Industrial Energy Efficient Retrofitting of Resident Buildings in Cold Climates

D2.2
Demonstrator Oulu

Project no: 260058 **Project acronym:** E2ReBuild

Due date: 2014-06-30 **Submission date:** 2014-06-24

Dissemination: Public

Partners: Aalto; NCCFI, PSOAS

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The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n°260058

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NCCFI	NCC Rakennus Oy, Finland
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Executive Summary

The pilot building in Virkakatu 8, Oulu, Finland, owned by PSOAS Student Housing Foundation of Northern Finland, is one of five student apartment buildings in a housing cooperative. The building has 8 apartments, and was originally built in 1984. The building was in need of a complete refurbishment and the student apartments were outdated.

NCC Construction Finland (NCCFI) was turnkey contractors to design, retrofit, commission and handover the building to PSOAS. The retrofit brought the building up to and above current new build standards, reduced the occupied building's space heating demand use to 26 kWh/m2/y, and introduced high efficiency heat recovery ventilation. The building method has replication potential for the retrofit of facades made from concrete sandwich elements. Solutions were focussed on industrialised manufacturing methods and standardised retrofit measures with high replication potential.

M3 Architects in Oulu were principal designers for a comprehensive makeover of the interior spaces for student families who are the target tenants at this location. Residents have completely new apartments with enlarged balconies, open plan living rooms and kitchens, improved indoor comfort and ventilation, and private saunas were added. The architects designed a contemporary architectural image for the housing in harmony with the other buildings around the shared yard.

The building exterior was retrofitted with 480m^2 of TES Energy Façade comprising large scale well-insulated prefabricated timber elements. The insulation level, windows specifications and airtightness targets were set to the Finnish passive house norm according to the national suggested definition by VTT. The building volume was simplified to reduce thermal transmission, and the roof was replaced for additional insulation and HVAC installations. New balconies and the roof overhang shade the south facade to reduce the summer overheating risk. Building services were entirely replaced, district heating renewed and water saving fixtures installed. Remotely controlled building automation systems monitor the energy performance, indoor air quality, outdoor conditions and building physics. Attention was paid to the monitoring of the building physics, due to the need to verify the performance of the prefabricated insulating facade and the high level of insulation necessary in cold Nordic climates.

Production began on site in August 2012 and the retrofit was finished in February 2013. Site works improve site drainage and ground frost insulation. Airtightness and ventilation rates were measured prior to construction and another airtightness test and a thermal survey was conducted in winter prior to hand-over. Air leaks were detected in the existing concrete shell prior to retrofit and holes were grouted to significantly improve airtightness. Further air leaks were detected in the ground slab after retrofit and four apartments were vacated for correctional work by December 2013 – March 2014. One full year of monitoring data was completed in March 2014.

Knowledge transfer between partners included expertise and experience on the production and detail design of TES elements, monitoring methods and equipment, and air tightness improvements. Aalto University interviewed tenants prior to and after the retrofit, inspected off-site production facilities, documented the progress of the construction work, assisted with quality control, and collected a year of monitoring data. Experiences from the Oulu demonstration were used to improve the tenant questionnaire.

The experiences and findings from the Oulu demonstration project have been disseminated to RTD work packages WP3, WP4 and WP5. Research and dissemination activity has included conference papers in residential retrofits in cold climates, user energy behaviour and the analysis of building physics, the experimental application of radar survey methodology investigating structural concrete, graduate works in building automation and monitoring, and education in passive house design and timber construction. The demonstration project was nominated for the 2013 Wood Prize in Finland.

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1 Introduction

1.1 E2ReBuild Demonstrations

E2Rebuild is a European collaboration project with the vision of transforming “the retrofitting construction sector from the current craft and resource based construction towards an innovative, high-tech, energy efficient industrialised sector.” (Seventh Framework Programme, Theme: EeB-ENERGY.2010.8.1-2, Demonstration of Energy Efficiency through Retrofitting of Buildings).

The demonstration projects in E2ReBuild are the core of the project (work package 2). E2ReBuild is driven by demonstration projects, whereas research activities feed into the demonstrations, and results of the demos feed into “bottom-up” research and evaluation of lessons learned in other work packages. The results and conclusions from the demonstrations will be gathered to produce an industrial platform for energy efficient retrofitting (work package 6).

The objective of the work package 2 projects is to demonstrate seven high energy efficient innovative retrofitting concepts for low energy performing buildings which are representative building types for a large geographical area in Europe.

Each project establishes and demonstrates sustainable renovation solutions that will reduce the energy use to fulfill at least the national limit values for new buildings according to the applicable legislation based on the Energy Performance of Buildings Directives (for 2010) and to reduce the space heat use by about 75%.

Monitoring and follow-up: Based on recommendations given by Work Package 5, monitoring takes place during at least one year within this project, in some cases for a longer period (also continuing after the completion of this project).

One of the main issues in initial refurbishment discussions concerns costs. This has been treated in depth in deliverable D3.4 *Holistic Strategies for Retrofit* where costs from all demonstration projects are reported, analysed and discussed[1].

The demonstrators are supported by work carried out in other work packages and provided detailed feedback to work packages 3, 4, 5 and 6.[2]

This deliverable is defined as a “demonstrator”. This document is the written record of the achievements of one of the demonstration projects.

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[1] As report D3.4 is restricted, public information can be found in GEIER, SONJA; EHRBAR, DORIS; SCHWEHR, PETER (2014); Holistic Strategies for the Retrofit to Achieve Energy-efficient Residential Buildings. In: Proceedings 9th International Masonry Conference 2014. Guimarães (P)

[2] The E2ReBuild Work package description for WP2 (page 8) stated: “The demonstrators should be supported by work carried out in WP1, WP3, WP4 and WP5 and the results should also feed into WP6”. In addition to receiving support, Task 2.2 Demonstration Oulu also provided detailed feedback to the RTD work packages due to the change from a top-down to a bottom-up RTD approach as requested by the Project Officer in 2012.

Figure 1: Virkakatu 8AB, Oulu demonstration object prior to refurbishment (photo collage, S. le Roux, 9.9.2011)

1.2 Demonstrator Oulu

NOTE: The Oulu demonstration object replaced the demo suggested in the original project plan for E2ReBuild. The new demo object is part of the amendment of the E2ReBuild Grant Agreement, approval dated on 2011-12-02.

The Finnish demonstration object is PSOAS 8AB, Virkakatu 8 student residence in Oulu, northern Finland. The housing cooperative consists of 5 apartment buildings and one building with communal facilities, of which one apartment building was a pilot within the E2Rebuild project.

Figure 2: Virkakatu 8 demonstration context with a shared yard and communal facilities

The possibilities of reaching the energy efficiency level of Passive House through building modernization in Oulu was studied in 2008-2009 in the form of a pilot project, the Pohjankaleva student residence, for the TES Energy Façade[3] and Square[4] projects. As a result of research done the building owner, PSOAS decided on the realization of a building renovation, including a comprehensive refurbishment of indoor spaces and a façade renovation with the TES method utilizing timber based, prefabricated elements for the renewal of the building envelope. The target is a small

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[3] TES Timber based element systems for improving the energy efficiency of the building envelope http://www.tesenergyfacade.com/

[4] SQUARE A System for Quality Assurance when Retrofitting Existing Buildings to Energy Efficient Buildings http://www.iee-square.eu/default.asp

object but with high replication potential due to its building technique and character, typical of standardized suburban construction in Finland.

The demonstration object is a two story, residential building completed in 1985. Results and experiences of the modernization process may later be replicated, due to the standardized construction system originally used for this demonstration building. The Finnish BES[5] system with standardized precast elements and joint details was widely used for housing projects across Finland, and therefore the findings and solutions used for this demonstration project offers good possibilities for replication in modernization of Finnish housing projects from 1970's onwards.

The structure is based on standardized load bearings end and partition walls, with non-load-bearing sandwich elements on the long exterior walls and the upper floor constructed with long precast hollow core slab elements. The main concrete facade elements are faced with face brick. The building has concrete element balconies as free-standing towers, tied back to the facade concrete elements.

The estimated existing wall U-value was 0.28 W/m2K according to Finnish building regulations with 140mm of mineral wool. The building was in the need of a complete refurbishment and the student flats were outdated and lacking in facilities. Condition surveys were made of all the buildings on the property in 2003, a condition analysis of the balconies was made in 2008, and a detailed condition analysis of the building was made in 2011, prior to the decision to go ahead with the refurbishment. The scope of the building renovation was decided to include a comprehensive refurbishment of indoor spaces and a façade renovation with the TES method utilizing timber-based, prefabricated elements for the renewal of the building envelope. The heating level was estimated to be 148 kWh/m2 and the target value was set to 30 kWh/m2.

The Demonstration targets for the pilot project in Oulu:

- *Demonstrate passive house level of energy efficiency in a building renovation in the climate of northern Finland*
- *demonstrate benefits for contractors of industrial scale of façade renovations provided by prefabrication and a fast renovation process on the building site*
- *demonstrate the application and usability of timber based, prefabricated elements for the renewal of a residential building constructed with a standardised concrete element system*
- *demonstrate the importance of efficient ventilation solutions with a high heat recovery rate*
- *demonstrate the benefits of a comprehensive approach to renovation in Finland*

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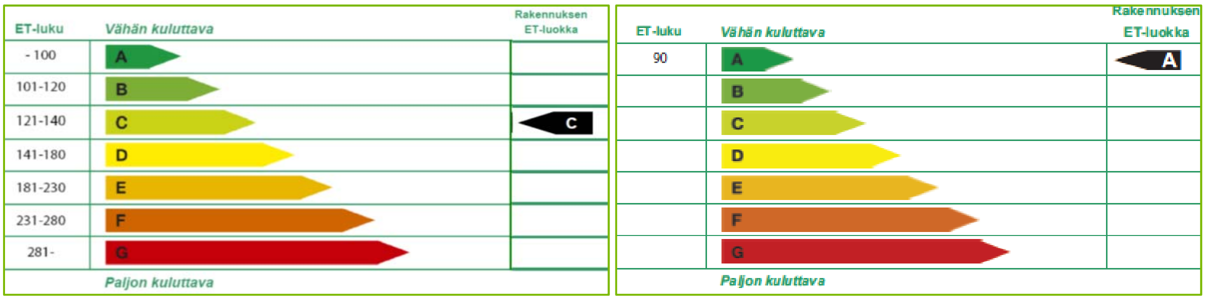
[5] *Betonielementtistandardi (BES)* concrete element standard developed by Finnish concrete industry in 1960's.

2 Energy Efficient Retrofitting

Figure 3: Oulu demonstration before retrofit in 2011 and at completion in 2013 (photos M3 Architects)



ET-luku	Vähän kuluttava	Rakennuksen ET-luokka
- 100	A	
101-120	B	
121-140	C	C
141-180	D	
181-230	E	
231-280	F	
281-	G	
	Paljon kuluttava	

ET-luku	Vähän kuluttava	Rakennuksen ET-luokka
90	A	A
	B	
	C	
	D	
	E	
	F	
	G	
	Paljon kuluttava	

Figure 4: Finnish Energy certificate[6] for Virkakatu 8 buildings before retrofit based on measured performance in 2012, and new certificate for demonstration building after retrofit based on calculated performance, 18.2.2013 (PSOAS / M3 Architects)

The Oulu demonstration underwent a complete retrofitting of the envelope. The outer façade layers of the existing prefabricated concrete sandwich elements were removed leaving only the inner concrete layer in place. A new façade was retrofitted using prefabricated timber based elements. The old roof was replaced completely by a new timber truss roof and a new thermal insulation layer of 550 mm blown loose fill mineral wool resulting in a U-value of 0.08 W/m2K. The existing ground floor slab was replaced, with a new in-situ ground floor slab with 200 mm graphite-enhanced EPS insulation.

Facts about the thermal performance of building envelope, Oulu demonstration:

	Before:	**After:**
Exterior walls and roof	0.28 W/m²K	0.11 W/m²K
Windows	2.1 W/m²K	0, 8 W/m²K
Ground slab	0.24/0.36 W/m²a	0.11/0.15 W/m²K
Roof	0.22 W/m²a	0.08 W/m²a

The design target levels for energy efficiency in the Oulu demonstration were based on the Finnish VTT passive house recommendation in northern Finland[7]:

Heating Energy Demand	30 kWh/m2 y (current 148 kWh/m2 y)
Air tightness	n50 ≤ 0,6 1/h (current 6,0 1/h)
Primary Energy Demand	130 - 140 kWh/m2

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[6] Energy audit in accordance with section D3 of the National Building Code of Finland.

[7] Nieminen J., Lylykangas K. 2009. "Passiivitalon määritelmä. Ohjeita passiivitalon arkkitehti-suunnitteluun", www.passiivi.info (accessed 20.05.2013)

2.1.1 Planning Retrofit Measures for Oulu Demonstrator

Retrofit measures enhanced the future rent ability of the building over a renewed expected further 50 year service life, improved the quality of life for tenants, and introduced energy-saving measures:

- New insulation on facades, roof and ground floor slab
- New district heat circuit and domestic water pipes from the service building
- New real-time automatic valve control of the flow of space heating from the district heat exchanger, which had been replaced in 2006 by PSOAS
- New thermostatic radiator control of indoor temperature
- LED energy efficient lighting in stairwells and apartments
- New windows with a U-value of 0,8 W/m2K
- Improved airtightness 3,3 to 0,8 l/h Air Changes per Hour under 50Pa pressure (n50 measurement typically used in Finland); improved from 3,1 to 1,2 m3/h*m2(q50) air volume changes at 50Pa compared to the building envelopes surface area.[8]
- Installed low-flow showers, water saving standard for PSOAS since 2009

2.1.2 New Build Building Regulations Applied to Renovation

The building works in Oulu took place before new Finnish statutory regulations were implemented for the improvement of energy efficiency of buildings during renovation and alteration works. Regulations for new building were applied to the project due to the extent of the retrofit, and the building permit application to local building inspectors was evaluated according to existing new building regulations. To a large degree current Finnish building regulations do not anticipate the real risks of deep retrofits and requirements for new built are not directly applicable. Regulations for new building focus on fire risks, concrete structural requirements and safety. The Oulu demonstration showed that in retrofit practice there were other priorities for inspection of building works than for new building. There was a need for inspection of construction tolerances in prefabricated elements, verification of airtightness improvements, precautions for differential structural movements in foundations and ground slabs under improved thermal conditions, and the moisture protection and quality control of timber structures.[9]

2.1.3 Passive House Renovation and Energy Retrofit Measure

Based on evaluation of the monitored energy performance of the demonstration building, it will be possible to apply for the EnerPHit Certificate for Energy Retrofits with Passive house Components[10].

The heating system for the demonstration building is based on the existing district heating system for the property, shared by all 5 houses, but with a retrofit valve actuator flow control based on the monitored supply and return temperatures and the real time outdoor temperatures, and controlled by new building automation to optimize the heating supply. The Oulu demonstration is the second retrofit in Finland realized with the TES Energy Facade - method.[11]

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[8] Building air leakage tests by Cramo Finland 12.7.2012 and 24.1.2013 in compliance with EN13829: Puotiniemi J. 2012. Ilmatiiveysmittausraportti PSOAS Virkakatu 8 90570 Oulu 15.7.2012. CRAMO. Oulu, Finland.

[9] Cronhjort, Y., le Roux, S. 2013. Legal and economic prerequisites for sustainable refurbishment of housing companies in Finland, submitted to Sustainable Building Conference 2013, TU Graz, Austria

[10] ”EnerPHit and EnerPHit+i Certification Criteria for Energy Retrofits with Passive house Components”, Passive house Institute, 2012.

[11] Lattke, F., Larsen, K., Ott, S., Cronhjort, Y. 2011. TES Energy Facade – prefabricated timber based building system for improving the energy efficiency of the building envelope, funded by: Woodwisdom Net, Research project from 2008-2009

The energy performance of the building was improved by adopting apartment-specific, balanced ventilation systems equipped with high efficiency heat recovery. Due to the small number of apartments, with only four per stairwell, a centralized ventilation system would not have achieved sufficient savings in maintenance costs to cover the additional installation costs. A centralized system requires a great scale for cost efficiency. Furthermore, a centralized ventilation system would have required additional duct work in passageways, but the existing ceiling height was already low. As a result, a distributed ventilation system was competitive with a centralized system, and since all apartments have similar sizes, windows and orientations, an identical apartment-specific ventilation unit was selected. A significant benefit gained from distributed ventilation units it that they provide apartment-specific monitoring data to a central building automation controller.[12]

2.1.4 Cost of Retrofit

The refurbishment was realized with PSOAS own funding and supported by EU Fp7 project funding. The EU funding was critical for research and development work, and follow-up monitoring of the project. However, the total refurbishment was expensive, with one third of the costs caused by energy retrofit and total construction costs comparable to new building at passive house level. The E2ReBuild report D3.4 "Holistic Strategies for Retrofit" (Geier S., Ehrbar D., Schwehr P., 2014) evaluates the demonstrator Oulu, and all the seven demonstration projects, along the lines of economic, ecological and social strategy, including the detailed cost breakdown and service life analysis. Industrialized retrofit offers opportunities for quality, time and cost optimization. The analysis of E2ReBuild projects reveals the added value of sustainability targets.

Overall measures	**Cost**	**%**	**Cost/m^2 leasable floor area**
design	49 200 €	**3 %**	85 €
surveys	12 300 €	**1 %**	21 €
site costs	86 100 €	**6 %**	149 €
contract general costs	84 200 €	**6 %**	146 €
∑ overhead costs subtotal	232 000 €	**16 %**	403 €
TES energy façade*	233 300 €	**16 %**	405 €
roof replacement	84 400 €	**6 %**	147 €
ground slab replacement	72 600 €	**5 %**	126 €
building services	80 000 €	**6 %**	139 €
monitoring and automation	27 300 €	**2 %**	47 €
∑ energy renovation measures	497 500 €	**35 %**	864 €
Interior renovation and balconies	700 500 €	**49 %**	1 216 €
∑ TOTAL	1 430 000 €	**100 %**	2 483 €

Figure 5: NCCFI cost breakdown for Oulu demonstration project. Façade size: total area approximately 480 m2. Facade cost includes passive house compliant windows, but excludes new roof and balconies. The cost is divided by 576 m^2 leasable floor area. As a result of the small size of the demonstration, the overhead site and contract costs were large. This overall cost level was considered comparable with new build market prices for passive house energy performance. As a result, the asset value of the property has been significantly improved for a renewed life expectancy of 50 years. (S. le Roux, 2012)

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[12] Memo from Oulu project HVAC designer: Insinööritoimisto Taltekon Oy, Ari Savolainen, DI, 29.8.2012

3 Retrofitting Process

Figure 6: Building in 2011, design stage 2012, TES assembly phase in 2012, and completed in 2013 (photos M3 Architects)

	From	To
Brief	April 2011	August 2011
Design	August 2011	August 2012
Construction	August 2012	February 2013
Monitoring	March 2013	March 2014

Table 1 Time frame for demonstrator

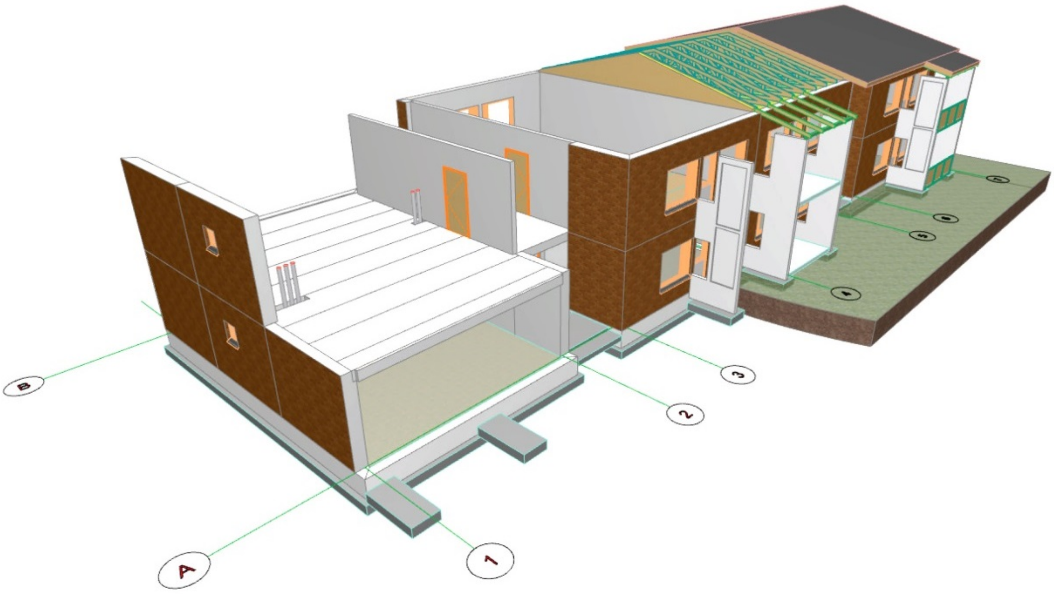

Figure 7: Existing prefabricated concrete structure of Oulu demonstration building (CAD visualisation, S. le Roux, 2011)

3.1.1 Condition Analysis Prior to Refurbishment

Before design work began the condition of the building was analysed.[13] Tests were made for moisture in the building envelope, VOC's, asbestos, lead, indoor air microbes, and capillary action. Minor moisture damage was found in some bathrooms and floor materials. The original ground slab consisted of a 70 mm reinforced concrete slab insulated with 50 mm polystyrene. Based on high levels of moisture measured in the existing ground fill, the contractor recommended replacing the ground floor slab, to improve insulation and reduce capillary action with ground fill to meet new building requirements. Building air leakage tests were performed prior to refurbishment (12.7.2012) and after completion (24.1.2013). Special effort was made to improve airtightness in the building envelope, and leaks in the concrete frame were grouted.

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[13] Condition analysis by WSP Finland 10.11.2011.

3.1.2 Construction Site Process

Building works on site started with the removal of the original in-situ ground floor slabs and the external layer of concrete and brickwork from the precast facade elements. The old thermal insulation layer was stripped away. Additional foundation structures were added, widening the existing concrete footing to carry the load of the new facade elements.

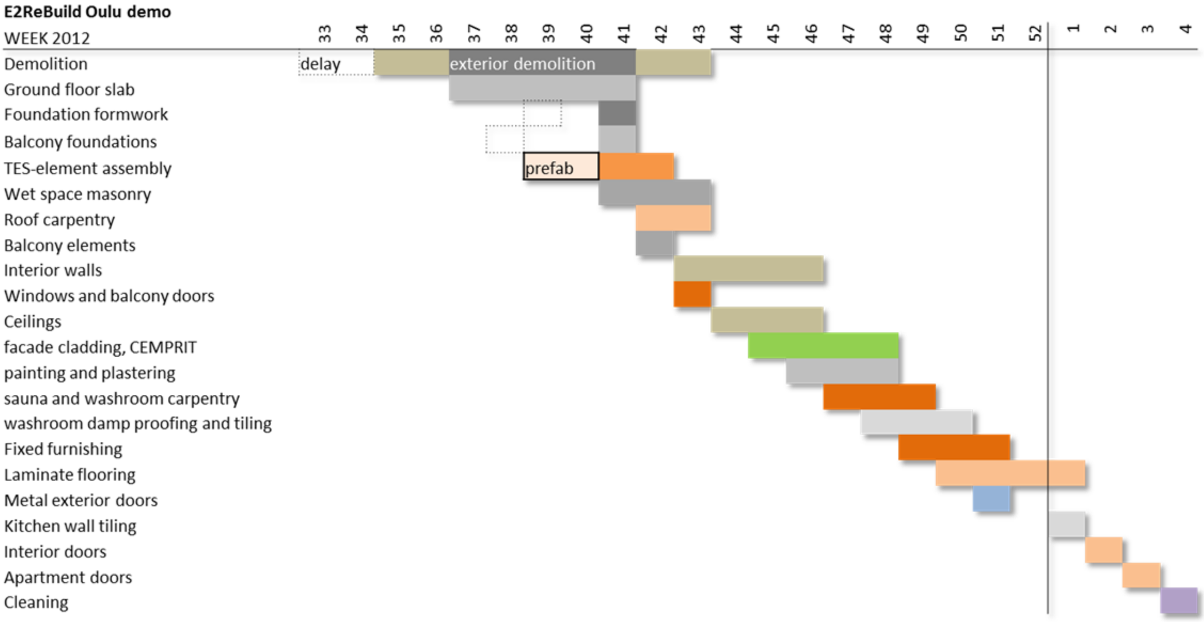


Figure 8: NCCFI site construction timetable from week 32 August 2012 to week 4 February 2013. Delays were cause initially waiting for final building permit and at mid-way waiting for windows to be delivered to site. (S. le Roux, 2012)

Figure 9: Retrofit process collage. From left: original state 2011, demolition phase 2012, and finishing off 2013 (S. le Roux)

3.1.3 TES Energy Facade for Oulu Demonstrator

External thermal insulation systems are commonly used to improve thermal performance of buildings, and five buildings of the E2ReBuild project employed the TES-method to improve the building envelope performance.

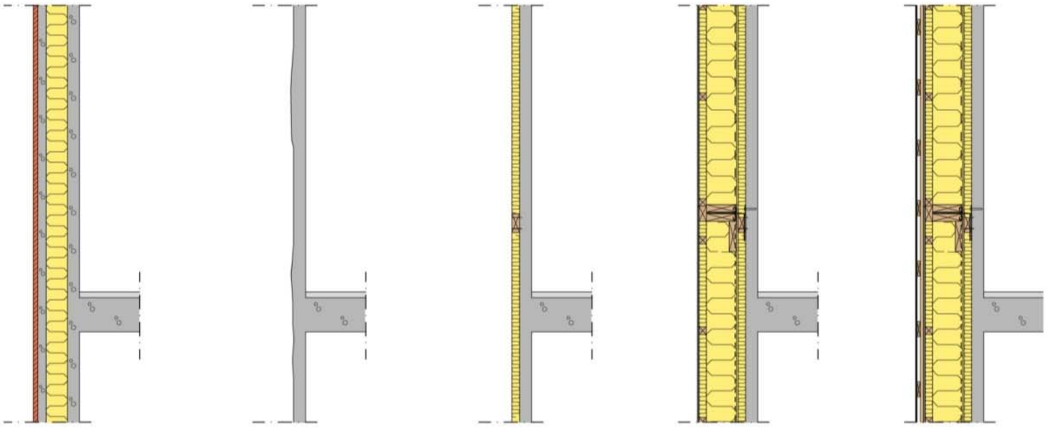
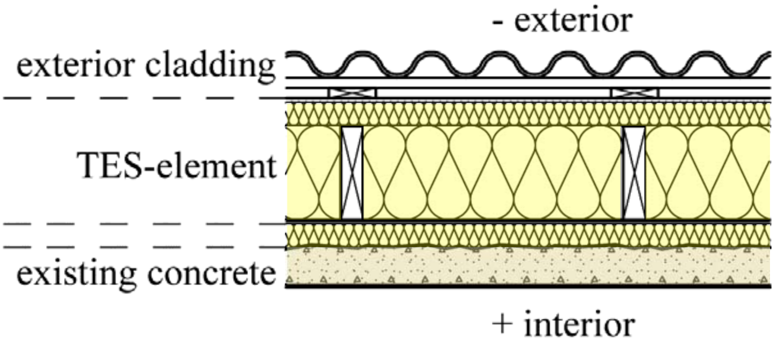


Figure 10: Process of facade retrofit. From left: original precast sandwich element, stripped concrete shell, adjustment layer to receive TES facade, prefabricated elements assembled on concrete shell, cladding applied in-situ. (M3 Architects, 2012)

The original facades consisted of prefabricated sandwich elements with 80-85 mm external brickwork, 130-140 mm of thermal wool insulation and an 80mm inner layer of concrete on the long facades and a 150mm inner layer of concrete on the short end facades, which carried the upper floor slabs. Detailed measurements of the existing building were made for the manufacturing of the retrofit facade elements. New facades were manufactured 125km away from the site in a northern Finland factory in Haapavesi from prefabricated, timber based elements. A thin thermal insulation layer was added to the elements on site as an adjustment layer between the elements and the uneven existing concrete surface. External cladding and windows were assembled on site. The total thickness of new thermal insulation in the completed facade is 300 mm. Inward opening wood aluminium passive house casement windows were installed. The TES Facade comprised of a prefabricated timber element system installed over an existing inner precast concrete shell:

- 7mm corrugated fibre cement facade cladding, colour black, installed in-situ
- 44 mm air gap (22 + 22x100mm - c600mm sawn timber battens)
- 9mm gypsum wind barrier
- 50 + 200mm glass mineral wool thermal insulation (declared Lambda value 0,033 W/mK)
- 42x48mm c600mm sawn timber horizontal battens
- 42x198mm c600mm sawn pine vertical load bearing frame
- 9 mm plywood board
- 50 mm thermal insulation for adjustment layer, installed in-situ
- 80mm inner layer of existing precast concrete sandwich element



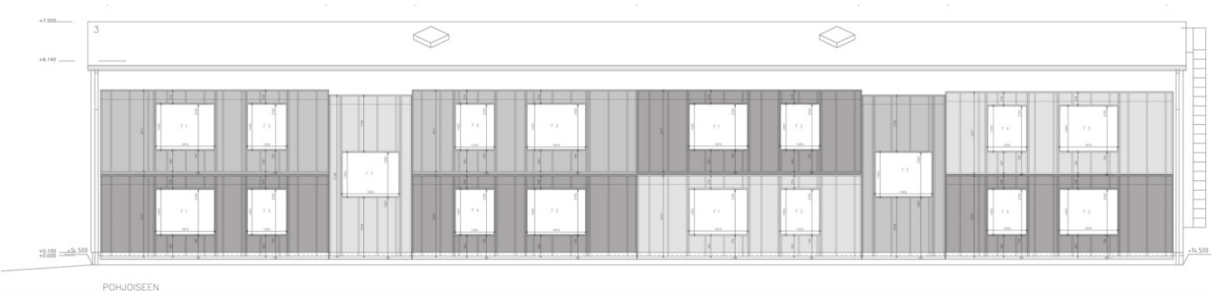
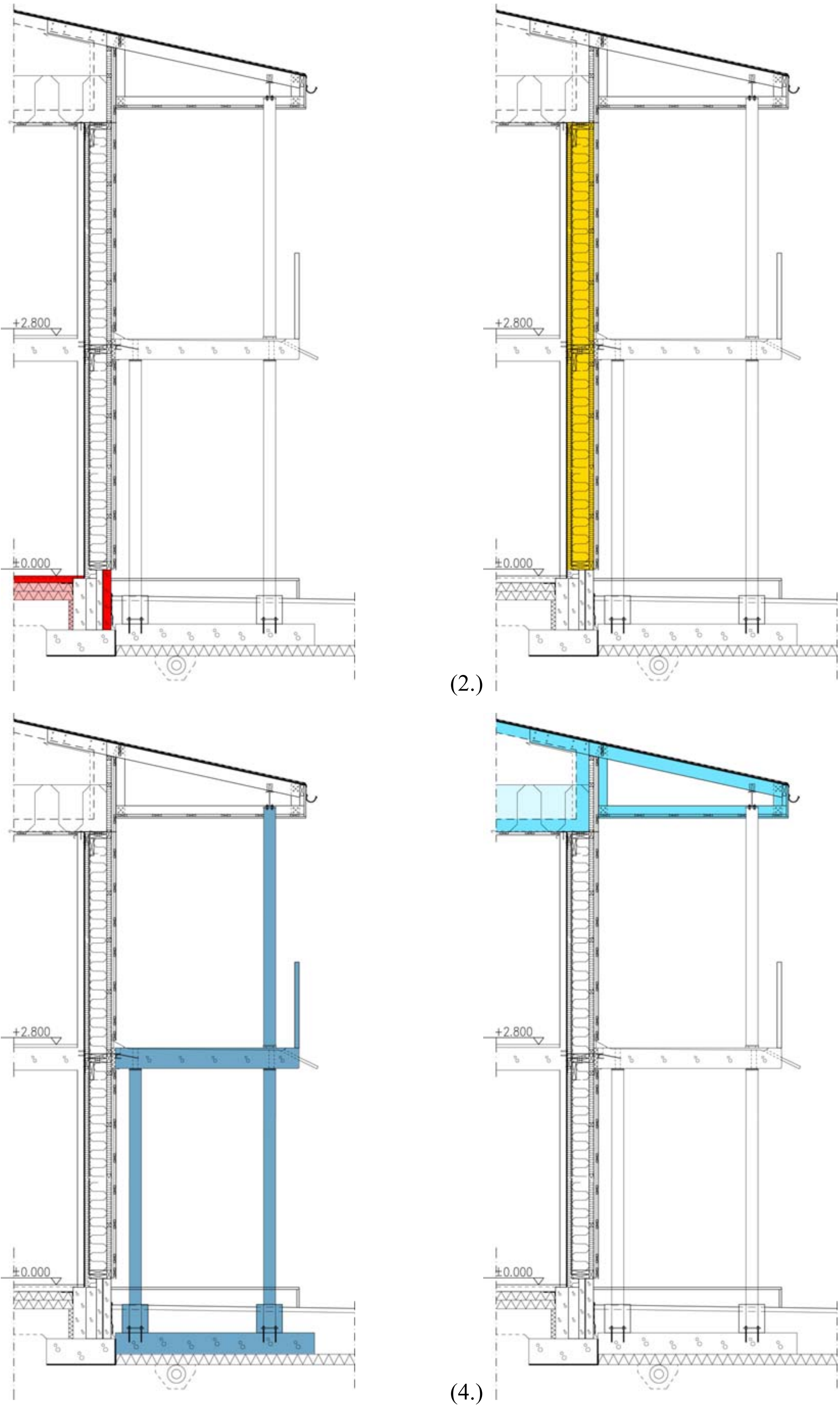


Figure 11: Arrangement of TES elements on north facade (M3 Architects; TES elements: Suomen Rakennustuote Oy)

Figure 12: Removal of the external layer of precast concrete sandwich elements in September 2012, and completed assembly in November 2012 of prefabricated timber facade elements, concrete balconies with steel supports, and a new roof assembled on site and lifted into place in 4 large sections (photos S. le Roux, September and November 2012).

Figure 13: TES element prefabrication in Haapavesi and assembly on site (photos M3 Architects, 2012)



(1.) (2.) (3.) (4.)

Figure 14: Section drawing of demo building's south facade highlighting (1) the new ground slab and foundations for TES-elements (2), the TES Timber-based Element System installed over the existing concrete shell, (3) new prefabricated steel and concrete balconies, and (4) the new roof and external shading (M3 Architects 2012)

3.1.4 Collaboration in Site Process

The site process of the Oulu demonstration has been thoroughly documented in collaboration with the NCC site foreman, and was a rewarding aspect of this project. Interpersonal communications and discussions about technical details are a useful method to make proposals from research, and to receive immediate feedback from the site application. For example, the discussion surrounding air tightness was multifaceted. Attention to detail was paid to filling cracks in existing concrete structures with grout. Ductwork penetrations required special sealing in facades, walls and floors. The fitting of windows and the selection of appropriate elastomeric materials required quick responses and ongoing communications, which included expert discussion with feedback from research colleagues. The partial removal of the outer layer from the existing sandwich elements required time-consuming work with rough tools, and there was always a risk of compromising the structural safety of the existing structural shell. Site rain protection was enhanced by retaining the existing roof as long as possible, and the quick assembly of facade elements on site was instrumental in reducing the construction moisture risks typically associated with new building. Compared to new building, a refurbishment project has good potential to be a safe and dry construction process, so long as the facade is well protected during the building site works.

Figure 15: Critical site details: partial demolition, window sill sealing, ventilation penetrations, rain protection (S. le Roux). Site management quality is needed to respond appropriately to existing conditions, maintain site waste management, ensure structural integrity, deliver good air tightness and moisture control, and accurately assemble and protect retrofit components.

The experience revealed that refurbishment not only relies on carefully measured prefabrication with standards in quality control, but also careful handwork and exacting machine work on site. This is clearly an area of specialization, and should be recognized as a future need for improved competency, as contractors gain valuable experience from demonstration projects like E2ReBuild.

The design of the monitoring scheme and the collection and analysis of measuring data has shown the importance of collaboration and discussion between the demonstration task leader, the building owner's Property Manager, the automation and monitoring subcontractor, design phase electrical and HVAC engineers, NCCFI energy specialists and the E2ReBuild research partners, especially representing WP5 "Innovation in Operation and Use." (SP Sweden). Since the demonstrator Oulu started construction work fairly late into the E2ReBuild project, there was only little time to verify the measurement data and reflect on the monitoring results. This project has however enabled the foundation of a valuable database and monitoring system for ongoing collaboration in future years and research projects.

The E2ReBuild report D3.1 "Evaluation of Collaboration Models"[14] summarizes the experiences and lessons in collaboration and action chains within the demonstration projects. Further information is available on the E2ReBuild website: www.e2rebuild.eu.

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[14] Geier Sonja et al.: Evaluation of Collaboration Models. Report D3.1 of the FP 7 project E2ReBuild. www.e2rebuild.com/en/links/deliverables/Sidor/default.aspx; [Download: 19.02.2013; 15:16]

Table 2 Key players involved in the Oulu retrofitting demonstrator:

Role	Name	Brief	Design	Construction	Monitoring
Building owner	*PSOAS*	*X*	*X*	*X*	*X*
Condition analysis	*WSP Finland*	*X*			
Architect	*M3 Architects*		*X*		
Energy specialist	*NCCFI (Optiplan)*		*X*		*X*
Structural engineer	*Insinööritoimisto Putkonen*		*X*		
HVAC engineer	*Insinööritoimisto Taltekon Oy*		*X*		
Electrical engineer	*Oulun Sähkö-Aika Oy*		*X*	*X*	
Contractor	*NCC Rakennus Oy*	*X*	*X*	*X*	
Subcontractor 1 TES prefab.	*Suomen Rakennustuote Oy*			*X*	
Subcontractor 2 monitoring	*Fidelix Oy*			*X*	*X*
University	*Aalto University*	*X*	*X*		*X*
Airtightness and thermal tests	*Cramo Finland Oy*				*X*

3.2 Monitoring the Demonstration Project

The E2ReBuild project made it possible to implement a high quality and robust monitoring scheme for the Oulu demonstration project, including monitoring equipment for district heating energy consumption and domestic hot water based on temperature and flow sensors, monitoring of indoor air quality and comfort based on air temperature, relative humidity CO_2 levels, detailed monitoring of domestic electricity and heat recovery ventilation, measurement of the use of domestic hot and cold water, and building physics monitoring of relative humidity and temperature in the facades, ground slab and roof. Outdoor light, temperature, wind and irradiation are monitored as baseline, weather data was collected for hygrothermal 2D-simulations in collaboration with WP5. The monitoring equipment was ordered and installed in 2012, and equipment was commissioned in January and February 2013. The collection of one full data was completed in March 2014 and included data from the full winter season of 2013-2014.

Oulu demonstration monitoring scheme

Main parameters for comparison	Comments
Purchased energy	Shared by 5 houses
Space heating	District heating
Domestic hot water	Flow, temperature, energy
Building electricity	Shared by 5 houses
Household/tenant electricity	8 apartments
Additional parameters	
Indoor dwelling temperatures and RH	4 rooms x 2 apartments
Indoor CO_2	2 apartments
Outdoor temperature, RH and irradiation	2 positions
Airtightness and thermal imaging	Before & after
Ventilation rates, electricity	In all apartments
Building envelope performance	4 facades, roof, ground

Monitoring equipment installed in Oulu demonstration project:[15]

- Digital building automation system collects measurement input to a programmable substation (FIDELIX FX-2025a Digital Controller), from which data is transferred via virtual private network to outside monitoring. The substation communicates with input modules using Modbus communication protocol (Modbus RTU RS-485), and also collects monitoring input from all eight apartment ventilation units (ENERVENT PINGVIN eco ECE ventilation unit Multi Web-ModBus).
- Each apartment has a FIDELIX Multi-LCD room panel with 3,5” colour LCD touch screen, programmed to display hot and cold water volume, electricity meter and outdoor temperature, daily, weekly and monthly use.
- The building automation controls the supply of heating water from the district heating heat exchanger according to the current outdoor temperature using a valve actuator (HRYD24-SR).
- Outdoor conditions are monitored with a weather station (DAVIS Vantage Pro2 Plus) and outdoor illumination and temperature sensors (PRODUAL LUX 11 + NTC 10).
- Ultrasonic compact energy meter (SHARKY 775) measures and calculates the total energy demand in district heating for space heating and domestic hot water. Immersion temperature

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[15] Cronhjort, Y., le Roux, S. 2014. Holistic retrofit and follow-up through monitoring: Case Virkakatu, Oulu, Finland, Submitted to the Nordic Symposium on Building Physics 2014, Lund, Sweden

sensors (PRODUAL TEAT NTC10) and the flow meter together measure the overall space heating delivered to the radiators and the domestic hot water supplied to each apartment.

- Two apartments are monitored for indoor temperature/humidity with transmitters in 4 rooms (PRODUAL KLH100), and with C02 transmitters in air intake and exhaust ducts (PRODUAL HDK).
- Structure humidity and temperature sensors are installed in four TES elements which face north, south, east and west, and in the ground floor slab (HONEYWELL HIH-4010 moisture sensors and PRODUAL TE NTC10 temperature sensors). The roof insulation is monitored with PRODUAL KLU-100 outdoor humidity and temperature transmitters.[16]

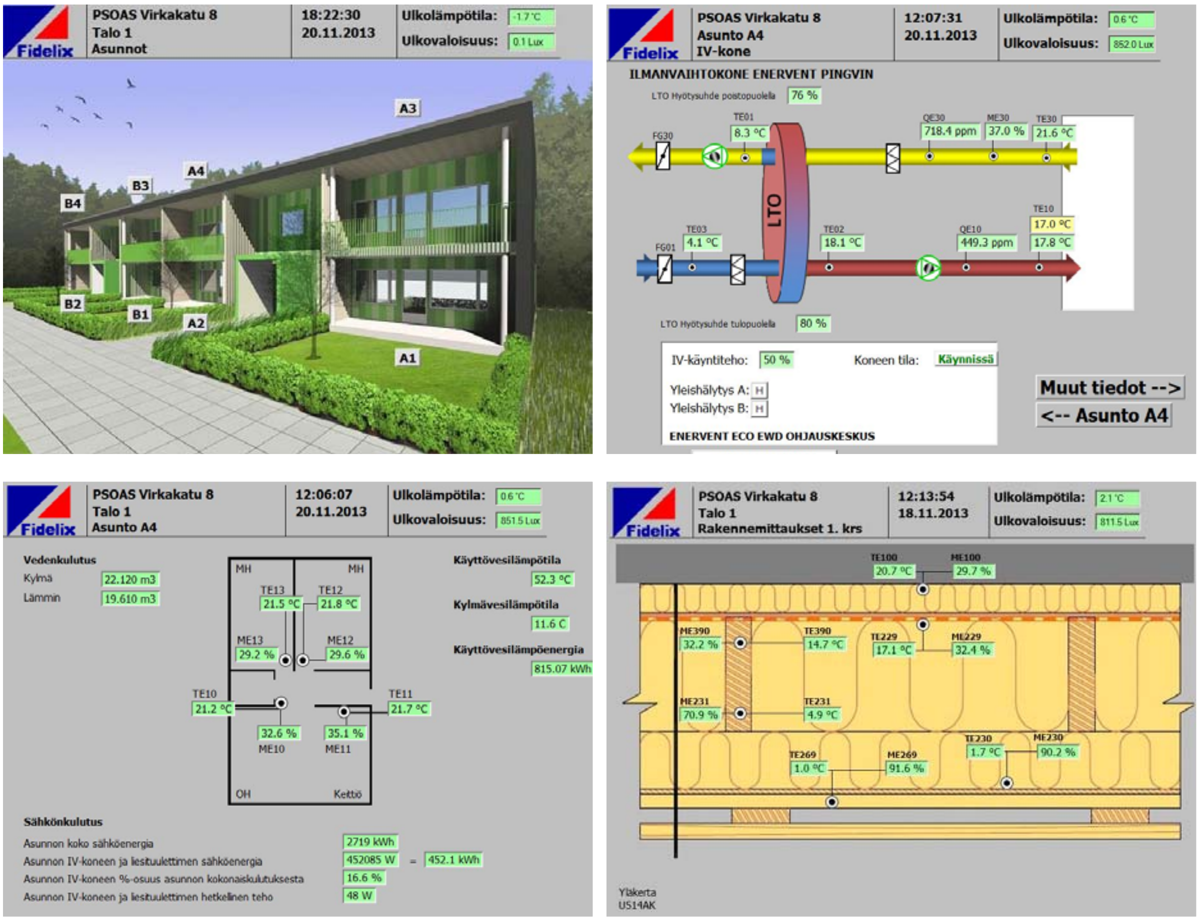

Figure 16: Screenshots from the online interface of the digital building automation system accessing monitoring data. Top left image shows the links to the monitoring data from eight apartments A1-B4. Top right image displays monitoring parameters as collected from all eight apartment ventilation units. Bottom-left image displays household energy use, and indoor temperature and relative humidity data as monitored in two apartments. Bottom right image displays building physics monitoring of temperature and relative humidity in one of the four monitored façade locations (Palosaari M, Fidelix. 2013)

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[16] Palosaari M. 2013. Rakennemittausten liittäminen Fidelix-automaatiojärjestelmään. Opinnäytetyö. Automaatiotekniikan koulutusohjelma. Oulun seudun ammattikorkeakoulu. Oulu, Finland.

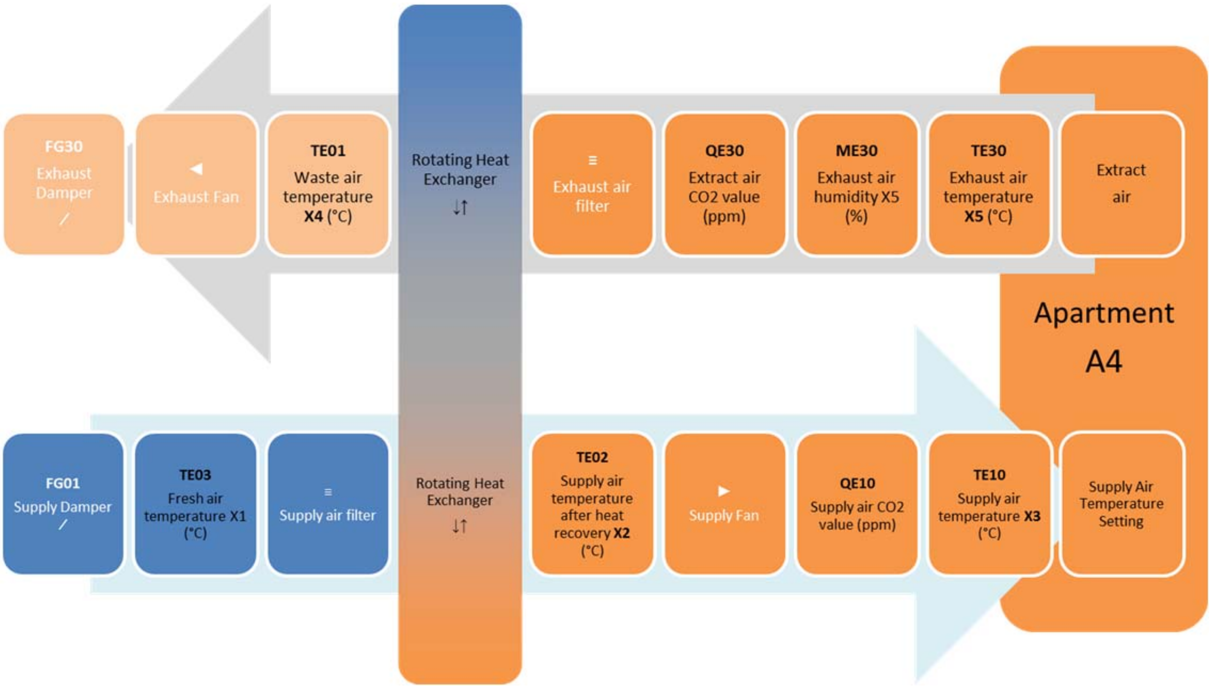

Figure 17: Diagram of heat recovery ventilation unit with monitoring positions for temperature and RH of air supply and exhaust before and after heat recovery, calculation of heat recovery efficiency, and CO_2 level monitoring. (S. le Roux)

3.2.1 Monitoring of Facade Building Physics

The TES elements were prefabricated with monitoring sensors for temperature and relative humidity installed in the factories. It was important to demonstrate that the hygrothermal performance of this retrofit facade can be accurately simulated. The hygrothermal study of the facade showed that the measured results collected during the E2ReBuild correlate well with simulated figures from the hygrothermal 2D-simulations performed with the WUFI building physics 2D analysis. In addition, the extra layer of insulation placed on the outer side the wooden studs had a beneficial influence on maintaining the temperature and safe relative humidity of the timber load bearing frame.[17]

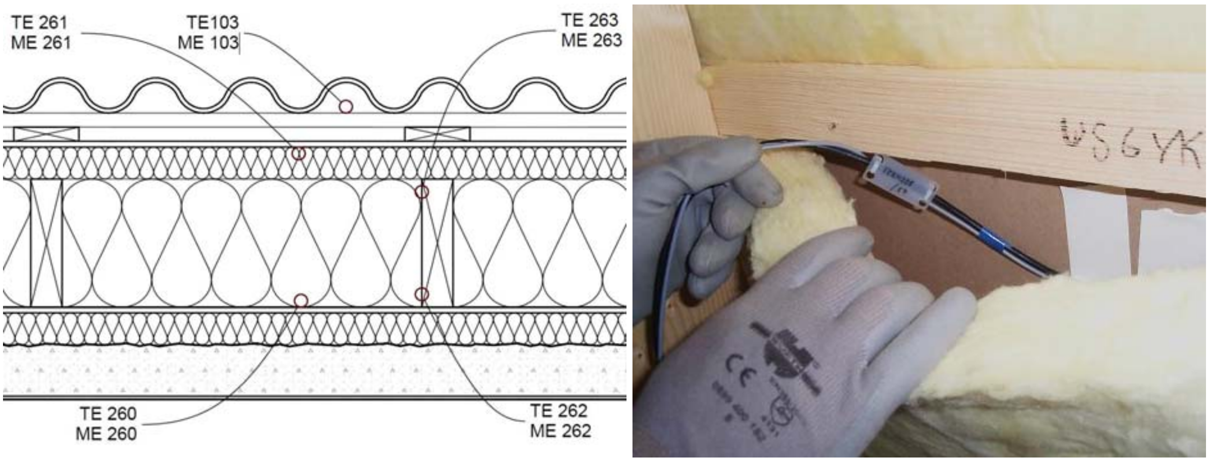

Figure 18: Monitoring positions of the Oulu TES facade element at location US10YK.

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[17] Capener C-M., Burke S., le Roux, S., Ott, S. 2014. Hygrothermal Performance of TES Energy Façade at two European residential building demonstrations – Comparison between Field Measurements and Simulations, Submitted to the Nordic Symposium on Building Physics 2014, Lund, Sweden

4 Results and Experiences

4.1 Tenant Experiences

The investment in deep refurbishment delivered a positive rise in living standards and comfort for tenants with the newly landscaped yard under construction, larger balconies, and greater indoor comfort balanced with enhanced energy efficiency. Private saunas are typically valued by Finnish families, open plan kitchens are more sociable, drafts were removed with improved airtightness, and surface radiant temperatures are now at satisfactory levels due to windows that meet passive house requirement. The bathroom humidity was reduced with higher ventilation rates and underfloor comfort heating. New internet installations were seen as essential for current user needs, and there was some concern about the performance of mobile networks in a well-insulated building. The project has met the initial brief which was tailored to tenants needs, and to ensure the long term rental viability of the accommodation.

4.1.1 Tenant Surveys before and after Refurbishment

E2ReBuild report D3.3 presents findings from the tenant perspective, in an investigation into the socio-architectural relations of the Oulu demonstator project, based of tenant surveys before and after the refurbishment. The subject for analysis was the tenant's experience of the retrofit process and its impact. The situation before and after were compared under aspects of health and well-being, experiences of the built environment and architectural quality, and the aspects of information, communication and the value of retrofit were evaluated without a time comparison. Prior to the E2ReBuild retrofit in Oulu in 2012, five tenant interviews were conducted by telephone and in person. After the refurbishment written feedback was gathered from four tenant households through an electronic questionnaire in 2014, by when all upstairs apartments had been occupied for one year.

Even though the tenants interviewed in 2014 did not occupy their apartments during the E2ReBuild refurbishment process they lived through 4 months of repair works downstairs, and 9 months of construction work in their yard and neighboring buildings. In June 2013 the four other apartment buildings on the Virkakatu 8 property around the common yard were vacated for renovation. The yard and playground had been used by the construction site, which was a major disappointment for tenant families with young children. The communal facilities were also closed. In January 2014 the communal laundry was opened again for use, but the sauna and club room were no longer in use. Tenants had been disturbed by the ongoing construction site outside their building.

Tenants were also disappointed in autumn 2013 after the refurbishment with a lack of communication and information about the need for remedial work for indoor air problems which emerged after refurbishment in downstairs apartments. The four downstairs apartments were occupied from March 2013 until November 2013. From December 2013 until March 2014 the downstairs apartments were vacant while the contractor repaired air leaks in the ground floor slab.

In the analysis of the tenant disturbances, it would appear that the owners had not anticipated the amount of disturbances that were created by the phasing of ongoing renovations around the yard, and received complaints due to unexpected remedial work after refurbishment. The post-occupancy tenant questionnaires provided valuable insight for PSOAS to understand the refurbishment process disturbances. Residents gave feedback on noise and dust from the renovations of adjacent buildings. The need for improved communication with tenants throughout and after the refurbishment process has been demonstrated.

4.1.2 Tenant Education

NCCFI performed post-occupancy resident training in April 2013[18], to explain the principles of indoor climate to tenants, and to give residents advice on saving energy. Based on the experience in this demonstration with post-refurbishment repairs, and experience by NCCFI in resident training there is a need for tenant education and communication at all phases to reduce complaints and disturbances, especially with post-retrofit repairs. Residents tolerate more disturbances and more variations in indoor climate when they understand the reasons. Indoor climate and user comfort are important topics for residents training, to explain different needs, personal preferences and satisfaction (draft, ventilation, surface temperature, humidity, heating and the influence of indoor furnishing). Increasing attention should be given to explain how heat recovery mechanical ventilation works, how to save electricity, how to avoid heat losses, how cooking and hot water use impacts on residents energy use, and why it is important to sort waste and recycle.

4.1.3 Tenant Indoor Comfort and Remedial Work for Air Quality

Indoor comfort in the Oulu demonstration has been evaluated both qualitatively with tenant questionnaires before and after retrofits, and quantitatively with ongoing monitoring of indoor moisture, temperature and carbon dioxide. One of the main drivers for the extensive indoor refurbishments had originally been tenants’ complaints about cold drafts from outside and dampness and cold in the bathrooms.

Some months after the building was occupied there were complaints in summer 2013 from tenants of musty smells in the ground floor apartments. Indoor air tests were performed, microbes were detected in the air which emanated from the ground fill under the ground floor slab, and the need for repairs to cracks and structural joints in the new ground floor slab was verified. The air leak tests and thermal survey performed in February 2013 had indicated a risk or air leaks, and in hindsight these air leaks should have been immediately repaired, prior to occupancy. Four ground floor apartments were vacated for repairs from November 2013 until March 2014, when the apartments' indoor air was again tested and found compliant with health standards. This highlights the diagnostic value of building physics tests as a predictive tool in occupant satisfaction.

Once the building had been occupied it became a significant disturbance to perform remedial action, replace floor surfaces and improve airtightness. This aspect of building envelope performance and indoor air quality does not show in energy monitoring alone, and would be a useful subject of future research, since it is a risk factor in refurbishment. Durable and robust connections are required in the combination of new and old structural components. The new mechanical ventilation installations could potentially make air-infiltration worse with under-pressure indoors, which means a greater risk of vulnerability in refurbishments with improved air tightness and retrofitted mechanical ventilation. High performance controlled ventilation systems display greater sensitivity to disturbances in airtightness.

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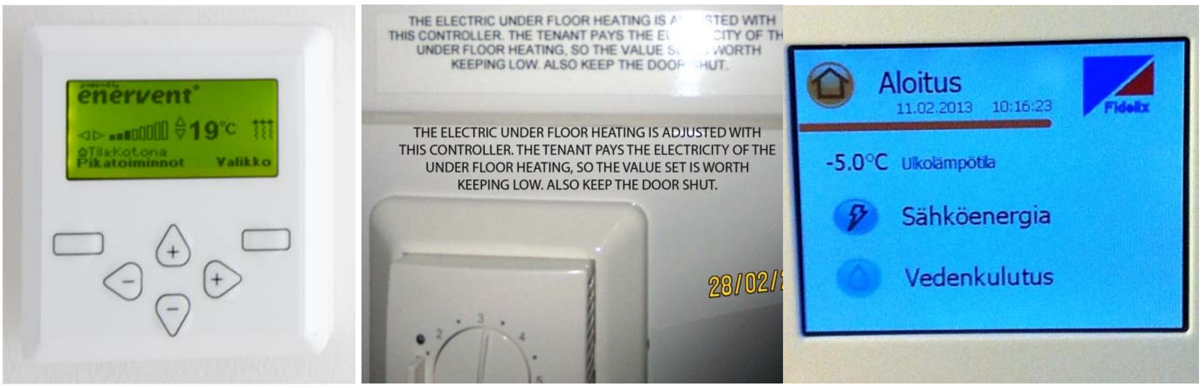
[18] NCCFI Project Development Manager Ilkka Alvoittu was interviewed at NCC Helsinki on 14.10.2013 by Simon le Roux for E2ReBuild Task 5.2.

4.2 Monitoring the Demonstration

4.2.1 End User Behavior

Monitoring of tenant electricity and hot water use patterns provided some surprises, since the real use of domestic hot water is substantially less than predicted in standardized energy calculations. This may be due to water saving shower fixtures, or due to uncertainty in hot water energy monitoring, which is based on automated calculations of water flow and temperatures. The first two months of hot water measurements produced extremely unreliable data, and a future follow-up and data verification in the hot water energy use would be recommended. The use of electrical underfloor heating, private saunas, and electrical air heating the high efficiency heat recovery ventilation units has resulted in ongoing debate within the demonstration project, since there is a trade-off between improved user comfort and standardized HVAC installations. In such a cold climate as in northern Finland the seasonal temperature extremes may result in peaks in electrical heating consumption, but the cost of sophisticated alternative low temperature heating systems and installations of renewables to reduce energy peak demand were considered too great an investment for this demonstration project.[19]

In the Oulu demonstration end user behavior has been monitored with energy monitoring in each apartment, with detailed monitoring of all ventilation units, and the provision of an electricity, water and weather display in each apartment. Despite the access to information about energy use, the analysis of household energy showed significant variations between apartments and mechanical ventilation units, and there is no measured data on the actual electrical use of underfloor comfort heating in bathrooms. Tenants have access to many settings to adjust appliances, heating and ventilation, and overall, these systems should be robust, fool-proof and easy to use and understand. Future surveys of end user questionnaires should ask specific questions about the usability of electricity displays, since there has not been tenant feedback on these displays. It should be noted that ongoing refurbishment and site work affected the consistency of energy data collection, and that the first year of monitoring is just the start. It should be stressed, that there is a real need to perform ongoing monitoring for the next few years, if the full benefit of this E2ReBuild demonstration project is to be realized.



THE ELECTRIC UNDER FLOOR HEATING IS ADJUSTED WITH THIS CONTROLLER. THE TENANT PAYS THE ELECTRICITY OF THE UNDER FLOOR HEATING, SO THE VALUE SET IS WORTH KEEPING LOW. ALSO KEEP THE DOOR SHUT.

Figure 19: Tenants may adjust ventilation settings, control underfloor heating, and follow their electricity and water use. Radiators can be adjusted. The use of the cooker extractor fan automatically reduces the ventilation unit fan power, to balance the apartment air pressure.

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[19] Based on discussions between PSOAS, NCCFI and Aalto during development of energy strategy

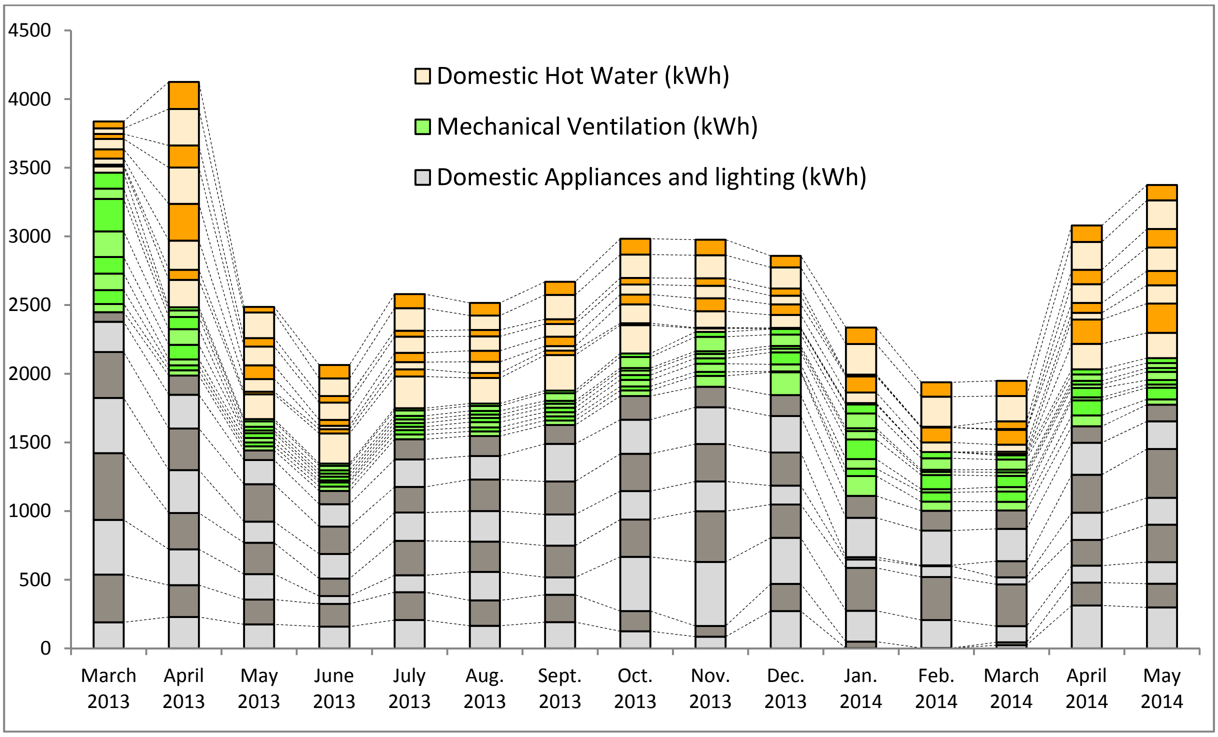

Figure 20: Monthly breakdown of household energy use for domestic hot water, ventilation and household electricity including lighting and appliances such as cooking and saunas, as well as underfloor heating. The figure shows the overall fluctuations in domestic energy use, and the effect of disturbances in regular behaviour (S. le Roux 2014)

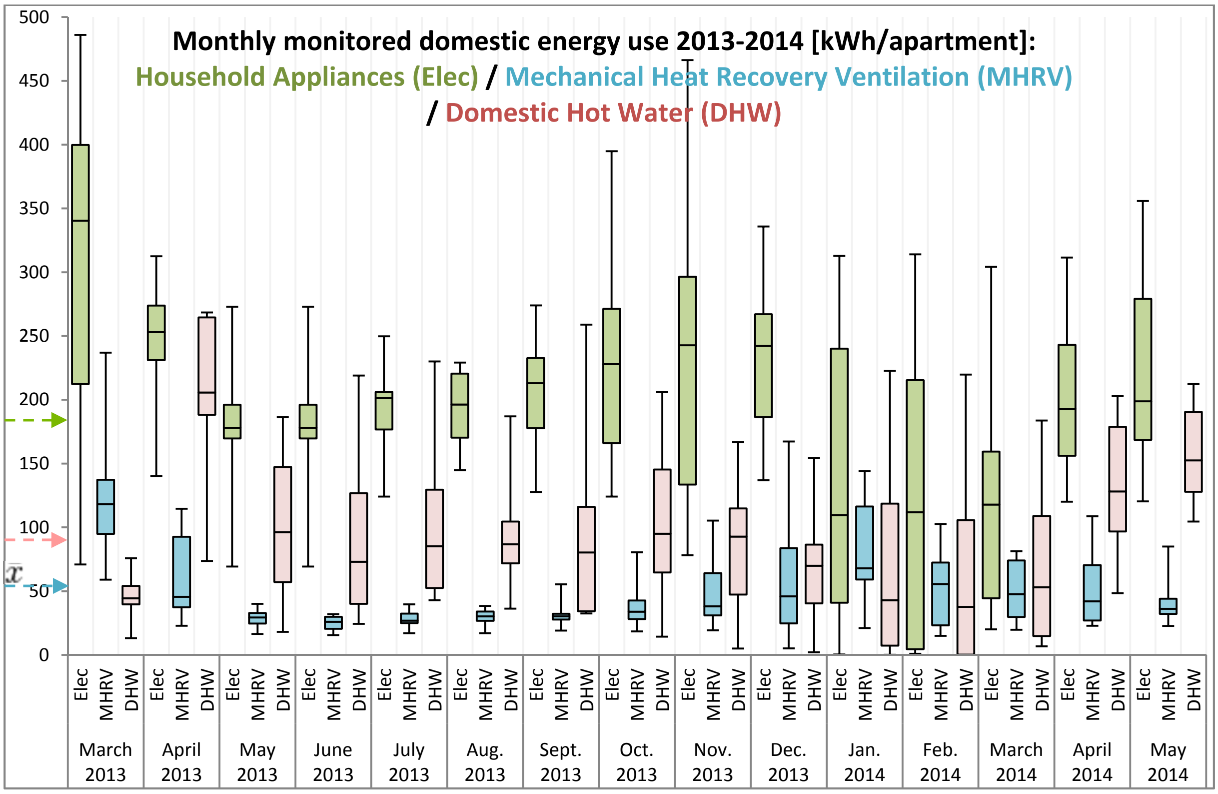

Figure 21: Monitoring of eight individual apartments revealed variations in energy behaviour. Maximum and minimum values, upper and lower quartiles, and median values are plotted for each parameter. For the monitoring period the average monthly household appliance electrical use was 185 kWh, average monthly domestic hot water energy 91 kWh, and average monthly electricity use for mechanical heat recovery ventilation units was 56 kWh (indicted by arrows on left). Some monitoring values were abnormal after occupancy of the building in March – April 2013, and disturbed by remedial works in January – March 2014. This supports a need to continue monitoring for several years to obtain reliable data trends. (S. le Roux, 2014)

4.2.2 Monitoring User Interfaces and Visualization of Results

The E2ReBuild project focused more on the specification and parameters of monitoring equipment, but less on the need for graphic user interfaces and visualization of energy performance, for the generation of monitoring reports and the verification of data. Hourly data collection produces a great volume of complex data, and requires an increasingly sophisticated development of tools to make use of the database. Monthly data is easier to visualize and report and compare, but more detailed monitoring requires future work to improve the online monitoring interface. The Oulu demonstration revealed a need to measure heat loss in the on-site distribution of district heating to assess its significance and to improve its prediction, to assess the return on additional insulation costs for this relatively low cost form of heating energy. Additionally it should be recommended to monitor the electrical energy use in underfloor comfort heating in bathrooms, since the heating has clear functional benefits reducing moisture, but the actual energy performance was not measured.

4.2.3 Collection of Climate Data

Outdoor climate data provides the essential benchmark for the evaluation and verification of energy performance and building physics. In this project the monitoring of outdoor climate data was performed with an onsite weather station, and with temperature, relative humidity and luminance sensors. Due to procedural difficulties collecting large amounts of reliable hourly weather data, it was also necessary to collect open data from the Finnish Meteorological Institute to verify the demonstration weather data. The automated collection of open weather data from a nearby weather station should be included in future monitoring schemes, but does require some knowledge of machine code to automate the data collection. European requirements for open data have now made it possible to access meteorological data in Finland since 2013, and this is a valuable data source.

4.2.4 Facade Monitoring Results

On the basis of the first year of monitoring temperature and relative humidity in the TES facades, and in comparison with the data collection in other demonstration projects, the hard-wired sensors used in the Oulu demonstration would seem to perform more reliably than wireless sensors. Data collected from the first year of monitoring validated the simulated building envelope performance in a WUFI building physics hygrothermal analysis, which was made in a comparison of the building physics of TES facades from the two E2ReBuild demonstration projects in Oulu and Munich.[20] Based on this experience which verifies the reliability of building physics simulations, it would be a useful research topic to simulated alternative compositions of the TES facade materials, and check them with different structural cores. For example, it would be useful to test the impact on building physics if one decided *not* to remove the existing outer layer from a building made with sandwich elements. The savings in demolition labour and the improvement of worker occupational safety would be significant if the existing precast structure could be left untouched, but the building physics of these additional construction layers would need to be simulated.

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[20] Capener C-M, Burke S., Ott S., le Roux S., 2014. Hygrothermal Performance of TES Energy Façade at two European residential building demonstrations – Comparison between Field Measurements and Simulations, NSB 2014, 10th Nordic Symposium on Building Physics

4.3 Overall Energy Monitoring Results

The aim for the refurbishment was passive house level of energy efficiency according to local suggestion by VTT. These targets have been verified comparing available data from the past eight years, existing energy certificated, IDA-ICE dynamic simulation results, and measured data from the first 14 months of E2ReBuild monitoring.

Comprehensive monitoring was used to verify energy results, performance of timber structures and interior air quality. These results have been used to support ongoing research and dissemination work and results from work packages WP3 and WP5.

Monitoring has proved a useful means to follow energy use and secure the functionality of building service systems. The availability of accurate data has been useful for both ongoing property management, and for the development of improved refurbishment practices.

The first two months showed unreliable measures for the monitoring of hot water, but since then results have stabilized. The monitoring subcontractor has supported the development of accurate and innovative methodology for measurement equipment, building automation and reporting of data.

The average water usage is less than assumed in regulations. This represents the worst case scenario, but does prompt building owners to install water saving fixtures for cost effective energy savings.

The monitoring scheme has been an efficient approach to verify results of ambitious refurbishment project. Without the monitoring data, the refurbishment targets would have been impossible to verify, and even so, there is still scope for improvement in monitoring system losses, property electricity, and significant household electrical appliances such as ovens, comfort underfloor heating and saunas.

PARAMETER	BEFORE	DESIGN PHASE	MONITORED 2014
Space heating	Certificate 2012 **81,4** kWh / (m^2 a)	Dynamic Simulation **26** kWh/m^2/a	Measured **36,6** kWh/m^2/a
Domestic Hot Water	Certificate 2012 **19,3** kWh/m^2/a	*Default assumption** **37** kWh/m^2/a	Measured **10,8** kWh/m^2/a
Heat loss in heating transfer 42m pipes	*Default assumption** **22** kWh/m^2/a	Calculation **12** kWh/m^2/a	*Excluded in E2ReBuild D5.1guidelines*
Total District Heat	Certificate 2012 **122,7** kWh/m^2/a	Dynamic Simulation **75** kWh/m^2/a	Measured **47,4** kWh/m^2/a
Building electricity	Average **16** kWh/m^2/a (exhaust ventilation only)	Simulated 2013 **5** kWh/m^2/a	Simulated 2014 **7,6** kWh/m^2/a
Residents ventilation		Simulated **6** kWh/m^2/a	Apartment Submeter **5,5** kWh/m^2/a
Residents lighting and appliance electricity	(Not known)	Simulated **15** kWh/m^2/a	Apartment Meter **22,7** kWh/m^2/a
Residents bathroom electrical floor heating	(None)	Simulated **9 - 12** kWh/m^2/a	

Figure 22: Comparison of existing, simulated and monitored energy in kWh/m^2 *Gross Floor Area*. “Before” figures are based on the Energy Certificate from 2012. Purchased district heat ranged from 150 to 110 kWh/m2a before retrofit, depending on winter weather and hot water use. Improvements had been made to the heating distribution centre (2006) and to water saving appliances (2009). ** Default assumptions given for domestic hot water and heat loss in Finnish regulations (RakMK D3).*

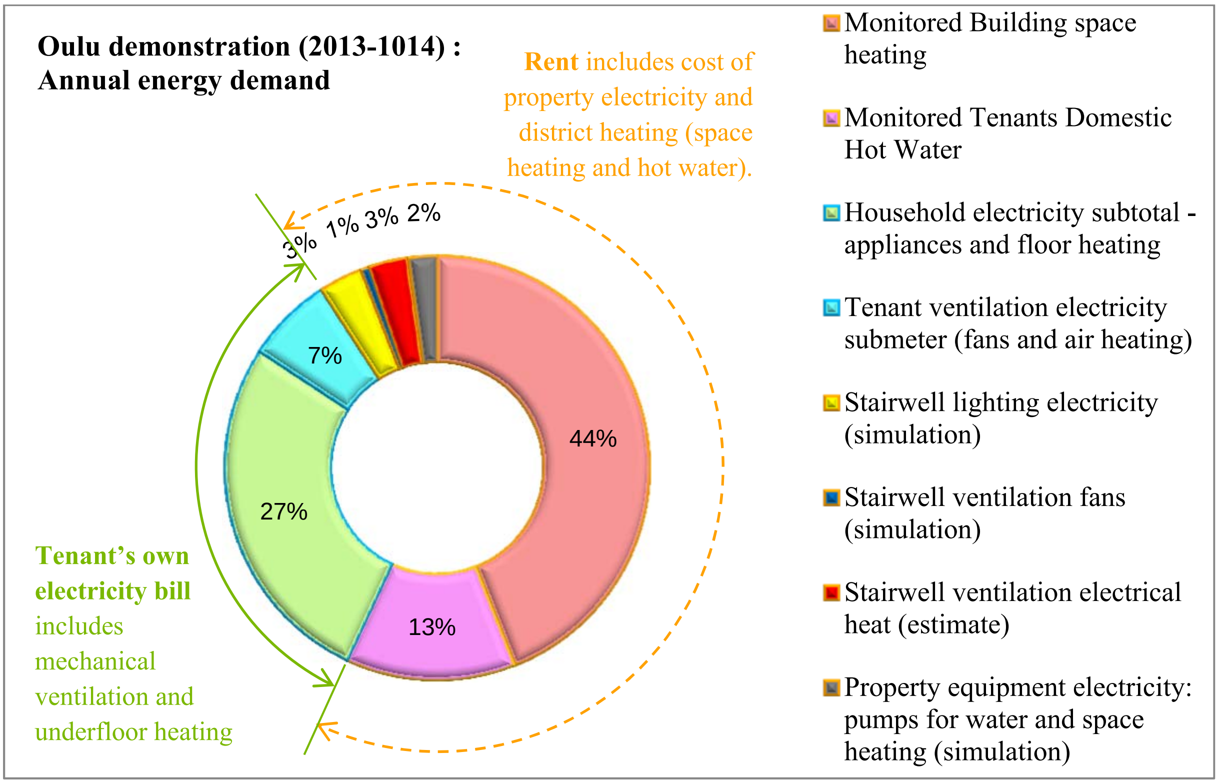

Figure 23: Distribution of monitored energy use, including tenants and owners, electricity and district heat (S. le Roux 2014). Tenants pay for 38% of the total energy consumption in private electricity contracts. As much as half of the tenants' electricity is used for mechanical ventilation and for underfloor comfort heating in bathrooms. The owner pays for district heating, hot water, and property electricity. Monthly fluctuations in heating costs use are not passed to residents.

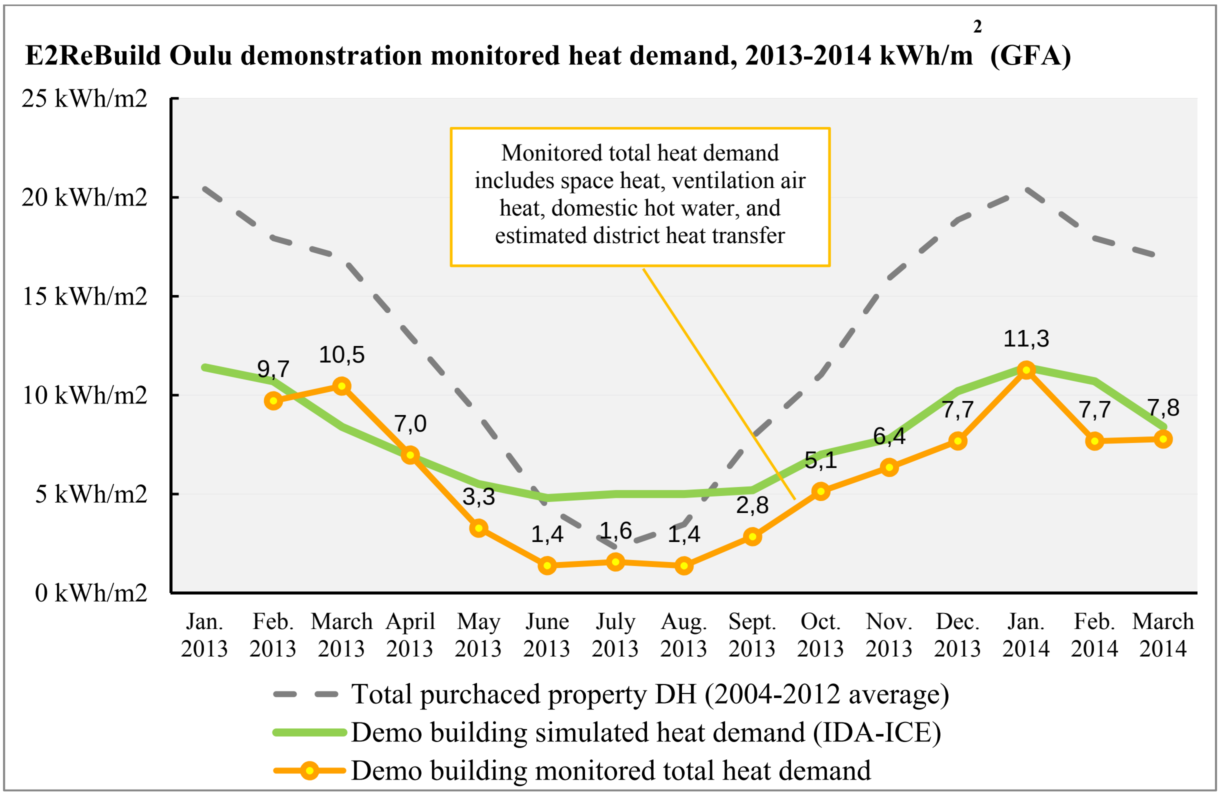

Figure 24: Comparison of Oulu demonstration monthly energy monitoring results prior to refurbishment, as simulated in the design phase, and during the monitoring period from February 2013 to March 2014. (S. le Roux 2014). The improvement compared to the last 8 year average purchased district heat is significant. Overall the measured performance is consistent with the curve of the simulated performance. The simulated performance overestimates domestic hot water in summer months.

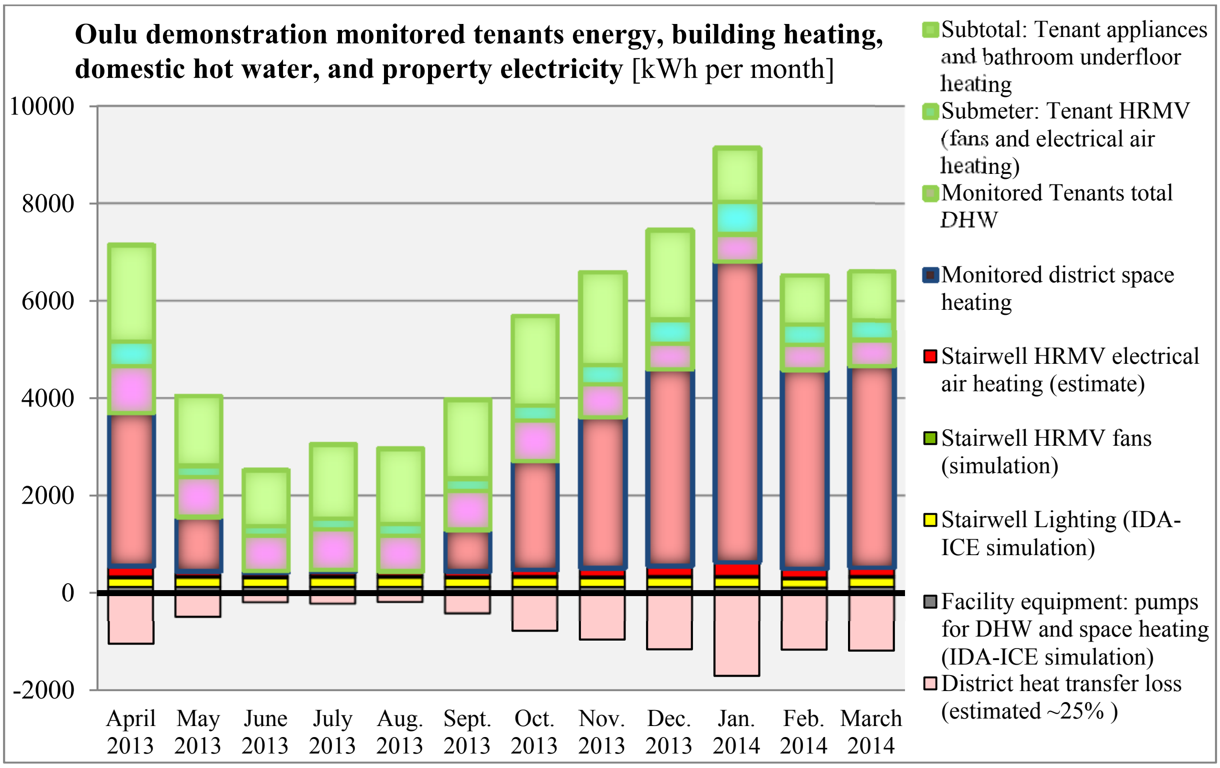

Figure 25: Detailed monthly breakdown of E2ReBuild monitored energy results of the Oulu demonstration. (S. le Roux 2014). D5.1 defines the monitoring system boundary as the building envelope, therefore excluding the district heat transfer loss from the service building to the demonstration building. Heat loss was calculated from available data, and is included for consideration in replication. Heating monitoring shows how weather fluctuations affect real time performance, especially in January 2014, when outdoor temperatures were between minus 15°C and 20°C for four weeks (9.1.2014 to 4.2.2014).

4.3.1 Verification of Energy Targets

In terms of the original E2ReBuild targets for energy efficiency to reduce space heating by 75%, and reduce the annual purchased energy to 30-50 kWh/m2 for space heat, heat losses, underfloor heating, ventilation heat, DHW, fans, and pumps from heat exchange, the Oulu demonstration has not been able to meet these ambitious targets. Space heating demand has been significantly reduced, with simulated energy demand for space heat down to passive house requirements. However the first year of space heating has not met this target in practice. This illustrates the exposure of cold Nordic climates to varying temperature extremes in winter, and the financial limits to extremely well insulated buildings. Additionally, the point of departure in Oulu was a building made to 1985 Finnish building regulations, which as a starting point is already a well-insulated building by central European standards. The future challenge will be to reduce tenant use of electricity, since standard solutions to building technical services improve the quality of life and indoor comfort, but with an increase in electrical installations.

The design target levels for energy efficiency in the Oulu demonstration were based on the Finnish VTT passive house recommendation for northern Finland[21]: According to this definition, the target for the calculated space heating demand is below **30 kWh/m2 y (*Gross floor area*)**, which has been verified in the Oulu demonstration by IDA-ICE dynamic simulation as **26 kWh/m2 y** (*Gross floor area*).

The passive house target for air tightness **n50 ≤ 0,6 1/h** was not quite met, and was measured in 2013 to be **0,8 l/h**. This value is however sufficient to meet airtightness requirements for the EnerPHit

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[21] Nieminen J., Lylykangas K. 2009. "Passiivitalon määritelmä. Ohjeita passiivitalon arkkitehti-suunnitteluun", www.passiivi.info (accessed 20.05.2013)

Certificate for Energy Retrofits with Passive house Components. Remedial work to reduce ground floor air leaks was done in four apartments in 2014, and the final air tightness should again be verified by blower door tests. The measured airtightness does represent a significant improvement over the 3,3 l/h measured in 2012 before refurbishment commenced.

The assessment of the target for total Primary Energy Demand of **130 - 140 kWh/m^2** depends on the definitions used for energy carrier coefficients, and measurements of floor area. Using national carrier coefficients from the calculation methodology of the energy audit in accordance with the National Building Code of Finland, the total primary energy is **118 kWh/m2/a** (Net Floor Area) based on monitored data, including purchased space heating, domestic hot water, auxiliary electricity and household electricity. Using the gross floor area is normal practice in Finland, and the result is then even better: **101 kWh/m2/a** (*Gross Floor Area*). Based on the IDA-ICE energy simulation results, the total primary energy is **127 kWh/m2/a** (NFA). This is due to high assumptions for the use of domestic hot water. However, the calculation according to primary energy conversion factors according to EN 15603 gives a completely different story, with a total primary energy of **243 kWh/m2/a** (NFA) after retrofit. This is due to much higher energy carrier coefficients for district heat and electricity. Since the original target for primary energy was based on the Finnish assumptions, it may be concluded that the Oulu demonstration did meet the target for total primary energy, and this is consistent with the Finnish energy certificate calculated in 2013 with an ET value of 90, and an "A" class energy certificate.

The inconsistencies in standardized calculation methodologies has been discussed in depth in the E2ReBuild report D3.5 "Building Simulations and LCA-data for the Relevant Building Types in Combination with Retrofit Strategies", and this issue has been problematic for the comparison of energy results from the E2ReBuild demonstration projects. As a recommendation for future European demonstration projects, the basis for energy comparisons should be defined and standardized in detail.

	Estimated Energy Demand Before [kWh/m2 NFA]	PE national [kWh/m2 NFA]	PE based on EN 15603 fp [kWh/m2 NFA]	Calculated Energy Demand Afterwards [kWh/m2 NFA]	PE national [kWh/m2 NFA]	PE based on 15603 fp [kWh/m2 NFA]	Measured Energy Demand Afterwards [kWh/m2 NFA]	PE national [kWh/m2 NFA]	PE based on 15603 fp [kWh/m2 NFA]	PE conv. fact. fp [kWh PE / kWH S] national /local	PE conv. fact. fp [kWh PE / kWH S] acc. EN 15603
District Heat: space heating	91	64	119	30	21	39	40	28	53	0,7	1,3
District Heat: DHW	45	31	58	42	30	55	13	9	17	0,7	1,3
Property electricity and ventilation	18	31	60	13	21	42	15	26	50	1,7	3,31
Domestic electricity	26	45	87	27	46	89	26	45	87	1,7	3,31
District Heat loss outside building	17	12	22	14	10	18	14	10	18	0,7	1,3
Total	**198**	**183**	**347**	**126**	**127**	**243**	**83**	**118**	**225**		

Figure 26: Comparison of primary energy results of the Oulu demonstration, based on the calculation template for the E2ReBuild report D3.5 "Building Simulations and LCA-data for the Relevant Building Types in Combination with Retrofit Strategies". (S. le Roux 2014)

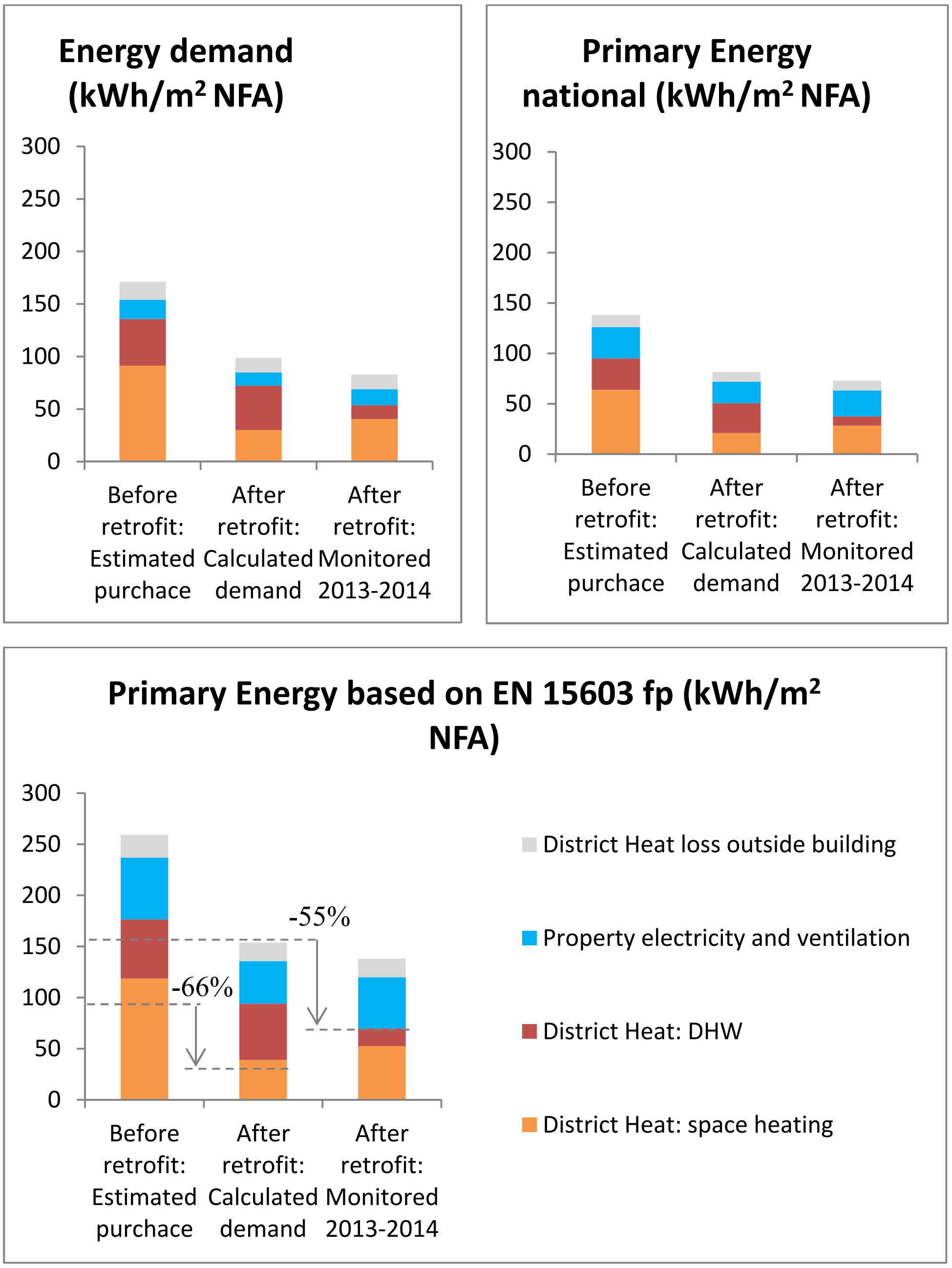

Figure 27: Energy comparison data for E2ReBuild report D3.5[22]: Total property purchased energy consumption has more than halved. Purchased district heat has dropped by 60%. The simulated space heating demand had dropped 66%, but the first year monitored space heating was only 55% less than before retrofit. The use of domestic hot water has been significantly less than anticipated. The use of property electricity has only dropped about 15% after retrofit, and this diminishes the overall drop in primary energy, due to the high weighting factors for purchased electricity. However, the property electricity now provides high efficiency controlled ventilation to a higher comfort standard. System losses in district heat transfer are noted, but not monitored. (Figures supplied by K. Flodberg with report update by S. le Roux)

4.4 Exploitation of Results

There is potential for spin-offs from the Oulu demonstration with ongoing work in advanced building monitoring, building physics, and replication of TES facades applied to the industrialized retrofit of prefabricated precast concrete structures.

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[22] Flodberg K. et al. E2ReBuild report D3.5 “Building Simulations and LCA-data for the Relevant Building Types in Combination with Retrofit Strategies”

The demonstration was in itself an exercise in business integration for NCCFI to gain experience in the specialized field of deep refurbishments, and for PSOAS to improve their tenant relations, and upgrade their property management skills with energy monitoring tools.

The PSOAS database for monitoring data from the Oulu demonstration project will retain 5 years of data, and the first year of data has been downloaded and formatted by Aalto University for dissemination via the E2reBuild project and Work Package 5.

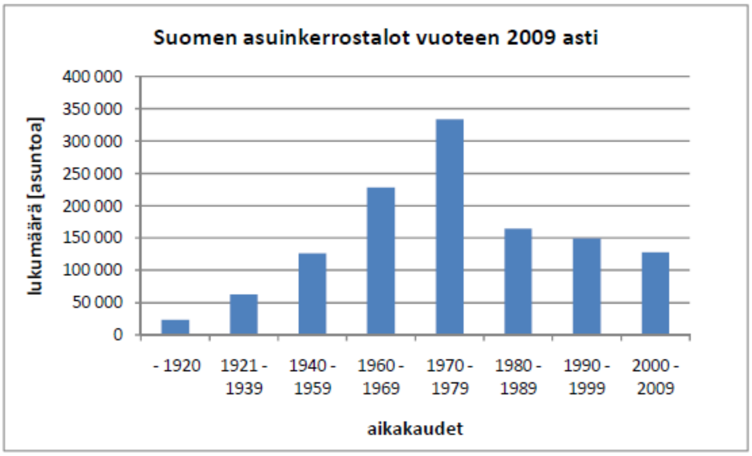
4.4.1 Dissemination and Education

The E2ReBuild visibility of work has been maintained through continuous education, conference papers, posters and presentations by Aalto, and through the PSOAS and E2ReBuild website. All dissemination activity was documented and reported through E2ReBuild.

The demonstration project provided opportunities for research and post-graduate education into the application of energy efficient refurbishment in cold climates. Student works and continuing education has been undertaken in the fields of on energy efficient building physics and building condition survey, industrialized timber technology, energy monitoring, building automation and programming, and on the certified competency training for Passivhaus under the guidance of consortium partners (NCC Finland and Aalto University) and in collaboration with the demonstration project designers M3 Architects, technical educational institutions in Oulu, and the building authorities of City of Oulu.

4.5 Replication Potential

The typology of the Oulu demonstration object may be seen in other building typical of the era (1946-1979), up to the mid 1980's, which represent the bulk of Finnish industrialized housing production from the post-war era. The first TES retrofit in Riihimäki[23] in Finland was a similar building type, and similar buildings have been proposed for future retrofits (e.g. Siltamäki housing area in Helsinki). It has been calculated that there are a total of 44 million m^2 of concrete facades in Finland, and of the 30000 apartment buildings built in 1965 – 1995, the majority is built with prefabricated facades and balconies. The repair costs of these facades were estimated in 2000 to be 125 million euro annually.[24]



Kuva 1.3. *Asuntorakentaminen Suomessa eri aikakausina [Tilastokeskus, 2010]*

Figure 28: Apartments in multi-storey apartment buildings built in Finland until 2010 (Statistics Finland, 2010) [25]

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[23] Riihimäki TES Retrofit: PAROC Innova – Project http://parocfi.virtual35.nebula.fi/innova/

[24] Arto Köliö - Diplomityö, Tampereen Teknillinen Korkeakoulu, 2011: BETONILÄHIÖIDEN JULKISIVUJEN TEKNINEN KORJAUSTARVE: PDF http://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/7105/kolio.pdf?sequence=3

[25] Finnish statistics on housing: http://www.stat.fi/til/asas/2010/01/asas_2010_01_2011-10-20_kat_002_fi.html

Figure 29: Riihimäki Innova project before TES retrofit, during facade assembly, and completed (S. le Roux 2011-2012)

Figure 30:Oulu demonstration project in 2011, TES assembly phase in 2012, and completed in 2013 (photos M3 Architects)

The Oulu demonstration was a good practical example of energy efficient refurbishment and buildings adapted for today's needs in cold climates. Detailed monitoring provided insight for research, and will allow construction practice to improve the design of retrofit facades through building physics analysis. Learning from empirical evidence of construction process has been documents, and analysis has been made of the cost structure and potential to optimize benefits and added value. Lessons from this building have been already used on the four neighboring houses owned by PSOAS.

Through this demonstration, it has been made possible to identify strengths and weaknesses in similar refurbishment strategies. The replication potential is to be exploited for the future retrofit of prefabricated concrete element housing in post 1960's Finland.

> Compared with the rest of the Europe, the Finnish thermal resistance requirements for new buildings have been notably stricter for quite some time. Because the Finnish building stock is relatively young, energy performance has been taken into account when the current buildings were built./…/ The amount of energy consumed in buildings is highly influenced by Finland's northerly location, and because of this, measures aiming at decreasing the amount of energy needed for heating are usually cost-effective.[26]

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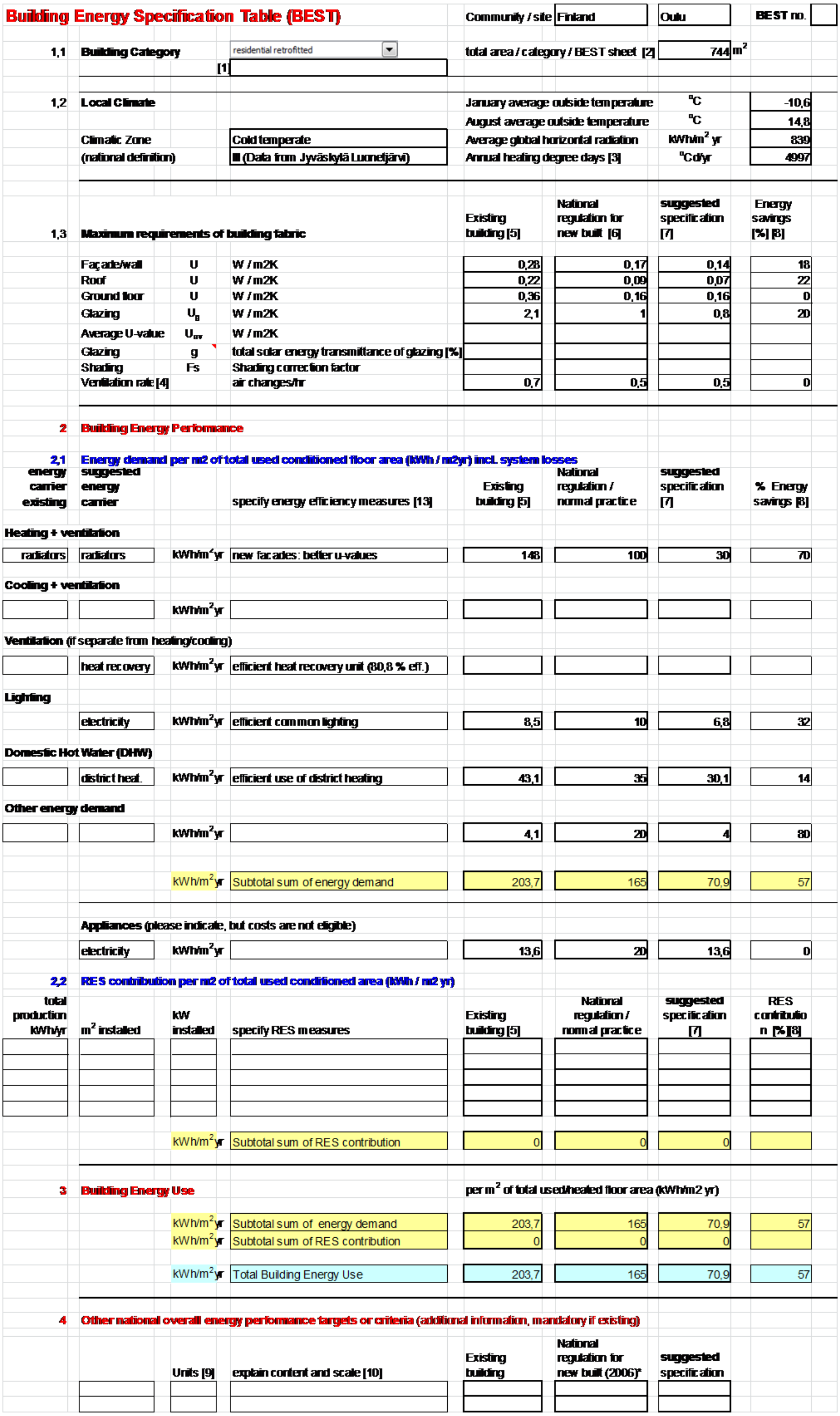
[26] Kauppinen J., 2013. Ministry of the Environment. Decree on Improving the Energy Performance of Buildings undergoing Renovation or Alteration, *Explanatory Memorandum* (unofficial translation), Finland. http://www.ym.fi/download/noname/%7B6E3BE53C-0C24-485B-A6C4-2F6F7D7030B4%7D/57171

Appendix A Original BEST Sheet



Building Energy Specification Table (BEST)

			Community / site	Finland	Oulu	BEST no.	
1,1	Building Category	residential retrofitted	total area / category / BEST sheet [2]	744	m^2		
	[1]						
1,2	Local Climate		January average outside temperature	°C	-10,6		
			August average outside temperature	°C	14,8		
	Climatic Zone	Cold temperate	Average global horizontal radiation	kWh/m^2 yr	839		
	(national definition)	II (Data from Jyväskylä Luonetjärvi)	Annual heating degree days [3]	°Cd/yr	4997		

1,3	Maximum requirements of building fabric			Existing building [5]	National regulation for new built [6]	suggested specification [7]	Energy savings [%] [8]
	Façade/wall	U	W / m2K	0,28	0,17	0,14	18
	Roof	U	W / m2K	0,22	0,09	0,07	22
	Ground floor	U	W / m2K	0,36	0,16	0,16	0
	Glazing	U_g	W / m2K	2,1	1	0,8	20
	Average U-value	U_{av}	W / m2K				
	Glazing	g	total solar energy transmittance of glazing [%]				
	Shading	Fs	Shading correction factor				
	Ventilation rate [4]		air changes/hr	0,7	0,5	0,5	0

2 Building Energy Performance

2,1 Energy demand per m2 of total used conditioned floor area (kWh / m2yr) incl. system losses

energy carrier existing	suggested energy carrier		specify energy efficiency measures [13]	Existing building [5]	National regulation / normal practice	suggested specification [7]	% Energy savings [8]
Heating + ventilation							
radiators	radiators	kWh/m^2yr	new facades: better u-values	148	100	30	70
Cooling + ventilation							
		kWh/m^2yr					
Ventilation (if separate from heating/cooling)							
	heat recovery	kWh/m^2yr	efficient heat recovery unit (80,8 % eff.)				
Lighting							
	electricity	kWh/m^2yr	efficient common lighting	8,5	10	6,8	32
Domestic Hot Water (DHW)							
	district heat.	kWh/m^2yr	efficient use of district heating	43,1	35	30,1	14
Other energy demand							
		kWh/m^2yr		4,1	20	4	80
		kWh/m^2yr	Subtotal sum of energy demand	203,7	165	70,9	57
	Appliances (please indicate, but costs are not eligible)						
	electricity	kWh/m^2yr		13,6	20	13,6	0

2,2 RES contribution per m2 of total used conditioned area (kWh / m2 yr)

total production kWh/yr	m^2 installed	kW installed	specify RES measures	Existing building [5]	National regulation / normal practice	suggested specification [7]	RES contribution [%][8]
		kWh/m^2yr	Subtotal sum of RES contribution	0	0	0	

3 Building Energy Use

per m^2 of total used/heated floor area (kWh/m2 yr)

kWh/m^2yr Subtotal sum of energy demand	203,7	165	70,9	57
kWh/m^2yr Subtotal sum of RES contribution	0	0	0	
kWh/m^2yr Total Building Energy Use	203,7	165	70,9	57

4 Other national overall energy performance targets or criteria (additional information, mandatory if existing)

	Units [9]	explain content and scale [10]	Existing building	National regulation for new built (2006)*	suggested specification

Appendix B Energy Data

Oulu Before

Average 5 similar buildings over the past 8 years

	Energy Demand Before [kWh/m2 NFA]	Source	PE conv. fact. fp [kWh PE / kWh S] national /local	PE national [kWh/m2 NFA]	PE conv. fact. fp [kWh PE / kWh S] acc. EN 15603	PE based on EN 15603 fp [kWh/m2 NFA]
Heating Source 1	80,0	DH	0,7	56	1,3	104
Heating Source 2				0		0
DHW Source 1	39,0	DH	0,7	27	1,3	51
DHW Source 2				0		0
Auxiliary	16,0	Electricity	1,7	27	3,31	53
Losses Source 1	15,0	DH	0,7	11	1,3	20
Losses Source 2				0		0
Total	**150,0**			**121**		**227**
Delivered to the grid	0			0		

Oulu Afterwards

Calculated IDA-ICE Simulation (Optiplan)

	Energy Demand Afterwards [kWh/m2 NFA]	Source	PE conv. fact. fp [kWh PE / kWh S] national /local	PE national [kWh/m2 NFA]	PE conv. fact. fp [kWh PE / kWh S] acc. EN 15603	PE based on 15603 fp [kWh/m2 NFA]
Heating Source 1	31,2	DH	0,7	22	1,3	41
Heating Source 2				0		0
DHW Source 1	42,4	DH	0,7	30	1,3	55
DHW Source 2				0		0
Auxiliary	11,1	Electricity	1,7	19	3,31	37
Losses Source 1	14,0	DH	0,7	10	1,3	18
Losses Source 2				0		0
Total	**98,7**			**80**		**151**
Delivered to the grid						

Conversion factors fp (total) acc. EN 15603:2008* Table E1 - Annex E

Electricity (UCTE Mix)	3,31	[kWh PE / kWh S]
Local-/District heating	1,3	[kWh PE / kWh S]

Reference national conversion factors: Government Decree on energy carrier factors for buildings (9/2013)
Act on Energy Certificates for Buildings (50/2013)
National Building Code of Finland 2012