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Building Physics in Living Lab

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Abstract. Team from Czech Technical University in Prague participated in prestigious international contest Solar Decathlon Europe 21-22. The topic of its FIRSTLIFE project was an extension of student dormitory by adding of new floors on the building together with a retrofit of the existing part. The paper deals with the pedagogical context of this activity. Students got an extraordinary opportunity to actually implement their theoretical proposals based on calculations. They also received feedback on the extent to which detailed designs are feasible in normal construction practice. New knowledge can be applied in future better estimation of the effect of imperfections, for example in calculations of heat conduction, the effect of thermal bridges, leaks for moisture transport and air tightness. Information about future research in Living Lab is given at the end of the paper.

1. International contest

Team from Czech Technical University in Prague (CTU) participated in prestigious international contest Solar Decathlon Europe 21-22 [1]. The topic of its FIRSTLIFE project [2] was an extension of student dormitory from the 1960s by adding of new floors on the building together with a retrofit of existing part. The overall solution was focused on compliance with the principles of sustainable construction, which includes very low energy consumption, use of renewable energy sources, ensuring comfort, use of nature based and recycled materials, integration of urban and social context, etc.

Within almost two years of activities, the student team delivered architectural and technical documentation and physical models of both, overall solution of the building retrofit and of functional unit (House Demonstration Unit, HDU – small house being an extraction of the overall solution). HDU was built by students supported by technicians of University Centre for Energy Efficient Buildings (UCEEB) CTU [3] during approximately 6 weeks. As a next step, the HDU being ready to approx. 60 % was disassembled and transported to the competition plot in Wuppertal. A time for final assembly and setting the HDU in operation was extremely short, only 227 hours.

After the end of the competition (3rd place in the Comfort category and 5th place in the House functioning category for the Czech team), and end of the exhibition being visited by 115.000 people, the HDU remains in place.

2. Tests and monitoring

2.1. First evaluations

As a part of the contest evaluation the organizers performed measurement of several parameters (temperatures, daylight, etc.) in one-minute step according to a detailed manual within contest rules [1]. Teams received data on-line and as a reaction had to choose an appropriate strategy to maintain indoor

comfort and maximize the HDU performance (opening/closing windows, setting up the regulation of mechanical ventilation and shading system etc.). The Comfort Contest has been evaluated without active cooling, heating or lighting.

The Temperature Sub-Contest used a slightly modified EN 15251 [4] approach and points were awarded based on the time in which the internal environment fulfilled the requirements of individual comfort classes. This meant, that each day the optimal interior temperature was different, based on the sliding weighted average of the outdoor temperature in the past seven days. 100 % of the points could have only been awarded, if all the measured indoor air temperatures were in the range of ±2 K around the optimal indoor air temperature for a given day. At the same time, the free-floating relative humidity has been be constantly measured and the maximal points could only have been awarded if all the measured values were in the range from 35 % to 65 %. The HDU has been fully operational during these measurements: the teams had to do laundry, let it dry, cook, simulate showering, prepare meals for other teams and also host dinners.

Organizers performed a set of short co-heating tests. The student teams then obtained the measured data – outdoor conditions, supplied energy and measured indoor conditions. Their task was to minimize the performance gap of previously set-up energy simulation models within the SimRoom software when compared with measured data. They were allowed to only adjust the basic model properties to account for the as-built state: areas of envelope components with U-values, thermal bridge surchage ΔUTB, glazing properties, shading and usable storage mass. They also could adjust the air tightness at n_{50}, to assume the envelope quality. They, however did not know the blowerdoor test results at the time of these calculations.

The relative air tightness was measured then [5]. The Czech team reached here the overall best result with n_{50} value of 0.89 h^{-1}. If we consider the extremely short construction time without the possibility of corrections, we accept it as a very satisfactory value.

External experts carried out a measurement of the air sound insulation of the perimeter wall [6] (the one with the largest proportion of windows and balcony doors was selected), where the Czech HDU also showed a very good result (41 dB), mainly thanks to the very high performing windows and the well-executed details of the connection to opaque parts.

2.2. Living Lab as a second step

Together with other seven HDUs, the Czech house becomes part of the newly emerging Living Lab, where it will be possible to monitor real properties under controlled conditions for at least the next 3 years, coordinated by University of Wuppertal (BUW) [7]. Data from the operation of technical systems, climatic data and data from the interior of the building will be used, among other things, for comparison with complex and simplified simulation calculations.

These may include overal building performance modelling using single-zone and multizone building models, investigation of accuracy of different floor-heating modelling approaches, analysis of windows and glazing performance, dedicated building energy systems simulations. Tools considered for these comparisons are assumed to be EnergyPlus based packages, such as OpenStudio, Ladybug Tools or Climate Studio. Furthermore, TRNSYS simulations and use of university-developed simulation algorythms are considered.

Operation in various modes is assumed, including repeated co-heating tests and free-floating situations. BUW increased its team by 5 new doctoral students focusing on the Living Lab and related sustainability agenda.

3. Education

3.1. Overall pedagogical context

The Czech team comprised bachelor's, master's and doctoral students from several study programs. The preparatory stages were integrated into the teaching in the design studio.

Students of architecture, architectural engineering and similar take classes in individual subjects from the field of building physics. They then apply the partial knowledge in the design studio subjects and in the final theses. However, the teaching is usually very theoretical. Participation in the competition, where in addition to conceptual questions and construction details, the actual implementation of the design is also solved, has an extraordinary benefit for students.

The students thus get a better idea of the properties of the materials and components they used in the design, if they are in a situation where they have to actually implement what they have drawn. Another important effect is the necessity to work in a team with students of different study programs, discuss proposals in variants and reach a final decision in each matter.

3.2. Increased practical knowledge in building physics

In the field of building physics, we can specifically mention as a possible permanent benefit for students the following:

(a) For some of them, the first real physical contact with the insulating material – getting a feel for how it is realistic to implement a specific detail, seal joints, etc. under real construction conditions.

(b) Getting a feel for what kind of imperfection needs to be accounted for in realistic calculations of heat conduction, moisture transport, soundproofing, etc. Let's mention, for example, an increase in thermal conductivity, linear and punctual thermal bridges, increase of thermal transmittance, increase of water vapour diffusivity due to not properly connected tight layers, reachable level of air-tightness used in calculation of efficiency of heat recovery and heat demand.

(c) Overall feedback from the analyses of the measured values in HDU in operation, especially for doctoral students.

(d) Detailed information about the technical solution is used as illustrative material in the lectures.

4. Concluding remarks

During the preparatory period the team organized a workshop for younger colleagues in a specialized design studio. After the end of the contest, an exhibition was organized in the premises of the university followed by a lecture, both presenting approaches of all 16 teams in the contest.

Practical lessons learned will be applied in the upcoming semester of teaching in the next specialized design studio: adding new floors to another student dormitory in Prague using the experience from the contest building.

Data obtained in the next 3 to 5 years in the Living Lab will also be interpreted in theoretical lectures. A cooperation among key persons from universities participating there is under preparation.

Moreover, there is a discussion among teaching staff about how to include practical (physical) construction work in the standard education, apparently using the UCEEB facilities [3].

In conclusion, it can be stated that in all respects the very demanding work of the students and the pedagogical management in the SDE contest brings a long-term positive effect. Of course, the ideal concrete result of our project would also be the real implementation of the extension of the student dormitory using the knowledge gained.

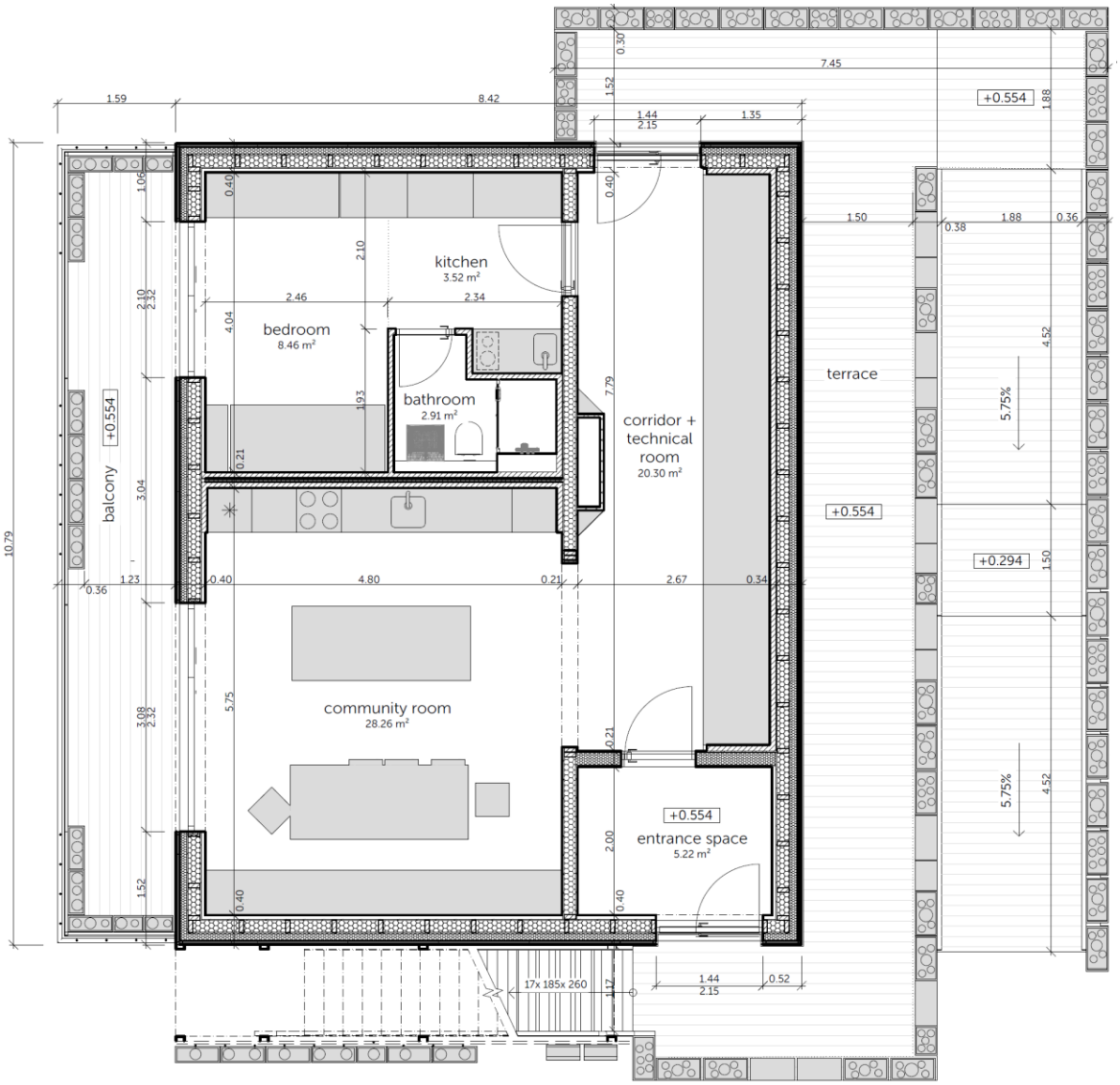
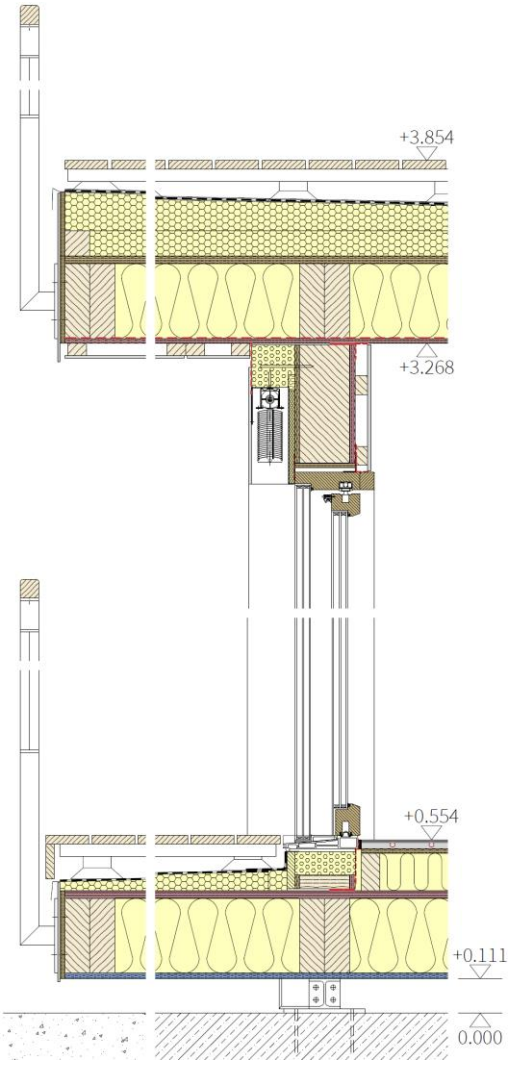


Fig. 1 HDU floor plan.



Roof

Terrace thermowood battens, anchored by stainless steel screws	27 mm
Laths 40x70 mm, á 500 mm	40 mm/70 mm
Height rectification pad	35–115 mm
Geotextile	
PVC waterproof membrane	
Geotextile	
Sloped expanded polystyrene (EPS)	20–160 mm
EPS	80 mm
OSB	25 mm
Blown cellulose between structural timbers (KVH) 80x240 mm	240 mm
Vapour barrier	
OSB	15 mm

Façade

Interior boards from recycled beverage cartoons	12 mm
Air gap between horizontal laths 40x60 mm	40 mm
OSB with sealed joints	18 mm
Blown cellulose between KVH 60x160 mm	160 mm
Vapour permeable wood fibre board (DHF)	15 mm
Soft wooden fibre thermal insulation between horizontal laths 60x100 mm	100 mm
Vapour permeable foil	
Ventilated gap between vertical spruce laths 40x60 mm	40 mm
Facade cladding fibre cement boards	8 mm

Floor

Recycled PVC floor covering	5 mm
Polystyrene underfloor mat	2 mm
Protective boards	4 mm
System carton boards with floor heating pipes	20 mm
OSB	15 mm
Hard wooden fibre insulation boards	120 mm
OSB with sealed joints	25 mm
Blown cellulose between KVH 80x240 mm	240 mm
Waterproof plywood	18 mm

Fig. 2 Construction detail (east façade) and structure compositions.

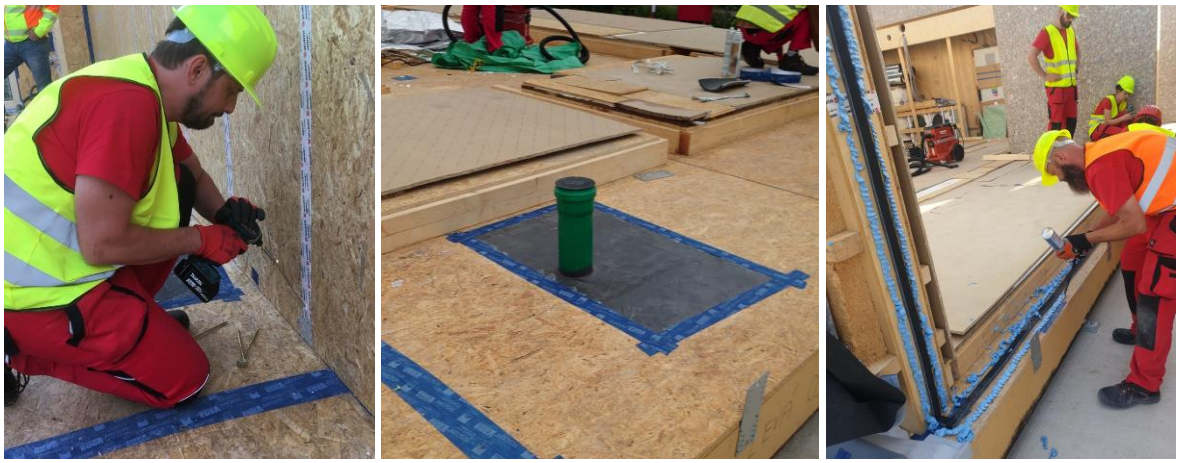


Fig. 3 Air tightness measures carried out precisely by the team members – the construction phase was the first practical experience with structural detail implementation for most of the students.

Fig. 4 Finished Czech HDU at the competition plot in Wuppertal, Germany.

References

[1] https://sde21.eu
[2] http://firstlife.cz
[3] https://www.uceeb.cz/en/home/
[4] sw SimRoom. www.ingefo.de/Werkzeuge/SimRoom/
[5] EN 13829 Thermal performance of building – Determination of air permeability of buildings – Fan pressurization method, CEN 2000
[6] EN ISO 16283-3 Acoustics – Field measurement of sound insulation in buildings and of building elements – Part 3: Façade sound insulation, CEN 2017
[7] https://www.btga-arch.uni-wuppertal.de