in Ljubljana's Brdo district. The architectural design of the multi-apartment low-energy structure involves vertical divisions into four distinct sections or "lamellas" (A, B, C and D). The lamellas differ from each other in terms of technology, structure and design/concept. This means that they differ above all in terms of the materials used for floor finishes and types of ventilation. As a Nearly Zero-Energy Building the building is also part of a special project researching living comfort in a multi-apartment building, which consist of a minimum three-year period of implementation, research and monitoring.

1. Introduction

Through its rational situation in the urban context, the new Zeleni Gaj residential development in Ljubljana's Brdo district presents itself as a distinctive, integrated structural concept in a green district of the city of Ljubljana. It is characterised by a general high quality of living comfort, energy efficiency and green technologies, which are the fundamental criterion of evaluation for larger residential systems. The Model House F3 has 52 dwellings and was planned in accordance with the findings of a research project as an alternative to standard residential architecture. As a concept it introduces the optimal ratio between innovation (use of materials, ventilation systems, combined heating systems, energy efficiency) and accessible prices. The modern design of the structure enables a range of options for the basic divisions of the residential units and offers a series of conversion solutions that are as neutral and flexible as possible [1].

Figure 1. Model House F3. [3]

The building as a whole is a low-energy structure and fulfils requirements for Nearly Zero Energy Building with a small yearly $C0_2$ emission of 7 kg/m2a. Energy efficiency is achieved by installation of quality building envelope, quality windows and modern mechanical installation. In addition the dwellings with heat recovery are meeting the passive standard. PHPP energy performance certificates have been obtained for 31 passive dwellings.

2. Main features of Model House F3

2.1. Architecture

The architectural design of the multi-apartment low-energy structure involves vertical divisions into four distinct sections or "lamellas" (A, B, C and D). The lamellas differ from each other in terms of technology, structure, design/concept, treatment of materials, floor finishes and types of ventilation. The dwellings are of various types and offers a wide range of options. The load-bearing structure is reinforced concrete up to the third floor, while the third floor and terrace floor have a wooden structure. External stairs and a lift connect the five aboveground levels of lamellas A and B, while the floors of lamellas C and D each have their own internal stairs and lift. Special dwellings which are also suitable for persons with reduced mobility are planned on the ground floor; the two floors above are taken up by typical dwellings, while the two attic floors consist of two-storey dwellings with terraces. Mechanical/electrical rooms, storage spaces and bicycle storage are located in the basement. [1].

Figure 2. Landscape. [3]

2.2. Building details

Number of dwellings:	52 (lamella A – 13, lamella B – 13, lamella C – 11, lamella D – 15)
Number of business premises:	2 (nursery school 207 m^2, office 15 m^2) – lamella D
Number of parking places:	110 (68 – underground garage, 42 – in front of the building)
Floors:	G+3+T, one-level underground garage
Building parcel:	6,796.18 m^2
Net floor area of lamellas A, B, C, D:	5,515.27 m^2
Net floor area of garage:	1,786.09 m^2
Total net floor area:	7,301.36 m^2
Structure:	G+2 reinforced concrete structure; 3+T wooden structure
Façade:	G+2 ventilated with fibre cement panels; 3+T ventilated wooden
Windows, balcony doors:	Aluminium - wood, triple glazing, external screen
Heating – Lamella A:	underfloor heating connected to a heat pump and supported by a biomass boiler system, all bathrooms also have towel radiators
Heating – Lamellas B, C, D:	underfloor heating connected to a common biomass boiler (woodchips) and solar energy collectors, all bathrooms also have towel radiators
Ventilation:	mechanical ventilation with heat recovery, humidity-sensitive ventilation
Energy standard:	energy class A2 – 14 kWh/m^{2}a

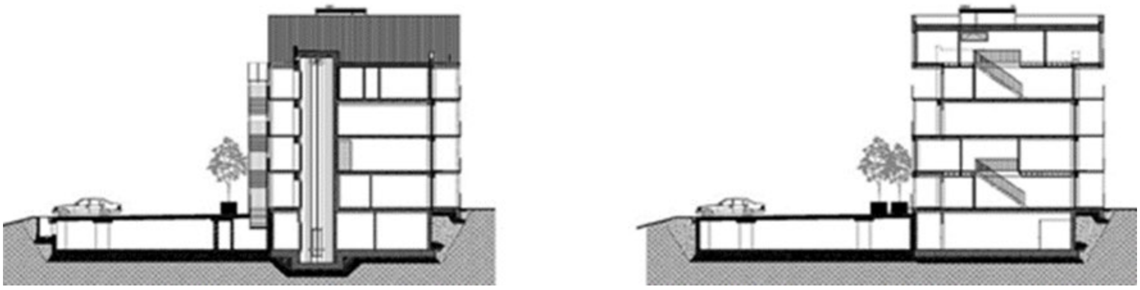

Figure 3. Cross section.

2.3. Façade / Structure

The facade is divided into two zones depending on the floors of the building. Ground floor and two upper floors have a facade made of fibre cement facade boards, the third floor and the terrace floor have a wooden facade made of vertical solid wooden lamellas with wooden substructure. The entire facade is designed as ventilated. Thermal insulation is made of rock mineral wool (λ=0.035 W/mK) in a thickness of 26 cm, and in some areas in a thickness of 28 cm. In the areas above the passageways, 2 cm thick vacuum insulation panels (λ=0.0045 W/mK) were built in due to lower available height [1]. Thermal transmittance of a typical reinforced concrete wall with a 26 cm thermal insulation layer is 0.128 W/m^{2}K, while the wooden construction wall with a thermal insulation of 28 cm has a thermal transmittance of 0.105 W/m^{2}K.

Structure of external reinforced concrete wall	**Thickness [cm]**
	55.5
fibre cement facade boards	0.80
air layer	3.20
wind barrier	0.02
Insulation: two-layer boards made of rock mineral wool (0.035 W/mK)	26.00
reinforced concrete wall C 25/30	25.00
internal finishing layer	0.50

Figure 4. Cross section of reinforced concrete bearing wall.

Structure of external wall wood construction	**Thickness [cm]**
	56.0
vertical, massive wooden battens 2×7/2 cm, larch	4.00
air layer	6.00
wind barrier	0.02
Insulation: two-layer boards made of rock mineral wool (0.035 W/mK)	28.00
cross laminated timber (CLT)	9.50
installation plane: metal subconstruction, in between rock mineral wool boards	6.00
Two-layer gypsum boards	2.50

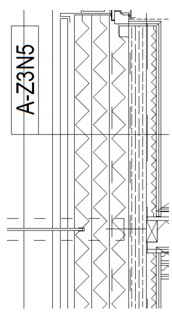

Figure 5. Section of cross laminated timber construction bearing wall

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2.4. Fenestration
With the aim of achieving a NZEB standard, the fenestration of entire building was made in accordance with the RAL installation standard with three-level sealing. Built-in fenestration is certified by Passivhaus. The criteria are thus fulfilled with the thermal transmittance of the glazing Ug = 0.50 W/(m^{2}K) and the thermal transmittance of the entire window Uw = 0.68 W/(m^{2}K). The requirement for laboratory sound insulation was determined with a minimum value of R_w 36 dB. Windows are wooden with alu protection, triple glazed with a gas fill and a low-emittance coating. The glazing has a g value of 0.5.

2.5. Mechanical installation and equipment
Dwellings with passive standard have mechanical ventilation with heat recovery, while others have humidity-sensitive ventilation. Depending on the size of the dwelling, 2 types of individual recuperators have been used: in small dwellings with the airflow of 180 m^3/h and in larger two-storey dwellings with the air flow of 270 m^3/h. According to PHPP analysis, the thermal efficiency of the installed devices is about 80 % at an average airflow of 55 m^3/h.
Depending on the design of the individual lamellas, the energy supply of the lamellas is derived from different types of energy supply. As a primary source of energy lamella A uses a compact air/water heating pump with a built in hydraulic module and a control regulator used for hot domestic water preparation and low temperature floor heating. The built-in heat pump has a nominal power of 11 kW and a COP value of 2.96 at an outdoor air temperature of 6 °C and inlet/outlet temperature of 40/45 °C. The supporting heating source for lamella A in case of low temperatures and increased heat inefficiencies is a biomass heating system. A built-in control system ensures heat is transported smoothly to lamella A through its own port at the divider. When temperatures fall below 0 °C, the heat pump switches off completely and heating is taken over by the biomass heating system.

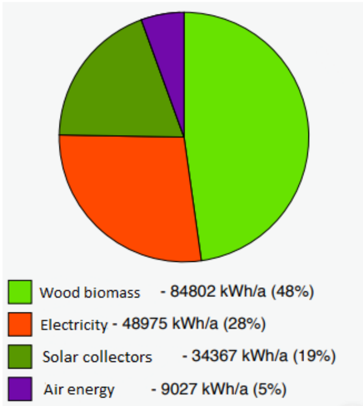

Figure 6. Structure of the total energy consumption for the operation of the building by energy sources (kWh/a). [4]

Lamellas B, C and D use wooden biomass as a main energy source from a mutual boiler room in conjunction with solar energy collectors located at the rooftop of the lamella A, installed with a 5 degree angle and oriented towards southwest. The biomass boiler has a combustion efficiency of 90.4 % and a nominal power of 150 kW. In the common boiler room, there is a built-in heat storage with 4000 l volume for receiving energy from solar energy collectors and common biomass (woodchips) boiler. The solar energy collectors installed on the roof of the building serve for the preheating of heating water and preparation of hot domestic water. Built-in evacuated tube solar collectors are arranged in a total area of 48 m^2 and have the absorption capacity α up to 93.5 %. The heating system is low temperature. All the dwellings have integrated underfloor heating. Figure 6 shows the structure of annual total energy consumption for the operation of the building by energy sources [4]. The annual heating demand of 14 Wh/m^{2}a ranks the building in A2 class of energy efficiency.

The Model House fulfils all the criteria of the Slovenian definition for NZEB building, as follows:
- Annual heat demand (max. 25 kWh/m^{2}a): 14 kWh/m^{2}a achieved;
- Primary energy (max. 80 kWh/m^{2}a): 36 kWh/m^{2}a achieved;
- Renewable energy sources (>50 %): 72 % achieved.

3. Construction process from the perspective of the investor
Construction of the building began in 2014. The entire building, including the construction of outdoor areas, has been completed in 2016. Because of the sheer complexity of the project, a lot of attention had to be placed on construction of the two upper wooden floors, including a huge number of demanding details and assembly drawings. All these facts demanded a very high level of professional skills from design engineers, field operators and all other participants.

Figure 7. Construction phase – construction of the upper two floors in a wooden construction.

Figure 8. Air tightness measurements of the building envelope.

Upon completion of the construction, an authorised company performed an air tightness measurement of the envelope. Air tightness measurements were made for all dwellings of a single lamella at a time. Thus, the air tightness test for lamellas A and B was carried out by a common pipe system, i.e. "octopus". For C and D lamellas, airtightness measurements were carried out as a whole, including interior corridors. The air tightness result was 0.6 h^{-1} for a single lamella and was obtained at a pressure difference of 50 Pa.

In order to avoid subsequent problems and due to the complexity of the operation of the installed mechanical installations and equipment, training for the commencement of operation - commissioning was carried out. The system as such requires a high level of professional skills from the facility manager.

4. Concept of monitoring of energy efficiency and well-being of residents

The conceptual design of the building integrates factors of energy efficiency, architectural design, use of materials and sociological aspects. For this reasons, the building is part of a special project researching living comfort in a multi-apartment building, which envisages a minimum three-year period of implementation, research and monitoring, where the involvement of users and their sense of well-being is a key factor, if not the most important factor [1].

The living comfort of users and the energy efficiency of the building is planned to be analysed as part of the monitoring. Both of these criteria will be obtained by energy consumption measurements, measurements of residential comfort parameters (temperature, CO_2, humidity), as well as surveys of internal environment, architectural design, material use and sociological aspects.

The following measurement systems were installed for monitoring purposes (Figure 9):

- measurement of supplied energy from the system (biomass boiler) into the heat storage tank (thermal energy meter No. 34)
- measuring the heat input from the solar heating system to the heat storage tank (thermal energy meter No. 36)
- measurement of energy supplied from the heat pump (thermal energy meter No. 35)
- measuring the heat input from a biomass boiler to a reheat for lamella A (thermal energy meter No. 38)
- measuring the heat input from a biomass boiler for hot domestic water in lamella A (thermal energy meter No. 39)
- measuring the heat input of a heat pump for hot domestic water (thermal energy meter No. 40)
- measuring the heat input of a heat pump for heating lamella A (thermal energy meter No. 41)
- measuring the heat input for lamella D - nursery school (thermal energy meter No. 42)
- measuring the heat input for heating and hot domestic water preparation in lamella B, C and D (thermal energy meter No. 43)
- measuring the amount of domestic hot water consumed in lamella A is carried out with internal counters of individual dwellings

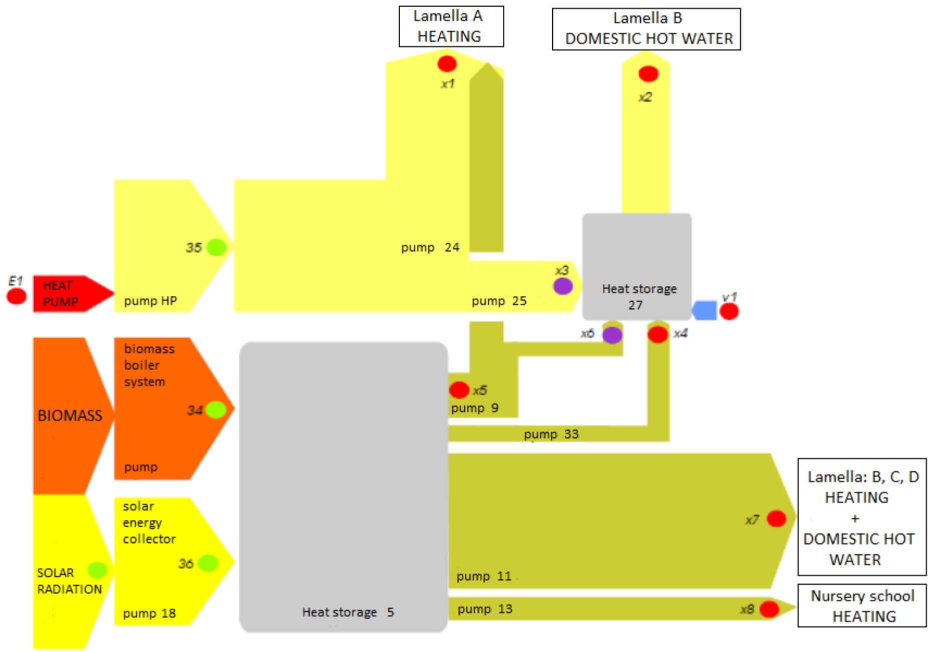

Figure 9. Schematic view of the concept of energy consumption monitoring and embedded technological equipment. [5]

All dwelling calorimeters are connected to a central data logger that generates files. In this way, the operation (control) of heat generators in the building will also be checked. The final result of the monitoring will be the data about the use of heat energy for heating and the graphical comparison of the specific use (kWh/m^2). As part of monitoring the well-being of residents, six different dwellings will be fitted with measuring devices. This part of the monitoring requires the approval of residents and appropriate measuring equipment for the parameters: temperature, humidity, CO_2 and total volatile organic compounds – TVOC. Built-in data loggers store data and have their own power supply.

Table 1. Estimated types of dwellings for implementation of monitoring

Number of dwellings	Structure	Type of mechanical ventilation
2	wooden	heat recovery
2	reinforced concrete	heat recovery
2	reinforced concrete	humidity-sensitive

Due to the complexity of the building, a survey with the content of the architectural design will be carried out in cooperation with the residents.

The implementation of monitoring is currently in the initial phase, so we can not yet present any tangible results and conclusions. Monitoring is expected to be carried out for at least three years. This is also in accordance with the instructions for energy audits of buildings.

The results of the construction “know-how” knowledge and monitoring will be used in the further development of the Fund's projects. The project Model House F3 have also been used as a research data for the European project CoNZEB’s from the Horizon 2020 Programme.

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