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Abstract:
This report provides an analysis and evaluation of the current historical building stock in countries represented in RIBuild - Belgium, Denmark, Germany, Italy, Latvia, Sweden and Switzerland. The main focus of the report is on historical building stock and its energy consumption, as well as most commonly found historic building structural elements of external walls, their physical properties, main historic building envelope deterioration symptoms and their possible causes. Historic buildings in RIBuild represent all types of protected¹ and non-protected buildings built before 1945. The survey is limited to buildings with heavy walls (stone, brick, timber framing), thus excluding wooden buildings.

Keyword list: Historical buildings, internal insulation, external wall materials, external wall types, massive walls, cavity walls, timber frame walls, heated area, energy consumption, energy saving potential.

¹ A protected building represented a potential high architectural degree of relevance and cultural heritage. The definition can be given at the national or local levels.
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ANNEX I. Building Stock

ANNEX II. Case Studies
Executive Summary

This report provides an analysis and evaluation of the current historical building stock in countries represented in RIBuild (Belgium, Denmark, Germany, Italy, Latvia, Sweden and Switzerland). The main focus of the report is on historical building stock and its energy consumption, as well as most commonly found historic building structural elements of external walls, their physical properties, main historic building envelope deterioration symptoms and their possible causes. Historic buildings in RIBuild represent all types of protected\(^2\) and non-protected buildings built before 1945. The survey is limited to buildings with heavy walls (stone, brick, timber framing), thus excluding wooden buildings.

Methods of analysis include survey of scientific literature, national statistics, data bases and other sources of literature about current historical building stock. Detailed description of all sources is available in description of each country.

Results of data analysis show that:

- Historical buildings account for 24% to 35% expressed in percentage of total building stock area and 27 % to 38 % expressed in number of buildings of total building stock.
- RIBuild partners represent countries with different climates which significantly affect heating energy consumption in buildings. Therefore, historical building stock, including both residential and non-residential buildings consumes from 27 to 42% of the total national energy consumption used for buildings while heating energy consumed by historical residential buildings alone constitute from 18% to 40%.
- The dominating wall type of historical building stock in the countries represented in RIBuild is brick masonry. It has been used in one, two or three leaf walls, in cavity walls, in massive walls, in combination with stones and in rubble walls. Both stone walls and wooden frame walls are more rare.
- In all countries represented in RIBuild only few studies on material properties of materials used in historical buildings have been carried out, except for Germany and Switzerland. One of the main goals of these studies was to produce bricks, mortars or plasters for restoration purposes of historic buildings.
- The most common types of mortars and plasters used in historical buildings in all countries are made of gypsum and lime.
- Historical buildings located in the countries represented in RIBuild are having most of the stone structural damages and alterations described in an ICOMOS-ISC\(S\) guide: Illustrated glossary on stone deterioration patterns, International Council on Monuments and sites (ICOMOS-ISC\(S\) guide, 2008). Brick masonry damages found in the countries are mostly related to damaging processes listed in report on Expert system for the evaluation of the deterioration of ancient brick structures (European Commission, 1999).
- Case studies of internal insulation methods and materials used in historical buildings are presented. Original wall type, internal insulation method, U-value before and after internal insulation as well as energy savings is presented.

\(^{2}A \text{ protected building represented a potential high architectural degree of relevance and cultural heritage. The definition can be given at the national or local levels.}\)
The main driving forces for implementation of internal insulation in historical buildings are studied and among the most popular are saving energy, improve indoor climate and preservation of facades.

The report finds that:

- Historical buildings are important part of existing building stock and energy balance. Therefore energy efficiency improvements in historic buildings should be an important part of national long-term building energy efficiency strategies.
- Hygrothermal properties of materials used in historical buildings have not been reported in Belgium, Denmark, Italy, Latvia, Sweden and partly in Switzerland. Materials have to be studied in the context of structural damages and alterations of historical materials.
- Case studies provide insight of application of different internal insulation materials and methods.

As the result findings from this report will be used for project’s activities within WP2, WP3, WP4, WP5 and WP6.

The analysis conducted has a number of limitations and they are:

- In some countries data about historic building stock are not available or are available only for residential building stock.
- Specific heat energy consumption per country cannot be compared as data available in literature sources are measured in different units, e.g. in Belgium per household or dwelling, and in Latvia, Denmark, Italy, Switzerland per heated floor area. In Sweden average U-values for historical residential buildings are available.
- In none of the countries energy consumption data for historical buildings are available hence they are calculated based on available information.
Introduction

The general objective of RIBuild is to develop effective, comprehensive decision guidelines to improve the energy performance of historic buildings by investigating internal insulation measures. The conservation of historic buildings’ cultural values and the improvement of their energy performance can be first seen as rather contradictory. Indeed, a thermal insulation cannot always be applied on the external walls e.g., due to the preservation of the façade. In that case, internal insulation measures should be investigated and currently represent the most difficult retrofit measure in historic buildings.

The main objective of WP1 is to examine most commonly found historic building structural elements, determine their physical properties, classify them by different types, observe and describe main historic building envelope deterioration symptoms and study their possible causes.

At the beginning of the project, it was defined that “historic buildings” in RIBuild represent all types of protected⁴ and non-protected buildings built in Europe before 1945. In this report, the “historic building” term will thus refer to this definition.

Due to this broad definition and scope, it is important to have a clear overview of the existing historic building stock compared to the overall building stock for each country, to characterise them in terms of energy consumption and its share in national energy balance.

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⁴ A protected building represented a potential high architectural degree of relevance and cultural heritage. The definition can be given at the national or local levels.
1 Countries overview

This section of the report summarises the following information across project partners’ countries:

- historical building stock and its energy consumption
- external wall types. The survey is limited to buildings with heavy walls (stone, brick, timber framing), thus excluding wooden buildings
- joints with adjoining building elements (ceiling/roof, suspended floor, and foundations)
- materials used in external walls
- most common types of structural damages of historical building walls and their causes
- case studies of energy efficiency renovation with internal insulation
- motivation to install internal insulation

More detailed overviews for each country are provided as separate sections (section 2-8) and in Annex I and II4.

1.1 Survey of historic building stock

Each of RIBuild project partners has done analysis of available information and data about historical building stock in their respective countries. Information sources and their level of detail differ from country to country.

Figure 1.1 illustrates historic building stock area (including both residential and non-residential buildings) in percentage of total building stock area and historic building stock (number of buildings) in percentage of total building stock per country.

In historic building stock area Denmark has the highest share (35%), followed by Latvia (26%) and Switzerland (24%). Data are not available for Belgium, Germany and Sweden.

Expressed in number of buildings in percentage of total building stock the highest share is in Belgium (38%), Latvia (37%), followed by Denmark (35%), Switzerland (31%), Italy (29%) and Sweden (27%). German data are available only for residential building stock. In Germany historical buildings account for 26% of total residential building stock.

4 Annex I and II are not included in this deliverable, but can be provided at any time by contacting Andra Blumberga or Ernst Jan de Place Hansen.
Energy consumption for space heating in the historic building stock

The building sector in the European Union consumes almost 40% of total energy consumption and is responsible for 36% of CO$_2$ emissions. Therefore the building sector has significant energy efficiency potential. Most of the existing buildings have high energy consumption and they have significantly lower thermal properties than can be achieved by currently available technologies.

RIBuild partners represent countries with different climates. It is illustrated by heating degree days in Figure 1.2. Sweden and Latvia are located in northern part of Europe and have the highest number of heating degree days. Belgium, Germany, Denmark and Switzerland have milder climate with an average of 3200 heating degree days. The least heating degree days are in Italy.

In neither of the countries represented in RIBuild statistical data on heating energy consumption in historical building stock are available. Hence energy consumption is calculated based on available data from different literature sources.
Figure 1.3 illustrates the percentage of energy consumed by historic residential building stock and historic total building stock from total final heating energy consumption in buildings per country. Historical building stock, including both residential and non-residential buildings, consumes important part from total final heating energy consumption in buildings in Denmark (42%), Latvia (31%) and Switzerland (27%). Heating energy consumed by historical residential buildings alone expressed in percentage of total final heating energy consumption in buildings is in Belgium 39%, Italy 36%, Denmark 34%, Latvia 25% and Switzerland 18%. Data for Sweden and Germany are not available.

Specific heat energy consumption cannot be compared as data available in literature sources are measured in different units, e.g. in Belgium per household or dwelling, and in Latvia, Denmark, Italy, Switzerland per heated floor area. In Sweden average U-values for historical residential buildings are available.

1.3 Main wall types of historical buildings

The dominating wall type of historical building stock in countries represented in RIBuild is brick masonry. It has been used in one, two or three leaf walls, in cavity walls, in massive walls, in combination with stones and in rubble walls. Both stone walls and wooden frame walls are more rare. A summary of historical building walls is presented below. For more details see description of each country report (Section 2-8).

- Massive walls:
  - Brick (Belgium, Denmark, Germany, Italy, Latvia, Sweden, Switzerland) with or without rendering
  - Stones:
    - Brick and limestone or sandstone (Belgium)
    - Dry stone or stone and mortar (Italy)
    - Granite and dolomite walls (Latvia)
    - Rendering with stone wall and rendering (Switzerland)
    - Rendering with brick and cut stone (Switzerland)
In cultural buildings such as churches, castle etc. external walls can be constructed of stone (Denmark)

- Cobbles, rubble, quarry stone and erratic were widely used, especially in rural areas. They were mostly combined with brick masonry for structural stability reasons. Sandstone, granite, limestone, syenite and tuff were used where they were naturally occurring (Germany)

- Limestone houses on the island of Gotland. Beyond this, exterior walls of stone are unusual except in churches, castles and manors. (Sweden)

  - Clay walls (Latvia, Germany)
  - Hollow concrete blocks and concrete blocks (Germany)
  - Wood doubling with hollow clay brick and rendering (Switzerland)

- Cavity walls:
  - Cavity walls for green houses and ice cellars. Tie stones were used, leading to an incomplete decoupling of outer and inner walls. Later steel wall ties were used (Belgium)
  - Between 1890-1930 cavity walls with header of brick. The walls were built on a foundation of bricks or concrete. After 1930 brick cavity walls were introduced (Denmark)
  - In 19-th century cavity walls were introduced. Often, in order to improve existing buildings, another internal brick layer was added to external walls. All buildings built from the end of 19-th century until the beginning of 20-th century are cavity walls (Latvia)
  - To avoid construction of thick stone walls in residential buildings, internal layer of brick and air gap with brick ties was allowed (Latvia)
  - Rendering with hollow clay brick, air, hollow clay brick, rendering (Switzerland)
  - Constructions range from small wall cavities up to cavity networks. Cavities are often divided or filled, e.g. with cork or saw dust (Germany)

- Rubble walls:
  - Multi-leaf walls with rubble core: a non-homogenous set-up; clear distinction between facings (often in regular brickwork, sandstone or limestone) and core material (Belgium)
  - Two leaf wall: the external leaves are usually made as a monolithic wall; the inner leaf is made by rubble stones of fragments of bricks and mortar. Rubble (listed) walls: they are made by irregular stone and mortar. Sometimes, they are regularised by horizontal bricks layers (Italy)
  - Constructions and materials used for buildings were with various, often divergent characteristics. Rubble walls are coated with plaster (Latvia)

- Timber frame:
  - Composed of wood and clay or wood and brick (Belgium)
  - In the older part of the building stock bricks are used in combination with timber framing where the bricks are applied a thin layer of lime-mortar or lime. Before approximately 1890 the buildings were constructed with half-timbered walls with and infill panel of typical burned or unburned bricks rendered with a thin layer of lime mortar or lime (Denmark)
  - Timber frame constructions are a centuries old tradition in Germany with diverse local characteristics. Timber frame / timber constructions represent about 2-3% each of the whole residential building stock (Germany)

- Facade finishes of historic masonry walls:
o ‘nude’, painted, lime-washed, plaster, natural stone cladding, glazed tiles (Belgium, Latvia)
o Massive walls ‘nude’ or with thin layer of lime mortar and lime. Lower part of buildings could be applied with rendering ruled to resembling dimension stone/ashlar (Denmark)
o Masonry walls are often externally protected by plaster, which is usually present even inside (Italy)
o Usually, the exterior plaster or ‘nude’ and the interior plaster. The external wall construction change little over the decades but the external design usually followed the architectural ideals of the time (Sweden)

Summary of main wall types of historical buildings built in each of countries during different time periods is presented in Appendix 1.

1.4 Materials used in historical building walls

In all countries represented in RIBuild only few studies on material properties of materials used in historical buildings have been reported, except for Germany where a systematic construction type overview for residential buildings for each German state and for defined time periods and envelope types and materials with about 800 data sets exists and Switzerland where 64 types of stones and their properties are listed. One of the main goals of these studies was to produce bricks, mortars or plasters for restoration purposes of older historic buildings.

1.4.1 Bricks

The typical material used in the historic buildings for wall structures was masonry consisting of bricks and lime mortar. In all countries represented in RIBuild brick have been locally produced, which means that a huge number of brickworks existed in all RiBuild partner countries. Hence a vast number of bricks with different hygrothermal properties have been used in historical building stock.

1.4.2 Stones

All types of the main rock classes related to the mode of differentiation in the terrestrial crust have been used in historical buildings in all countries represented in RIBuild:

- Magmatic (volcanic lava origin), like granite, porphyry, tuff and gneiss
- Sedimentary (due to degradation and sedimentation of existing rocks), such as limestone, dolomite, travertine and sandstone
- Metamorphic (due to the transformation of magmatic and sedimentary at high pressures and temperatures), like schist, quartzite and marble.

Massive walls made of natural stone differ strongly due to local availability and construction know how in particular region. In all countries stones were mostly combined with brick masonry for structural stability reasons. The most widespread stones used in historical buildings are sandstone, limestone, gneiss, granite. Less popular types of stones used for the historical buildings are dolomite, schist, tuff.
1.4.3 Mortars and plasters

The most common types of mortars and plasters used in historical buildings in all countries are made of gypsum and lime. Air hardening binders and hydraulic binders using lime, as well as hydraulic binder using Roman cement and Portland cement, have been used.

1.5 Most common types of structural damages of historical building walls and their causes

Masonry and stone walls alterations and their associated causes are complex. UNESCO ICOMOS-ISCS guide of the terms to be used for the stone structural damages and alterations (ICOMOS-ISCS, 2008) definitions are:

- Alteration: "Modification of the material that does not necessarily imply a worsening of its characteristics from the point of view of conservation. For instance, a reversible coating applied on a stone may be considered as an alteration”
- Damage: “Human perception of the loss of value due to decay”
- Decay: “Any chemical or physical modification of the intrinsic stone properties leading to a loss of value or to the impairment of use”
- Degradation: “Decline in condition, quality, or functional capacity”
- Deterioration: “Process of making or becoming worse or lower in quality, value, character, etc...; depreciation”
- Weathering: “Any chemical or mechanical process by which stones exposed to the weather undergo changes in character and deteriorate”.

Historical buildings located in countries represented in RIBuild are having most of stone structural damages and alterations described in an ICOMOS-ISCS guide.

Brick masonry damages found in countries represented in RIBuild are mostly related to damaging processes listed in report on Expert system for the evaluation of the deterioration of ancient brick structures (European Commission, 1999). Damaging processes that interfere with damage types and are defined as a set of causes are:

- Frost damaging process
- Salt crystallisation process
- Environmental pollution process
- Surface erosion process
- Water penetration process
- Mechanical damaging process
- Surface deposition process
- Condensation process
- Structural damaging process
- Iron corrosion process
- Biological process
1.6 Screening of case studies on internal insulation of historic buildings walls

In Table 1.1 summary of examples of internal insulation methods and materials used in historical buildings are presented. Original wall type, internal insulation method, U-value before and after internal insulation as well as energy savings are presented. More detailed information about each case study is available in country’s report.

Table 1.1. Overview of case studies of internal insulation methods and materials used.

<table>
<thead>
<tr>
<th>Case study ID</th>
<th>Name of building</th>
<th>Original wall type</th>
<th>Internal insulation material/method</th>
<th>U-value before internal insulation, W/(m²K)</th>
<th>U-value after internal insulation, W/(m²K)</th>
<th>Energy savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Belgium</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE1</td>
<td>Lier</td>
<td>Massive masonry walls (0.29 m)</td>
<td>Cellulose (0.15 m)</td>
<td>1.55</td>
<td>0.22</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Massive masonry walls (0.29 m)</td>
<td>Foamglas (0.12 m)</td>
<td>1.72</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>BE2</td>
<td>Gontrode</td>
<td>Massive masonry walls (0.20 m)</td>
<td>Multipor (0.08 m)</td>
<td>2.19</td>
<td>0.42</td>
<td>N/A</td>
</tr>
<tr>
<td>BE3</td>
<td>Sint-Niklaas</td>
<td>Massive masonry walls</td>
<td>Cellulose blown-in between wooden framework (0.10 m)</td>
<td>1.76</td>
<td>0.32</td>
<td>N/A</td>
</tr>
<tr>
<td>BE4</td>
<td>De Schipjes Brugge</td>
<td>Massive masonry walls (0.27 m)</td>
<td>Aerogel plastering at inside (thickness 11 to 25 mm)</td>
<td>1.97</td>
<td>0.33</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Denmark</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DK1</td>
<td>Elmehuset</td>
<td>Brick (0.47 m), air cavity (0.05 m, ventilated)</td>
<td>Mineral wool (0.07 m), gypsum (0.025 m)</td>
<td>1.07</td>
<td>0.39</td>
<td>67%*</td>
</tr>
<tr>
<td>DK2</td>
<td>Ryesgade 30</td>
<td>Brick (0.59 m)</td>
<td>Mineral wool (0.25 m)</td>
<td>0.88</td>
<td>0.13</td>
<td>50% *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brick (0.35 m)</td>
<td>Mineral wool (0.25 m)</td>
<td>1.35</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brick (0.71 m)</td>
<td>Aerowolle (Aerorock) (0.04 m), fibre gypsum (Aerorock) (0.01 m)</td>
<td>0.75</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brick (0.59 m)</td>
<td>Aerowolle (Aerorock) (0.04 m), fibre gypsum (Aerorock) (0.01 m)</td>
<td>0.88</td>
<td>0.28</td>
<td></td>
</tr>
</tbody>
</table>
### Germany

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>Material Details</th>
<th>Energy (kWh/m²)</th>
<th>Co₂e (kg/m²)</th>
<th>Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK3</td>
<td>Glumsøparken</td>
<td>Brick (0.36 m) Mineral wool (0.125 m), vapour barrier, gypsum board (0.013 m)</td>
<td>1.28</td>
<td>0.28</td>
<td>45% *</td>
</tr>
<tr>
<td>DK4</td>
<td>Knivholt Hovedgaard, Østre Lade</td>
<td>Massive fieldstone (assumed to be of granite) (0.6 m) iQ-Therm (0.08 m)</td>
<td>2.93</td>
<td>0.34</td>
<td>N/A</td>
</tr>
<tr>
<td>DE1</td>
<td>Dresden</td>
<td>iQ-Therm Insulation Board</td>
<td>2.1</td>
<td>0.12</td>
<td>95% *</td>
</tr>
<tr>
<td>DE2</td>
<td>Görlitz</td>
<td>Natural stone masonry (0.55 m), plaster, lime cement plaster (12 mm) Calcium Silicate (55 mm), insulation plaster (0.1 m)</td>
<td>2.36</td>
<td>0.41</td>
<td>84% *</td>
</tr>
<tr>
<td>DE3</td>
<td>Freiberg</td>
<td>Natural stone masonry (0.6 m), plaster, lime cement plaster (85. mm) Knauf perlite (0.14 m), Calcium silicate (55 mm), mineral wool (0.14 m), Isover Styrodur (0.14 m)</td>
<td>1.89</td>
<td>0.12</td>
<td>52% (planned savings)</td>
</tr>
</tbody>
</table>

### Italy

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>Material Details</th>
<th>Energy (kWh/m²)</th>
<th>Co₂e (kg/m²)</th>
<th>Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT1</td>
<td>Casa Graziosi</td>
<td>Lime and gypsum base plaster (0.02 m), bricks (0.25 m), lime and cement base plaster (0.02 m) EPS Insulation board (0.06 m), lime and gypsum base plaster (0.01 m)</td>
<td>1.76</td>
<td>0.48</td>
<td>47% *</td>
</tr>
<tr>
<td>IT2</td>
<td>Palazzo degli Anziani</td>
<td>Bricks (0.58 m), lime and gypsum base plaster (0.02 m) EPS insulation board (0.08 m), lime and gypsum base plaster (0.01 m). Insulation is not installed yet.</td>
<td>1.0</td>
<td>0.33</td>
<td>24% (planned savings)</td>
</tr>
<tr>
<td>IT3</td>
<td>Palazzo Barilari</td>
<td>Lime and gypsum base plaster (0.02 m) EPS insulation board (0.08 m), lime and</td>
<td>1.08</td>
<td>0.34</td>
<td>52% (planned</td>
</tr>
<tr>
<td>Country</td>
<td>Project</td>
<td>Material Details</td>
<td>Savings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>------------------</td>
<td>---------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latvia</td>
<td>Spīķeri</td>
<td>Brick (0.51 m), Polysiocyanurate insulation (0.1 m)</td>
<td>79% *</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brick (0.51 m), Vacuum insulation panel (0.05 m)</td>
<td>50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brick (0.51 m), Aerogel mat insulation (0.05 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latvia</td>
<td>Dankepi</td>
<td>Dolomite walls (0.6 m), internal gypsum plaster (0.015 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mineral wool (0.05 m)</td>
<td>4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latvia</td>
<td>Creativity Center</td>
<td>Brick wall (0.55 m), XPS (0.05 m)</td>
<td>13%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brick wall (0.77 m), XPS (0.05m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>Hausknecktska</td>
<td>Mineral wool and Styrofoam (50-70 mm)</td>
<td>53% *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>Bavois</td>
<td>Stone and mortar masonry (0.50 m), Glass wool (0.23 m)</td>
<td>36% *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>Niederwangen</td>
<td>Bricks (0.135 m), mortar, wood, Isofloc (0.16 m)</td>
<td>24% *</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concrete (0.45 m), mortar, XPS (0.10 m), Rockwool (0.03 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>Heremence</td>
<td>Wood (0.015 m), concrete (0.5 m), PUR (0.1 m)</td>
<td>42% *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>Siviriez</td>
<td>Two layers of bricks (0.2 m, 0.125 m), PUR (0.12 m)</td>
<td>42% *</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Three layers of bricks (0.15 m, 0.15m, 0.12 m), EPS (0.12 m), PUR (0.06 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bricks (0.295 m), PUR (0.12 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bricks (0.17 m), wood (0.16 m), PUR (0.07 m), EPS (15 mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.7 Motivation for the application of internal insulation

The main driving forces for implementation of internal insulation in historical buildings are:

- Saving energy
- Improve indoor climate
- Preservation of facades
- External insulation difficult to execute due to masonry relief in facade
- To develop solutions for renovation of historical buildings and test the solutions
- National/regional legal requirements, for example, not allowed to build over the building alignment line, or external volume of buildings located in an agricultural area cannot exceed 1000 m³
- Tenants were unable to utilize space close to walls, as it was very cold
- To clarify both expenses associated with an internal insulation and the nuisances experienced by the residents
- The thermal transmittance values of the individual components of the building envelope are compulsory in the event of renovation of existing buildings envelopes
- Tax deductions for the energy upgrading of buildings

1.8 References


*-including all energy efficiency measures
2 Belgium

2.1 Survey of historic building stock

The main sources of information were the Belgian Land Register, the Energy Consumption Survey for Belgian Households – ECS Study (VITO et al. 2012) and the National energy balances of 2010 (FOD ECONOMIE 2010).

As can be seen from Table 2.1 and figure 2.1, 38% of the total Belgian building stock consists of buildings built before 1945. The residential buildings represent 82% of the total building stock and 39% of all these residential buildings is built before 1945.

Table 2.1. The cadastral Belgian statistics for the year 2014: division of the Belgian building stock in construction periods, building typologies and building usage. (VITO et al. 2012), (FOD ECONOMIE 2010).

<table>
<thead>
<tr>
<th>Construction Period</th>
<th>Closed</th>
<th>semi-detached</th>
<th>detached/farms</th>
<th>apartment buildings</th>
<th>commercial buildings</th>
<th>other</th>
<th>% of TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1900</td>
<td>281 429</td>
<td>163 924</td>
<td>132 845</td>
<td>13 782</td>
<td>50 113</td>
<td>73 555</td>
<td>16%</td>
</tr>
<tr>
<td>1900 - 1918</td>
<td>182 283</td>
<td>68 681</td>
<td>41 254</td>
<td>9 479</td>
<td>20 965</td>
<td>25 465</td>
<td>8%</td>
</tr>
<tr>
<td>1919 - 1945</td>
<td>295 426</td>
<td>140 418</td>
<td>86 589</td>
<td>17 015</td>
<td>29 887</td>
<td>57 242</td>
<td>14%</td>
</tr>
<tr>
<td>1946 - 1961</td>
<td>169 743</td>
<td>173 403</td>
<td>143 946</td>
<td>26 120</td>
<td>20 536</td>
<td>86 249</td>
<td>14%</td>
</tr>
<tr>
<td>1962 - 1970</td>
<td>71 274</td>
<td>101 083</td>
<td>161 219</td>
<td>26 440</td>
<td>9 392</td>
<td>85 308</td>
<td>10%</td>
</tr>
<tr>
<td>1971 - 1980</td>
<td>77 395</td>
<td>116 227</td>
<td>272 521</td>
<td>24 230</td>
<td>6 272</td>
<td>106 316</td>
<td>14%</td>
</tr>
<tr>
<td>&gt; 1980</td>
<td>91 722</td>
<td>178 289</td>
<td>547 820</td>
<td>59 690</td>
<td>10 939</td>
<td>198 671</td>
<td>24%</td>
</tr>
<tr>
<td>TOTAL (= 100 %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4455157</td>
</tr>
</tbody>
</table>

Figure 2.1. Total Belgian building stock in 2014: division based on building usage (left) and further division based on construction period (right).
2.2 Energy consumption for space heating in the historic building stock

Energy consumption data have only been found for the residential building stock. In the ECS-study (VITO et al. 2012) a representative set of 3396 households has been interviewed, providing also information on the household’s dwelling and annual energy consumption. Comparison with the Land Register data showed a very satisfying agreement in terms of the dwelling typology distribution (almost equal percentages of detached, semi-detached, closed houses and apartments). However, the dwellings built before 1945 are underrepresented in the ECS-study: 26% of all ECS-houses are built before 1945 compared to the 39% of the Land Register (see above).

Still though, the ECS-study can be useful because it contains an overview of the average annual end energy use of the households in function of the construction period of the dwellings – see Table 2.2.

Table 2.2. Average annual household end energy use (kWh per year) per building age category and typology following the ECS-study (VITO et al. 2012). The end energy use is defined as the household’s energy used for space heating, hot tap water production and appliances – electricity is NOT converted to primary energy.

<table>
<thead>
<tr>
<th>Category</th>
<th>Detached</th>
<th>Semi-detached</th>
<th>Detached, farms, castles</th>
<th>Apartment buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1945</td>
<td>26 075</td>
<td>27 793</td>
<td>32 369</td>
<td>17 535</td>
</tr>
<tr>
<td>1946 - 1961</td>
<td>22 923</td>
<td>25 625</td>
<td>31 517</td>
<td>19 625</td>
</tr>
<tr>
<td>&gt; 1980</td>
<td>21 446</td>
<td>25 285</td>
<td>31 586</td>
<td>14 752</td>
</tr>
</tbody>
</table>

When multiplying the values of Table 2.2 with the respective amount of residential buildings found in the Land Register (Table 2.1), the total energy consumption of all residential buildings in Belgium is then estimated at 100 TWh = 8.60 Mtoe per year\(^5\). This is in reasonable correspondence with the 9.17 Mtoe of residential end-energy use as found in the Belgian energy balances of 2010 (FOD ECONOMIE 2010). The division based on the age category is shown in Figure 2.2, showing that the historic residential building stock approximately accounts for 39% of the total residential energy consumption.

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\(^5\) The value of 8.60 Mtoe per year is likely to be an underestimation because the Land Register only counts the amount of apartment buildings (containing different apartment units), while the ECS study considers the energy use at the level of the apartment units.
2.3 Main wall types of buildings

In (Hens et al. 2001) a bottom-up model of the Belgian building stock is constructed, for which the following assumptions are made: “Most houses constructed before 1945 have masonry massive walls with a thickness of 30 cm. From the Second World War on, masonry cavity walls become the new reference for external walls. After 1970, mainly for comfort reasons and as a consequence of the energy crisis of 1973, roof and cavity wall insulation and the use of double glazing turn into normal practice.“

In the manual of the Flemish Agency of the Immovable Heritage (Vernimme 2013) guidelines are given to link the U-values of different wall types to their dominant construction period – see Table 2.3.

Table 2.3. Guidelines for wall U-values in function of the wall’s construction period. Source: (Vernimme 2013) Introduction of the EPB-directive in Belgium.

<table>
<thead>
<tr>
<th>Period</th>
<th>Type external wall (masonry)</th>
<th>typical U-value [W/(m²K)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1945</td>
<td>massive wall 1.5 brick (0.28 m)</td>
<td>2.37</td>
</tr>
<tr>
<td>1945 – 1975</td>
<td>massive wall 2 bricks (0.38 m)</td>
<td>1.95</td>
</tr>
<tr>
<td>1975 – 2006¹</td>
<td>Air cavity wall</td>
<td>1.53</td>
</tr>
<tr>
<td>2006¹ – present</td>
<td>Moderately insulated cavity wall</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>Insulated cavity wall</td>
<td>0.30 – 0.77</td>
</tr>
</tbody>
</table>

In the KU Leuven Master course ‘Renovation – lesson 3: Historical constructions’ (Verstrynge & Stevens 2014a) three different historic wall types in Belgium are discussed:

2.3.1 Massive wall

- Very often composed of brick and lime- or sandstone between the 16th and 18th century. The use of natural stone gradually evolved from structural to aesthetic.
- Multi-leaf walls with rubble core: a non-homogenous set-up. Clear distinction between facings (often in regular brickwork, sandstone or limestone) and core material – see Figure 2.3.
- In smaller scale, residential buildings regular brickwork with a wall thickness of 0.3 m was common practice up to the beginning of the 20th century.

Abbey Vlierbeek, Kessel-Lo

First city wall of Leuven

*Figure 2.3. Rubble walls in Belgium. Source: (Verstrynge & Stevens 2014a).*

### 2.3.2 Cavity wall

Already from the 19th century on, a first decoupling of the wall occurred, mainly to avoid rain penetration. Cavity walls for green houses and ice cellars even date back from as early as the 17th century (Kooij 2013). As can be seen in Figure 2.4, showing a drawing from 1871, tie stones were used, leading to an incomplete decoupling of outer and inner walls. It is only later that steel wall ties are used. From the 70’s (oil crises in 1973) insulated cavity walls turned into common practice.

*Figure 2.4. Historic cavity walls in the Netherlands, drawing from 1871 – Source: (Kooij 2013).*
2.3.3 Timber framing

Composed of wood and clay or wood and brick. An example is given in Figure 2.5.

![Figure 2.5. Wood and brick wall in Groot Begijnhof, Leuven, 16th - 17th century. Source: www.belgiumview.com](image)

Different types of facade finishes of historic masonry walls are found in the KU Leuven Master course ‘Renovation – lesson 4: Historical finishes and window frames’ (Verstrynge & Stevens 2014b):

- ‘Nude’
- Painted
- Lime-washed
- Plaster
- Natural stone cladding
- Glazed tiles

2.4 Materials used in historical building walls

For the material properties of the brick, reference is made to the information found in (Vereecken et al. 2015), in which 3 different kinds of brick are considered – see Table 2.4.

**Table 2.4. Brick material properties. Source: (Vereecken et al. 2015).**

<table>
<thead>
<tr>
<th></th>
<th>Dry thermal conductivity $\lambda$ [W/K]</th>
<th>Capillary absorption $A_{cap}$ [kg/(m²s⁰.⁵)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick 1</td>
<td>0.9</td>
<td>0.125</td>
</tr>
<tr>
<td>Brick 2</td>
<td>1.08</td>
<td>0.460</td>
</tr>
<tr>
<td>Brick 3</td>
<td>0.996</td>
<td>0.040</td>
</tr>
</tbody>
</table>
2.4.1 Joints with adjoining building elements (ceiling/roof, suspended floor, and foundations)

In the Belgian historical buildings, the internal floors are often composed of wooden beams, which are often embedded into the external walls. When applying internal insulation, these wooden beams turn into (point-) thermal bridges and are likely to be subjected to higher moisture loads than before internal insulation. A sketch is given in Figure 2.6, showing the original masonry massive wall, the insulation layer, internal finishing layer and the wooden beams bearing into the external walls.

![Image of the original masonry massive wall, the internal insulation layer (yellow), internal finishing layer (grey) and the wooden beams bearing into the external walls. Source: provided by Evy Vereecken, post-doc researcher at the KU Leuven Building Physics Section and involved in ongoing and yet unpublished research concerning wooden beam ends in internally insulated massive walls.]

2.5 Most common types of structural damages of historical building walls and their causes

- Mechanical degradation (erosion, cracking)
- Moisture problems (rain penetration, rising damp, internal condensation)
- Biological degradation (salt crystallization, algal growth, mold growth)
2.6 Case studies on renovation of historic buildings

2.6.1 Lier: Single family-dwelling

Year of construction: 1903.

Year of energy renovation (and internal insulation): 2013.

Short description of building: single family-dwelling, terraced, ground floor+2 levels+mansarde, total volume +/- 709 m³, total heated floor area 189 m², massive masonry walls 290mm.

Internal insulation material: Foamglas, cellulose.

Internal insulation method:
- Ground floor: 0.18m Foamglas clued against masonry wall which was first plastered with cement + gypsum boards glued with L-gips against the foamglas (= maximum reduction of thermal bridging).
- All other floors: 0.10 m metalstuds that are 0.05 m apart from the masonry wall, allowing for 0.15m of cellulose, OSB against metalstuds (taped) + gypsum board.
- Additional attention to avoid thermal bridging: the boarded floors and ceiling have been locally removed at the external walls to allow for a continuous insulation layer.

Motivation for renovation:
- In essence for the total renovation:
  o Creating a comfortable indoor climate, according to new standards:
  o The improvement of the air tightness level to allow for the installation of a mechanical ventilation system (both inlet- and exhaust mechanically driven), which requires an air tightness level of n50 < 1h⁻¹.
  o The ability to have large choice in heating systems (heat loss according to EN12831 is below 10 kW, so heat pump becomes an option).
- Concerning internal insulation: preservation of front facade.

Other energy efficiency measured implemented at same renovation: insulation pitched roof 0.35m cellulose, external insulation back facade 0.12m STO eps TOP32, new aluminium window frames + triple glazing back façade.
Achieved results, including energy savings: Since the insulation of the external walls the indoor temperature has not dropped below 21°C, despite the current (temporary) absence of a heating system and the outdoor temperatures going below 6 °C.

2.6.2 Gontrode: Single family-dwelling

Year of construction: 1938.

Year of energy renovation (and internal insulation): in progress.

Short description of building: rural family-dwelling + craft’s place, detached, ground floor+1level+mansarde, total volume +/- 714 m³, total heated floor area 178.5 m², massive external masonry walls (200mm masonry - only external cement plastering at side wall - front facade has ‘cavity’ wall: air cavity (40-50 mm) + thin internal brick wall of 60 mm is added in later stage) - pitched roof constructed with wooden beams and externally finished with ceramic tiles (no underlay, no insulation) - uninsulated slab on ground floor - wooden beam internal floors with wooden boarded floor.

Internal insulation material: Multipor and fibreboard Gutex Thermo Room.

Internal insulation method:

- Internal insulation (both surfactant, vapour open systems):
  - Multipor 80 mm, glued in clay and plugged (on side wall with existing cement plaster on the outside): mostly implemented.
  - Fibreboard Gutex Thermo Room 80 mm and 100 mm, glued in clay and plugged: in implementation.
- Specific attention (thermal, airtightness, vapour transport) to the wall penetrations such as existing beams, sockets, and for connecting building components such as windows, roof, starter, interior walls etc.

Motivation for renovation: Concerning the application of the internal insulation, the house owner mentioned the following reasons:

- Saving energy and comfort enhancement (following the trias energetica).
- Conservation of the front facade and side walls (typical rural house workman, specifically here: masonry pattern, guillotine windows, steel window lintels, vents and anchors, cornices, etc.).
- Due to legal reasons: the case study is located in agricultural areas, implying that the volume for residential purposes cannot be larger than 1000 m³; the current volume already is 1000 m³; in Belgium external dimensions are used so applying external insulation
results in a volume increase, which is not obvious: when expanding the house, there would have been no legal guarantee for obtaining a renovation license.

*Other energy efficiency measured implemented at same renovation*: complete reconstruction of pitched roof + insulation 0.35 m cellulose.

*Achieved results, including energy savings*: no results available yet.

### 2.6.3 Sint-Niklaas: Single family-dwelling

*Year of construction*: approx. 1930.

*Year of energy renovation (and internal insulation)*: 2011.

*Short description of building*: single family-dwelling, terraced, ground floor+2 levels, total volume approx. 640 m³, total heated floor area 158 m², massive masonry walls.

*Internal insulation material*: cellulose.

*Internal insulation method*: cellulose blown-in between wooden framework – only applied at front facade.

*Motivation for renovation*:
- Overall: Saving energy and comfort enhancement (certainly concerning the replacement of the original single glazing).
- Internal insulation: not possible to apply external insulation.
- Due to restriction of buildings code of city Sint-Niklaas – code is recently changed, enabling the application of external insulation.
- Difficult to execute due to masonry relief in external front facade.

*Other energy efficiency measured implemented at same renovation*: insulating attic floor: 0.2 m cellulose; insulating slab on ground floor 80 mm cellulose; new wooden window frames with highly insulating glazing (\(U = 1.1 \text{ W/(m²K)}\)); insulating flat roof: 0.3 m cellulose; external insulation of back façade (100 mm flax insulation).
Achieved results, including energy savings: tenants are very satisfied – no drop in energy use known.

2.6.4 De Schipjes Brugge: group of residential dwellings

Year of construction: approx.1908.

Year of energy renovation (and internal insulation): scheduled for 2015-2016.

Short description of building: residential area with small single person-dwellings, ground floor+1 level, total volume approx. 130m³ per dwelling, total heated floor area+/- 48 m² per dwelling, massive masonry walls (270mm).

Internal insulation material: aerogel plastering and vacuum insulation panels.

Internal insulation method:
- External wall: aerogel plastering at inside (between 11to 25 mm thicknesses).
- Slab on ground floor: vacuum insulation panels (20 mm) between screed and reinforced concrete.

Motivation for renovation:
- Saving energy.
- Moisture problems and condensation.
- Comfort issues.
- Concerning internal insulation: historically valuable facade.

Other energy efficiency measured implemented at same renovation: none.

Achieved results, including energy savings: measures to be executed.
2.7 Motivation for the application of energy efficiency measures and internal insulation

Global renovation:
- Saving energy
- Moisture problems and condensation
- Creating a comfortable indoor climate
- The improvement of the airtightness level to allow for the installation of a mechanical ventilation system, which requires an air tightness level of n50 < 1h⁻¹
- The ability to have large choice in heating systems (heat loss according to EN12831 is below 10 kW, so heat pump becomes an option)
- Comfort enhancement

Internal insulation:
- Preservation of facades
- External insulation difficult to execute due to masonry relief in facade
- Saving energy
- Comfort enhancement
- For legal reasons:
  - When located in an agricultural area, the volume for residential purposes cannot be larger than 1000 m³. Whenever current volume already is 1000 m³ and more, external insulation is not possible (in Belgium external dimensions are used so adding external insulation results in a volume increase). So when applying external insulation, there would have been no legal guarantee for obtaining a renovation license.
  - In the past, the Belgian and local city building codes did not allow to build over the building alignment line (= line between public road and building property), implying that external insulation was not possible. Recently, the codes have been adapted, allowing for the external insulation of front façade to extend over the building alignment line for a maximum of 140 mm.

2.8 References

Belgian Land Register
(http://statbel.fgov.be/nl/statistieken/cijfers/economie/bouw_industrie/gebouwenpark/)


3 Denmark

3.1 Survey of historic building stock

The Danish building stock up to 1950 can roughly be divided into 3 time periods: before 1890, 1890-1930 and 1931-1950, representing changes in building style. In this study, the buildings stock constructed before 1950 is classified as residential and non-residential buildings and distributed as given in figure 3.1. Data found in (Wittchen et al., 2014) was used to give an overview of the Danish building stock, where 1950 was the year closest to RIBuilds time period ending at 1945. However, it is understood that the buildings constructed in this period from 1945 to 1950 are represented in the buildings style of Denmark that is investigated. Wittchen et al. (2014) have obtained the data from energy labelling and the Building and Housing Register in 2012.
Residential buildings are subdivided into three groups; (1) single-family buildings e.g. farmhouse, detached house and terrace house, (2) multi-family buildings and (3) other dwellings e.g. dormitory, 24-hour care centre and other permanent residence. Non-residential buildings represent e.g. offices, commercial buildings and summerhouses. Figure 3.2 shows the number and percentages of residential and non-residential buildings constructed in the period before and after 1950.
Number of buildings of heated building stock

- Residential <1890: 13.491.959 (1%)
- Residential 1890-1930: 121.458 (8%)
- Residential 1931-1950: 243.562 (16%)
- Residential >1950: 150.786 (10%)
- Non-residential <1890: 137.938 (9%)
- Non-residential 1890-1930: 839.393 (55%)
- Non-residential 1931-1950: 11.457 (1%)
- Non-residential >1950: 13.491 (1%)
- Residential <1890: 9.959 (0%)

Number of building

- Single-family: 818.881
- Multi-family: 150.786
- Other residential: 34.908
- Non-residential: 16.978
- 0-100K: 468.320
- 100-200K: 234
- 200-300K: 34.304
- 300-400K: 3.534
- 400-500K: 2.334
- 500-600K: 150.786
- 600-700K: 137.938
- 700-800K: 243.562
- 800-900K: 121.458
- >900K: 13.491

Dissemination level: CO
From the energy labelling of buildings it is possible to extract the external wall area. These numbers give clear indications of the type of building with the most external wall; hence where most internal insulation can be installed. Based on total square metre and the average share of external walls Figure 3.3 shows the three types of residential buildings with their respective external wall area.

Figure 3.2. Number and percentage of residential and non-residential buildings constructed before and after 1950.
3.2 Energy consumption for space heating in the historic building stock

The energy usage of the Danish building stock is only available from theoretical calculations. However, the energy usage was compared to the energy statistics from the Danish Energy Agency (Kragh & Wittchen, 2010, p. 11). The deviations between the statistics and the calculation ranged from -0.6% to 2.1%. In figure 3.4 the energy usage is given based on the building type and construction time.
Figure 3.4. Energy usage for heating and hot water in buildings constructed before 1950.

### 3.3 Main wall types of buildings

The predominant building material used in the Danish building stock for the external walls are bricks. In the older part of the building stock bricks are used in combination with timber framing where the bricks are applied a thin layer of lime-mortar or lime. Moreover, in cultural buildings such as churches, castle etc. external walls can be constructed of stone. The residential building stock is constructed with mainly bricks with or without rendering. Around 1850-1930 buildings were constructed with massive external walls contrary to the period after 1930 where brick cavity walls were introduced.

Figure 3.5. Typical materials used for external walls for multi-family buildings.
3.3.1 Massive wall

From around 1850 single-family houses were constructed with solid brick walls, they could be rendered with a thin layer of lime mortar or lime. However, in the period 1890-1930 the solid brick walls were alternated by cavity walls with header (of brick). The walls were built on a foundation of bricks or concrete. The floor divisions were wooden beams with clay pugging. The roof is often constructed as pitched or mansard roof with clay roof tiles. From around 1900 house began to have wall without rendering, thus the masonry is not surface treated (Erhvervsstyrelsen, 2015).

The multi-family buildings constructed before 1890 were a direct continuation of the half-timbered buildings, but with solid brick external walls. From around 1875 cavity walls with header was introduce for walls with limited load-carrying capacity e.g. end walls. The thickness of the facades is largest at ground floor and decreases with the height of the building, see Figure 3.6 (Engelmark, 1983).

![Figure 3.6. Wall thickness in multi-family buildings with solid masonry. The numbers indicate the wall thickness in bricks where half a brick is approximately 11 cm (Engelmark, 1983).](image)

To enhance the facades visual character, the buildings were gradually applied rendering ruled to resembling dimension stone/ashlar, see Figure 3.7.
3.3.2 Cavity wall

In the period 1890-1930 the solid brick walls in single-family buildings were alternated by cavity walls with header (of brick). From 1931 to 1950 cavity walls with wall tie of steel was the majority but in-situ concrete walls were also constructed but not as the dominant wall type. The external walls of concrete were rendered contrary to the buildings with brick external walls. Concrete foundations were used. Most floor divisions were wooden beams but the concrete floor gained ground. Roofs were constructed with lower slopes than earlier and the roof materials varied among several products (Erhvervsstyrelsen, 2015).

The multi-family buildings constructed from 1931 to 1950 were also constructed similar to those from earlier periods of multi-family buildings with brick masonry. At the later period the solid masonry walls were gradually replaced by hollow walls with headers, see Figure 3.8; especially in the end walls.
3.3.3 Timber framing

Before approximately 1890 the single-family buildings were constructed with half-timbered walls with and infill panel of typical burned or unburned bricks rendered with a thin layer of lime mortar or lime, see Figure 3.9. The wall thicknesses were typically ½ a stone (12 cm). From around 1850 houses were constructed with solid brick walls rendered with a thin layer of lime mortar or lime. The houses have a stone foundation and a wooden roof structure with thatch or clay roof tile as in the later periods. The attic was not used for living (Erhvervsstyrelsen, 2015).

Multi-family buildings with half-timbered wall were mainly built up to the 1700s and typically up to 4 storeys. In the 1700s they were prohibited by law due to the risk of fire and facades were changed into solid brick walls as shown in Figure 3.9b. The end walls are not load carrying walls and have half or one brick (12 or 24 cm) thickness (Engelmark, 1983).
3.3.4 Joints with adjoining building elements (ceiling/roof, suspended floor, and foundations)

Foundations were constructed of bricks which were a one brick wider than the wall. This type of foundation was 5 bricks high and used until approximately 1900, see Figure 3.10. Hereafter cast concrete was introduced as the traditional material used in foundations (Engelmark, 1983).

Floor divisions were constructed of wooden beams with clay pugging and were the dominant type of construction until the 1950s; however, iron beams and concrete floors were also used. The wooden beams with a size of ca. 20 x 20 cm were carried by the outer walls as shown in Figure 3.11 depending on the given story of the building (Engelmark, 1983).
Figure 3.11. In facades the beams are covered with at least one brick. Different ways of carrying the beams depending on wall thickness, and if the beam is above windows or in the solid wall (Engelmark, 1983).

Floors with iron beams were mainly used in cases where buildings were equipped with balconies and bay windows and also in the buildings constructed around 1930s. It was also in the 1930s cast concrete floors began to be used as floor divisions.

Similar to the floor divisions of wood are the ceilings to attics, as the roof structure was constructed in wood. An example of a roof construction on a multi-family is shown in Figure 3.12.

Figure 3.12. Roof structure for a multi-family building constructed in the period ca. 1850-1930. The slope of the roof was in the period after 1930 decreased (Engelmark, 1983).
3.4 Materials used for historical building walls

The typical material used in the historic buildings for wall structures was masonry consisting of bricks and lime mortar. In Denmark brick have been locally produced, which means that a huge number of brickworks existed, e.g. in 1830 around 1000 brickworks existed (Oestbirk-avis, 2015).

In Rörig-Dalgaard et al. (2012) material properties for a brick produced for restoration purposes of older historic buildings is given. Bricks produced by Falkenløwe (termed Munkesten) were used. The name Munkesten is related to the dimensions which is the old traditional Danish brick size (approximately 28 cm x 7 cm x 14 cm). The brick properties are given in Table 3.1.

Table 3.1. Material properties for three bricks produced for restoration purposes of older historic buildings (Rörig-Dalgaard et al., 2012).

<table>
<thead>
<tr>
<th>Brick colour</th>
<th>Saturation coefficient (%)</th>
<th>Open porosity (%)</th>
<th>Dry density (kg m(^{-3}))</th>
<th>Water absorption coefficient (kg m(^{-2}) s(^{1/2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright</td>
<td>12.9</td>
<td>34.9</td>
<td>1750.2</td>
<td>0.23</td>
</tr>
<tr>
<td>Medium</td>
<td>12.6</td>
<td>33.0</td>
<td>1787.6</td>
<td>0.30</td>
</tr>
<tr>
<td>Dark</td>
<td>9.8</td>
<td>31.4</td>
<td>1800.6</td>
<td>0.32</td>
</tr>
</tbody>
</table>

3.5 Most common types of structural damages of historical building walls and their causes

Timber framing:
- Rot in wooden parts e.g. from ingress through the roof.
- Subsidence of walls.

Brick buildings:
- Rot of wooden floors above basement, due to moisture from the terrain and rising damp.
- Rot of wooden strut in ceilings/external wall behind the cornice and floors in attic from water ingress.
- Efflorescence (salt) from salt contained in materials or from absorbed water.
- Painted rendering falling off the walls due to salt crystallisation.
3.6 Case studies on renovation of historic buildings

3.6.1 Glumsøparken Ågerupvej 10-16, Brønhøj

*Year of construction:* 1942

*Year of energy renovation (and internal insulation):* 1977

*General description of building:* 3-storey apartment/residential building, unheated attic and basement, 360mm brick walls.

*Internal insulation material:* Mineral wool

*Internal insulation method:* A steel/wood stud frame, (steel: profile height 80 mm, wood: 50x75 mm), is mounted at the ceiling and floor every 60cm, 50 mm from the wall. 50mm continuous mineral wool slabs are placed between wall and frame, 75 mm mineral wool is placed in the frame, and 13 mm gypsum board with an adhered vapour barrier (plastic foil) on the back, is fastened to the frame. In the bathrooms, 50 mm mineral wool behind 50 mm aerated concrete.

*Motivation for renovation:* Objective is first of all, reduction in energy consumption and to assess the method and energy savings that could be achieved. That said, the project also aims to clarify, not only expenses associated with an internal insulation project, but also the nuisances experienced by the residents.

*Other energy efficiency measured implemented at same renovation:* Energy efficient windows, roof insulation, thermostatic valves on radiators, insulation towards basement, walls towards staircases insulated, all main pipes insulated.

*Achieved results:* A 45 % reduction in energy consumption was achieved.
3.6.2 Ryesgade 30, Ryesgade 30, Copenhagen

Year of construction: 1896

Year of energy renovation (and internal insulation): 2011-2012

General description of building: 7-storey apartment/residential building, unheated basement, utilized attic space (after renovation), 350-710 mm bricks (varying thickness in different storeys).

Internal insulation material: Aerorock and Kingspan

Internal insulation method: The inside walls are thoroughly cleaned from all organic matter. To eliminate possible air pockets behind insulation, a coat of plaster is applied, and insulation adhered. 20 cm from the floor, the insulation was discontinued to create thermal bridges and ensure warmer conditions at beam ends, and thus less risk of mold growth - and to give room for installations (this technique not implemented in the top storey). In 2/3 of the building Aerorock (2x20 mm + 10 mm fibre gypsum) is used, and Kingspan (Kooltherm K17 , 40 mm + 12.5 mm gypsum assumed*) in the last.

Motivation for renovation: Objective is to develop solutions for renovation of older apartment buildings, and test the solutions.

Other energy efficiency measured implemented at same renovation: External insulation of fire gable, energy efficient windows, mechanic ventilation, insulation towards basement, solar panels

Achieved results: Aim was to demonstrate solutions for energy renovations in old apartment buildings, and reduce energy consumption to 35kWh/m2/year (former low energy class 1).Low energy class 1 was not reached, but the energy consumption was reduced to 79.7 kWh/m2/year (including solar gains), which is approximately 50 %. The user behaviour plays a vital part in the energy reductions. If the new mechanical ventilation systems were used properly (instead of natural ventilation (windows)) a significantly higher reduction in energy consumption could be achieved.
3.6.3 Knivholt Hovedgaard, Østrelade, Hjørringvej 180, Frederikshavn

Year of construction: 1852

Year of energy renovation (and internal insulation): 2013

General description of building: 1-storey barn for assemblies, 600 mm field stone walls, no attic or basement.

Internal insulation material: iQ-Therm

Internal insulation method and material: The surface is cleaned, and a mineral based adhesive mortar is applied to both wall surface and iQ-Therm plates, and the 80 mm thick iQ-Therm plates are adhered to the wall in running bonds. iQ-top serves as a reinforcing plaster, and is applied in a 5-10 mm layer. iQ-Fill, a capillary active mineral filler, is applied to achieve a finer surface (max 2 mm), which is painted with vapour permeable paint, iQ-Paint. Only half of the building has been insulated (the building can be divided in two sections).

Motivation for renovation: Tenants were unable to utilize space close to walls, as it was very cold.

Other energy efficiency measured implemented at same renovation: floor and ceiling/roof insulated with 150 mm Rockwool.

Achieved results: Very satisfied client. The room seems bigger as the space near the walls is useable.

3.6.4 Elmehuset, Alléen 3, Copenhagen
Year of construction: 1887

Year of energy renovation (and internal insulation): 2010

General description of building: 4 storey building for care of handicapped children, unheated basement, utilized attic space (after renovation), 470-590 mm brick walls

Internal insulation material: Mineral wool

Internal insulation method:
- Only gable ends: A 120 mm secondary wall/stud wall is installed with 70 mm mineral wool placed 25 mm away from the outer wall. At no point does the secondary wall/insulation come in contact with the heavy outer wall. A vapour barrier is tightly installed on the inner surface of the insulation.
- Two layers of 12.5 mm gypsum boards are put up on the wall. The joints between adjacent building elements were sealed with soft grout.

Motivation for renovation: The objective was to achieve an indoor climate and energy consumption corresponding to the guidelines and requirements from the Danish Building Regulations.

Other energy efficiency measures implemented at same renovation: New roof including insulation, energy efficient windows, district heating, insulation of distribution pipes, new ventilation system with heat recovery

Achieved results: Through the renovation, the building energy class evolved from G to C. The tenants are satisfied. The windows and doors now fulfil authority requirements, and the heat loss and comfort have been improved. Roof and dormer windows also successful; meets authority requirements in regard to energy savings. The internal insulation of the gables has improved comfort levels.

3.7 Motivation for the application of energy efficiency measures and internal insulation

- The objective was to achieve an indoor climate and energy consumption corresponding to the guidelines and requirements from the Danish Building Regulations.
- Tenants were unable to utilize space close to walls, as it was very cold.
- Objective is to develop solutions for renovation of older apartment buildings, and test the solutions.
- Objective is first of all, reduction in energy consumption and to assess the method and energy savings that could be achieved. That said, the project also aims to clarify, not only expenses associated with an internal insulation project, but also the nuisances experienced by the residents.

3.8 References


4 Germany

4.1 Survey of historic building stock

4.1.1 General facts about data sources

The following statistics is based on a representative questioning among house owners across Germany which was conducted by IWU (Institut für Wohnen und Umweld, Darmstadt) and BEI (Bremer Energie Institut). This survey includes about 7500 data sets which cover around 50 per cent of all German cities and rural districts. Two main questions should be clarified within the study. One was about the present energetic standard in German residential buildings, how efficient were energy-saving politics in the past, starting with the German Heat Insulation Ordinance in 1995 and ending with the last edition of the German regulation for energy saving in buildings and building systems in 2009\(^6\). The second question was about the renovation activities in Germany, to which extend should modernization activities be carried on to ensure currently defined energy-saving objectives of the federal government.

An important extract of this study is the fact that energetic restoration quote in Germany is much smaller than needed to reach the German objectives of a nearly carbon-dioxide-neutral building stock in 2050. (Bundesregierung, 2010) Actually less than 1% of the entire building stock is renovated per annum while more than 2% would be necessary.

4.1.2 Building Types

Figure 4.1 shows the distribution of the years of construction for the German residential building stock.

![German Residential Building Stock](image)

*Figure 4.1. German Building Stock (Data Source: BMWi2014, p.5).*

\(^6\) In fact, the last edition of EnEV (German regulation for energy saving in buildings and building systems) was published in 2014. This was not relevant for the study which was undertaken in 2009/2010.
Nearly 90 per cent of all buildings are private property, around 5% are owned by communities and the remaining 5% by building companies. This equals a privacy quote of nearly 100% of all single- and two-family houses and 50% of apartment buildings. (Diefenbach, Cischinsky, Rodenfels, & Klausnitzer, 2010, S. 42) About 70% of the analysed single- and two- family buildings were free-standing single-family houses, double and row houses each 15%. (Diefenbach, Cischinsky, Rodenfels, & Klausnitzer, 2010, S. 43)

4.2 Protection levels and energy consumption

About 38% of the final energy consumption in Germany attributes to the building sector. The majority of this part is consumed by residential buildings. (BMWi2014)

![Final Energy Consumption in 2013 by Sector in Germany](image)

*Figure 4.2. Final Energy Consumption in Germany for Building Sector (Data Source: BMWi2014, p.7).*

About 3% of all German residential buildings are listed buildings. Among all residential buildings erected before 1978, approximately 5% are listed ones. Restriction for these buildings are reflected in a reduced refurbishment quote for external walls (15.5%) compared to the entity of all buildings built before 1978 (21.1%). (Diefenbach, Cischinsky, Rodenfels, & Klausnitzer, 2010, S. 58).

Number of residential buildings built before 1949 related to the total number of residential buildings in Germany: 25.9 % (LSN 2014, p. 15).

The German Heat Insulation Ordinance from 1995 made first demands on the heat resistance of envelope parts for all new buildings. Out of all residential buildings nearly 40% are nowadays
equipped with external insulation at the walls, 75% at the roof and 40% at the basement. An analysis of this insulation quote for the different construction periods shows much higher insulation quotes for younger buildings (after 2005: 66% walls, 99% roof, 87% basement) than for the older ones (before 1978: 36% walls, 68% roof, 23% basement). The figures are no 100% because for walls there are alternative constructions, e.g. coring brick, which show a sufficient insulation standard and don’t need an additional insulation layer. For basement/roof – it depends on the construction. If the basement is an unoccupied zone (area for service and house connections), there’s no need to insulate it. In this case, basement ceiling is insulated instead of the basement itself. A difference is also given for the fraction of insulated area for different construction years. If there is any insulation, modern buildings show an insulated part of the whole area close to 100% while old buildings are only partly insulated (buildings before 1978: 78% of external wall area, 91% of roof area, 85% of basement area). (Diefenbach, Cischinsky, Rodenfels, & Klausnitzer, 2010, S. 44)

Insulation practice differs a lot among the construction types. While 84% of all timber constructions show an insulation layer, only 24% of single-leaf masonry and 32% of the timber constructions are insulated. 51% of the double-leaf masonry and 64% of solid constructions are provided with insulation. (Diefenbach, Cischinsky, Rodenfels, & Klausnitzer, 2010, S. 53)

The dominating type (55%) of insulation among residential buildings in Germany is external insulation. Interspace insulation is realized for 27% and internal insulation for 12% of all external walls. As expected, the major insulation type for single-leaf masonry (85%) and solid constructions (86%) is external insulation, for double-leaf masonry interspace insulation (64%). Internal insulation dominates the timber frame constructions with a quote of about 54% and it’s mainly realized in older buildings where 16% of all constructions show internal insulation. (Diefenbach, Cischinsky, Rodenfels, & Klausnitzer, 2010, S. 54)

Among listed residential buildings, mainly internal insulation (53%) is added. Several restrictions could be the reason. Some of them are also valid for non-listed buildings, e.g. external walls adjacent to a neighbour- lot (all buildings: 14%, buildings before 1978: 16%) or public sidewalk (all: 21%, before 1978: 26%) as well as a façade worth preserving (all: 5%, before 1978: 7%). (Diefenbach, Cischinsky, Rodenfels, & Klausnitzer, 2010, S. 59).

Insulation thickness is strongly depending on the building construction year. The average insulation thicknesses for buildings, built before 1978, is around 8.4 cm and thus much thinner than for new buildings (after 2005) with 14.1 cm. Internal insulation for these buildings was added with an average thickness of 7.3 cm. In the case of later installed insulation layers (all types of insulation), 9.1 cm insulation were chosen at the average for all buildings erected until 1978. Among these buildings, highest average insulation thickness is given for buildings which were renovated after 2005 and funded by governmental advance (KfW).

4.3 Main wall types of buildings

German building stock can be classified into different external wall construction types, namely single-leaf masonry, double-leaf masonry, timber frame / timber constructions and solid constructions (element building, concrete and others).
61% of all residential buildings in Germany are single-leaf masonry and 30% are double-leaf masonry. Other types are less common and represent only about 2-3% each of the whole residential building stock in Germany. New buildings with construction years after 2005 show less diversity and a higher part (13%) of timber constructions. (Diefenbach, Cischinsky, Rodenfels, & Klausnitzer, 2010, S. 52)

Further research on German building types was conducted by IWU and published in 2015 (Loga, Stein, Diefenbach, & Born, 2015) Basic typologies were developed within EU-project TABULA and completed within EU-project EPISCOPE. A summary of specific German residential building types is documented in (Loga, Diefenbach, Stein, & Born, 2012).

4.3.1 Massive wall

A systematic construction type overview for residential buildings is provided by ZUB ("Zentrum für umweltbewusstes Bauen") for each German state and for defined time periods and envelope types (Zentrum für Umweltbewusstes Bauen e. V., 2010). It includes about 800 data sets of typical German envelope constructions and materials.

Until the end of 19th century most wall construction were designed based on experiences and common rules of thumb. One example for external (load-bearing) walls is given by (Heine 1842) who suggests wall thickness of 1/6 of the bench height for rubble stone walls and of 1/8 for brick masonry. Another rule is provided by (Lämmerhirt 1869) who supposes wall thicknesses of 1.5 brick length for load bearing external walls. These rules were replaced with local construction regulations which were published from the 1870th on. These local regulations remained valid in parallel to the enactment of diverse national standards (e.g. DIN 1053 from 1937: first common masonry standard, DIN 4106). (Ahnert, R., Krause, K. H., et.al., 1985).

In 1872 the metric system was adopted in Germany. This led to a common brick format, called "Reichsformat" with dimensions of 25cm (length), 12cm (thickness), 6.5 cm (height). The usual perpend joint thickness was 1.2 cm, bed joints 1cm.

Faced brickwork made of premium frost-resistant brick shows beneficial moisture buffering effects. Due to cost reduction, this premium layer was often combined with low-budget brick backing. Another effect is given for masonry made of clinker. These bricks are less moisture permeable and provided moisture buffering mainly through the joints. For cost reasons, clinker was also used as facing layer and sometimes in a reduced form (perforated clinker). (Ahnert, R., Krause, K. H., et.al., 1985).

Massive walls made of natural stone differ strongly due to local availability and experiences. Cobble, rubble, quarry stone and erratic were widely used, especially in rural areas. They were mostly combined with brick masonry for structural stability reasons. Sandstone, granite, limestone, syenite and tuff were used where they were naturally occurring, e.g. Saxon sandstone mountains near Dresden. Further distribution of natural stone was forwarded with the railway network expansion after formation of the German national state in 1871.

Another typical massive wall type is clay constructions. These can be adobe walls (air-dried clay bricks in small format), Weller-walls (made of pisé in large format of wall thickness), clay stud walls (wooden stud surrounded by clay) and cob constructions (several clay layers in portable formworks).
From 1919 on, several special forms of masonry were developed to improve the thermal insulation of these walls. Approaches ranged from density reduction (e.g. increased porosity by adding organic substances which were burned out), format and hole enlargement, optimization of hole shape to reduction of joint dimensions. Alternative materials were developed, e.g. hollow concrete blocks and concrete blocks.

Table 4.1. Typical German masonry for load-bearing external walls in residential (and other) buildings according to (ZUB,2010)

<table>
<thead>
<tr>
<th>Construction</th>
<th>Time period</th>
<th>Detail drawing</th>
<th>Photography</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive brick / clinker wall</td>
<td>Until 1968</td>
<td></td>
<td></td>
<td>Typical thicknesses are 25, 30 and 38 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sometimes made of clinker and brick (facing)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sometimes plastered inside and outside</td>
</tr>
<tr>
<td>Massive vertical coring brick wall</td>
<td>1919-1948</td>
<td></td>
<td></td>
<td>Typical thickness is 30 cm plus 1 cm plaster on both sides</td>
</tr>
<tr>
<td>Massive natural stone wall</td>
<td>Until 1918</td>
<td></td>
<td></td>
<td>Different natural stone types, e.g. sandstone, granite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>In many cases used for semi basement constructions only</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Typical thickness &gt; 40 cm</td>
</tr>
<tr>
<td>Poroton brick wall</td>
<td>Until 1918, mod.</td>
<td></td>
<td></td>
<td>Special case of vertical coring brick wall</td>
</tr>
<tr>
<td></td>
<td>until today</td>
<td></td>
<td></td>
<td>Typical thickness 20 cm plus 1 cm plaster on both sides</td>
</tr>
</tbody>
</table>
4.3.2 Cavity wall

The objectives for placing cavities in external walls were an improvement of insulation standard, reduction of moisture in the masonry and material saving. Constructions range from small wall cavities up to cavity networks. Second constructions show cavities passing through the entire external wall, spanning several storeys and connected to ceilings with airing from the basement or roof. Connections between both wall layers (load-bearing layer and facing) were realized with perpenders (often treated with tar or bitumen), wire-wound armature or flat steel. From 1918 on, several cost-efficient construction and material types were developed, especially for small single family dwellings. This led also to very thin masonry walls with load-bearing layers of only 12 cm thickness for these cavity walls. (Ahnert, R., Krause, K. H., et.al., 1985).

Problems were thermal and moisture bridges through the connections between both layers or at the edges of the construction (corner, reveals etc.) and increased convective heat transfer due to strongly circulating air in the cavity. Therefore, cavities were often divided or filled, e.g. with cork or saw dust. Radiative heat exchange was sometimes reduced by the help of a foil at the internal side of the external masonry layer (Ahnert, R., Krause, K. H., et.al., 1985)
Table 4.2. Typical German cavity walls for residential (and other) buildings according to (ZUB, 2010)

<table>
<thead>
<tr>
<th>Construction</th>
<th>Time period</th>
<th>Detail drawing</th>
<th>Photography</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-layer brick wall</td>
<td>1919-1948</td>
<td>![Detail Drawing]</td>
<td>![Photography]</td>
<td>Consisting of two brick layers (load-bearing layer (mostly inner layer), 12 to 25 cm, and one face brick layer, 12 cm) Rendering on both sides</td>
</tr>
</tbody>
</table>

4.3.3 Timber framing

Timber frame constructions are a centuries old tradition in Germany with diverse local characteristics. It was strongly repressed in urban areas from about 1850 on, due to its bad fire protection and individual appearance. (Ahnert, R., Krause, K. H., et.al., 1985)

Table 4.3. Typical German timber framing walls for residential (and other) buildings according to (ZUB, 2010)

<table>
<thead>
<tr>
<th>Construction</th>
<th>Time period</th>
<th>Detail drawing</th>
<th>Photography</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber frame wall with loam infill</td>
<td>Until 1918</td>
<td>![Detail Drawing]</td>
<td>![Photography]</td>
<td>Wooden framework, infill made of stakes with pure or straw-enriched loam Typical thickness about 15 cm plus loam rendering inside</td>
</tr>
<tr>
<td>Timber frame wall with adobe infill</td>
<td>Until 1918</td>
<td>![Detail Drawing]</td>
<td>![Photography]</td>
<td>Wooden framework, infill made of adobe Typical thickness about 15 cm plus loam rendering inside</td>
</tr>
</tbody>
</table>
4.3.4  Joints with adjoining building elements (ceiling/roof, suspended floor, and foundations)

Table 4.4. Construction Details for Historic Buildings with Facades worth preserving (Schöberl et al. 2012)

<table>
<thead>
<tr>
<th>Construction</th>
<th>Time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>External wall - Ceiling</td>
<td>Until 1919</td>
</tr>
</tbody>
</table>

Timber frame wall with brick infill

Until 1918

Wooden framework, infill made of brick

Typical thickness about 12 cm plus loam rendering inside

Timber frame wall with rubble stone infill

Until 1918

Wooden framework, infill made of rubble stone and clay

Typical thickness about 17 cm plus loam rendering inside
Roof- Ceiling  
Until 1919

External Wall- Basement  
Until 1919

Window Reveal  
Until 1919
### 4.4 Materials used for historical building walls

Table 4.5. Material Data for Refurbishment, Selection from MASEA- Database (ZUB,2010).

<table>
<thead>
<tr>
<th>Material</th>
<th>Density [kg/m³]</th>
<th>Thermal Conductivity [W/mK]</th>
<th>Water Vapour Diffusion Resistance [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick</td>
<td>1246-1967</td>
<td>0.66-0.96</td>
<td>9.5-19.8</td>
</tr>
<tr>
<td>Sandstone</td>
<td>1919-2268</td>
<td>1.7-2.87</td>
<td>10.5-86.8</td>
</tr>
<tr>
<td>Lime Plastering</td>
<td>1600</td>
<td>0.7</td>
<td>7.0</td>
</tr>
<tr>
<td>Rendering</td>
<td>2000</td>
<td>1.2</td>
<td>25.0</td>
</tr>
<tr>
<td>Lime Sand Brick</td>
<td>1744-1900</td>
<td>0.85-1.04</td>
<td>4.75-39.8</td>
</tr>
<tr>
<td>Granite</td>
<td>2453</td>
<td>1.72</td>
<td>53.9</td>
</tr>
<tr>
<td>Tuff</td>
<td>1450</td>
<td>0.48</td>
<td>10.4</td>
</tr>
<tr>
<td>Travertine</td>
<td>2424</td>
<td>1.8</td>
<td>530</td>
</tr>
<tr>
<td>Oak (old)</td>
<td>740</td>
<td>0.18</td>
<td>223</td>
</tr>
<tr>
<td>Spruce</td>
<td>455</td>
<td>0.23</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Others: see http://www.masea-ensan.de/

### 4.5 Most common types of structural damages of historical building walls and their causes

Typical Damage Risks in Historic Buildings according to (Giebeler et al. 2008) are:
• General:
  • Infestation of timber components (fungus, mould, rot etc.)
  • Removal of hazardous substances, materials
  • Water damage due to defect waste-water pipes, drains, roof drain, roof covering, water installation etc.
  • Moisture damage from ground water due to missing sealing, horizontal barrier etc.
• External walls:
  • Efflorescence, salt deposits
  • Exposed reinforcement
  • Erosion of masonry joints
  • Spalling of external material layers (masonry, plastering etc.)
  • Surface mould growth due to bad insulation standard, high moisture loads etc.
• Other parts:
  • Sooting up of chimneys

4.6 Case studies on renovation of historic buildings

4.6.1 Warehouse City Building in Potsdam

Year of Construction: 1688

Short Description: The Warehouse City is located in the centre of Potsdam and was built in 1688. It was used to supply the Prussian army with cereals and other food. It creates the genius loci, which is among the best places along the shore, with prestigious addresses and tradition. The pre-intervention diagnosis and analysis includes an assessment of the energy balance, a report on moisture status, an evaluation of the horizontal structural waterproofing and an analysis of construction details: all prerequisites for retrofitting.

Internal insulation material: 60 mm and 80 mm loam cork clay insulation

Insulation Method: internal insulation

Motivation for Renovation: Moisture damages, reduction of energy demand.

Other energy efficiency measures implemented at same renovation: Renovation and insulation of all envelope parts, Renewal of windows, heating and domestic hot water system etc.
Achieved results, energy savings: Since the energy-use has been reduced by 28%, more than is required by law, the focus turns to possible condensation and critical moisture contents in the wood construction and the risk of mould growth. Furthermore an analysis and evaluation of driving rain protection on two of the building’s brick facades was done, based on adaptive hydrophobic impregnation. A hygrothermal examination of the construction details was therefore carried out in order to serve as the basis for the selection of an internal insulation system.

Source: (Troi et al. 2014)

4.6.2 Wilhelminian building in Dresden

Year of Construction: 1870

Short Description: This listed Wilhelminian-style building in Dresden was most likely built in 1870; it was altered in 1912. In 1980 the first floor and the first and second attic floors were inhabited, as well as part of the basement. The arrangement of rooms suggests that the house was originally designed for one family: it had three grand floors connected by open stairs, service rooms in the basement and servant bedrooms on the attic floors. Traces of this first design were found during the reconstruction work. On the first floor the three rooms looking onto the road originally opened into one another through an alignment of double doors.

Insulation Material: iQ-Therm Insulation Board

Insulation Method: internal Insulation

Motivation for Renovation: Reduction of energy demand, Structural damages (ceiling, windows, pipes, roof), mould growth at thermal bridges (kitchen, bath), flaking (plaster), rot (wooden beam ends)

Other energy efficiency measures implemented at same renovation: Renovation and insulation of all envelope parts, Renewal of windows, heating and domestic hot water system: use of geothermal energy, heat pump for preheating, gas condensing boiler.

Achieved results, including energy savings: Reduction of heating energy demand from appr. 290 kWh/m²a to 90 kWh/m²a. Non-bridged construction details to ensure reduced losses, mould growth etc.

Source: (Troi et al. 2014)
4.6.3 Baroque building in Görlitz

Year of Construction: 1250

Short Description: The listed historic building stands in the oldest quarter of the German city of Görlitz in Saxony. The main structure dates from 1250, but in 1726 the building was gutted by fire, so the rest had to be rebuilt. As it is now, the building presents a plain plaster facade and a regular window grid on three axes at the front and back. To the right is the entrance with a segmental arch, while to its left on the ground floor there is only one window. The construction of the outer walls consists of plastered masonry and the ceilings are supported by wooden beams.

Insulation Material: Calcium Silicate (5.5 cm), insulation plaster (10 cm), mineral wool (12 cm), insulation plaster (5 cm)

Insulation Method: internal Insulation

Motivation for Renovation: Reduction of energy demand

Other energy efficiency measured implemented at same renovation: Renewal of windows, reduction of thermal bridges, improved air tightness, mechanical ventilation with heat recovery, solar thermal energy etc.

Achieved results, including energy savings: Heating energy demand was reduced from original 173 kWh/m²a down to 28 kWh/m²a. Energy measures and maintenance work contribute to the sustainable refurbishment of protected monuments as well as to their preservation. They are a prerequisite for continuing use of these historic buildings, so long as the current requirements are met. The historic building is thus saved from decay. Its appearance after energy-efficient refurbishment corresponds to the original period.

Source: (Troj et al. 2014)
4.6.4 Renaissance building in Freiberg

**Year of Construction:** 1500-1600

**Short Description:** This Renaissance building in Freiberg is a listed building and was constructed in the sixteenth century. It is situated in the oldest quarter of Freiberg, in Saxony, Germany. It is a typical example of the mediaeval buildings in the historic city centre. The building comprises different types of construction, as parts of it were built at different times. The basement was built during the Middle Ages, while the ground floor dates from the Renaissance. The first floor and the roof are more recent. The street facade and a small part of the rear facade have a Renaissance appearance. The main structure consists of masonry in natural stone (gneiss) and plaster, wooden beam ceilings and a wooden roof construction.

**Insulation Material:** Calcium Silicate and TecTem Insulation Boards

**Insulation Method:** internal Insulation

**Motivation for Renovation:** Reduction of energy demand. Passive House standard should be reached, that would mean saving about 95% of the prior energy consumption of the building in Freiberg.

**Other energy efficiency measured implemented at same renovation:** In order to achieve this goal, a complete set of technical systems was installed in the house: solar thermal system, photolytic system, hot water storage, ventilation system and control system, as well as a weather station and various measurement sections. Windows of Passive House standard with insulation glazing (U < 0.7 W/m²K), which matched the old window openings, were used in the whole building. The existing old roof structure was retained. The facade was preserved in its original form by creating a kind of buffer zone. This zone is used both as an entrance and a stairwell. The buffer zone also reduces the heat loss of the building.

**Achieved results, including energy savings:** The insulation of external walls was consistently implemented up to U <0.1 W/m²K. Capillary internal insulation with calcium silicate climate boards and TecTem insulation panels were used in some parts. The roof structure was improved by creating a double-layer roof, with insulation both above and between the rafters. The calculated
annual heat energy demand amounts to 19.8 kWh/m²a. The calculated heat energy consumption corresponds very well to the measured data. This means that the intervention made it possible to save approx. 95% of the energy previously consumed by the building in Freiberg.

Source: (Troi et al. 2014)

### 4.7 Motivation for the application of energy efficiency measures and internal insulation

According to a questioning among private house owners, several motivations are relevant for refurbishment projects. A leading goal is the reduction of heating energy demand and thus running costs. Other reasons can be non-economic, e.g. improved living comfort, interest in modern technologies, climate protection or independence on fossil energy sources. Activating aspects are e.g. a bad visual appearance of the building, required maintenance tasks or defect building components. (Albrecht et al. 2012)

### 4.8 References


5 Italy

5.1 Survey of historic building stock

The Italian building stock accounts about 14,452,680 buildings and 3,140,000,000 m² of building floor area, out of which 85.43% are located in residential buildings (ISTAT 2011). Among the residential building surface, the 29% is located in single-family house and 71% in multi-family houses (ISTAT 2011; ISTAT 2001; ENEA 2012).

Among the whole building stock, about the 29% of buildings were built before 1945 and they could be then considered as historic buildings (ISTAT 2011, ENEA 2009).

No data concerning the historic buildings area in Italy is available. The only available data concern (ISTAT 2001):
- the total residential building stock area (TA)
- the total number of rooms in residential buildings (tnr)
- the number of rooms in residential buildings for period of construction (nr)
- the number of dwellings for period of construction (nd)
- the mean size of a dwelling (mad)

From these data we obtained:
- the mean size of a room (mar=TA/tnr)
- the historic buildings area (hba=mar*nr -before ‘45)

The result was checked with the historic residential buildings area obtained in another way, that is:
- mad*nd – before ‘45

The difference is under 1%. We obtained that the historic residential building stock area share from total residential building stock area is about 24%. We assumed that this data is acceptable.

No data concerning not-residential buildings area is available at the moment.

A consistent part of the Italian historical buildings could be classified in:
- Nationally listed buildings belong to Cultural heritage” according to Italian Decree 42/2004 (D.Lgs. 22/01/2004). They are buildings which, showing elements of artistic, historical, archaeological interest, are subject to protection. Any intervention on such buildings must be preceded by a “coherent, coordinated and programmed study, prevention, maintenance and restoration activity”. In this kind of buildings preservation necessities could be prevalent in respect to other necessities such as energy saving. Furthermore, some typologies (churches, abbeys, towers…) derogate from the application of national energy regulations.
- Locally listed buildings are listed according to local legislations and codes. They are buildings and aggregates inside historical centres or rural areas, which are subject to protection by the competent local authorities (municipalities), considering their historical interest or the necessity of landscape protection; usually the protection is related to the conservation of the shape, of the materials and of the colours and the external facades;
Among the residential and offices historic buildings, considering categories as palaces and villas, nationally listed buildings\(^7\) are about 60,000 buildings (2% of the total stock) (web database “Vincoli in Rete”), while locally listed buildings are assumed to be about 3,570,000 (27% of the total stock).

Figure 5.1 represents the breakdown of the historic buildings stock related to categories mentioned above by age from VII to XX century. About 75% of the historic building currently present in Italy were built between the XVIII and XX centuries.

5.2 Energy consumption for space heating in the historic building stock

Since no data on energy consumption for heating of historical building stock in Italy are available, it was estimated by making the assumptions described below.

Concerning residential buildings, the only available data concern (ISTAT 2001, ISTAT 2011):

- the yearly consumption of natural gas for domestic use in Italy ([kWh])
- the yearly consumption of natural gas for domestic use, distributed in the provinces of the Italian territory (cng [kWh]);
- the occupied surface of the residential buildings, distributed in the provinces of the Italian territory (s [m\(^2\)]);

As the main source of energy supply of heating is natural gas, used in Italy for about 70% of households (Statistique Report 2013), the data on the residential surface area was reduced proportionately (70%). Consumption of methane gas for cooking was considered negligible.

The overall consumption for heating in residential building is about 228 million MWh, estimated by processing data coming from (ENEA, 2012).

\(^7\) We consider only NLB classified as Palaces and Villas, considering that other building typologies (i.e. Churches and religious buildings) are not subjected to energy saving measures.
The annual energy consumption for heating per inhabited unit area (kWh/m$^2$) has been then estimated in different Italian climatic zone from: cng/s*70%.

The annual energy consumption for heating per inhabited unit area (kWh/m$^2$) in historic residential buildings has been evaluated, calculating the energy performance of real cases of Italian historical buildings in all the Italian climatic areas.

Figure 5.2 represents the annual energy consumption for heating per inhabited unit area obtained for the whole Italian building stock. Box-plots (blue and grey) represents its distribution in the Italian climatic areas, from the coldest F to the hottest B (A is numerically insignificant), obtained from provinces data.

In comparison, the coloured circles represent the energy consumption of the calculated real cases of Italian historical buildings (described in case studies section). Red line represents the median values of the heating energy consumption of calculated historical buildings. Since energy consumption estimates are made for the whole Italian building stock, the median value for real historical buildings is slightly higher than the whole stock (which obviously also includes the modern and recently retrofitted buildings).

Given these median values and the built surface of historic buildings for each climatic zone, the overall consumption for heating in residential historical buildings is assumed to be about 92 million MWh, on a total heating consumption of about 256 million MWh. This total value has been calculated considering data on final consumption of residential for space heating (22.08 Mtoe) (Odyssee EU project) and considering natural gas as the main source.

![Figure 5.2. Heating Energy Consumption evaluation for the whole Italian building stock. Box-plots represents the distribution of the heating energy consumption by the Italian climatic areas, from the coldest F to the hottest B (A is numerically insignificant). The empty colored circles represent the energy consumption for heating of case studies analysed by UNIVPM. The full colored circles represent a parametrization of the case studies, calculated in different climatic zones. Red line represents the median values of the heating energy consumption of historical buildings.](image-url)
Concerning *not residential buildings*, the only available data is related to public offices and schools\(^8\) (about 56,580 buildings): the total energy consumption for heating is about 14.5 million MWh (ENEA 2009).

### 5.3 Main wall types of buildings

A noteworthy common feature of the Italian historic buildings is their ability to sustain modifications: their aspect is today the result of slow but sometimes radical transformations (Vallucci, Quagliarini & Lenci 2014; Doglioni & Mazzotti 2007). Each historical building is in fact a ductile, evolving organism, able of changing to solve the new necessity of its users, the new situations in which it can find itself within the urban texture. Walls are knocked down, built anew or built alongside others. Besides, windows are closed, opened or transformed and so on (Giuffrè 1996; Doglioni & Mazzotti 2007).

The nowadays-urban texture of the Italian historic centres is the result of the evolution of spaces during the centuries: the increases of the population that occurred (typically during the 17th century) led to the progressive filling of free spaces between buildings. New buildings came up close to the existing ones, often sharing the border wall (Giuffrè 1996). Thus, a firstly single monumental building can now appear inserted into a more complex scenario.

From a survey of historic buildings in different Italian regions, it clearly emerges that there exists a common matrix translated into reality by using particular interpretations (Giuffrè 1996).

Historic buildings of the urban texture are made by elementary cells aggregated differently in plan and superimposed so as to form units of more than one floor. The differences depend on the urban texture in which the building is built (i.e.: pre-existing elements, available spaces). Representative or monumental historic buildings have however similar constructive techniques.

The masonry walls, which form partitions, support the horizontal elements: floors and roofs. A connecting structure between the various levels is present: the staircase. From this common matrix each local community has worked out its own construction language during centuries, in close dependence on the local resources and on the conditioning derived from long years of indigenous experience (Giuerrieri 1999; Giovannetti 1992; Giovannetti 1997; Giovannetti 2000; Giuffrè 1991; Giuffrè 1999; Giuffrè 2003).

Thus, in this reference framework, looking at the Italian historical masonry buildings, it is possible to distinguish between three main different construction elements: the masonry walls, the wooden floor and the wooden roof, by paying attention about how these three elements are connected (Figure 5.3).

Considering what is reported above, it clearly emerges that building construction techniques are substantially unchanged from the Middle Age, even if each local community can have used a different constructive language (Giuerrieri 1999; Giovannetti 1992; Giovannetti 1997; Giovannetti 2000; Giuffrè 1991; Giuffrè 1999; Giuffrè 2003).

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\(^8\) The analysis refers to buildings of the public sector and in particular schools and offices, in buildings that are entirely devoted to these purposes and not with mixed uses, excluding the typologies derogating from the application of national energy regulations. It should also be noted that, with regard to the offices, only the buildings occupied by entities related to the Public Administration were taken into account.
5.3.1 Massive wall

The high architecture (i.e.: religious or military) has been almost always made by worked stones. Vitruvio named this kind of masonry “opus quadratum” (Figure 5.4). It is possible to observe the regularity of its horizontal layers and the regular interlocking of the stones across the wall, to make it monolithic. The squared stone masonry (opus quadratum) does not necessarily require mortar, because its monolithism is achieved by means of the suitable arrangement of the stones. When it is made by fired bricks, mortar is instead necessary (Figure 5.4).

At the same time, masonry buildings have also a “popular” tradition. As an “evolution” of the Roman “opus concretum”\(^9\), from about the Middle Age, two or three-leaf masonry is present. Usually, the external leaves are made as a monolithic or, sometimes, as a rubble masonry (see also below), while the internal core is made by rubble stones and/or bricks fragments and mortar (Figure 5.5).

Another common masonry met in Italian historical buildings is made by irregular stones connected by mortar (rubble masonry), but in spite of their unevenness, the technique of the “raw” stones masonry is not without rules. In all ancient treatises, up to the beginning of the 20th century, the description of the raw stone masonry is present. Requirements are always the same: every i.e. three feet of height, a horizontal layer shall be settled; big stones oblong shaped shall be placed across the wall as frequently as possible. Other rules regard as to fill the voids among the stones with little pieces of brick and mortar, how to place stones accounting for their particular shape, and so on. The trend to obtain a masonry as close as possible to the squared (monolithic) masonry one is evident (Giuffrè 1996). In this way, a layer of fired bricks was sometimes placed across the wall, to achieve the horizontal laying and regularise the masonry (rubble listed masonry).

All of these masonry walls are often externally protected by plaster, which is usually present even inside.

5.3.2 Joints with adjoining building elements

Floors are usually made by large main beams and placed at rather close intervals. They are simply supported by lateral walls (Figure 5.7). Wooden planks, a layer of mortar and a tile pavement usually constitute the finishing layers. Sometimes, smaller secondary beams are placed orthogonal to the main beams, placed at a distance which allows for covering of thin bricks, the traditional “half-brick”, which form the structure of the floor above (Giuerrieri 1999; Giovannetti 1992; Giovannetti 1997; Giovannetti 2000; Giuffrè 1991; Giuffrè 1999; Giuffrè 2003).

Steel (iron) simply supported beams can substitute the wooden ones after about 1850 (Figure 5.8). In this case, fired flat or curved tile elements can be present on the lower surface.

Besides, reinforced concrete beams can occur after about 1930 (Figure 5.9). In this case, fired hollow flat tile elements are present between them. In this case, reinforced concrete beams can be

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\(^9\) About at the end of the 1st century BC, the Romans invented the opus concretum made by alternate layers of little stones (caementa) and mortar (material) put into forms and beaten. At fixed intervals, a layer of large bricks (bipedali) was placed across the wall, to achieve the horizontal laying, while the monolithism was assured by the coesion of the mortar. Everybody knows how extraordinary works the Romans built with this kind of masonry. Nevertheless, it should be observed that the most of the Roman monuments have not arrived at our days: their monolithism was assured by the mortar, but if it was not a good mortar the wall was easily broken up (Giuffrè 1996).
simply supported by the surrounding masonry walls, or, supported by reinforced concrete confining rings made inside and along the surrounding masonry walls.

The roof has usually beams parallel to the street front, simply supported by gable walls or wooden truss, or sloped, simply supported beams perpendicular to the street front (Figure 5.10). Wooden planks with tile elements represent the finishing layers. Sometimes, smaller secondary beams, placed orthogonal to the main beams at a distance which allows for covering of thin bricks, the traditional “half-brick” can substitute the wooden planks (Giuerrieri 1999; Giovannetti 1992; Giovannetti 1997; Giovannetti 2000; Giuffrè 1991; Giuffrè 1999; Giuffrè 2003).

Sometimes, the first floors are made by vaulted masonry structures in some geographical areas (Figure 5.11), reminder of a Roman practice. This is a less simple structure than the wooden floor. It requires a greater degree of construction skill. Besides, the static thrust must be countered by increasing the thickness of the surrounding walls (Giuerrieri 1999; Giovannetti 1992; Giovannetti 1997; Giovannetti 2000; Giuffrè 1991; Giuffrè 1999; Giuffrè 2003).

In many historical Italian buildings built between the 16th and the 19th century, light vaults or ceilings are present instead of heavy (masonry) vaults. These were usually made by mats of reeds and plaster nailed to an upper wooden framework (Figure 5.11). The mat of reeds was made up of either small reeds, set side by side, or larger reeds broken and twisted to create an orthogonal grid. The wooden framework included a main structure of permanent arches, made by usually irregular wooden boards joined together by nails, braced by a secondary structure of small section wooden beams (Quagliarini & D’Orazio 2005).

![Figure 5.3. Typical construction elements of an Italian historical building.](image-url)
Figure 5.4. Monolithic wall. Materials: dry stone or stone and mortar (up); fired bricks and mortar (down).

Figure 5.5. Two leaf wall. The external leaves are usually made as a monolithic wall; the inner leaf is made by rubble stones of fragments of bricks and mortar.

Figure 5.6. Rubble (listed) walls. They are made by irregular stone and mortar (left). Sometimes, they are regularised by horizontal bricks layers (right).
Figure 5.7. Wooden floors. They are made by wooden beams and planks or fired bricks. A layer of mortar and then a layer of fired bricks represent the finishing layers.

Figure 5.8. Steel (iron) floors. They are made by steel (iron) beams and, usually, fired tile elements, mortar and then fired bricks.

Figure 5.9. Reinforced concrete slabs. They are usually made by reinforced concrete beams and fired hollowed tile elements.
5.3.3 Cavity wall

In 19-th century cavity walls were introduced, but they are not very widespread.

5.3.4 Timber framing

This construction technology is not widespread in Italy, although it comes from the Roman opus craticium (Margani 2009).
The wooden architecture of the Alpine regions in Italy is typically built in block-bau (stacked trunks) rather than in timber framing. The timber framing is used occasionally to make the attic floor of the mountain buildings, designed to store hay, or to make sheds, small stables, annex buildings to the primary residences (Frattari & Garofolo 1996).

Further rare examples can be found in other Italian regions from XVII century, developed for security reasons after earthquakes: the “baraccate” houses near Messina, the “accapannate” houses in the Etna Volcano area, the “opere beneventane” in Campania Region. Other examples can be found in Calabria and Abruzzo Regions (Margani 2009).

5.4 Materials used for historical building walls

The most common types of walls built from Roman times in Italy are essentially attributable to the three types previously described:

- Monolithic masonry made by stones or fired bricks and mortar
- Rubble masonry with mortar
- Two or three leaf masonry made by rubble masonry or bricks and mortar

Until the beginning of '900 such construction techniques have continued virtually unchanged with regional peculiarities and differences due primarily to the availability of local materials.

We describe below the materials used for historic buildings most widespread at national level.

5.4.1 Stones

The stone for buildings could be:

- Rough stone: alluvial (rounded shape) or from shredding (sharp-edged)
- Carved stone: blocks of squared stone (Giuliani 1993)

It is well known the modern classification of rocks into three main classes that relate to the mode of differentiation in the terrestrial crust:

- Magmatic (volcanic lava origin), like granite, porphyry, gneiss, etc.
- Sedimentary (due to degradation and sedimentation of existing rocks), such as limestone, dolomite, travertine, sandstone, etc.
- Metamorphic (due to the transformation of magmatic and sedimentary at high pressures and temperatures), as schist, quartzite, marble, etc.

The most archaic Roman masonry is in tuff, abundant material in Lazio region. In imperial times, the colonization allowed the import to Italy of materials coming from remote regions too. They have been used for building stones such as: red Egyptian porphyry, red Aswan granite, diorite, sandstone, porphyry from the Orient, from Greece, from Africa. These materials are very rare outside Rome and practically are not used elsewhere in Italy (Rocchi 1990).

In the Middle Ages the correlation between resources of local quarries and use of stone material in place is especially true in smaller settlements, while large cities continue to absorb materials also coming from far away. Very popular is the Istrian stone across the north-central Italy; in Po Valley the stones of the Alps; in the south peperino tuff. From medieval to modern times there has been a partial impoverishment of stone masonry, increasingly performed with materials less resistant but
more workable, even for the growing use of the plaster that hide the quality of the stone. Serene sandstone and white marble are widely used (Rocchi 1990).

In general in Italy, the most common types of stones used in construction and are:
- Slates, of poor quality if used for masonry, but spread for the construction of floors and coverings
- Limestone (travertine, marble, stone of the mountain, dolomites), suitable to obtain lime and as rubble for the conglomerate
- Sandstones, widely used for the realization of masonry
- Tuffs, where present widely used for their ease of processing

### 5.4.2 Bricks

In ancient times (Roman period / Middle Ages) the bricks were manufactured from clay mixed with water and the mixture was compressed by hand or with rudimentary equipment into special molds (Giuliani 1993). The bricks were fired in the furnace at a temperature of about 800 °C; their quality depended from mixing and cooking temperature.

The Romans used even mix clay to finely chopped tuff, to give a reddish hue to the brick (Rocchi 1990).

Even in the XIX century the mixture of clay with water was done by hand, only in the modern age bricks began to be made with machines (Rocchi 1990).

The variability of the characteristics of traditional bricks (those modern extruded have more uniformity) depends on two key features (Rocchi 1990):
- The porosity (which also determines the frost susceptibility).
- The content of soluble salts (which in a brick well-cooked should be very low, to avoid phenomena of crystallization).

### 5.4.3 Mortars and plasters

The most common types of binder used in ancient times were gypsum and lime. From the historical manuals, we learn the use of natural or artificial additives.

Gypsum plasters or mortars are prepared by heating gypsum minerals or selenite rocks (both composed of hydrated calcium sulphate) at moderate temperatures. As calcium sulphate is slightly soluble in water, gypsum was not normally used in exposed surfaces in damp climates (Torraca 1988).

Most often in ancient masonry lime plasters and mortars were used. Lime was obtained by heating limestone, which is composed essentially of calcium carbonate, at about 900°C.

In Roman times, the lime was obtained from pure limestone (calcium carbonate) cooked and mixed with water. It was able to set and harden only in contact with air. Lime mortar was obtained mixing lime to silica sand.
Hydraulic lime was obtained from the impure limestone or from the limestone marl. The presence of impurities in the limestone, as silica and alumina, confers hydraulic properties to lime, i.e. the setting and hardening take place even in the absence of air and under water. The Romans did not know the use of hydraulic lime as a binder, but they manufactured the hydraulic mortar using natural (pozzolan) or artificial (brick dust) additions (Giuliani 1993).

In the Middle Ages the pozzolan was no longer used, until the Renaissance when it was discovered that the burning of limestone marl produces hydraulic lime to be used to achieve hydraulic mortar.

In Roman times concrete was made with sand, pozzolan, lime, fragments of stone and water. The use of hydraulic compounds permitted the execution of water works in the Roman period.

In the Middle Age the technology of concrete and hydraulic mortars appears to have been scarcely employed although the filling with rubble of cores of large masonry-lined walls might involve the use of hydraulic materials (Torraca 1988). In Middle Age concrete was achieved with gravel (crushing or alluvial), sand, lime (air or hydraulic), water.

The “cocciopesto” is a mixture of lime, sand or pozzolan and fragments of brick. It had hydraulic characteristics favored by both the pozzolan is by brick fragments mixed with lime that gave hydraulic properties to the mortar. It was used for wall cladding in damp places and as subfloor (Giuliani 1993). In architecture manuals of the XV-XVII century, various recipes are reported of plaster obtained by mixing lime and powdered brick (D'Orazio 1999).

From the XIX century in Italy "new materials" started to be employed, including cement (artificial hydraulic limes) (D'Orazio 1999).

5.5 Most common types of structural damages of historical building walls and their causes

Brick, mortar, plaster and porous stones, the main materials that compose the historical Italian building walls, undergo deterioration processes when exposed to the aggressive action of the environment. The rate and symptoms of such processes are influenced by a number of variables, partly depending upon the properties of the material itself and partly upon several environmental factors, acting separately or in various combinations (Torraca 1988). In Italy a standardized classification of the most common pathologies in these materials was produced by the Commission NOR.MA.L (Normativa per i Manufatti Lapidei). It is collected in the recommendations NORMAL 1/88, today having prescriptive and normative value because inserted in the UNI 11182:2006. The Table 5.1 provides the most common types of structural damages of historical building walls and their causes, taken from this legislation and also reported in other sources (Torraca 1988).
**Table 5.1. Most common types of structural damages of historical building walls and their causes, collected in the Italian recommendations NORMAL 1/88 and inserted in the standard UNI 11182:2006.**

<table>
<thead>
<tr>
<th>Damage Type</th>
<th>Description</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alveolar erosion (honeycomb, cavernous decay)</td>
<td>Presence of cavities of variable size and shape (alveoles), often interconnected with non-uniform distribution</td>
<td>Salt crystallization during fast evaporation phenomena in warm and windy areas. Mainly in very porous materials with a high content of soluble salts.</td>
</tr>
<tr>
<td>Biological crust, climbing plants</td>
<td>Macroscopically detectable presence of micro and / or macro organisms (algae, fungi, lichens, mosses, higher plants)</td>
<td>Presence of favourable biological conditions (mainly presence of water from groundwater infiltration or atmospheric humidity)</td>
</tr>
<tr>
<td>Incrustation</td>
<td>Modification of the surface layer of the material. Of varying thickness and generally resistant, the crust is distinguishable from the underlying parts for the morphological characteristics and often for the colour. It can spontaneously detach from the substrate that, in general, is disintegrated and / or powder</td>
<td>Presence of pollutants and humidity (carbonic acid, sulphuric acid)</td>
</tr>
<tr>
<td><strong>Disaggregation, crumbling</strong></td>
<td>Decohesion with the fall of the material in the form of powder or tiny fragments.</td>
<td>Salt crystallization; freeze-thaw cycles; Presence of pollutants and humidity (carbonic acid, sulphuric acid)</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Detachment:</strong></th>
<th>Solution of continuity between layers of material, either among themselves or relative to the substrate, which is a prelude, in general, to the fall of the layers themselves.</th>
<th>Presence of water (groundwater infiltration; damaged roof; atmospheric humidity; leakage from the building systems; strong side rain; condensate infiltration), Thermal expansion</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>Efflorescence</strong></th>
<th>Superficial formation of crystalline or powdery or filamentous appearance, usually whitish</th>
<th>Evaporation of water and deposit of salts (sulphates, carbonates, nitrites, chlorides) from the ground, the air, the material itself</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exfoliation, flaking</td>
<td>Degradation which is manifested by detachment, often followed by fall, of one or more surface layers sub parallel between them (sheets)</td>
<td>Presence of water (groundwater infiltration; damaged roof; atmospheric humidity; leakage from the building systems; strong side rain; condensate infiltration), Thermal expansion, freeze-thaw cycles</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Cracking, splitting</td>
<td>Solution of continuity in the material implies that the mutual displacement of the parts</td>
<td>Mechanical stresses (Loads, Soil movement; changes in building use; vibration), thermal expansion, freeze-thaw cycles</td>
</tr>
<tr>
<td>Front of capillary rise</td>
<td>Limit of water migration which is manifested by the formation of efflorescence and / or loss of material. It is generally accompanied by changes in colour saturation in the zone below</td>
<td>Groundwater infiltration</td>
</tr>
</tbody>
</table>
Pitting degradation, which is manifested through the formation of many blind holes closely spaced. The holes have basically cylindrical shape with a maximum diameter of a few millimetres.

5.6 Case studies on renovation of historic buildings

5.6.1 Town Hall “Palazzo degli Anziani”, Ancona

*Year of construction:* 425 (destroyed in 839 and rebuild in 1270)

*Year of energy renovation (and internal insulation):* 2011

*Short description:* Palazzo degli Anziani is a medieval stone and brick building, built in the thirteenth century, as the ancient town hall of the city. It has been recently renovated and became the seat of the municipal council. The structure has a particular architectural form, due to the steep terrain on which it stands. There are two main fronts: one gives on the sea front and the other one on a small square. The sea front, seven storeys high, has a base with ogival arches in white Conero stone and the rest of the structure in brick. The front of the square, just two storeys high, preserves the interesting architectural remains. The building base area is about 1028 m², while the net volume is about 15614 m³. External wall are made by bricks and internal plaster with different thicknesses (from 0.25 to 2.25 m) with a mean U-value of 1.19 W/m²K.

*Internal insulation:* An intervention for the internal insulation of the building has been proposed to achieve a U-value of 0.34 W/m²K (law limit). During the renovation works in 2011 (internal
renovation and installation of new heating generators), the original building envelope remained intact, works of thermal insulation were not actually carried out but studies on the feasibility are in course considering new Italian Regulations.

_OTHER energy efficiency measures:_ In 2011 the replacement of heating system (installation of condensing boilers) has been implemented.

_Motivation for renovation:_ 2010/31/EU directive for the retrofitting of public buildings.

_Planned energy savings:_ The estimated energy consumption for heating of the building before energy efficiency measures is 128.9 kWh/m² per year. The estimated energy consumption for heating of the building after the energy efficiency measures is 98.3 kWh/m² per year (24% energy saving).

### 5.6.2 Apartment Building “Palazzo Barilari”, Ancona

*Year of construction:* 1745-1784

*Year of energy renovation (and internal insulation):* 2007

*Short description:* The building, dating from the late eighteenth century, is built in a neoclassical architectural style, with the exception of the two late Baroque portals placed in via Barilari. It is characterized by a composite form consisting of a trapezoidal main building, including the courtyard, combined with a second L-shaped body and is composed by three levels above ground, a basement and a level of ramified caves below. The building has a residential use and hosts 11 apartments, its structure is composed by bearing brick walls and internal plaster (thicknesses from 0.27 to 0.68 m and mean U-value 1.08 W/m²K) and wood ceilings.

*Internal insulation:* The proposed intervention on the external wall consisted in placing EPS insulation boards, but it has been finally unrealized for restrictions by institutions.
Motivation for renovation: Energy Saving and improvement of indoor comfort; Legislative obligations.

Other energy efficiency measured implemented at same renovation: Replacement of windows, new heating systems (condensing boiler + radiant floor).

Planned energy savings: The estimated energy consumption for heating of the building before energy efficiency measures is 184 kWh/m² per year. The estimated energy consumption for heating of the building after the energy efficiency measures is 89.1 kWh/m² per year (52% energy saving).

5.6.3 Apartment Building “Palazzo Magnanini”, Mirandola (MO)

Year of construction: XVIII century

Year of energy renovation (and internal insulation): 2015

Short description: This building, dating from the XVIII century, is part of the historic urban settlement of Mirandola, a typical medieval town in the Po valley that still retains in the octagonal plan traces of its structure of Renaissance city-fortress. Being fully inserted into the urban texture, the building shares much of its walls with the adjacent buildings. The palace has an interior courtyard, and the structure is made of bearing brick walls (thicknesses from 0.16 to 0.68 m and mean U-value 1.08 W/m²K) and wooden ceilings. This mixed-use building features a ground floor for commercial use, a first floor with offices, while the upper floors, last of which is mansard, are for residential use.

Internal insulation: Due to restrictions by institutions on a possible intervention with internal insulation, the intervention on the external walls was limited to an "insulation plaster" (2 cm thickness in the internal wall and 3 cm thickness in the external wall), so that the thermal transmittance finally achieved has been 0.865.

Motivation for renovation: Energy Saving and improvement of indoor comfort; Legislative obligations

Other energy efficiency measured implemented at same renovation: Roof insulation, Replacement of windows, Replacement of heating system.
Achieved results, including energy savings: The estimated energy consumption for heating of the building before energy efficiency measures is 184 kWh/m² per year. The estimated energy consumption for heating of the building after the energy efficiency measures is 114.9 kWh/m² per year (38% energy saving).

5.6.4  Single Family House “Casa Graziosi”, Cattolica (RI)

Year of construction: 1935

Year of energy renovation (and internal insulation): 2003

Short description: Three-storey single family house for 3 people. The building has a base area of 96 m² and 3 floors for a total volume of 690 m³. It is designed in Art Nouveau style. It is not a nationally listed building but show interesting architectural elements that should be preserved. External wall before renovation were made by bricks and plasters (0.29 m) with a U-value of 1.76 W/m²K.

Internal insulation: Walls have been insulated with 6 cm EPS (Expanded Polystyrene) and plaster (ETICS technique) to obtain a U-value of 0.48 W/m²K.

Motivation for renovation: Energy Saving and improvement of indoor comfort.

Other energy efficiency measured implemented at same renovation: Insulation of roof; insulation of basement; replacement of windows; renewal of heating and DHW system.

Achieved results: The estimated energy consumption for heating of the building before energy efficiency measures is 264.7 kWh/m² per year. The estimated energy consumption for heating of the building after the energy efficiency measures is 140.4 kWh/m² per year (47% energy saving).
5.7 Motivation for the application of energy efficiency measures and internal insulation

5.7.1 Private Buildings

As for the private buildings in Italy, the energy efficiency measures implemented over the past decade are mainly due to regulatory, economic and cultural motivations.

- Regulatory motivations

Over the past decade, energy regulations in Italy have evolved significantly: new legislation and methodologies have been introduced according to the European Directives on the energy efficiency of buildings.

Directive 2002/91/EC, also known as the EPBD (Energy Performance of Buildings Directive), was implemented in Italy by Legislative Decree No. 192/2005 as amended and supplemented (mainly by Legislative Decree No. 311/2006 for what concerns the renovation of building envelope). As to existing buildings, the thermal transmittance values of the individual components of the building envelope are compulsory in the event of renovation of existing buildings envelopes.

Directive 2010/31/EU, also known as “EPBD recast”, updated the principles relating to the improvement of energy performance of buildings. The Directive was transposed in Italy by Decree Law No 63/2013, converted by Law No 90/2013. This law was applied with the recent Ministerial Decree 26/06/2015 establishing new methods of calculation and the new minimum requirements for the energy performance of buildings. In addition to the new calculation methods, the decree reinforces the minimum energy standards for new buildings and refurbished ones, optimizing the costs/benefits ratio of interventions, to meet the Nearly Zero Energy Buildings standard required by the European Directive.

For new buildings and those undergoing major renovation (intervention on more than 50% of the dispersing surface), the minimum requirements will be verified by comparing the building with a reference building (with identical geometry, orientation, location, purpose of use). For buildings affected by minor energy renovations (intervention on more than 25% of the dispersing surface), related to the building envelope and technical installations, minimum requirements are prescribed.

In both cases it must be verified the heat exchange average coefficient (related to the thermal transmittance of the envelope). In the case of minor renovation, among the verifications to do, there are in particular:

- Verification of the thermal transmittance of the structures subject to intervention.
- In case of interspace or internal insulation measures check that: \( U_i \leq 1.3 \ U_{\text{limit-i.}} \).
- Verification of the heat exchange average coefficient with the limit set for this kind of intervention.

Cultural motivations

Finally we may include a limited number of interventions made on the initiative of the building owners in order to reduce energy consumption and/or improve the indoor comfort.
**Economic motivations**

Tax deductions for the energy upgrading of buildings were introduced in Italy by the Budget Law for 2007 and are still in force. These deductions have been in recent years key drivers of energy efficiency improvements in the housing sector. The tax deductions (which are granted for both residential and commercial buildings) consist of reductions of tax in respect of actions to improve the energy efficiency of existing buildings (i.e. envelope insulation).

In the framework of the Government’s housing policy, Article 6 (1)(a) of the Decree Law of 31 August 2013, converted into Law No 124 of 28 October 2013, allocates EUR 2 billion to support access to home-buying loans. The Fund supports renovation and energy efficiency improvement projects, giving priority to young couples, families with one or more disabled person and large families (Italian Energy Efficiency Action Plan 2014).

**Table 5.2. Comparison of U-value limits for walls according to the Italian legislation:** Decree 311/2006 (now repealed); Decree 26/01/2010 for tax deductions; Decree 26/06/2015 (the decree currently in force). Values of Decree 26/06/2015 concern buildings affected by minor energy renovations; the values in the case of major renovation are higher.

<table>
<thead>
<tr>
<th>Italian Climatic Zones</th>
<th>Decree 311/2006</th>
<th>Decree 26/01/2010 (for tax deductions)</th>
<th>Decree 26/06/2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>from 01/01/2006</td>
<td>from 01/07/2015</td>
<td>from 01/01/2021</td>
</tr>
<tr>
<td>A</td>
<td>0.85</td>
<td>0.54</td>
<td>0.40</td>
</tr>
<tr>
<td>B</td>
<td>0.64</td>
<td>0.41</td>
<td>0.40</td>
</tr>
<tr>
<td>C</td>
<td>0.57</td>
<td>0.34</td>
<td>0.36</td>
</tr>
<tr>
<td>D</td>
<td>0.50</td>
<td>0.29</td>
<td>0.32</td>
</tr>
<tr>
<td>E</td>
<td>0.46</td>
<td>0.27</td>
<td>0.28</td>
</tr>
<tr>
<td>F</td>
<td>0.44</td>
<td>0.26</td>
<td>0.26</td>
</tr>
</tbody>
</table>

**5.7.2 Public Buildings**

The Directive 2010/31/EU states that “[...] The public sector in each Member State should lead the way in the field of energy performance of buildings, and therefore the national plans should set more ambitious targets for the buildings occupied by public authorities. [...] Member States should include within their national plans measures to support public authorities to become early adopters of energy efficiency improvements. [...] Buildings occupied by public authorities and buildings frequently visited by the public should set an example by showing that environmental and energy considerations are being taken into account and therefore those buildings should be subject to energy certification on a regular basis. [...]”

The Energy Efficiency Directive 2012/27/EU places energy savings requirements on EU countries’ buildings. This includes making central government buildings more energy efficient and requiring EU countries to establish national plans for renovating overall building stock. Article 5
requires each Member State to ensure that as from 1 January 2014, 3% of the total floor area of heated and/or cooled buildings owned and occupied by its central government is renovated each year to meet energy performance requirements.

To address the challenge of improving the energy and environmental performance of urban centres, some Italian cities are making efforts to improve their set-up and to encourage application of new technology solutions for sustainable development (Italian Energy Efficiency Action Plan 2014).

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Legge 27 dicembre 2006 n. 296 Disposizioni per la formazione del bilancio annuale e pluriennale dello Stato

Legge 28 ottobre 2013, n. 124 (in G.U. n. 254 del 29 ottobre 2013 - Suppl. Ord. n. 73) Conversione in legge, con modificazioni, del decreto-legge 31 agosto 2013, n. 102, recante disposizioni urgenti in materia di IMU, di altra fiscalità immobiliare, di sostegno alle politiche abitative e di finanza locale, nonché di cassa integrazione guadagni e di trattamenti pensionistici

Legge 3 agosto 2013, n. 90 Conversione, con modificazioni, del decreto-legge 4 giugno 2013, n. 63 Disposizioni urgenti per il recepimento della Direttiva 2010/31/UE del Parlamento europeo e del Consiglio del 19 maggio 2010, sulla prestazione energetica nell'edilizia per la definizione delle procedure d'infrazione avviate dalla Commissione europea, nonché altre disposizioni in materia di coesione sociale (G.U. n. 181 del 3 agosto 2013)


National Institute of Statistics, ISTAT, Population and housing census 2011
National Institute of Statistics, ISTAT, Population and housing census 2001


NORMAL 1/88 Alterazioni macroscopiche dei materiali lapidei: lessico.


RAEE, Rapporto Annuale Efficienza Energetica, Agenzia nazionale per le nuove tecnologie, l’energia e lo sviluppo economico sostenibile (ENEA), 2012.


Report RSE/2009/161 Agenzia nazionale per le nuove tecnologie, l’energia e lo sviluppo economico sostenibile (ENEA) “Analisi statistica sul parco edilizio non residenziale e sviluppo di modelli di calcolo semplificati”


UNI 11182:2006 Cultural heritage, Natural and artificial stone, Description of the alteration - Terminology and definition.

6 Latvia

6.1 Survey of historic building stock

The building sector in Latvia consumes almost 40% of total national energy consumption. Therefore the building sector has a significant energy efficiency potential. Most of the existing buildings have high energy consumption and they have significantly lower thermal properties than can be achieved by currently available technologies. Table 6.1 illustrates total number of residential and non-residential buildings and respective built area constructed before and after 1941 or 1945.

Table 6.1. Total number of residential and non-residential buildings and respective built area constructed before and after 1945. (EM, 2014; CSBL, 2015)

<table>
<thead>
<tr>
<th>Building type</th>
<th>Area, mio.m2</th>
<th>Number of buildings</th>
<th>Area, mio.m2</th>
<th>Number of buildings</th>
<th>Area, mio.m2</th>
<th>Number of buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>built before 1941 or 1945*</td>
<td></td>
<td>built before 1941 or 1945*</td>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-fam. buildings</td>
<td>8.5</td>
<td>16586</td>
<td>38.0</td>
<td>20029</td>
<td>46.5</td>
<td>36615</td>
</tr>
<tr>
<td>One family buildings</td>
<td>12.2</td>
<td>109376</td>
<td>21.3</td>
<td>186866</td>
<td>33.5</td>
<td>296242</td>
</tr>
<tr>
<td>Non-residential</td>
<td>4.2</td>
<td>5135</td>
<td>11.2</td>
<td>15077</td>
<td>15.4</td>
<td>20212</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>131037</strong></td>
<td><strong>62.7</strong></td>
<td><strong>221972</strong></td>
<td><strong>95.4</strong></td>
<td><strong>353069</strong></td>
</tr>
</tbody>
</table>

* - data available for one family buildings are before 1945 (CSBL, 2015) and data for multi family buildings and non-residential buildings are available before 1941 (EM, 2014).

Figure 6.1 shows number of buildings and respective built area of historical building stock built before 1945. It is assumed that multi-family buildings and non-residential buildings were not built during the Second World War. It demonstrates that while one family buildings are dominating (83%) in number of buildings, they take only 49% from built area. It can be explained by the nature of historic buildings – building stock constructed before 1945, is largely made up of one or two floor buildings.

Figure 6.1. Historical building stock built before 1945: (a) number of buildings and (b) respective built area.
Latvian State Inspection for Heritage Protection has listed 8765 objects as cultural monuments out of which 3441 are architectural monuments (or approximately 1% from total historical building stock in Latvia): 1291 of these monuments are of national significance, while 2150 monuments are of local significance. (VKPI, 2014).

### 6.1.1 Multi-family buildings

Share of historical multi-family buildings in total multi-family building stock based on number of buildings and built area is presented in Figure 6.2 (EM, 2014) These buildings include both wooden buildings and masonry buildings. Historical multi-family buildings constructed before 1941 make up 45% of the total number of multi-family buildings in Latvia. Despite the large number of buildings, the proportion of the built area before 1941 consists of only 18% of the total multi-family building area. This is due to the historic building characteristics - buildings constructed before 1941, are largely one or two floors buildings. During Soviet time (after 1941) 52% multi-family building stock was built.

**Figure 6.2. Share of historical multi-family buildings in total multi-family building stock based on number of buildings and built area (EM, 2014).**

### 6.1.2 One family buildings

Table 6.2 shows number of different types of one family buildings constructed in different time periods based on population census 2011(CSBL, 2015). Latvian government adopted the Agrarian Reform Law in 1920, which initiated construction boom of one family buildings. (Kursīte, 2014)

**Table 6.2. Number of different types of one family buildings based on construction year (CSBL, 2015).**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of one family buildings</td>
<td>20801</td>
<td>76936</td>
<td>38047</td>
<td>26152</td>
<td>27018</td>
<td>35856</td>
<td>23355</td>
<td>8136</td>
<td>13925</td>
<td>270226</td>
</tr>
<tr>
<td>Total number of two families buildings</td>
<td>2415</td>
<td>3540</td>
<td>2087</td>
<td>1029</td>
<td>456</td>
<td>218</td>
<td>65</td>
<td>54</td>
<td>222</td>
<td>10086</td>
</tr>
<tr>
<td>Total number of twin buildings</td>
<td>1347</td>
<td>2059</td>
<td>2503</td>
<td>1081</td>
<td>788</td>
<td>563</td>
<td>209</td>
<td>181</td>
<td>921</td>
<td>9652</td>
</tr>
<tr>
<td>Total number of row buildings</td>
<td>1292</td>
<td>986</td>
<td>912</td>
<td>536</td>
<td>677</td>
<td>340</td>
<td>167</td>
<td>287</td>
<td>1081</td>
<td>6278</td>
</tr>
<tr>
<td>Total number of one family buildings</td>
<td>25855</td>
<td>83521</td>
<td>43549</td>
<td>28798</td>
<td>28939</td>
<td>36977</td>
<td>23796</td>
<td>8658</td>
<td>16149</td>
<td>296242</td>
</tr>
</tbody>
</table>
Figure 6.3 illustrates share of historical one family buildings in total one family building stock of buildings and built area based on data presented in Table 6.2. As detailed data on built area before 1945 are not available, it is assumed that average built area of one family building is 112 m². It is calculated based on total number (299,866 buildings) and total built area of one family buildings in Latvia in 2009 (33.5 mio m²) (CSBL, 2015). Both historical one family buildings built area and building number accounts for 36% from total one family building stock.

![Figure 6.3. Share of historical one family buildings in total one family building stock based on number of buildings and built area.](image)

6.1.3 Non-residential buildings

Figure 6.4 presents share of different types of non-residential historical buildings. Total number of these buildings is 5137 occupying in total 4.19 million m². In number of buildings, office buildings and wholesales buildings are dominating while in built area, buildings occupied by offices and education and research facilities dominate.

![Figure 6.4. Non-residential building stock built before 1941: (a) number of non-residential buildings; (b) built area (EM, 2014).](image)

Share of historical non-residential buildings in total non-residential building stock based on number of buildings represents 25% while in built area 27% (see figure 6.5).
6.2 Energy consumption of historical building stock

Long and cold winters (above 4000 heating degree days) determine that the greatest energy consumption in the buildings is for space heating. Measured specific energy consumption for space heating in different historical buildings varies in a broad range from 30 to 920 kWh/m² per year. (Žogla (2008), Kašs et al.(2015)). Figure 6.6 illustrates correlation between thermal energy consumption for space heating and heated space. The higher heated area of building, the lesser specific heat energy consumption. This is due to thermal properties of building envelope, volume/heated space ratio and climate.

Figure 6.6. Specific heat energy consumption in historical buildings in Riga, Ventspils and Kuldiga. (Žogla (2008), Kašs et al.(2015))
Calculations of heating energy consumption of historical building stock are based on the following assumptions:

- registered residential area in the Latvian Real Estate Cadastre Information System (LRESCIS) (EM, 2014) differs from the Central Statistical Bureau of Latvia (CSB) data on the housing stock (CSBL, 2015). LRESCIS accounts total gross area of residential buildings, while CSB accounts total net area, i.e. without corridors, stairways, basements and other common spaces (in multi-family buildings). At the end of 2009 according to the CSB data housing stock was 61.1 million m², while LRESCIS data accounted 86.9 million m². Further calculations of heat energy consumption in historical multi-family residential buildings are based on assumption that net space of buildings is heated area and net area is calculated as fraction from gross area: 61.1 mill.m²/86.9 mill.m² = 0.7.

- average energy consumption for space heating in multi-family buildings with wooden walls: 300 kWh/m²/year; 1-2 floor buildings: 300 kWh/m²/year; 3-5 floor buildings: 200 kWh/m²/year; more than 6 floor buildings: 100 kWh/m²/year (see figure 6.6).

- average energy consumption for space heating in one family buildings 280 kWh/m²/year;

- average energy consumption for space heating in non-residential buildings 230 kWh/m²/year.

Total historical residential and non-residential building sector annual energy consumption is 5.8 TWh or approximately 31% from total final heating energy consumed by both residential and non-residential building sector in 2011 (EM, 2013). Figure 6.7 shows that the largest volume consumes one family buildings, followed by multi-family buildings and non-residential buildings. It corresponds to nation energy balance data (CSB, 2015).

![Figure 6.7. Final heat energy consumption in building stock built before and after 1945.](image)

### 6.3 Main wall types of buildings

#### 6.3.1 Massive wall

The first available data on masonry buildings in Latvia are from 12th century. The first of fired bricks buildings in Riga are mentioned in the beginning of 13th century. During this time, bricks were considered a new and innovative material, which allowed it to take a big step in the
construction development. The accelerating factor of brick diffusion in construction industry was development of brick kilns. From 12th to 15th century only external shell has been built of brick, the rest of the wall was filled with lime mortar, construction work residues and irregular stones.

Because of wars, during 16th and 17th centuries more buildings were destroyed than constructed. Buildings from this period are with very poor quality with rubble walls. Constructions and materials used for buildings were with various, often divergent characteristics. If the previous centuries walls masonry was characterized by a precise masonry structure and pattern, during this period masonry became sloppy, with irregularly shaped stones and bricks and walls were coated with plaster. (Krastiņš, 2008)

![Image](image1.png)  ![Image](image2.png)

(a) in old Riga  (b) Trīsvienības church in Jelgava built in 1567

Figure 6.8. Rubble wall.

For a long time brick masonry technology did not change. New construction technology approached only in 19th century when cavity walls were introduced. More detailed bibliographical information about Riga construction and sculptural monuments from Gothic to Art Noveau (13-th century till 1914) is available in Bibliography, (1997).

In rural areas the main building materials were wood, stone and clay. The oldest buildings did not have a massive stone foundation and hydro isolation but it slowly was introduced later. At the second half of 19th century the foundations were made of quarried stone with lime mortar. The walls were built of logs and at the beginning of 19th century clay was used for external walls. (Bērziņš, 1957)

Wall thickness of clay walls is at least 0.7 m for residential buildings and for other type of buildings without space heating between 0.3 and 0.5 m. To protect external walls from moisture impact are plastered with lime-gravel or roman cement-gravel mortar. (Bērzupe, 1933)
6.3.1.1 Rough stone wall

The size of stone used for external walls could not exceed 0.75 m, with the minimal size of 0.1 m. Stones with size less than 0.3 m could not exceed 15% of the overall volume of wall. Residential buildings were built with at least 75cm thick walls, because the stones are good heat transmitters. If the wall built from granite, dolomite and limestone is plastered from both sides, wall can be built only 60 – 65 cm thick. To avoid construction of thick stone walls in residential buildings, internal layer of ¼ to ½ brick and about 6 cm wide air gap with brick ties was allowed. When granite stone were used for walls, larger stones were placed in corners and in the middle, filling the gap between the stones with construction material residues, thus reducing mortar consumption. In some cases, in the corners and in the middle of the building façade brick columns were built like a frame and the rest of the wall was built from granite stones. Every 0.8-1.2m a brick layer was built to flatten the stone layer. (Bērzupe, 1933)

6.3.1.2 Ashlar wall

Buildings from ashlar a very rare. Mostly such masonry was built only for upper part of foundation and to clad walls built from stone and brick. In Latvian climate hard species of stones
are used— granite, gneiss, sandstone, syenite, etc. These walls always used cement-gravel mortar with a fine gravel. (Bērzupe, 1933)

Figure 6.11. Building façades covered with ashlar in old Riga.

6.3.1.3 Brick walls

Due to cold climate, external walls in residential buildings are 2 ½ brick or at least 2 brick (51cm) thick. Wall thickness increases every ½ bricks every two floors down inward so the external side of wall is smooth. Mortar could not be thicker than 30mm. The walls and foundations built from stones and brick masonry were built with cement-lime, cement or lime mortar. (Bērzupe, 1933)

Figure 6.12. Examples of buildings with massive brick walls.

6.3.2 Cavity wall

For a long time brick masonry technology did not change. New construction technology approached only in 19th century when cavity walls were introduced. The air gap served as heat insulation layer. Often, in order to improve existing buildings, another internal brick layer was added to external walls. Newly built internal layer was covered with stucco and painted or covered
with wallpaper. All buildings built from the end of 19-th century until the beginning of 20th century are built this way. (Lejnieks, 2007; Krastiņš, 2008)

To avoid construction of thick stone walls in residential buildings, internal layer of \( \frac{1}{4} \) to \( \frac{1}{2} \) brick and about 6cm wide air gap with brick ties was allowed.

![Brick cavity wall diagram](image)

**Figure 6.13.** Brick cavity wall (0.56 m) with 1.5 brick on external facade (0.38 m), 6 cm air gap and 0.5 brick on internal side (0.12 m) (Bērzupe, 1933)

![Examples of buildings with cavity walls](image)

(a) Brick cavity walls with plaster  
(b) Brick cavity walls without plaster

**Figure 6.14.** Examples of buildings with cavity walls.
6.3.3 Timber framing

Only few buildings are built with timber frame in Latvia.

6.3.4 Joints with adjoining building elements

Wooden beam ends in masonry wall are shown in figure 6.15. Beam end is wrapped in pasteboard.

![Figure 6.15. Wooden beam ends in masonry (Bērzupe 1933)](image)

6.4 Materials used for historical building walls

The historical building materials used in Latvian historical buildings are not widely studied. Studies are available on a separate building structural elements (Riga City Council, the Riga Stock Exchange) mainly for restoration needs, but they do not provide an in-depth insight in hygrothermal properties of materials used.

6.4.1 Stones

Stones that are used in historical buildings in Latvia are locally found different types of rock: granite, gneiss, syenite, dolomite lime (solid limestone, porous limestone, dolomite), etc. Non-splintered stones are used only for foundations or small agricultural buildings. For residential buildings only splintered stones have been used. (Bērzupe, 1933)

Litological morphological types of dolomites used for Riga architectural monuments used are studied by Hodireva et al. (2010). Stone materials have been investigated in Riga Stock Exchange by Igaune-Blumberga et al. (2011), and in Riga Doma Church by Grave et al. (2011).

6.4.2 Bricks

First bricks in Latvia have been used in 13-th century, mainly in churches as finishing material for stone walls. In 14-th century first buildings from bricks were built. Until 1856 a ban on masonry
buildings outside the city protection walls in Riga existed, thus until 1870-ies bricks were burned in so called field furnaces and only later industrial brick kilns were used. In 1911 brick industry was the leading industry with annual production capacity of 230 million bricks. (Gusta, 2006)

Unfired clay bricks have been used for internal masonry layer, while the outer layer was made of fired bricks.

Only a few studies have been carried out about bricks used in historical buildings in Latvia. Blumberga et.al (2012) have investigated 10 historical brick buildings in Riga in the scope of EU financed project Coolbricks, Bajare et.al (2000) have studied 13th-17th centuries bricks from Ventspils castle. Table 6.3 shows physical and mechanical characteristics of materials used in historical buildings in Latvia collected from different literature sources.

*Table 6.3. Physical and mechanical characteristics of materials used in historical buildings in Latvia.*

<table>
<thead>
<tr>
<th></th>
<th>Porosity (%)</th>
<th>Pore size, μm</th>
<th>Freeze–thaw cycles</th>
<th>Pressure strength (MPa)</th>
<th>Density (kg/m³)</th>
<th>Water absorption, W (%)</th>
<th>Heat conductivity, (W/(mK))</th>
<th>Saturation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fired ceramic bricks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13th-17th century</td>
<td>26-31</td>
<td>1-2</td>
<td>25-50</td>
<td>1680-1810</td>
<td>17.8-19.5</td>
<td>0.75-0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Bajāre et.al (2000))</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>19th-20the century</td>
<td></td>
<td></td>
<td></td>
<td>4.2-18.3</td>
<td></td>
<td>19.4-29.8</td>
<td></td>
<td></td>
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<tr>
<td>(Grava (2015))</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>19th-20the century</td>
<td></td>
<td></td>
<td></td>
<td>10-24</td>
<td></td>
<td>18-25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Blumberga et al 2012)</td>
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<td></td>
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<tr>
<td><strong>Granite</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>bulk peace of granite</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>5850-5980</td>
<td>30</td>
<td></td>
<td></td>
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<tr>
<td>of foundation of Riga</td>
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<tr>
<td>Stock Exchange</td>
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<tr>
<td>Igaune-Blumberga et al.</td>
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<td></td>
</tr>
<tr>
<td>weathered granite</td>
<td>2-6</td>
<td></td>
<td></td>
<td></td>
<td>2520-2800</td>
<td>50-68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface of foundation</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>of Riga Stock Exchange</td>
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<tr>
<td>Igaune-Blumberga et al.</td>
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</tr>
<tr>
<td><strong>Dolomite (Hodireva et al. (2010))</strong></td>
<td>&lt;5</td>
<td></td>
<td></td>
<td></td>
<td>50-100</td>
<td>100-140</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Quartz type</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
6.4.3 Mortars

Most often as mortars for masonry were used lime mortar, obtained from limestone (calcium carbonate), which is fired in the oven down to the calcium oxide. It is mixed with water, thus calcium hydroxide is derived. Sand, gravel and water is added. This way mortar attracts water and carbon dioxide over time, and changes back into the limestone (calcium carbonate) (Zviedrāns, J., 2003).

Plastering mortar binding substance is dolomite, calcium, Roman cement and portland cement, plaster, but as additives are used magnesium, dolomite, etc. (Bērzupe, 1933)

Krāģe et.al (2012) have investigated mortar from 16-th century Cēsis castle, and Barbane et.al (2013) have studied mortar from 19-th century. Sētiņa et.al (2012) have investigated lime based historical mortars.
6.4.4 Plasters

Plasters are made of water, gravel and binders (lime, dolomite roman cement and Portland cement, but excipients are gypsum, magnesium, dolomite etc.). Plaster types: coarse plaster (1.5 cm), simple plaster, smooth plaster, three layer plaster or fine plaster, granite grain, Edelputz, white or marble cement, marble dust plaster, artificial marble, mosaic plaster, water resistant plaster. Details about each of types are described in Bērzupe (1933).

6.5 Most common types of structural damages of historical building walls and their causes

Damages caused to historical buildings in Latvia have been studied by Bajāre et al. (2000) and Lindiņa et al. (2007) in Riga Dome church. Damage caused to historical buildings in Riga by NaCl is studied by Vītiņa et al. (2003). Water soluble salts (chlorides Cl\(^-\), nitrates NO\(_3\)\(^-\), sulphates SO\(_4\)\(^2-\)) in historical building bricks were studied by Blumberga et al. (2012) and Grava (2015).

The most common structural damages and their causes in Latvia are listed in Table 6.4.

Table 6.4. The most common structural damages and their causes in Latvia

<table>
<thead>
<tr>
<th>Structural damage</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture in walls</td>
<td>groundwater infiltration; damaged roof; atmospheric humidity (snow, rain, etc.); leakage from the building systems; strong side rain; condensate infiltration</td>
</tr>
<tr>
<td>Stone decomposition</td>
<td>soluble salts; chemical and physical structure of stone; freeze-thaw cycles</td>
</tr>
<tr>
<td>Brick decomposition</td>
<td>groundwater infiltration; freeze-thaw cycles; atmospheric humidity (snow, rain, etc.); strong side rain</td>
</tr>
<tr>
<td>Mortar damage, decomposition</td>
<td>groundwater infiltration; freeze-thaw cycles; increased drying because of central heating of building; salts transport in structures (with a moisture transport)</td>
</tr>
<tr>
<td>Brick and stone surface flaking</td>
<td>Salt crystallisation; freeze-thaw cycles</td>
</tr>
<tr>
<td>Cracks in walls</td>
<td>Soil movement; changes in building use; rust of metal constructions; vibration</td>
</tr>
<tr>
<td>Cracks in plaster</td>
<td>Soil movement; changes in building use; vibration; freeze-thaw cycles; groundwater infiltration</td>
</tr>
<tr>
<td>Facade paint peeling</td>
<td>infiltration and evaporation of water containing salts; moisture in walls; freeze-thaw cycles; poor maintenance of buildings including damaged rain water drainage systems, damaged roofs, damage of external painting/plaster etc.; atmospheric humidity (snow, rain, etc.)</td>
</tr>
<tr>
<td>Mould</td>
<td>Long term moisture impact; high internal relative humidity; poor ventilation</td>
</tr>
<tr>
<td>Salt crystallisation on surfaces</td>
<td>Salt used on streets during winters; salts transport in structures (with a moisture transport)</td>
</tr>
<tr>
<td>Dry-rot of wood</td>
<td>Biological (Fungus, insects); poor ventilation; poor maintenance of buildings, e.g. damaged rain water drainage systems, damaged roofs</td>
</tr>
<tr>
<td>Corrosion</td>
<td>The main corrosion product of historical materials is magnesium sulphate (MgSO4).</td>
</tr>
</tbody>
</table>

Some examples of damaged historical building walls are presented in Figure 6.17.
(a) Moisture in walls
(b) Brick decomposition
(c) Salt crystallisation on surface
(d) Brick decomposition
(e) Paint peeling
(f) Cracks in wall

Figure 6.17. Damaged historical building walls.
6.6  Case studies on renovation of historic buildings

6.6.1  Spīķeri, Maskavas street 8, Riga

*Year of construction:* 1930

*Year of energy renovation (and internal insulation):* 2013

*Short description:* 1 storey building: ½ used as tourist information centre, ½ used as public toilet. The building has an area of 56.3 m². The estimated energy consumption for heating of the building before energy efficiency measures is 35.8 MWh per year, or 633 kWh/m² per year.

*External wall before renovation:* brick walls (0.51m). The building has an area of 56.3 m². External wall of the building has an area of 129 m². Measured thermal heat transfer coefficient for bricks is lower (1.32 W/m²K) than the values, which are based on the element structure and obtained using ISO 6946-1 (1.48 W/m²K). Building has not been heated for long period of time and it has resulted in increased bricks’ moisture content: 2-8% in 4 cm depth and 1-9% in 30 cm depth.

*Insulation material:* 10 cm thick polyisocyanurate insulation, 5 cm thick Vacuum insulation panel, 5 cm thick Aerogel mat insulation

*Motivation for renovation:*

- To develop a state of art project, which will prove that high energy efficiency levels in historical buildings are reality.
- The most innovative insulation materials and technological solutions have to be used.
- The project will be state of art even for regular buildings, possibly the most advanced energy efficient project in Latvia.

*Other energy efficiency measures implemented at same renovation:* roof and floor insulation, energy efficient windows, air heat pump, new ventilation system with heat recovery.

*Achieved results:* energy consumption after renovation is 130 kWh/m² year.
6.6.2 Daņķepi, Seces district

Year of construction: 1886

Year of energy renovation (and internal insulation): 2007

Short description: 2 storeys one family building with heated area 300 m². The calculated energy consumption for heating of the building before energy efficiency measures is 340 kWh/m² per year. Building had insulated roof with 0.2m mineral wool and double-glass windows with U-value of 1.8 W/(m²K).

External wall before renovation: dolomite walls (0.6m), internal gypsum plaster (0.015m).

Internal insulation material: 5 cm mineral wool covered with internal gypsum board.

Motivation for renovation: to decrease energy consumption; preserve external facade.

Achieved results: energy consumption after renovation in 170 kWh/m²year. Energy savings 50%.

6.6.3 Creativity Center, Ventspils

Year of construction: 1912
Year of energy renovation (and internal insulation): 2010

Short description: Initially building was used as Latvian Society House, in the soviet times building was used for military purposes and, after the collapse of the Soviet Union, the building was returned to its initial owner. Due to lack of finances, building was poorly maintained and the building façade had severe deterioration signs. In the year 2007, the ownership of the building was handed to Ventspils municipality, which started to plan full renovation process to revive the building and integrate it in the historical cultural heritage ensemble of the city. The renovation of the historical building along with the newly built building part was completed in 2010. Nowadays building houses Ventspils creative house, which allows scholars to engage in qualitative and educational remedial classes.

External wall before renovation: brick masonry 0.51m – 0.77m.

Internal insulation material: 50mm of Extruded Polystyrene (XPS) boards

Motivation for renovation: As the building was poorly maintained, it was lowering the overall appearance and value of the historical building ensemble in the respective district. The city council showed an initiative to attract funding for building deep renovation and fully restore the buildings historical presence. During the building phase, thermography was performed to assess the quality of construction works and potential energy efficiency. Thermography results were showing insufficient results, therefore additional measures were planned to ensure required energy efficiency levels.

Achieved results: Heat energy consumption after energy efficiency measures 69 kWh/m²/year.

6.7 Motivation for the application of energy efficiency measures and internal insulation

- To develop a state of art project, which will prove that high energy efficiency levels in historical buildings are reality
- The most innovative insulation materials and technological solutions have to be used
- The project will be state of art even for regular buildings, possibly the most advanced energy efficient project in Latvia
- To decrease energy consumption
- Preserve external facade.

6.8 References


Bibliography, (1997). Rīgas celtniecības un tēlniecības pieminekļi no gotikas līdz jūgendstilam (13.gs.līdz 1914.g.) [Riga construction and sculptural monuments from Gothic to Art Nouveau (13th century till 1914), Bibliographic list], Bibliogrāfijas rādītājs, Latvijas Nacionālā bibliotēka.


Ле́йнек, Ж., (2007). Latvijas mazā enciklopēdija. [Small encyclopedia of Latvia], Апгāds Zvaigzne ABC.


7 Sweden

7.1 Survey of historic building stock

The Swedish building stock consist of some 2.1 million buildings. That includes single-family and multi-family buildings and premises. Approximately 27 percent of these buildings are built before 1945 but only 0.4 percent of the Swedish buildings stock is listed (Eriksson 2015).

The built environment has a general protection in the Swedish planning law that states that historical, cultural historical, environmental and artistic values of the built environment should be protected. In addition to this, restrictions are given by local building plans. Thus preservation targets have to be defined in each context based on an interpretation of the legal requirements and the priorities of the owner. However, the Swedish building regulation indicate that the same property requirements shall be applied for both the construction of a new building as well as an altered building.

A few years ago the Swedish National Board of Housing, Building and Planning (Boverket in Swedish) studied approximately 1800 buildings that were statistically selected to represent the entire Swedish building stock (Boverket 2009 and 2010). Most of the information in this chapter is derived from that study, from now on called the BETSI project. Unfortunately, only 263 of these buildings are built in 1945 or earlier, which makes these buildings underrepresented in this study.

In the BETSI project, buildings are divided into three building categories: single-family dwellings, apartment buildings and premises. Table 7.1 shows the number of buildings of these three categories there are in Sweden, in the BETSI project and how many buildings in the BETSI study which are built in 1945 or earlier.

Table 7.1. Number of buildings in Sweden and in the BETSI study divided into three categories.

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Number of buildings, BETSI, building year - 1945</th>
<th>Number of buildings, BETSI, building year - 2005</th>
<th>Number of buildings in Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single family or semidetached houses</td>
<td>115</td>
<td>826</td>
<td>1 888 000</td>
</tr>
<tr>
<td>Multi family buildings</td>
<td>60</td>
<td>560</td>
<td>165 000</td>
</tr>
<tr>
<td>Premises</td>
<td>88</td>
<td>367</td>
<td>47 000</td>
</tr>
</tbody>
</table>

Single family or semidetached buildings with massive or cavity masonry outer walls are rare in Sweden. These and approximately half of the multi family buildings built before 1945 are usually built with wooden framing. However, the multi family buildings with wooden framing are small and only around 15 percent of the number of apartments are situated in buildings with wooden framing (Björk et al 2003).
7.2 Energy consumption of historical building stock

The heating degree days vary quite significantly in Sweden from 2000 for some years in the south of Sweden to above 6000 in the north of Sweden. The heating degree days are also very dependent on the local climate. A normal year the heating degree days are between 3000 and 4000. The average heating degree days for Sweden is 3734 (Boverket 2010). The latter number is also based on a number of locations but weighted by the number of inhabitants of that municipality. Most people live in the south of Sweden, hence the lower average.

There is no source that has estimated the energy use in Swedish masonry buildings built before 1945. Multi family buildings built before 1960 has an average U-value of the external wall of 0.58 ± 0.07 W/m²K and the average area of the external wall is 629.8 ± 99.4 m² (Boverket 2010). This estimation also includes buildings with other external wall constructions. The average U-value of the external wall of the multifamily buildings from the BETSI project that is built before 1945 is 0.56 W/m²K but the basis for this estimation is very limited (60 buildings). For this limited number of buildings, the average U-value of the building envelope is estimate to 0.68 W/m²K. The average U-value of the building envelope of the single family buildings built before 1945 in the BETSI project is around 0.58 W/m²K. Around 15 percent of the multifamily buildings have additional insulation on the external wall and for less than a third of these buildings external additional insulation was considered a viable energy saving measure (Ståhl et al 2014, Boverket 2010).

The BETSI project has estimated the heat losses through the building envelope of Swedish buildings in different age categories. The oldest building category includes buildings built 1960 and before. Premises have not been divided into aged groups and are therefore not presented in table 7.2.

Table 7.2. Estimated total heat loss through the building envelope of Swedish residential buildings built before 1961 (Boverket 2010)

<table>
<thead>
<tr>
<th></th>
<th>Multifamily buildings (-1960)</th>
<th>Single family buildings (-1960)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of buildings</td>
<td>77 000</td>
<td>846 000</td>
</tr>
<tr>
<td>Number of apartments</td>
<td>1 031 000</td>
<td>-</td>
</tr>
<tr>
<td>Total heated area A_{temp} (m²)</td>
<td>99 000 000</td>
<td>146 000 000</td>
</tr>
<tr>
<td>U-value external wall (W/m²K)</td>
<td>0.58±0.07</td>
<td>0.47±0.15</td>
</tr>
<tr>
<td>Average area external wall (m²)</td>
<td>629.7±99.4</td>
<td>158.0±19.9</td>
</tr>
<tr>
<td>Total area external wall (m²)</td>
<td>48.4±8.8 \cdot 10^{6}</td>
<td>133.7±17 \cdot 10^{6}</td>
</tr>
<tr>
<td>External wall U·A (W/K)</td>
<td>28.3±5.7 \cdot 10^{6}</td>
<td>62.4±24.3 \cdot 10^{6}</td>
</tr>
<tr>
<td>Total heat losses through the</td>
<td>2.5</td>
<td>5.6</td>
</tr>
</tbody>
</table>
### 7.3 Main wall types of buildings

#### 7.3.1 Massive wall

Masonry buildings have been built in Sweden since the Middle Ages but then almost exclusively as churches. Brick was for a long time an expensive building material and even in 1600 and 1700's bricks were too expensive to use in residential buildings. It is only in the latter half of the 1800s as the bricks were produced in large quantities and became affordable. Brick was the dominant building material in the outer walls of large buildings until the mid-1900s when it gradually was replaced by aerated concrete and then by infill walls.

For historic buildings the most common external wall materials combination is brick with both external and interior rendering. Brick walls without the external rendering are also quite common.

There are not many Swedish buildings with external rock masonry walls. Rock masonry walls of granite or gneiss was used as basement walls until the turn of the century when it was gradually replaced by concrete. In the island of Gotland there are around 3000 buildings with masonry walls made of limestone. Almost all of them were constructed before 1900 (Eriksson et al 2013).

#### 7.3.2 Cavity wall

There are buildings with cavity walls in Sweden but they are not that common.

#### 7.3.3 Timber framing

A vast majority of Swedish single family buildings and many small multifamily buildings have a timbered frame. The building technology has developed from timbered boarded houses to timber framed house, some of which are clad in brick. However, there are not many buildings with a half-timber framing in Sweden. However, in the city of Ystad there are around 300 half-timbered buildings. This building technique was only used in south of Sweden.

<table>
<thead>
<tr>
<th>external walls (TWh/year)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average U-value building envelope (W/m²K)</strong></td>
<td>0.67±0</td>
<td>0.57±0.1</td>
</tr>
<tr>
<td><strong>Building envelope total U·A (W/K)</strong></td>
<td>89.0±15.2 · 10^6</td>
<td>212.4±30.8 · 10^6</td>
</tr>
<tr>
<td><strong>Total heat losses through the building envelopes (TWh/year)</strong></td>
<td>8.0</td>
<td>19.0</td>
</tr>
</tbody>
</table>
7.3.4 Joints with adjoining building elements (ceiling/roof, suspended floor, and foundations)

Table 7.3 gives a rough estimate of the development of materials and dimensions of the intermediate flooring of multifamily buildings in Sweden.

Table 7.3. Intermediate floorings of Swedish multifamily masonry buildings

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Year 1870-1890</th>
<th>Year 1890-1940</th>
<th>Year 1930-1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td>175x250 mm, c/c 600mm</td>
<td>150x225 mm, c/c 600mm</td>
<td>Steel beams, c/c 1000 mm</td>
</tr>
<tr>
<td>Floorboards</td>
<td>63 mm</td>
<td>50 mm</td>
<td>30 mm on wood studs</td>
</tr>
<tr>
<td>Ceiling</td>
<td>Wood 25 mm, rendering</td>
<td>Wood 25 mm, rendering</td>
<td>Reinforced concrete 80-100 mm</td>
</tr>
<tr>
<td>Insulation</td>
<td>Lime gravel or sand</td>
<td>Lime gravel or sand</td>
<td>Lime gravel or coke ash</td>
</tr>
</tbody>
</table>

The floor of the attic was usually had a similar construction that the intermediate floorings in Table 7.3 but was covered in a layer of bricks as fire protection. The ground floor was before 1900 made of wood beams or brick vaults. Later this construction was replaced by floorings reinforced with steel beams. Around 1950 reinforced concrete was the dominating ground floor construction (Bjerking 1974).

7.4 Materials used for historical building walls

A rough division regarding building technical design of Swedish apartment buildings can be done according to the following:

- Brick building 1870-1890 South Sweden, maximum 3 stories plus basement, 250 mm bricks.
- Brick building 1870-1890 north and middle of Sweden, maximum 4 stories plus basement, 300 mm bricks, plaster on the outside.
- Brick building 1890-1940, maximum 6 stories plus basement, both plastered and non-plastered façade, (300 mm brick south, 250 mm bricks in the north and middle of Sweden)
- Brick building 1930-1960, with internal insulation, 3-5 stories plus basement, in some case up to 9 stories, internal wood wool insulation 30-50 mm.

The outer wall construction change little over the decades but the external design usually followed the architectural ideals of the time.
7.5 Most common types of structural damages of historical building walls and their causes

The most common structural damages in multifamily residential buildings built in the 1880s are discolourations, cracks and rendering fallout. In buildings from the 1930s with an internal insulation of the external wall, the most common problems are external rendered surface painted with plastic paint and interior discolouration of the walls (Bjerking 1987).

7.6 Case studies on renovation of historic buildings

7.6.1 The Hausknecktska building in the city of Laholm

Year of construction: 1799

Year of energy renovation (and internal insulation): 2007-2010

Short description: Hausknecktska is a 2-storey building constructed with half-timber framing. The first floor consists of two apartment and the bottom floor consist of two commercial premises (Hansson 2010 and Ståhl et al 2011). It is believed that the façade always has been rendered with some sort of plaster. Originally the building measured 15 m in length. It was later on extended sometime during the 1820-1830s, and is measured as of today 26 m in length. The extension was also built with timber framing.

Internal insulation method: From the inside a metal frame has been added where the new insulation could be applied, coated with a gypsum board internally.

Internal insulation: Mineral wool, Styrofoam.

Motivation for internal insulation: The main reason why the Hausknechtska was renovated is because a fire broke out in the nearby the building in 2004. The owner decided to buy the plot where the fire occurred, to build a new office building. Meanwhile, they also started the renovation of the Hausknechtska with the goal to preserve the historic value of the building.

Other energy efficiency measures: besides the added insulation in the outer walls, a couple of other measurements were done towards an energy-efficient building:
- In the attic space 250 mm of mineral wool was applied between the joists.
- Windows were not replaced since it would not give the desired energy reduction based on the pre-made calculations. Instead a restoration of the windows was made.
- A truss was built on the existing floor, where Styrofoam was applied.
- Natural ventilation was replaced with a HVAC unit.
- Before the renovation the building had electrically powered radiators, some of them placed alongside the inner walls. After the renovation the new hydronic heating system was installed and the radiators were instead placed alongside the outer walls, to reduce the negative impact of cold downdraught.

Achieved results, including energy savings: The estimated energy consumption was reduced from 203 kWh/m² to 95 kWh/m².

7.6.2 Motivation for the application of EE measures

The main purpose of the renovation was to preserve the Hausknecktska building and its historic value as the building structure was severely damage by rot. At the same time, the building had to be fully operational for its user (offices on the ground floor and apartments on the first floor) and meet the requirements of a modern building.

7.7 References


8 Switzerland

8.1 Survey of historic building stock

This section presents the Swiss building stock and presents the main specificities of the Swiss historic building stock (i.e., built before 1945).

8.1.1 Overall building stock characterisation

The building stock will be introduced according to a simple segmentation, i.e., buildings with residential purposes and buildings with no residential purposes (e.g., administration, school, etc.). Then, a segmentation per construction period will be also introduced.

8.1.2 Residential buildings

In Switzerland, there are about 1.63 million buildings with complete or partial residential purposes. Table 8.1 presents the number of buildings per construction periods and type according to the Swiss Federal Office of statistics (SFOS 2015).

Table 8.1. Number of buildings with residential purpose per construction periods\(^{10}\)

<table>
<thead>
<tr>
<th>Year</th>
<th>Single family house</th>
<th>Multi-family house</th>
<th>Multi-family house with partial other use</th>
<th>Building mostly non residential</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1919</td>
<td>126055</td>
<td>87370</td>
<td>93918</td>
<td>28426</td>
<td>335769</td>
</tr>
<tr>
<td>1919-1945</td>
<td>109070</td>
<td>52684</td>
<td>26364</td>
<td>11365</td>
<td>199483</td>
</tr>
<tr>
<td>1946-1960</td>
<td>109734</td>
<td>55100</td>
<td>17162</td>
<td>8635</td>
<td>190631</td>
</tr>
<tr>
<td>1961-1970</td>
<td>94468</td>
<td>55617</td>
<td>14511</td>
<td>8464</td>
<td>173060</td>
</tr>
<tr>
<td>1971-1980</td>
<td>123843</td>
<td>50649</td>
<td>13282</td>
<td>7526</td>
<td>195300</td>
</tr>
<tr>
<td>1981-1990</td>
<td>135759</td>
<td>44232</td>
<td>14130</td>
<td>7405</td>
<td>201526</td>
</tr>
<tr>
<td>1991-2000</td>
<td>120588</td>
<td>39538</td>
<td>11788</td>
<td>5079</td>
<td>176993</td>
</tr>
<tr>
<td>2001-2005</td>
<td>61717</td>
<td>15781</td>
<td>2141</td>
<td>1226</td>
<td>80865</td>
</tr>
<tr>
<td>2006-2013</td>
<td>86797</td>
<td>36494</td>
<td>4038</td>
<td>2351</td>
<td>129680</td>
</tr>
</tbody>
</table>

\(^{10}\) The explanation of the building classification is given in (Swiss Federal Office for statistics 2014)
Based on the statistics presented in Table 8.1, about 20% of the Swiss buildings were built before 1919 and 11.8% between 1920 and 1945. In figure 8.1 a geographical repartition of these buildings built before 1945 over the entire territory is presented according to the cities’ delimitation.

Figure 8.1. Percentage of buildings per cities built before 1945 in Switzerland

8.1.3 Non-residential buildings

The total number of non-residential buildings is estimated at 167’073 according to the database on buildings (RegBL) provided by the Federal Office of Statistics (SFOS, 2015). Among these buildings, there are offices, schools, hospitals, etc. These statistics also enable to know the period of construction for these buildings. Historical buildings with non-residential purposes are estimated at 39’189, i.e., 23.5% of the entire non-residential stock. This share is slightly less than for the one for residential buildings (~32%).
8.2 Energy consumption for space heating and potential savings in the residential historic building stock

8.2.1 Heated surface area

8.2.1.1 Historic residential buildings

Available statistics of the Swiss building stock building do not provide values on heated surface area or operational energy consumption for space heating per construction periods i.e., for buildings built before 1920 and buildings built between 1920 and 1945. To that purpose, we used data provided by the Swiss Federal Office for statistic (SFOS) and a specific model developed at the HES-SO (University of Applied Sciences and Arts Western Switzerland). They enable to estimate the reference heated surface area per construction period according to a simplified building segmentation i.e., with Single-Family Housing and Multi-Family housing. In this approach, the reference heated surface area is extrapolated from the overall surface area of residential buildings based on a conversion factor of 1.245 defined by Khoury (2014) for the Canton Geneva. Table 8.2 presents the heated surface area values for the two time periods relevant in the RIBuild project.

Table 8.2. Heated surface area for historic buildings in Switzerland and the heated surface area for all building segmentation

<table>
<thead>
<tr>
<th>Period</th>
<th>Single family house [M m²]</th>
<th>Multi family house [M m²]</th>
<th>TOTAL const. Period [M m²]</th>
<th>TOTAL ALL [M m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>before 1919</td>
<td>19.1</td>
<td>64.6</td>
<td>83.7</td>
<td>491.6</td>
</tr>
<tr>
<td>1919-1945</td>
<td>16.0</td>
<td>31.5</td>
<td>47.5</td>
<td></td>
</tr>
<tr>
<td>1946-1960</td>
<td>19.1</td>
<td>35.7</td>
<td>54.9</td>
<td></td>
</tr>
<tr>
<td>1961-1970</td>
<td>14.1</td>
<td>46.4</td>
<td>60.5</td>
<td></td>
</tr>
<tr>
<td>1971-1980</td>
<td>19.8</td>
<td>42.7</td>
<td>62.5</td>
<td></td>
</tr>
<tr>
<td>1981-1990</td>
<td>19.3</td>
<td>35.8</td>
<td>55.1</td>
<td></td>
</tr>
<tr>
<td>1991-2000</td>
<td>15.2</td>
<td>33.9</td>
<td>49.1</td>
<td></td>
</tr>
<tr>
<td>2001-2005</td>
<td>10.6</td>
<td>13.9</td>
<td>24.5</td>
<td></td>
</tr>
<tr>
<td>2006-2014</td>
<td>18.0</td>
<td>36.0</td>
<td>54.0</td>
<td></td>
</tr>
</tbody>
</table>

Heated surface area results for the overall residential building stock are consistent with other studies conducted in Switzerland e.g., Prognos (2013), SFOE (2013). From Table 8.2, historic buildings represent 26.7% of the reference heated surface area in Switzerland (17% for buildings before 1919 and 9.7% between 1920 and 1945). The heated surface area share of historic buildings compared to the entire building stock is far from being negligible. Developing energy efficiency measures specific to these buildings is thus important in order to meet the Swiss energy reduction targets by 2050.

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11 The heated surface area is a national surface area metric used in the thermal analysis
12 Indeed, in its report on the Swiss energy strategy 2050, Prognos states a heated surface area of 444 Mio. m² in 2005 and 486.7 Mio. m² in 2010 while our model gives a value of 449 Mio.m² and 482 Mio.m² respectively.
8.2.1.2 Historic non-residential buildings

Regarding the heated surface area estimation for the non-residential buildings e.g., from industry and tertiary sectors (services etc.), few reliable sources in Switzerland exist. According to the data of Prognos, Infras and TEP Energy Gmbh (2014), the overall heated surface area is about 152 Mio. m$^2$ for the tertiary sector and 87 Mio. m$^2$ for the industry sector in 2010 (cf. Table 8.3):

<table>
<thead>
<tr>
<th>Year</th>
<th>Tertiary [Mio. m$^2$]</th>
<th>Industry [Mio. m$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>140</td>
<td>83</td>
</tr>
<tr>
<td>2010</td>
<td>152</td>
<td>87</td>
</tr>
</tbody>
</table>

The heated surface area is thus lower compared to residential buildings (50% less) and its growth between 2000 and 2010 is less important. However, Prognos, Infras and TEP Energy Gmbh (2014) did not breakdown the heated surface area per construction period. Indeed, to the authors’ knowledge, no previous studies have estimated the historic building’s heated surface area. In that context, a simplified calculation is proposed below to get an estimation of it. Two different approaches are considered and presented below in order to get an interval representing the possible uncertainty associated with this estimation.

First, the heated surface area for historic non-residential buildings can be estimated by dividing the overall surface area by the number of buildings. In this case, it is assumed that there is no increase or decrease of the surface area for new buildings unlike what is commonly observed for Swiss residential buildings (OFS 2015). By doing so, a surface of about 50.2 Mio. m$^2$ (14.5 for the industry and 35.7 for the tertiary sector) was found. The second way to estimate the heated surface area for historic buildings of the industry and tertiary sectors is to use the information of the Geneva Canton (SITG 2015) where data on the heated surface area and heat index information, i.e., giving the final energy demand per m$^2$ of heated surface area, are available (for residential purpose it is mandatory but for other buildings it is optional so far). Based on this data source, the share of historical buildings in the industry is 14.5% and the share of the tertiary sector is 22.1%. It gives an overall heated surface of 46.2 Mio. m$^2$ (12.6 for the industry and 33.6 for the tertiary sector). Results of the first approach based on national data and the second one based on Geneva Canton data present a difference of 11.8% different which is in the same order of magnitude.

We can thus assume that the historical non-residential building stock heated surface range between 46.2 to 50.2 Mio. m$^2$ in Switzerland.

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13 According to the Swiss Federal Office for Statistics, the surface of dwelling is increasing per construction period.
### 8.2.2 Energy demand for historic residential buildings

As there is no available disaggregated energy consumption data for different construction periods and building segmentation, a simplified approach is proposed here to derive the space heating demand for the residential historic building stock. It is based upon the use of available energy consumption data sources for residential buildings in Canton Geneva e.g., through the “Geographic Information System of the Geneva Canton” (in French “Service d’Information du Territoire Genevois” (SITG 2015)). Building energy consumptions are expressed with an heat index “Indice de Chaleur” (Final energy consumption index) which quantifies the real\(^\text{14}\), but climatically corrected, final energy consumption for space heating and domestic hot water (DHW) for residential single-family housing and multi-family housing buildings (Office Cantonal de l’Energie de Genève 2014).

In this simplified approach, final energy consumption index values only take into account the final energy consumption for space heating, excluding the DHW consumption\(^\text{15}\). Final energy consumption index coefficients are also expressed in useful energy consumption using a standard value for heating efficiency of the Swiss building stock of 88.2% in 2010 according to Prognos energy strategy document (2010). Finally, final energy consumption index are climatically corrected\(^\text{16}\). Table 8.4 presents the estimation of the useful energy consumption for space heating for historic residential buildings in Switzerland:

**Table 8.4. Useful energy consumption for space heat in Switzerland for multi-family housing and single-family housing according to the different construction periods**

<table>
<thead>
<tr>
<th></th>
<th>Multi-family housing [MJ/m(^2)]</th>
<th>Single-family housing [MJ/m(^2)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1919</td>
<td>323</td>
<td>400</td>
</tr>
<tr>
<td>1920-1945</td>
<td>336</td>
<td>425</td>
</tr>
<tr>
<td>1946-1960</td>
<td>354</td>
<td>459</td>
</tr>
<tr>
<td>1961-1970</td>
<td>335</td>
<td>401</td>
</tr>
<tr>
<td>1971-1980</td>
<td>334</td>
<td>359</td>
</tr>
<tr>
<td>1981-1990</td>
<td>296</td>
<td>387</td>
</tr>
</tbody>
</table>

\(^\text{14}\) Measured via the volume of fuel used (or kWh if electricity)

\(^\text{15}\) The values for DHW being respectively 128 MJ/m\(^2\) for multi-family housing and 85 MJ/m\(^2\) for single-family housing are subtracted from the total Final energy consumption index calculated according to the Final energy consumption index calculation procedure.

\(^\text{16}\) for the reference heating degree day (HDD, 16/20) of the Geneva canton (for Final energy consumption index after 2010), i.e, 3322 HDD. We decided to harmonize the value for the Swiss climatic conditions considering also HDD 12/20. The HDD 12/20 for the reference year are given, i.e, 3290 HDD (Prognos AG, Infras AG, and TEP Energy GmbH 2013).
Using heated surface area values of Table 8.2 and useful energy consumption values of Table 8.4 allows to estimate the overall useful energy for space heating of the residential buildings to be 158 PJ in 2010.

The breakdown per construction period is presented in Table 8.5. In the Prognos energy strategy 2050 report, the useful energy consumption for space heating of the residential sector in 2010 is estimated to be 164 PJ, thus the difference between our simplified model and the detailed model of the literature is less than 4.1% which is estimated to be sufficient for the goal and scope of RIBuild’s WP1. It is important to mention that this simplified approach is fully transparent and uses only publicly available data.

**Table 8.5. Total Useful energy consumption for space heat in Switzerland for the residential buildings according to the different construction periods**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1919</td>
<td>28,5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1920-1945</td>
<td>17,4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1946-1960</td>
<td>21,4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1961-1970</td>
<td>21,2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971-1980</td>
<td>21,4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981-1990</td>
<td>18,1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991-2000</td>
<td>15,0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001-2005</td>
<td>5,8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006-2015</td>
<td>8,9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>157,6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Useful energy consumption estimations for historic buildings are graphically represented according to their heated surface area in table 8.2. For comparison purposes, the other construction periods from 1945 to 2013 are also reported.
8.2.3 Energy demand for historic non-residential buildings

From Prognos, Infras and TEP Energy Gmbh (2014), the final energy needs for space heating can be found for the industry and the tertiary sector (no construction period segmentation), Table 8.6.

Table 8.6. Final energy needs for space heat of the non-residential buildings

<table>
<thead>
<tr>
<th>Year</th>
<th>Final Tertiary and Primary [PJ]</th>
<th>Final Energy Industry [PJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>71,6</td>
<td>23,9</td>
</tr>
<tr>
<td>2010</td>
<td>80,1</td>
<td>23</td>
</tr>
</tbody>
</table>

By assuming on average the same final energy demand without any considerations due to the age of the buildings, we can estimate the final energy needs of the historical non-residential building stock, table 8.7.
Table 8.7. Final energy needs for space heat of the non-residential buildings

<table>
<thead>
<tr>
<th>Year</th>
<th>Final Energy Tertiary and Primary only historical building [PJ]</th>
<th>Final Energy Industry only historical building [PJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>17.6</td>
<td>4.1</td>
</tr>
<tr>
<td>2010</td>
<td>19.7</td>
<td>4</td>
</tr>
</tbody>
</table>

Remark for the non-residential energy estimation

- Estimating the non-residential energy need for space heat is much more complex than for the residential one. Indeed, the usage of the buildings are more variable (hospital, retail, offices, museum, etc.) leading to variability in the energy needs. An accurate estimation of the energy needs is thus much more complex to achieve. In addition, no segmentation per construction periods are found in the literature since it is highly probable that the usage influence will be predominant on the building typologies. The results presented above for non-residential buildings should only be used as first estimations for the purpose of the RIBuild WP1.

From this estimation of the final energy consumption of the non-residential building stock and the results of the more detailed study of the residential one, we can estimate that the overall final energy need for the space heat of the historical building in Switzerland is 75.7 PJ (69% for the residential part and 31% for the non-residential one).

8.2.4 Renovation of the residential building stock: Potential energy savings

Note: Due to the large heterogeneity of usage in the non-residential buildings and the lack of detailed and reliable energy data related to the various type of buildings, HES-SO decided to only focus on the residential part of the building stock for the estimation of the energy consumption, the related potential savings and the main wall types of historic buildings.

Estimations of energy consumption for space heating of the residential sector shows in Table 8.5 that historic buildings represent a large share of useful energy consumption, i.e., 45.8 PJ, which represent 29.1% of the total useful energy consumption. It is thus important in this pre-renovation assessment work package (WP1) to estimate their potential energy savings. Considering the Swiss Society of Engineers and Architects 380/1 standard, it is possible to calculate the normative useful energy consumption of historic residential buildings after the improvement of the thermal envelope (normative expectation assuming all historic buildings are insulated). To do so, we used the equation given in the standard:

\[
Q_{h,li} = Q_{h,li0} + \Delta Q_{h,li} \cdot \left( A_{th}/A_{E} \right)
\]
With \( Q_{h,\text{li0}} \) and \( \Delta Q_{h,\text{li}} \) standard values (from Swiss Society of Engineers and Architects 380/1 standard) and \( A_{th}/A_e \) the envelope factor (ratio between the thermal shell and the heated surface), given by Wallbaum et al. (2010).

**Table 8.8. Values used to calculate the standard energy consumption for renovated historical buildings**

<table>
<thead>
<tr>
<th>Envelope factor before 1945 [-]</th>
<th>( Q_{h,\text{li0}} ) [MJ/m(^2)]</th>
<th>( \Delta Q_{h,\text{li}} ) [MJ/m(^2)]</th>
<th>Energy target for space heat according to Swiss Society of Engineers and Architects 380/1 standard [MJ/m(^2).y]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-family housing</td>
<td>2.06</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Multi-family housing</td>
<td>1.99</td>
<td>55</td>
<td>65</td>
</tr>
</tbody>
</table>

Results of Table 8.8 show that if all historic buildings were entirely renovated (all elements of the buildings and all buildings), about 15 PJ of energy would be saved which represent an energy reduction of about 30.6% compared to the current situation. It has to be noticed that the energy saving potential calculated here considers the entire renovation of the buildings (windows replacement, wall insulation, etc.). Estimating the energy saving potential only related to the wall surface would require to characterize the building typology (in order to express the surface of wall per m\(^2\) of heated surface area for example), which is, to date, unavailable for the Swiss building stock. The insulation of historical façades would thus contribute to a large share of the overall saving of 15 PJ given that façades represent a large surface for the transmission losses and their U-values are generally high.

Thereby, the energy saving potential associated with the renovation of historic buildings remain a key issue. In Switzerland, massive renovations of historic and other types of buildings will be needed if we want to meet the Swiss energy strategy of the Confederation that aims at reducing the energy for space heat of buildings from 301 PJ today (including all the buildings classes) to 141 PJ in 2050, i.e., a reduction of 53% (Prognos, 2012).

### 8.3 Main wall types for residential buildings

Previous sections showed that historic buildings have a high potential of energy consumption reduction and internal thermal insulation has to be applied on the facade in order to comply with the Swiss Society of Engineers and Architects 380/1 (2009) standard. However, these potential savings’ calculations remain theoretical and it exists a large diversity of historic building types in terms of wall compositions and possible degradations. Prior to any technical work related to insulation solutions, it is necessary to describe the existing facade typology for these historic buildings. Indeed, the physical and hygrothermal characteristics inside the wall will have a key importance on the possible internal insulation choice and durability.
Previous research projects have already tried to characterise the external wall types of historic buildings in Switzerland. It appears that a systematic classification of external walls is not easy to develop due to the heterogeneity of the walls even for a same wall type (SuRHiB, 2013). Based on this first national study, an on-going research project conducted at the University of Applied Sciences Western Switzerland (HES-SO) proposed a pragmatic and accurate enough classification of wall types based on the analysis of a sample of Western Switzerland historic residential buildings (eRen, 2015)\textsuperscript{17}. Figure 8.4 to 8.6 presents these main wall types and compositions according to eRen (2015).

### Table 8.9. Wall types of historic buildings in Switzerland based on eRen (2015)

<table>
<thead>
<tr>
<th>Constructive system</th>
<th>Wall type</th>
<th>Scheme</th>
<th>Composition</th>
<th>Time period</th>
</tr>
</thead>
</table>
| Massive wall with variable thickness depending on the height of the building | Type 1 | ![Scheme](image) | - Rendering  
- Stone wall  
- Rendering | Before 1919 |
| Type 2 | ![Scheme](image) | - Rendering  
- Brick  
- Cut stone | Before 1919 |
| Type 3 | ![Scheme](image) | - Rendering  
- Brick (full)  
- Rendering | Before 1919 and first quarter of 1919-1945 |
| Half-timbered wall | Type 5 | ![Scheme](image) | - Rendering  
- Filling material  
- Rendering  
- Wooden frame | Before 1919 and early 1919-1945 |
| Type 6 | ![Scheme](image) | - Rendering  
- Hollow clay brick  
- Rendering | 1919-1945 |
| Type 7 | ![Scheme](image) | - Wood doubling  
- Hollow clay brick  
- Rendering | 1919-1945 |
| Simple or composed wall without insulation | Type 8 | ![Scheme](image) | - Rendering  
- Doubling hollow clay brick  
- Hollow clay brick  
- Rendering | Second quarter 1919-1945 till 1960 |
| Type 9 | ![Scheme](image) | - Rendering  
- Hollow clay brick  
- Air  
- Hollow clay brick  
- Rendering | Late 1919-1945 till 1960 |

NB: The wall type 4 referring to a massive wall in wood is not presented here as it is out of the scope of RIBuild. Similarly, no wall types referring to Type 5 or 8 were found in the sample of historic buildings: as a result, they will be not considered.

\textsuperscript{17} The HES-SO project « eRen » characterize the residential buildings architecture (including historic buildings and all other building types)
Table 8.9 showed that three main external wall systems exist: the massive wall, the timber wall and the simple or composed wall. For all of these systems, nine wall types exist. Based on the analysis of a sample of 66 buildings and 97 facades, only four types were found predominant in historic residential buildings in Western Switzerland: type 1, type 2, type 3 and type 4. As an illustration, figure 8.3 presents the repartition of these different wall types.

![Diagram showing repartition of wall types](image)

**Figure 8.3. Main wall types found in existing residential historic buildings in Western Switzerland according to eRen (2015)**

Results show that the rock wall masonry (Type 1) and the “cut stone, brick and rendering” wall type (Type 2) represent together 57% of the wall types while the “brick with rendering” (Type 3 and 4) represents 37% of the wall types. The type 9 “rendering / brick / air cavity / brick / rendering” only represents 4% while all the other wall types are negligible based on the surveyed buildings analysed in Switzerland. These results mainly represent residential historic buildings located in Western Switzerland. Not all the main wall types found in Switzerland are represented in our sample. As an example, the half-timber wall type, which is more developed in Northern and Eastern Switzerland was not found in the eRen building sample.

In addition to this document, the Annex I presents more information and description of the wall types in terms of wall type description as well as wall and rendering thicknesses and possible diagnose issues.

### 8.3.1 Joints with adjoining building elements (ceiling/roof, suspended floor, and foundations)

Based on the building stock survey done in Western Switzerland (eRen 2015), figure 8.4 to figure 8.6 present the sketches of the façade/floor junctions. These sketches provide an insight into the situation between the floors and façades junctions for wall types 1, 2 and 4.

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18 It is thus important to recall that while these results show some clear tendencies for residential historic buildings of Western Switzerland, they may not reflect all the regional particularities of Switzerland. Extrapolations to other regions in Switzerland should be handled with care. Ideally, similar research projects similar as eRen for Western Switzerland should be conducted to have a clear overview of the situation in the entire Switzerland.
When adding internal insulation, the condensing risk simulations will be applied with these type of junction characteristics.

Figure 8.4. Junction between the floor and the type 1 façade
Figure 8.5. Junction between the floor and the type 2 façade (behind the cut stone, it is possible to find either rubble stone or bricks; here, the sketch is presented with rubble stone)

Figure 8.6. Junction between the floor and the type 3 façade
8.4 Materials used in historical building walls

8.4.1 Stones

In the past (e.g., before 1919), buildings were generally constructed using locally available materials. For example, stones used for massive walls were taken from the closest quarry. For some façade embellishments of luxurious buildings, even if different materials could be used, most of them were also locally extracted.

If we take a look at the quarries in operation before 1919 (i.e., time period corresponding to the type 1 and type 2 walls in figure 8.3), their location should be in line with the material locally used for the façade constructions. In Switzerland, a large historical survey of operated quarries for four reference years i.e., 1915, 1965, 1980 and 1995 was performed by the Geotechnical Commission.

By analysing the quarries in operation in 1915, it is possible to classify them according to the different stone types used for buildings at that time. The illustration is presented in figure 8.7.

From figure 8.7, three main types of stone are found predominant:

- Limestone (in blue): essentially localized in the mountain area, the Jura (from the North of Geneva to Basel) and in the Alpine region.
- Sandstone (in yellow): essentially localized in the Swiss plateau (from the Leman lake to the Constance lake).
- Gneiss (in light pink): localized in the Italian speaking part of Switzerland, South East.

Some other types of stones were found such as the shists but their uses in 1915 were more marginal compared to the three main stones mentioned above. Indeed, according to Schwarz (1983), the shares of the various stone types in Switzerland in 1915 are presented in Table 8.9.
Table 8.9. Share of the stone type in 1915 according to Schwarz 1983

<table>
<thead>
<tr>
<th>Share in 1910/1915 [%]</th>
</tr>
</thead>
</table>
| Granite and Gneiss     | 18%  
| Sandstone              | 27%  
| Limestone              | 45%  
| Schists                | 7%   
| Other                  | 3%   

The observations made with the assessment of the Swiss quarries in 1915 are also confirmed by Zerbi (2015). In addition, Zerbi (2015) mentions that sandstone, limestone, gneiss and sometimes calcareous tuf are the type of stones used for the building façades. Other types are used for other applications (stairs, embellishments or non-building applications). Figure 8.8 illustrates the various stone façades that can be observed in Swiss historic buildings.
Figure 8.8. Façade in stone in Switzerland: 1) sandstone façade from Lausanne, 2) limestone façade from Neuchâtel, 3) gneiss façade from Ticino

The figure 8.8 shows the main type of facades per stone groups. However, within a stone group, according to the quarry location, subcategories can be found, generally associated with the name of the region, such as:

- Sandstone: Bern molasses, Rorschader sandstone, etc.
- Limestone: Mikritischer limestone, Oolithischer limestone, etc.
- Gneiss: Augen gneiss, Zweiglimmergneis, etc.

In Switzerland, 64 types of stones are listed (Kündig et al, 1997). These different stones present a variability of their properties (e.g., density, water absorption coefficient etc.). More detailed information can be found in Kündig et al. (1997).

8.4.2 Mortar and binder

Four types mortars and binders are found before 1945:

- Air hardening binder using lime, from the 18th century to the second part of the 19th century.
- Hydraulic binder using hydraulic lime, from about the 19th century to the first part of 20th century.
- Hydraulic binder using natural cement (Roman cement) during the 19th century (in lower proportions than the two above).
- Hydraulic binder using Portland cement from 1920 to 1945\textsuperscript{19}.

### 8.4.3 Bricks

As described in the wall type characterization, clay bricks were used in Switzerland during the 19\textsuperscript{th} century and until 1945. The manufacturing was mainly found in the Swiss plateau as shown in figure 8.9.

\textit{Figure 8.9. Brick plant in Switzerland in 1907}

### 8.4.4 Other types of materials

Stones, bricks and mortars are the main materials found in historic buildings in Switzerland and particularly in Western and Southern Switzerland (French and Italian speaking parts). It is also important to keep in mind that regional particularities can be found e.g., in Northern Switzerland where some historic buildings are built with half-timbered walls. However, as the focus of the screening of case studies for Switzerland is only on stones and bricks’ wall types, this type of materials and walls is not described in more details in this chapter.

\textsuperscript{19} The use of hydraulic binder using Portland cement still continues until today
8.5 Most common types of historical building walls alterations and their causes

An extensive and comprehensive description of stone walls alterations and their associated causes is complex. To have a common understanding worldwide, a UNESCO ICOMOS-ISCS guide provides a standardisation of the terms to be used for the structural damages and alterations (ICOMOS-ISCS, 2008).

In this chapter, some of the observed deterioration in Switzerland are presented using, as far as possible the appropriate terms of the ICOMOS-ISCS guide. In that context, the ICOMOS-ISCS definitions are introduced prior to the description of deterioration in Swiss historic buildings:

- Alteration: ”Modification of the material that does not necessary imply a worsening of its characteristics from the point of view of conservation. For instance, a reversible coating applied on a stone may be considered as an alteration”
- Damage: “Human perception of the loss of value due to decay”
- Decay: “Any chemical or physical modification of the intrinsic stone properties leading to a loss of value or to the impairment of use”
- Degradation: “Decline in condition, quality, or functional capacity”
- Deterioration: “Process of making or becoming worse or lower in quality, value, character, etc...; depreciation”
- Weathering: “Any chemical or mechanical process by which stones exposed to the weather undergo changes in character and deteriorate”

The census of the alterations found in Switzerland is based on the course “Stone materials and conservation of the built heritage” proposed by the company “Conservation Science Consulting Sàrl” (CSC) at the Swiss Federal Institute of Technology of Lausanne. CSC is a consulting company in charge of expertise related to historical buildings’ alterations and faced a large panel of wall alterations. According to CSC experts, most of the alterations presented in the ICOMOS-ISCS guide are found in all countries.

Table 8.10 presents the stone degradation, which affects the condition, quality and/or functional capacity of the buildings. The weathering phenomena are described and a picture illustrating the processes is also represented.
### Table 8.10. Weathering forms of the historical buildings with stone façade

<table>
<thead>
<tr>
<th>Weathering and deposit</th>
<th>Description</th>
<th>Sub-category</th>
<th>Origin</th>
<th>Remark</th>
<th>Pictures</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discoloration and deposit</td>
<td>Chromatic alteration</td>
<td>Change of the stone colour in one to three of the colour parameters: hue, value and chroma.</td>
<td>Stains</td>
<td>Generally correlated with alien materials (rust, copper salt, etc.)</td>
<td>Does not depend strictly on exposure conditions of water supplies</td>
<td><img src="Cressier" alt="Picture" /></td>
</tr>
<tr>
<td>Discolouration</td>
<td>The original colour of a material changes because of processes like water penetration, exposure to sunlight, formation of metallic oxide in the structure</td>
<td></td>
<td></td>
<td>Does not strictly depend on exposure conditions of water supplies</td>
<td><img src="Lausanne" alt="Picture" /></td>
<td>Lausanne</td>
</tr>
<tr>
<td>Red Staining</td>
<td>Local oxidation of iron components on the stone surface often caused by a fire</td>
<td></td>
<td></td>
<td>Does not depend on whether exposure conditions</td>
<td><img src="Romainm%C3%B4tier" alt="Picture" /></td>
<td>Romainmôtier</td>
</tr>
<tr>
<td>Moist Area</td>
<td>Caused either by water absorption by capillarity from the ground at the base of walls or from a surface of retention (Moisture goes through the walls, wets the internal and external surfaces where a horizontally limited stain is visible), or by water vapour adsorption by the hygroscopic salts present in the porosity of the</td>
<td></td>
<td></td>
<td>Take place in zone where water supplies from the wall bases (or from a surface of retention) are important or on old masonries polluted in the past with hygroscopic salts (from manure, salt or gun-powder storage,...)</td>
<td><img src="Montheron" alt="Picture" /></td>
<td>Montheron</td>
</tr>
<tr>
<td>Subflorescence</td>
<td>Accumulation of salt crystals just under the external surface of building stones. There are harmful as the pressure exerted by crystals can cause damages</td>
<td>Commonly the result of evaporation of saline water present in the porous structure of the stone. As subflorescences develop inside the porous structure, they often result in scaling of the surface.</td>
<td>Subflorescences are hidden, unless the stone layer over them detaches. In that case, salt crystals become visible on the newly exposed surface.</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>-----</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efflorescence</td>
<td>Any visible salt deposit on the surface of the building stones. There are less harmful than subflorescence</td>
<td>Commonly the result of evaporation of saline water present in the porous structure of the stone. Whitis, powdery or whisker-like crystals on the surface. Efflorescences are generally poorly cohesive and commonly made of soluble salt crystals</td>
<td>Generally poorly bonded to the stone surface</td>
<td>Chur</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crust</td>
<td>Surface layer of colour, structure, chemistry and mineralogy different from the substrate</td>
<td>Coherent accumulation of materials on the surface.</td>
<td>A crust may include exogenic deposits in combination with materials derived from the stone. Crusts may have an homogeneou s thickness, and thus replicate the stone surface, or have irregular</td>
<td>Neuchatel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Features induced by material loss

<table>
<thead>
<tr>
<th>Features induced by material loss</th>
<th>Chemical and/or mechanical erosion</th>
<th>Loss of original surface, leading to smoothed shapes, can be due to water, wind, too aggressive methods of cleanings, etc.</th>
<th>Differential erosion</th>
<th>Erosion of variable intensity on various sector of the material, due to inhomogeneity of the stone material</th>
<th>Common on the sedimentary stones made of different strata. Take place in zones exposed to more or less direct water supplies and to wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Film</td>
<td>Thin covering or coating layer generally of organic nature, generally homogeneous, follows the stone surface.</td>
<td>- Exogenous (anthropogenic) application</td>
<td>A film may be opaque or translucent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Alveolization</strong></td>
<td>Formation, on the stone surface, of cavities (alveoles) which may be interconnected and may have variable shapes and sizes (generally centimetric, sometimes metric).</td>
<td></td>
<td></td>
<td></td>
<td>Appears on surfaces exposed to strong winds where the crystallization of salts occurs underneath the surface. Take place in zones exposed to direct water supplies and wind</td>
</tr>
<tr>
<td><strong>Mechanical damage</strong></td>
<td>Loss of stone material clearly due to a mechanical action.</td>
<td></td>
<td></td>
<td>Does not depend on the exposure conditions, mainly anthropogenic causes</td>
<td></td>
</tr>
</tbody>
</table>

**Lausanne**

**Fribourg**

**Cressier**

**Neuchâtel**
<table>
<thead>
<tr>
<th>Detachment</th>
<th>Fragmentation</th>
<th>Splintering</th>
<th>Granular disintegration</th>
<th>Delamination</th>
<th>Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detachment</td>
<td>The complete or partial breaking up of a stone, into portions of variable dimensions that are irregular in form, thickness and volume.</td>
<td>Detachment of sharp, slender pieces of stone, split or broken off from the main body.</td>
<td>Occurs in granular sedimentary (e.g. sandstone) and granular crystalline (e.g. granite) stones. Granular disintegration produces debris referred to as a rock meal and can often be seen accumulating at the foot of a wall actively deteriorating. The grain size of the stone determines the size of the resulting detached material.</td>
<td>Corresponds to a physical separation into one or several layers following the stone laminae. The thickness and the shape of the layers are variable and may be oriented in any direction with regards to the surface.</td>
<td>Detachment of a stone layers parallel to the stone surface but not following any stone structure.</td>
</tr>
<tr>
<td>Montheron</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Biological colonization

| Biological colonization | Algae, Lichen, Moss | Colonization of the stone by plants and microorganisms such as bacteria, cyanobacteria, algae, fungi and lichen (symbioses of the latter three). Biological colonization also includes influences by other organisms such as animals nesting on and in stone. | Algae form can be found mainly in situations where the substrate remains moistened for long periods of time. Lichen is a common feature on outdoor stone and is generally best developed under clean air conditions, but growth may be facilitated by certain pollutants. Mosses often grow on stone surface open cavities, cracks, and in any place permanently or frequently wet (masonry joints), and usually shady. | Outside but also inside of a building, at the stone surface. Require water (liquid supply or condensation), luminosity and adequate nutrients |

Crack and deformation

| Crack and deformation | Crack | Individual fissure, clearly visible by the naked eye, resulting from separation of one part from another | Fracture | Crack that crosses completely the stone piece | Can be either limited to the material surface or affect the material in depth. Can result from static problems, use of a too hard mortar, accident, frost action... |

8.6 Case studies on renovation of historic buildings

The case studies have been selected by contacting the insulation material manufacturer located in Switzerland and by performing a survey toward owners of buildings who recently requested for building authorizations to the local authorities of the French speaking Swiss cantons (Vaud, Genève, Fribourg, Neuchâtel). Based on this approach, we selected four case studies illustrated in figure 8.10.
HES-SO choice for the screening of historic building’s renovation case studies is based as far as possible on residential buildings to be online with the analysis of section 8.1 in terms of energy consumption and wall type’s assessment.

However, due to historic building’s renovation data scarcity, other historic buildings’ types were also considered. Indeed, according to experts’ knowledge (architects, historic buildings experts), the main wall types found for historic residential buildings are also representative of other buildings’ types (e.g., school, university, offices etc.

### 8.6.1 Old farm in Bavois

Year of construction: 1833

Year of energy renovation (and internal insulation): 2014-2015

Short description of building: This building is located in Bavois, a small village of the "Gros de Vaud" region in the canton of Vaud. Built in 1833, there were originally one apartment and
unheated areas for the storage needs of the farm. Recently, the building has been renovated and the unheated volume has been transformed in apartments. Since a change in the building usage was expected, the renovation had to comply with the energy regulation of the canton and since the building was protected (class 3 of the cantonal classification), external insulation of the facade was forbidden. Original external wall is built from stone and mortar masonry (0.5 m).

*Insulation material:* Glass wool (for façade and roof) (23 cm) and PUR (basement) (12 cm)

*Insulation method:* Internal thermal insulation

*Motivation for renovation:* Better thermal comfort, higher living quality, creation of new apartments

*Other energy efficiency measures implemented at same renovation:* Thermal solar panels, heat pump and floor heated system, roof insulation, floor against unheated area insulation

*Achieved results, including energy savings:* Limit value: 135 MJ/m$^2$; heating needs: 86 MJ/m$^2$ (energy savings 36%).
8.6.2 School in Niederwangen

Year of construction: 1892

Year of energy renovation (and internal insulation): 2014

Short description of building: The school, built in 1892 has been classified by the Bern cantonal office for patrimony as “worthy of conservation” and listed in the inventory of historic building for the city of Köniz. The old school has thus been completely renovated. The façade has been renovated in order to get back its original appearance. This case study has been suggested by the insulation manufacturerISOVER.

Insulation material for the facade: 150 mm of glasswool on the interior side (30 mm against the wall and 2*60 mm).

Insulation method: Internal thermal insulation

Motivation for renovation: NA

Other energy efficiency measures implemented at same renovation: Connection to district heating network and new heat distribution

Achieved results, including energy savings: Limit value: 191 MJ/m², heating needs: 145 MJ/m² (energy savings 24%).
8.6.3  House in Hérémence

*Year of construction:* 1937

*Year of energy renovation (and internal insulation):* 2013

*Short description of building:* The “Val d’Herens” is a valley of the Wallis canton. The architecture of the buildings is famous and typical of the Swiss historic alpine constructions. Large houses were initially used by the family clan (one floor per family, with one fireplace located on the stone wall). The case study 3 is the property of two persons, and one of them, expert in energy, decided to renovate the building. Since the building is classified according to the Wallis rule for the historical buildings, the façade had to be preserved. Residential building with 2 floors and basement.

*Insulation material:* Glass wool and PUR (10 cm)

*Insulation method:* Internal thermal insulation

*Motivation for renovation:* Heating system to be replaced and choice of the owner who is an energy professional

*Other energy efficiency measures implemented at same renovation:* Heat pump, roof insulation, windows replacement

*Achieved results, including energy savings:* Limit value: 247 MJ/m², heating needs: 142.4 MJ/m² (energy savings 42%).
8.6.4 Building in Siviriez

Year of construction: 1895

Year of energy renovation (and internal insulation): 2015

Short description of building: The village of Siviriez is located in the Fribourg Canton. Initially, this building was a café, closed several year ago. Recently, the municipal council decided to renovate the building and to change its usage into apartments and a space for municipal activities. The building was protected by the Fribourg cantonal legislation and the façade had to be preserved. Since the building was deeply renovated (only the wall remained from the initial construction), it is considered as a new building and has to fulfil the energy rule for new buildings (Minergie label in the case of the Fribourg Canton). 3 apartment building house. Only the external walls were maintain. The technical floor is outside the periphery of the old building.

Insulation material: PUR principal and some EPS

Insulation method: Internal thermal insulation

Motivation for renovation: Old café, not used during a long period. Transformation into apartments. The Renovation was necessary and it had to comply with the legislation on transformation from Fribourg canton.

Other energy efficiency measures implemented at same renovation: Photovoltaic Solar panels, geothermal heat pump, roof and floor against ground insulated.

Achieved results, including energy savings: Limit value: 247 MJ/m², heating needs: 142.4 MJ/m² (energy savings 42%).
8.7 Motivation for the application of internal insulation and energy efficient measures

In 2012, a survey on the motivations for energy efficient (EE) retrofit has been performed in four Swiss cantons, namely Aarau, Basel, Bern and Zürich, (Farsi, Banfi, and Jakob 2012). This survey encompassed renovations that occurred between 1996 and 2010. Over a sample of 276 multi-family housing building owners, the motivations reasons and shares are presented in Table 8.11.

Table 8.11. Motivations for energy efficient renovation of the facades in four Swiss cantons (Farsi, Banfi, and Jakob 2012)

<table>
<thead>
<tr>
<th>Reasons why measures were conducted (after 1996) to improve the condition of building elements</th>
<th>EE facade retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relative to # of answers of respondents</td>
</tr>
<tr>
<td>Damage and end of lifetime</td>
<td>10%</td>
</tr>
<tr>
<td>Complaints from tenants</td>
<td>1%</td>
</tr>
<tr>
<td>Long term planning (Portfolio management)</td>
<td>4%</td>
</tr>
<tr>
<td>Maintenance of value of building</td>
<td>16%</td>
</tr>
<tr>
<td>Increase value of building</td>
<td>9%</td>
</tr>
<tr>
<td>Aesthetic</td>
<td>7%</td>
</tr>
<tr>
<td>Noise protection, increase attractiveness</td>
<td>7%</td>
</tr>
<tr>
<td>Environment and climate protection</td>
<td>12%</td>
</tr>
<tr>
<td>High energy prices</td>
<td>12%</td>
</tr>
<tr>
<td>Incentive programs (financial)</td>
<td>3%</td>
</tr>
<tr>
<td>Increase rent and rate of return</td>
<td>4%</td>
</tr>
<tr>
<td>Increase in living area</td>
<td>8%</td>
</tr>
<tr>
<td>Energy consulting</td>
<td>1%</td>
</tr>
<tr>
<td>Reduction dependency on fossil fuel</td>
<td>4%</td>
</tr>
<tr>
<td>Other</td>
<td>1%</td>
</tr>
<tr>
<td>No response</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>100%</td>
</tr>
</tbody>
</table>

According to Table 8.11, the main motivation for energy efficiency renovation is to maintain/increase the value of the building (25% of the first column). Indeed, a clean and renovated building with low energy consumption will be attractive for the tenant while the overall value of the building will remain high.

Environmental aspects was also found to be of high interest for the building owners (12% plus 4% of “reduction of the dependency to fossil fuels”), which is very positive. Education, promotion of the current environmental issues seems to be now accepted and understood by non-energy specialists.

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20 Since one owner could choose several motivations, two percentages are calculated, one on based on the sum of all the answer (left column total = 100%) and one relative to the number of owners (276 respondents). The average number of motivations per owner is 4.5.
The economic motivation is found to be important in Switzerland since the third motivation (during the interval 1996 to 2010) was the high energy prices. This motivation is rather counter-intuitive since in Switzerland there is a high share of tenancy who are actually paying for the energy that is consumed in the apartments while the owner does not pay for this (in other word, the investment is made by owner but the benefits are for the tenants). Still, this aspect has been answered as important in the survey\(^{21}\).

The legislation aspect, representing one important aspect, is not covered in the study of Farsi et al. (2012) as the buildings (i.e., multi-family housing type) were not subjected to a change of allocation (e.g., from non-residential building to residential building). Indeed, in the case of an allocation change, the owners have to comply with current building legislations e.g., in terms of energy performance and U-values limits. In Switzerland, these limits are set cantons per cantons\(^{22}\). In the canton of Vaud (i.e., the Lausanne region), a building transformation has to comply with the Swiss Society of Engineers and Architects 380/1 standard on energy in buildings and its specification for transformation/renovation. Some cantons can also define higher requirements. For example, in the canton of Fribourg, public renovated buildings have to comply with the Minergie label for renovation.

As a result, energy efficient renovations for historic buildings (with or without an allocation change) are generally mandatory and follow at least the lowest level of requirements i.e., the 380/1 standard for transformation/renovation. As the external walls usually represent a large share of the building’s transmission losses, they are also in many cases renovated.

From the discussions with the owners of historical buildings case studies presented in chapter 8.6, the internal insulation was decided because of two reasons:

- The energy legislation and standard
- The historic value of the building and its classification by each canton\(^{23}\) making impossible a renovation with an external insulation.

Finally, in tax rebates and financial incentives (at the cantonal level via the “Programme Bâtiment” or even at the communal levels) are important levers to initiate energy efficient renovation. For historical buildings, these incentives shall comply with insulation levels of the Swiss Society of Engineers and Architects 380/1 target value, i.e., 0.20 W/m\(^2\).K plus a tolerance of 0.05 W/m\(^2\).K because of the historical value of the building.

\(^{21}\) However, this aspect might not be relevant currently (i.e., in 2015) due to the relatively “low” cost of energy.

\(^{22}\) That is the reason why it is often said that Switzerland has “26 different energy legislations”

\(^{23}\) The classification of historical buildings depends on every canton in Switzerland.
8.8 Acknowledgments

The University of Applied Sciences and Arts Western Switzerland represented in the RIBuild project by the Laboratory of Solar Energetics and Building Physics (LESBAT) gratefully thank all the Swiss partners and colleagues that provided data, text and information about the historic building stock in Switzerland, including the related case studies, causes of degradations and main building materials and wall types.

We thank particularly:

- The different insulation manufacturers for providing case studies (ISOVER, swisspor) and experiences of the internal insulation of historic buildings (PAVATEX, Isofloc). We thank particularly M. Bohnenblust from ISOVER and M. Sarrasin from swisspor.
- The different services (Patrimony, Buildings and Energy) of the Swiss Cantons in Western Switzerland (Geneva, Fribourg, Vaud, Neuchâtel)
- The Swiss Programme Bâtiment / Gebäude Programm (Mrs. Von Felten and M. Molinari) for providing the necessary help and support to get access to some examples of historic buildings renovations with internal thermal insulations of private landlords.
- Finally we thank all the architects, engineering firms and private landlords that accepted to provide us with detailed information of historic buildings renovation. We thank particularly M. Grünig from weber+bauphysik in Bern for providing the necessary data of the "Niederwangen Schulhaus" case study, M. Bovier for providing the necessary data of the "Val d’Hérens" case study, M. and Mrs. Laferrière for the farm located in Bavois (technical data provided by Beauverd architecte) and the city of Siriviez for its administrative building (technical data provided by Pierre Chuard consulting group and Gilon architect).
- Dr. Bénédicte Rousset (from CSC consulting), M. Kündig and Mr. Zehnder (from the Swiss Geotechnical Society) and M. Stefano Zerbi (from the HES-SO Hepia Geneva) for the discussion about stone architecture, stone physical characteristics, stone alterations in historic buildings and for providing us relevant pieces of information that contributes to the improvement of the stone walls characteristics and degradations chapters.

Last but not least, we also thank our colleagues of the HES-SO Fribourg (Mme Schwab and M. Jaquerod) for sharing the HES-SO eRen project’s database on the characterisation of residential buildings’ wall types.
8.9 References


Kündig Rainer et al., 1997, „Die mineralischen Rohstoffe der Schweiz“, Zürich : Schweizerische Geotechnische Kommission


Swiss Society for Engineers and Architects, 2009, „, SIA 380/1 : L’énergie thermique dans le bâtiment » (English: Thermal energy in the building)

SITG. 2015. “Le Système D’information Du Territoire À Genève (SITG).”


Swiss Geotechnical commision, 1997 « Rohstoffinventar »


Zerbi, Stefano, 2015, Personal communication with Zerbi and the authors of the Swiss RIBuild contribution
## Appendix 1. Summary of main wall types of historical buildings

<table>
<thead>
<tr>
<th>Countries</th>
<th>Before 16th century</th>
<th>16th-17th centuries</th>
<th>18th century</th>
<th>19th century</th>
<th>20th century</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Very often composed of brick and lime or sandstone.</td>
<td>Massive wall 1.5 brick (28 cm); massive wall 2 bricks (38 cm)</td>
<td>Massive wall 1.5 brick (28 cm); massive wall 2 bricks (38 cm)</td>
<td>The multi-family buildings constructed before 1890 were a direct continuation of the half-timbered buildings, but with solid brick external walls. From around 1850 single family houses were constructed with solid brick walls rendered with a thin layer of lime mortar and lime. The houses have a stone foundation.</td>
<td>From around 1900 house began to have wall without rendering.</td>
</tr>
<tr>
<td>Denmark</td>
<td>In cultural buildings such as churches, castle etc. external walls can be constructed of stone.</td>
<td>Around 1850-1930 buildings were constructed with massive external walls.</td>
<td>Around 1850-1930 buildings were constructed with massive external walls.</td>
<td>61% of all residential buildings in Germany are single-leaf masonry and 30% are double-leaf masonry.</td>
<td>For massive walls materials used are (1) dry stone or stone and mortar; (2) fired bricks and mortar.</td>
</tr>
<tr>
<td>Germany</td>
<td>Until the end of 19th century most wall construction were designed based on experiences and common rules of thumb. These rules were replaced with local construction regulations which were published from the 1870th on. These local regulations remained valid in parallel to the enactment of diverse national standards.</td>
<td>Wall thickness of clay walls is at least 0.7 m for residential buildings.</td>
<td>Wall thickness of clay walls is at least 0.7 m for residential buildings.</td>
<td>In residential buildings are 2 ½ brick or at least 2 brick (51cm) thick. Wall thickness increases every ½ bricks every two floors down inward so the external side of wall is smooth.</td>
<td>61% of all residential buildings in Germany are single-leaf masonry and 30% are double-leaf masonry.</td>
</tr>
<tr>
<td>Latvia</td>
<td>External shell has been built of brick, the rest of the wall was filled with lime mortar, construction material residues and irregular stones.</td>
<td>Residential stone buildings were built with at least 75cm thick walls. If plastered from both sides, wall is 60 – 65 cm thick.</td>
<td>Residential stone buildings were built with at least 75cm thick walls. If plastered from both sides, wall is 60 – 65 cm thick.</td>
<td>Wall thickness of clay walls is at least 0.7 m for residential buildings.</td>
<td>61% of all residential buildings in Germany are single-leaf masonry and 30% are double-leaf masonry.</td>
</tr>
<tr>
<td>Sweden</td>
<td>Masory buildings have been built in Sweden since the Middle Ages but then almost exclusively as churches.</td>
<td>Swedish apartment buildings: brick building 1870-1890 South Sweden, maximum 3 stories plus basement, 250 mm long bricks</td>
<td>Swedish apartment buildings: brick building 1930-1960, with internal insulation, 3-5 stories plus basement, in some case up to 9 stories, internal wood wool insulation 30-50 mm</td>
<td>Swedish apartment buildings: brick building 1870-1890 South Sweden, maximum 3 stories plus basement, 250 mm long bricks</td>
<td>Swedish apartment buildings: brick building 1930-1960, with internal insulation, 3-5 stories plus basement, in some case up to 9 stories, internal wood wool insulation 30-50 mm</td>
</tr>
<tr>
<td></td>
<td>Swedish apartment buildings: brick building 1870-1890 north and middle of Sweden, maximum 4 stories plus basement, 300 mm long bricks, plaster on the outside.</td>
<td>Swedish apartment buildings: brick building 1890-1940, maximum 6 stories plus basement, both plastered and non-plastered façade, (300 mm brick south, 250 mm bricks North and middle)</td>
<td>There are not many Swedish buildings with external rock masonry walls. In the island of Gotland there are around 3000 buildings with masonry walls made of limestone. Almost all of them were constructed before 1900.</td>
<td>Swedish apartment buildings: brick building 1890-1940, maximum 6 stories plus basement, both plastered and non-plastered façade, (300 mm brick south, 250 mm bricks North and middle)</td>
<td>Swedish apartment buildings: brick building 1890-1940, maximum 6 stories plus basement, both plastered and non-plastered façade, (300 mm brick south, 250 mm bricks North and middle)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Before 1919: Massive wall with variable thickness depending on the height of the building: (1) Rendering with hollow clay brick and rendering.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### CAVITY WALL

<table>
<thead>
<tr>
<th>Country</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Cavity walls for green houses and ice cellars. Tie stones were used, leading to an incomplete decoupling of outer and inner walls. Later that steel wall ties are used.</td>
</tr>
<tr>
<td>Denmark</td>
<td>Between 1890-1930 cavity walls of single family buildings with header of brick. The walls were built on a foundation of bricks or concrete. From around 1875 cavity walls of multi family buildings with header was introduce for walls with limited load-carrying capacity e.g. end walls. From 1931 to 1950 cavity walls with wall tie were used in single family buildings. The multi-family buildings constructed from 1931 to 1950 were also constructed similar to those from earlier periods of multi-family buildings with brick masonry. At the later period the solid masonry walls were gradually replaced by hollow walls with headers.</td>
</tr>
<tr>
<td>Germany</td>
<td>From 1918 on, several cost-efficient construction and material types were developed, especially for small single family dwellings. This led also to very thin masonry walls with load-bearing layers of only 12 cm thickness for these cavity walls.</td>
</tr>
<tr>
<td>Italy</td>
<td>In 19-th century cavity walls were introduced, but they are not very widespread.</td>
</tr>
<tr>
<td>Latvia</td>
<td>In 19-th century cavity walls were introduced. Often, in order to improve existing buildings, another internal brick layer was added to external walls. Newly built internal layer was covered with stucco and painted or covered with wallpaper. All buildings built from the end of 19-th century until the beginning of 20-th century are built this way. To avoid construction of thick stone walls in residential buildings, internal layer of ¾ to ½ brick and about 6cm wide air gap with brick ties was allowed.</td>
</tr>
<tr>
<td>Sweden</td>
<td>There are buildings with cavity walls in Sweden but they are not that common.</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Rendering with hollow clay brick, air, hollow clay brick, rendering</td>
</tr>
</tbody>
</table>

### RUBBLE WALLS

<table>
<thead>
<tr>
<th>Country</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Multi-leaf walls with rubble core: a non-homogenous set-up → clear distinction between facings (often in regular brickwork, sandstone or limestone) and core material</td>
</tr>
<tr>
<td>Italy</td>
<td>Two leaf wall: the external leaves are usually made as a monolithic wall; the inner leaf is made by rubble stones of fragments of bricks and mortar. Rubble (listed) walls: they are made by irregular stone and mortar. Sometimes, they are regularised by horizontal bricks layers.</td>
</tr>
<tr>
<td>Latvia</td>
<td>Buildings from this period are with very poor quality with rubble walls. Constructions and materials used for buildings were with various, often divergent characteristics. Rubble walls were coated with plaster.</td>
</tr>
</tbody>
</table>

### TIMBER FRAME

<table>
<thead>
<tr>
<th>Country</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Composed of wood and clay</td>
</tr>
<tr>
<td>Country</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td><strong>Denmark</strong></td>
<td>In the older part of the building stock bricks are used in combination with timber framing where the bricks are applied a thin layer of lime-mortar or lime. Before approximately 1890 the buildings were constructed with half-timbered walls with and infill panel of typical burned or unburned bricks rendered with a thin layer of lime mortar or lime. Half-timbered buildings were built up to the 1700s and typically up to 4 storeys.</td>
</tr>
<tr>
<td><strong>Germany</strong></td>
<td>Timber frame / timber constructions represent about 2-3% each of the whole residential building stock in Germany. From 1918 on, several cost-efficient construction and material types were developed, especially for small single family dwellings. This led also to very thin masonry walls with load-bearing layers of only 12 cm thickness for these cavity walls.</td>
</tr>
<tr>
<td><strong>Italy</strong></td>
<td>Timber framed buildings are not very widespread.</td>
</tr>
<tr>
<td><strong>Latvia</strong></td>
<td>Timber framed technology has not been used.</td>
</tr>
<tr>
<td><strong>Sweden</strong></td>
<td>Not many buildings with a timber framing. This building technique was only used in south of Sweden.</td>
</tr>
</tbody>
</table>

### FACADE FINISHES OF HISTORIC MASONRY WALLS

<table>
<thead>
<tr>
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<th>Description</th>
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<tbody>
<tr>
<td><strong>Belgium</strong></td>
<td>- 'nude' - painted - lime-washed - plaster - natural stone cladding - glazed tiles</td>
</tr>
<tr>
<td><strong>Denmark</strong></td>
<td>Massive walls with thin layer of lime mortar and lime. Half-timbered walls: the buildings were applied rendering ruled to resembling dimension stone/ashlar.</td>
</tr>
<tr>
<td><strong>Italy</strong></td>
<td>Masonry walls are often externally protected by plaster, which is usually present even inside.</td>
</tr>
<tr>
<td><strong>Latvia</strong></td>
<td>- 'nude' - painted - lime-washed - plaster - natural stone cladding</td>
</tr>
</tbody>
</table>
### Abstract:

This annex I relates to the D1.1 report ‘Report on historical building types and combinations of structural solutions’.

The annex contains for each country involved in RIBuild data and information on the building stock: Properties of building materials, composition of external walls and joints with suspended floors (including illustrations), number of buildings divided on building types, and heated areas divided on building types.

### Disclaimer:

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<table>
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<td>Robust Internal Thermal Insulation of Historic Buildings</td>
</tr>
<tr>
<td><strong>Project Acronym:</strong></td>
<td>RIBuild</td>
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<tr>
<td><strong>Deliverable no.:</strong></td>
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<tr>
<td><strong>Author(s):</strong></td>
<td>Andra Blumberga (RTU), Dagnija Blumberga (RTU), Edite Kamendere (RTU), Agris Kamenders (RTU), Kristaps Kass (RTU), Reinis Purvins (RTU), Gatis Zogla (RTU)</td>
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<td>AAU, RTU, TUD, KUL, UNIVPM, DTU, SP, HES-SO</td>
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**Abstract:**

This annex II relates to the D1.1 report ‘Report on historical building types and combinations of structural solutions’.

The annex contains for each country involved in RIBuild description of a number of case buildings that have been renovated. Data contains general information of the building and building envelope materials, heat energy supply and distribution, energy consumption, objectives and motivation for executing the renovation, kind of renovation, the used design tools and guidelines, and whether the aim of the renovation was reached.

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