# Robust and reliable deep renovation by advanced prefabricated façade elements. Air-tightness performance and assessment of a demo case

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## ABSTRACT

Deep renovation of the existing building mass is an important task to reach the target of energy efficient buildings and neighbourhood.

However, the current renovation rate is only 1% of the European building stock each year, and barrier for increased rate must be addressed. Attaching prefabricated elements with integrated technologies such as photovoltaic panels or ventilation equipment to the façades and roofs can improve energy performance and indoor climate as well as provide local renewable energy supply. The construction period can be short, with limited disturbance to building usage.

The project 4RinEU has developed and demonstrated solutions suitable for several climates. Building airtightness of the renovated buildings is an important design goal of the refurbishment, and is determined by blower-door tests before and after renovation.

This paper presents air-tightness results from a demo case study in Norway. In the demo case the airtightness as determined by blower-door tests quite unexpectedly deteriorated, while the design goal for the projects was a major improvement. Probable causes for the discrepancy are discussed, and include leakage from the ground, in element joints and in unplanned openings.

## INTRODUCTION

Reducing the energy demand of existing buildings is identified as important to achieve UN Sustainability goals of affordable and clean energy and climate action. The European Union is committed to increase energy efficiency of the building stock through increasing the rate of building renovation improving energy performance and indoor climate *European Parliament and the Council, (2018)*.

The project "Robust and Reliable technology concepts and business models for triggering deep Renovation of Residential buildings in EU" (4RinEU) has the overall objective of defining robust and reliable models for deep renovation *Pernetti, Pinotti et al. (2020)*. This entails technology packages supported by usable methodologies which will feed into reliable business models. Prefabricated façade elements including technical installations, such as a Renewable Energy Source (RES) and ventilation with heat recovery, is one of the defined renovation technologies within 4RinEU *European Commission, (2016*). Barriers are identified and recommendations to stakeholders to overcome these presented *Thunshelle, et. al (2018)*. Prefabricated façade elements for renovation have also been studied in several projects. *Ott, Loebus et al. (2014), Kalamees, Pihelo et al. (2017), Pihelo, Kalamees et al. (2018).* It is postulated that this renovation technology can reduce heating and cooling demand, improve indoor climate and add local renewable energy production through a cost-efficient process. Moreover, as there is little need for a rig area and the construction process can be done without relocating the inhabitant, there are also little impact on the building users and the environment.

The airtightness perspective is an important aspect that needs to be considered if prefabricated elements are applied to existing constructions. In a Nordic climate, a building's airtightness is important for energy efficiency and indoor climate, and for more than 60 years methods for airtightening building envelopes have been systematically studied *Granum (1951)*.

Elements are designed to provide excellent airtightness of the elements themselves as well as in the joints between elements.

Within the framework of 4RinEU, a deep renovation demo project was developed together with Boligbygg Oslo KF – a municipal enterprise that owns, manages and lets social housing in Oslo. For this Norwegian demo, integration of PV panels and ventilation ducts were chosen to be integrated in the elements. Prefabricated technical rooms allow space for air handling unit and technical equipment.

In this paper we report the airtightness goals, results, causes and consequences.

## METHODS

### Demo Building

The building selected for deep renovation (Figure 1) is a two-storey timber-frame building from 1971, with only minor later upgrades, owned by Boligbygg Oslo KF. The building contains in total eight apartments, each with a floor area of approximately 42m2, distributed around two staircases. The building is situated in a suburban area (Haugerud) in Oslo.

Prior to refurbishment, apartments had electrical heating, one electrical heated boiler per apartment and natural (stack) ventilation.

*Figure 1 The demo building prior to refurbishment.*

## Design goals

In the design process, energy and ventilation-related targets as given in Table 1 were set *Pinotti, Thunshelle et al. (2021).*

*Table 1 Selected design goals for the refurbishment*

| | Before | Target |
|---|---|---|
| U-values ($W/m^2K$) | | |
| -Roof | 0.30 | 0.11 |
| -Façades (av) | 0.36 | 0.13 |
| -Windows | 1.8 | 0.8 |
| Ventilation rate | unknown | 1.2 $m^3/m^2h$ 1) |
| Ventilation air heat recovery | - | 80% |
| $N_{50}$ | 2.55 | 1.0 |

1) Ventilation requirements cannot be expressed by a single figure, but given as the general rate for occupied rooms.

## Refurbishment actions

External, insulated woodframe elements with integrated supply air ducts (north façade), preinstalled windows, PV-panels (south façade) and external cladding were added to the existing external walls. During the condition assessment prior to refurbishment, it was determined that the load bearing capacity of the existing construction was insufficient for the added loads, and a new foundation for wall elements was prepared around the perimeter of the building.

In addition to the new façade elements, roof elements and a prefabricated space for ventilation equipment was added to the existing construction. A new entrance area was also built at site for each of the two staircases. The building after refurbishment is shown in figure 2.

*Figure 2 The demo building after refurbishment.*

## Air leakage measurements

Blower door tests were performed according to EN ISO 9972:2015 using Energy Conservatory Model 4 fans and Energy Conservatory SG 700 micromanometers. Test procedure and data collection were semiautomatic using TecTite Express ver 5.1.8.4. (Blowerdoor Gmbh).

Results are reported as $n_{50}$($h^{-1}$), using internal depressurization only.

To visualize leakages, indoor thermography at - 50 Pa (Outdoor – indoor air pressure) according to EN 13187 and smoke generators at 50 Pa were used.

Where accessible leakages were detected, the leakages were remediated by expanding polyurethane foam, or with the aid of airtight spun bond polyethylene fabric (housewrap) and tape.

## RESULTS AND DISCUSSION

### Building airtightness

Table 2 provides the measurement of the building leakages during different stages. The target of 1.0 was not reached.

*Table 2. Building leakage before and after refurbishment*

| Stage | $n_{50}$ ($h^{-1}$) |
|---|---|
| Prior to refurbishment | 2.55[a] |
| After refurbishment | 3.5 |
| After remediation of accessible leakages | 2.82 |

### Observed leakages

By thermography from the inside, substantial leakages were detected around the no longer used ventilation openings, around internal hatches, as well as between dividing walls and existing external walls, and around windows and doors in new entrance area. However, it was noted that the temperature of the leakage air was intermediate between outdoor and indoor temperatures.

The smoke test detected that smoke was emerging from the ground around new fundaments, through holes in the façade in the newly established technical room, at vent pipe guards on new roof elements, and between wall and roof elements. Metal sheet coverings made the exact observation of leakages difficult.

Minor leakages were also observed around a few windows and doors. More details are given in table 3

### Assessing and designing airtightness

Data on the air permeability of building materials and many key components readily are available, which in principle allows the estimation of the airtightness of a construction in the design stage *Relander, Holøs et al. (2012)*. Some leakage pathways, typically in joints between components and penetrations depend on construction detail and quality of workmanship, and could introduce significant uncertainties to airtightness estimates *Kalamees, Alev et al. (2017)*. This uncertainty is normally larger in refurbishment projects, as some leakage pathways – usually from the ground – are typically not changed by refurbishment. No generally usable method for quantifying individual leakages in an existing building is available, and any estimates of airtightness post-refurbishments are uncertain. In the described case, it was assumed that many of the leakages would be addressed as newer and more airtight windows and doors would be more tightly sealed against a continuous external housewrap. Even if the achievable improvements were only roughly estimated, it came as a surprise that airtightness deteriorated through the refurbishment process, especially as there was a close focus on joint details between elements and elements and foundations.

### Leakage Pathways identified in literature

The typical location of leakage pathways in Nordic buildings was recently reviewed *Gullbrekken, Schjøth Bunkholt et al. (2020)*. According to the review, the most common air leakages reported from field measurements in the literature are located in the connections between external wall and ceiling or floor, external wall and window or door, and external wall and penetrations in the barrier layers.

### Leakage detection and possible pathways

Internal thermography at depressurization is a powerful technique to detect where outdoor air enters the internal space. When a layer close to the indoors is designed to be the primary barrier against air leakage, the technique is very useful, as it can both point out weaknesses in the designed airtight layer and suggest where remediation should be attempted. However, when the primary airtight barrier is designed to be a layer on the outside of an external element, the method proved to provide limited useful information, as the leakage air mainly entered the indoor spaces at some distance from the leakage in the external barrier.

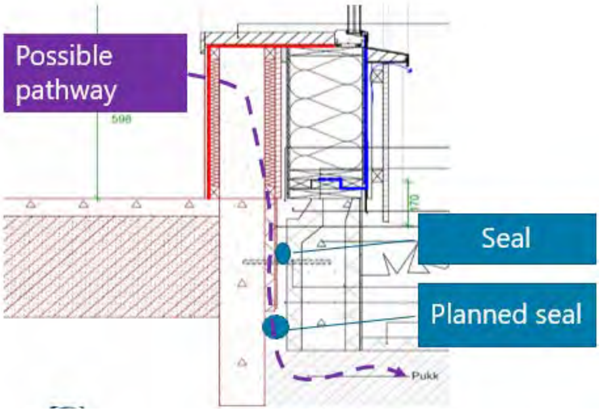

*Figure 3. Construction detail existing and new construction at foundation level, indicating possible pathway for leakages.*

In the examined case, the use of internal smoke generation and pressurization represented an improvement over internal thermography, as more leakages could be located. Unsealed holes in wall in technical rooms after relocation of exhaust ventilation ducts, leakages around pipes and cables, and at vent guards became immediately obvious, and further remediation was possible.

External thermography would possibly have detected some of the leakages detectable by smoke but has the additional problem of being disturbed by solar radiation.

Some air leakages could be quantified as they were accessible for remediation, and in total, the remediated leakages amounted to 0.7 air changes per hour at 50 Pa.

Still, a substantial part of the smoke was in all likelihood transported some distance behind sheeting or cladding before becoming visible, and the actual leakages were not visible without substantial dismantling. Construction details were then discussed closely by the architect, element producer and scientific advisors. Possible pathway detected by foundation is showed in figure 3. Experience show that existing construction is often not exactly as expected, and small adjustments at site can have consequences for the air tightness. Possible improvements were also detected in airtightness details between new wall and roof elements.

### Consequences

Air leakages in buildings can have different consequences, depending on the available driving forces, the leakage pathways, the indoor and outdoor climate as well as usage. When balanced heat-recovery ventilation replaces stack or mechanical extract ventilation without heat-recovery, the airtightness of the building is very important for the achievable energy efficiency improvement. Balanced ventilation will provide neutral or a slight underpressure to prevent moisture accumulation in the building envelope in cold climate. Wind pressure and stack effect can increase infiltration in an untight construction, and cause heat loss. For the examined case, leakages below ground are not affected by wind, while leakages in joints wall/roof are more exposed. The actual energy usage in the pilot case is monitored and will be reported elsewhere.

From an indoor environmental perspective, drafts associated with direct leakage pathways and a positive pressure difference between the outdoors and the indoors is undesirable. The effect is normally immediately noticeable by inhabitants. The inhabitants in the examined case expressed higher thermal satisfaction after the deep renovation, which indicate few such direct leakages. Detected leakages are regarded as to a semi-heated space, cavities between new and existing construction, and previous cold attic.

Infiltration air can be contaminated, e.g. by microorganisms from crawl spaces M*attsson, Carlson et al. (2002), Airaksinen, Kurnitski et al. (2004), Airaksi*nen, Pasanen et al. (2004) or other materials infected by microorganisms, by compounds such as aldehydes emitted from materials in the building envelop *Poppendieck, Ng et al. (2015)*, or by radon or other contaminants from the ground *Pacheco-Torgal(2012).* The actual radon risk depends on local geological conditions., and in the reported case is regarded as moderate as the pilot building situated in an area with moderate to low exposure to radon (Geological survey of Norway).

### Remediation and prevention

Some of the leakages were due to insufficient attention to known penetration of sewage pipes and cables. These can be prevented by improving penetration details in production and mounting, and ensuring compliance, e.g. via checklists.

Details in joints between wall and roof elements will be improved for new projects. Construction details between walls elements and elements/foundations are more mature than the above mentioned.

The leakages from the ground occurred due to unexpected/unknown properties of the existing construction and could only have been prevented by a more thorough assessment and analysis before refurbishment. In general, more focus is needed towards airtightness details below ground and existing condition when doing a deep renovation.

Some leakages occurred post refurbishment. Examples are ventilation ducts penetrating walls that later were moved without sealing the original opening, and internal drainpipes that were lead through the façade elements. The latter can serve as examples of actions that are typically out of control by the building entrepreneur. Airtightness is an important maintenance subject for the responsible building owner.

## CONCLUSIONS

In a case study, deep renovation with prefabricated wooden elements did not improve building airtightness, mainly due to a leakage pathway from the ground, that as far as we know has not been described in the scientific literature.

Deep renovation with prefabricated elements increases the complexity of the building envelop and may, if not checked, create complex pathways for air movement within the construction. Consequently, thermography of inner surfaces has limited applicability in detecting leakages that need remediation. Smoke generation in the pressurized interior may be a useful supplementing method in leakage detection.

Complex pathways and leakage from the ground could pose a risk for intrusion of radon and moisture and should be avoided by assessing all leakage pathways in the design process. Particular attention should be given to all works performed by actors not responsible for airtightness, to all existing penetrations of the airtight barrier, and to maintaining the achieved airtightness during the operation phase.

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*Table 3 Detected leakages. a): Internal leakages refer to detectable air leakages in layers not intended to be airtight / continuous. b): detectable after dismantling metal sheet.*

| Pathway | Detectable by thermography | Detectable by smoke test | Evaluation |
|---|---|---|---|
| Operable window / window frame | Yes | Yes | Minor leakage |
| Window frame / wall | Yes | Hardly | Minor leakage |
| Inspection hatch to crawl attic | Yes | No | "Internal leakage" [a] |
| Old air inlet openings (closed but not sealed) in existing wall | Yes | No | "Internal leakage" [a] |
| Dividing wall / external wall | Yes | No | "Internal leakage" [a] |
| Sewer vent pipe penetrations | No | Yes | Major leakages, effectively repaired |
| Unsealed openings after moved ducts in wall of technical room | No | Yes | Major leakages, effectively repaired |
| Penetrating drainpipes | No | Yes | Medium leakage, effectively repaired |
| Penetrating cables | No | Yes | Small leakages partially repaired |
| Wall element joints | No | Yes | Minor leakage, inaccessible |
| Wall / roof element joints | No | Yes[b] | Medium leakage, inaccessible |
| New / old fundament | No | Yes | Major leakage, inaccessible |