Hygrothermal Performance of TES Energy Façade at two European residential building demonstrations – Comparison between Field Measurements and Simulations

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SUMMARY:
In this study, the retrofitted facades of two European multi-unit residential buildings built in the 1950's and 1980's are investigated. The demonstration buildings, situated in Munich, Germany and Oulu, Finland, are part of the EU FP7 project E2ReBuild, a European collaboration project, researching and demonstrating industrialised energy efficient retrofitting of residential buildings in cold climates. The demonstration project in Munich, Germany, consisted of two blocks of residential multi-storey buildings in the suburb of Sendling, built in 1954. The buildings were typical examples of the concrete brick constructions, built throughout Germany in the post-war era. The pilot building in Oulu, northern Finland is one of five student apartment buildings in a housing corporation. The building was completed in 1985 according to a Finnish industrialized building system developed in the late 1960's using prefabricated concrete elements for residential buildings, called the "BES system". To improve their energy performance, the retrofit included a façade refurbishment with the TES method utilizing timber based, prefabricated façade elements for the renewal of the building envelope and improved thermal insulation. As part of an advanced monitoring programme, hygrothermal gauges were installed in the walls and they have been monitored for more than one year after the retrofitting. This paper presents the results from the in-situ measurements of the two demonstrations and compares the findings to calculated transient hygrothermal 2D-simulations of the facades utilising the monitored data from the sites in Finland and Germany.

1. Introduction

According to European standards and the EU's energy roadmap, the energy performance of multi-unit residential buildings from the 1950's and later in Europe is poor. External thermal insulation systems are commonly used to improve the thermal performance of such buildings, and for the two selected buildings of the E2ReBuild project the TES-method was chosen for improving the building envelope performance. The TES-system and method utilises timber based and insulated prefabricated façade elements for the renewal of the building envelope and to improve its thermal performance (Lattke 2011, Cronhjort 2014). In this study, the hygrothermal effects caused by the refurbishment are investigated and the TES-system is monitored.

This paper presents the findings from two investigated European multi-unit residential demonstration buildings. The demonstration buildings, situated in Munich, Germany and Oulu, Finland, are part of the EU FP7 project E2ReBuild, a European collaboration project, researching and demonstrating industrialised energy efficient retrofitting of residential buildings in cold climates.

The demonstration project in Munich, Germany, consisted of two blocks of residential multi-storey buildings in the suburb of Sendling, built in 1954. The buildings were typical examples of the concrete brick constructions, built throughout Germany in the post-war era.

The pilot building in Oulu, northern Finland is one of five student apartment buildings in a housing corporation. The building was completed in 1985 according to a Finnish industrialized building system developed in the late 1960's using prefabricated concrete elements for residential buildings, called the "BES system" (Cronhjort 2014).

To improve the buildings’ energy performance, the retrofit included a façade refurbishment with the TES method utilizing timber based, prefabricated façade elements for the renewal of the building envelope and improved thermal insulation. As part of an advanced monitoring programme, hygrothermal gauges were installed in the walls and they have been monitored after the completion of the retrofitting.

This paper presents the results from the in-situ measurements of the two demonstrations and compares the findings to calculated transient hygrothermal 2D-simulations (Künzel 1995, Holm 2000) of the facades utilising the monitored data from the sites in Finland and Germany.

2. Description of the demonstration buildings and field measurements

The FP7 project E2ReBuild includes seven demonstration buildings throughout northern and central Europe and this paper investigates the hygrothermal performance of timber element system (TES) (Lattke 2011) as external thermal insulation method and compares measured hygrothermal performance with simulation results from WUFI 2D models.

In this paper two of these demonstration buildings are presented and monitoring results from their retrofitted north-facing walls are shown.

2.1 Demonstration buildings

2.1.1 Background on Munich demo

The Munich demonstration was built in 1954 and is located in the suburb of Sendling. It consists of two blocks of residential buildings. They are examples of typical concrete block constructions built throughout Germany after World War 2.
(http://www.e2rebuild.eu/en/demos/munich/Sidor/default.aspx)

The heating demand of the building after the retrofit is calculated to be about 21 kWh/m²a. This is about 38 % lower, than the national requirement, EnEV2009. The overall energy demand after the retrofit is equivalent to a primary energy use of 23.5 kWh/m²a. This number is low because it includes a bonus for regenerative energy sources like solar thermal collectors, and a primary energy factor of fp = 0.7 for district heating.

The refurbishment concept includes a significant dismantling of the existing dwellings, built from light weight concrete block walls and concrete ceilings. The building was stripped down to the primary structure and the roof was taken off, see Figure 1, left. Additional changes in floor plan layout and new circulation cause interventions on the interior walls as well as on the window openings. A new attic floor and a roof were added together with an entire new building envelope made from TES Energy Façade elements.

Figure 1: Left: Dismantled structure of Munich demonstration with new elevator shaft (Picture: Lichtblau Architects). Right: Oulu demonstration during assembly of prefabricated TES elements (Picture: Simon Le Roux).

The highly insulated exterior wall with triple glazed windows is the backbone of the building envelope, see Table 1. The heating system is supplied from the district heating grid. On sunny days it is supported by solar thermal panels on the roof with a large accumulator tank containing 20000 litres of water as buffer. Room heating is done by radiators. The apartments have decentralised ventilation units with plate heat exchangers. The highly insulated building envelope, together with a modern and efficient ventilation system with heat recovery, means that the tenants enjoy an energy-efficient apartment with a high level of thermal comfort.

Table 1 Facts about thermal performance of envelope and building services, Munich demonstration.

	before	after
Exterior walls and roof	1.8 W/m^{2}K	0.15 W/m^{2}K
Windows	2.5 W/m^{2}K	0.9 W/m^{2}K
Basement ceiling	1.55 W/m^{2}a	0.45 W/m^{2}K
Heating energy (calculated)	280 kWh/m^{2}a	21.2 kWh/m^{2}a
Primary energy (calculated)	343 kWh/m^{2}a	23.5 kWh/m^{2}a

2.1.2 Background on Oulu demo

The E2ReBuild demo building in Oulu, northern Finland is one of five student apartment buildings in a housing corporation.

(http://www.e2rebuild.eu/en/demos/oulu/Sidor/default.aspx)

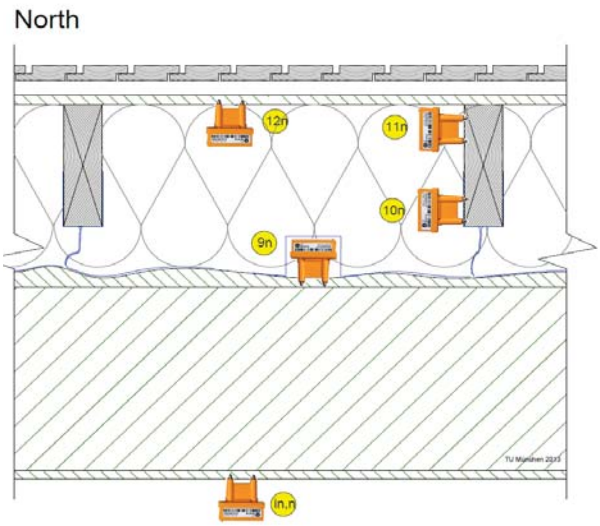
The Finnish demonstration building underwent a complete retrofitting of the envelope, see Table 12. The old façade layers of the previous BES-systems were removed leaving only the inner concrete layer in place. A new façade was retrofitted using prefabricated timber based elements, see Figure 1, right. The old roof was replaced completely by a new timber truss roof and a new thermal insulation layer of 550 mm resulting in a U-value of 0.08 W/m2K. ISOVER blown loose fill mineral wool, λ=0.041 W/mK. The existing ground floor slab was replaced, with a new in-situ concrete ground floor slab with 200 mm BASF Neopor EPS insulation.

Table 2 Facts about thermal performance of building envelope, Oulu demonstration.

	before	After
Exterior walls and roof	0.28 W/m^{2}K	0.11 W/m^{2}K
Windows	2.1 W/m^{2}K	0.8 W/m^{2}K
Ground slab	0.24/0.36 W/m^{2}a	0.11/0.15 W/m^{2}K
Roof	0.22 W/m^{2}a	0.08 W/m^{2}a

2.2 On-site hygrothermal monitoring of the facades

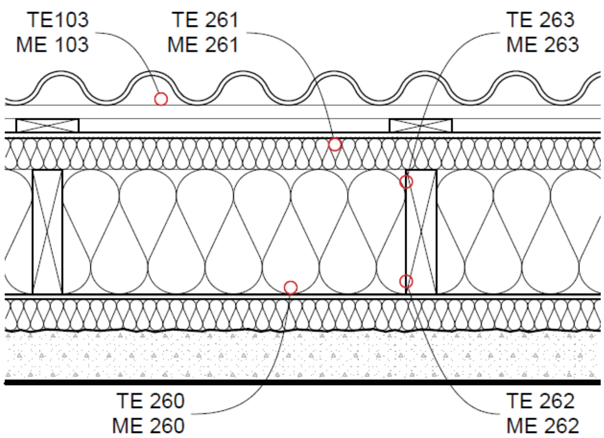
Part of this project includes an analysis of the TES Energy Façade elements with regards to hygrothermal performance, or the temperatures and moisture performance of the exterior wall. Figure 2 shows where each of the GE HygroTrac sensors was placed in the north façade of the Munich demonstration.



- wood shuttering formwork 24 mm
- air layer / lathing horizontal 24 mm
- gypsum fibre board 15 mm
- construction wood / cellulose 200 mm
- adaption layer – cellulose 60 mm
- membrane, Sd-value = 5 m
- exist. plaster, lime-cement plaster 25 mm
- existing exterior wall, light-weight concrete building blocks 300 mm
- exist. plaster, lime-cement plaster 15 mm

Figure 2: Monitoring positions of the presented Munich TES Façade element.

For the Oulu demonstration in Finland there was a similar set up of monitoring positions of the facades, as shown in Figure 3. Also facing north, the retrofitted wall construction consisted of:



TES façade element description: US10YK
Declared U-value of the finished wall is 0.11 W/m^{2}K

- 7mm corrugated fibre cement cladding
- 44 mm air gap
- 22 + 22x100mm timber battens
- 9mm gypsum wind barrier
- 50 + 200mm glass mineral wool slab (Lambda 0,033 W/mK)
- 42x48mm c600mm horizontal timber battens
- 42x198mm c600mm timber load bearing frame
- 9 mm plywood board
- 50 mm soft thermal insulation
- 80mm existing precast concrete

Figure 3: Monitoring positions of the presented Oulu TES Façade element.

2.2.1 Measured data

For the Munich demo temperature, RH, and moisture content were measured at the measurement points shown in Figure 3 between 2012 and 2013. This data was measured every hour and was uploaded to GE's homepage where it could be monitored and downloaded. The sensors are wireless and had difficulties in sending their data every hour during the measurement period so a number of data points are missing. The sensors have also stopped recording data between February and April, 2013.

The data has been downloaded and sorted to match the times from the WUFI calculations for comparison purposes.

Similarly, for the Oulu demo, temperature and relative humidity is monitored at the measurement points shown in Figure 3 since February 2013.

3. Hygrothermal modelling and simulation

The hygrothermal behaviour of the demonstration buildings facades has been modelled by the two-dimensional hygrothermal building envelope tool WUFI 2D 3.3. The software has been experimentally verified for many types of building component assemblies (Künzel 1995, Karagiozis 2001) and similar set-ups (Holm 2000, Tariku 2006).

Material data and initial moisture conditions were supplied from material databases such as MASEA Datenbank (Materialdatensammlung für die energetische Altbausanierung) and the IBP Fraunhofer Material Database. As the buildings are between 30 to 60 years old, the German demonstration originates from the early 1950-ies, there is some lack of precise historic material data and appropriate assumptions had to be made.

3.1 Munich demonstration

WUFI 2D simulations were done using the drawing shown in Figure 2 together with measured climate data during the period of January 1, 2012 to October 28, 2013. Material properties were mostly taken from the Default materials database in WUFI.

The specific material in the existing wall is unknown with unknown thermal and moisture properties. It is known that the material is a type of Leca block with aerated aggregate. The real lambda value of the old wall was calculated using the measured indoor temperatures, temperatures in the adaption layer and temperatures in the exterior part of the mineral wool. These calculations showed that the lambda value of the old wall in reality is between 0.09 and 0.12 W/mK, which is similar to the thermal properties of the default materials Light Expanded Clay Aggregate and Aerated concrete. The default material's lambda value in WUFI 2D was modified to the measured value for the actual wall. Other thermal and moisture properties were obtained based on a report from an on-line database U-wert (www.u-wert.net). The default moisture properties for Light Expanded Clay Aggregate were used in the calculation since the actual moisture properties of the existing wall are unknown. At the beginning of the calculation, the initial moisture levels of all materials were set to about 80 % RH, based on measured values.

3.2 Oulu demonstration

For the Finnish demonstration the WUFI 2D simulations were set-up according to the drawing shown in Figure 3 together with measured climate data for the period of March 2013 to March 2014. An initial relative humidity throughout the existing construction of 60 % was assumed since this was an old construction and should not contain any excess moisture and a modest ventilation rate in the air gap behind the cladding of 5 air changes per hour (5 ACH) was selected.

4. Results

Both the Munich and Oulu simulated results agree quite well with the measured results in the new wall. The temperatures correlate very well with the measured results. The moisture levels also correlate very well, however the measured data shows much more variation in moisture levels than the simulated data.

4.1 Munich

The measured data indicates that the moisture measurement points are in a mineral wool layer. The simulated results are also taken from mineral wool. It is interesting to see that even though they are the same points, the calculations show a much more stable moisture level in the wall than in reality.

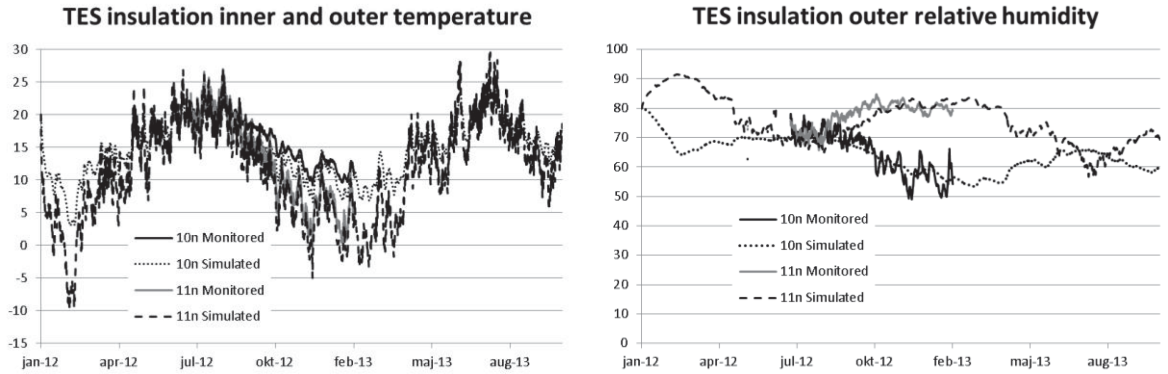


Figure 4: Temperature and relative humidity for the Munich TES Façade elements insulation, inner (10n) and outer (11n) locations.

The moisture levels in the exterior of the wall correlate well however, the calculated moisture level in the middle of the wall (point 9n in Figure 2) does not match the measured values. Further calculations seem to indicate that the plastic may be punctured at the sensor. If we calculate the moisture levels of the wall with the vapour barrier (SD 5m), the moisture level at the interior of the vapour barrier is both more stable and much higher than calculated, while the remaining moisture levels show very good correlation between measured and calculated values. If we lower the SD value of the vapour barrier to that of a weather barrier (SD = 0,1m) the simulated moisture values at point 9n agree with the measured data, however all the other measurement points have more error than simulations with the vapour barrier. This seems to indicate that measurement point 9n is affected by the exterior climate more than it should be if the vapour barrier was complete.

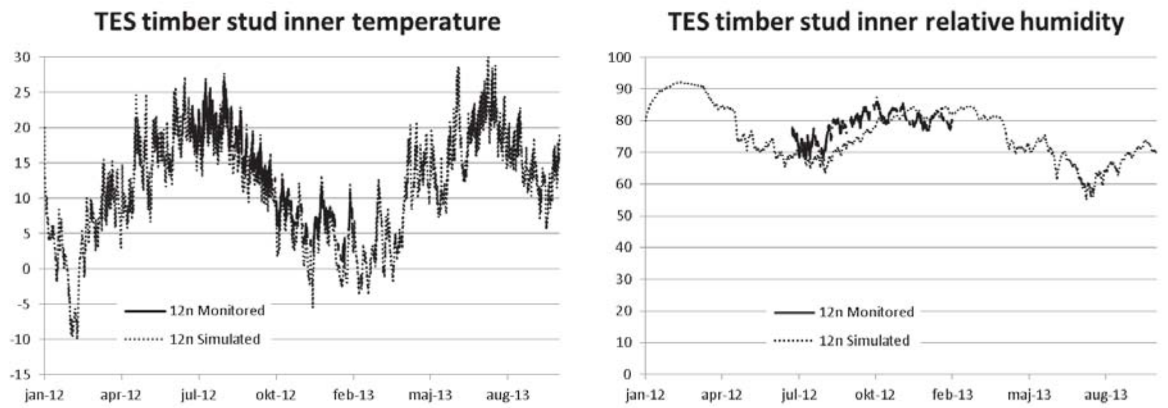


Figure 5: Temperature and relative humidity for the Munich TES Façade elements timber stud (12n).

In both the calculated and measured results, there does not appear to be a significant moisture risk associated with TES Energy Façade in Munich over the long term. The trend that can be seen in the WUFI calculation is that the construction dries out over time.

4.2 Oulu

The measured results correlate well with the simulated figures. It is clear that the initial moisture level has a great influence on the simulated values, the relative humidity is too low for the outer part of the wooden studs but for the inner part the simulation is well in accordance with the monitored result. After some months however, the levels are very close to the measured values, as the monitored wall gets drier. Also, the ventilation rates seem to have an influence, at least for the outer parts of the simulated wall. The low, 5 ACH, ventilation rate give accurate readings during many periods, but often seem to be underestimated as larger fluctuations can be seen in the relative humidity on the inside of the outdoor gypsum board. Another possible reason for the fluctuations can indicate insufficient air tightness over the wind barrier, causing larger fluctuations in the monitored results of the insulation compared to the simulated results.

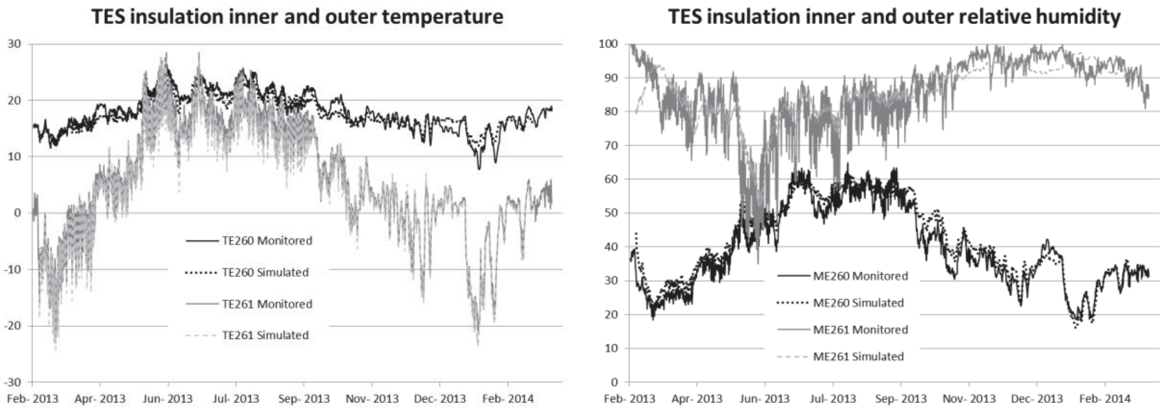


Figure 6: Temperature and relative humidity for the Oulu TES Façade elements insulation, inner (TE/ME260) and outer (TE/ME261) locations.

It is clear that the extra insulation placed outside the wooden studs has a beneficial influence on the temperature and relative humidity of the studs. Comparing the relative humidity for the monitoring position of the TES outer insulation (ME261) to the relative humidity at the TES outer part of the timber studs (ME263), clearly shows the reduction in relative humidity. Not only does the insulation break the thermal bridge, it also raises the temperature of the studs outer parts compared to a case without extra insulation, and this gives lower relative humidity and risk of moisture damage.

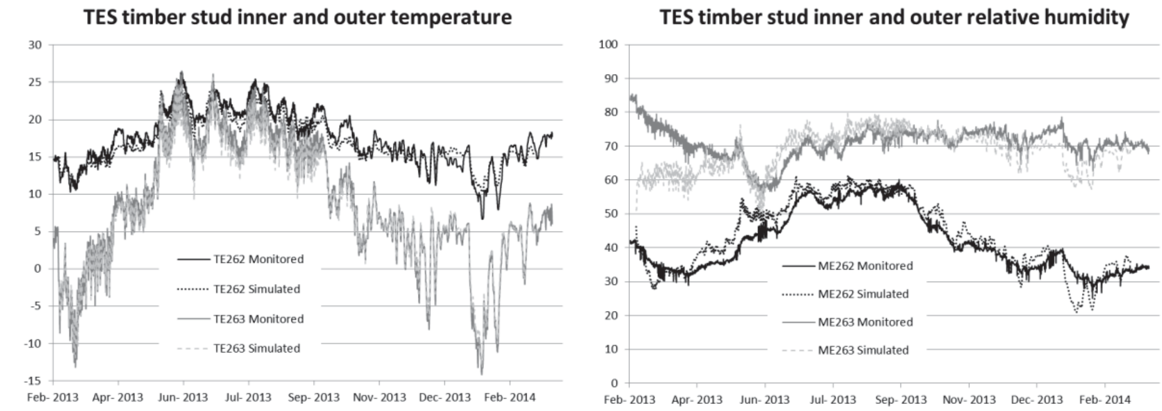


Figure 7: Temperature and relative humidity for the Oulu TES Façade elements timber studs, inner (TE/ME262) and outer (TE/ME263) locations.

5. Conclusions

In conclusion, the two cases from Munich and Oulu show that WUFI 2D is a good tool to determine the moisture performance of the TES Energy Façade after a renovation however, the results are very sensitive to the input data such as the existing wall, climate data, the new building materials and if there is any problem with the quality of the work. The demo cases also show that the risks for moisture damage in the form of mould growth in the TES Energy Façade are quite low in both cases for the measured climate. This gives an excellent possibility to evaluate TES Energy Façade with different modifications and in new locations using WUFI 2D before actually starting the retrofit of a building. Initial moisture can pose a risk for wooden construction, both elevated moisture contents in the TES wooden studs themselves, but also in the interior and existing wall material where the TES will be placed can be a source of excess moisture, especially for materials such as concrete and lightweight concrete.

For future work it would be interesting to see the effect of built-in moisture in the existing wall on the hygrothermal performance of the external TES timber studs and the risk of moisture damage this would impose. Also, the robustness and sensitivity of the system to moisture from envelope leakage or from transport to construction site is a topic that needs further investigation, as well as the effect of the extra layer of insulation on the timber studs in the Finnish demo compared to the German TES build-up without extra insulation.

6. Acknowledgements

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