Lessons from Exemplary Housing Renovations

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Task 37 Advanced Housing Renovation with Solar and Conservation / Subtask B

Lessons from Exemplary Housing Renovations

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Thanks to all the experts who documented these exemplary renovations and the owners, designers and engineers who contributed material. This report is only possible because of this excellent international collaboration among good friends!

[1] Funded by the Swiss Federal Office of Energy, Gebäude Program, Andreas Eckmanns & Charles Filleux

1. Introduction

60 exemplary housing renovations achieving dramatic energy savings have been documented in brochures as part of a project of the International Energy Agency*. This summary presents lessons learned from a collective look at these brochures from ten countries:
AT, BE, CA, CH, DE, DK, I, NL, NO and SE.

For analysis, the projects were grouped by housing type as follows:

- APT: apartment buildings
- ROW: row houses and
- SFH: single family detached houses
- HIS: historic --housing.
- ATC: attica apartments added

The successes of the renovations are the result of a combination of strategies, including:

- extreme conservation measures
- installing efficient systems for ventilation and heat production
- adding a solar thermal system or PV-system
- minimizing ecological impact
- redesigning the housing to enhance living quality.

The first step is consistently to add insulation while eliminating air leakage and to replace old windows with very good windows. The next step is to compliment such conservation measures with a solar thermal system. In locations with high kWh buy-back prices, a roof mounted, PV system has been added to the renovation package.

The performance of the modernizations is impressive. Primary energy consumption for space heating and water heating has been reduced up to 90 percent. This is all the more impressive because it reflects the source energy needed to produce the energy, not just the end energy. Equally impressive is the dramatic improvement in the living quality of the projects, which in most cases was the motivation.

It is interesting to note the different approaches taken across Europe as well as the three examples from Canada to achieve these savings. Each country and building culture adds an insightful dimension to finding the most cost effective, energy saving and quality of life winning solutions.

These examples are presented to encourage housing owners to be ambitious when planning a renovation. A mediocre renovation blocks a deeper, more effective renovation for decades. If the inflation of energy costs is considered, the marginal costs of energy saving measures during a modernization will pay back nicely.

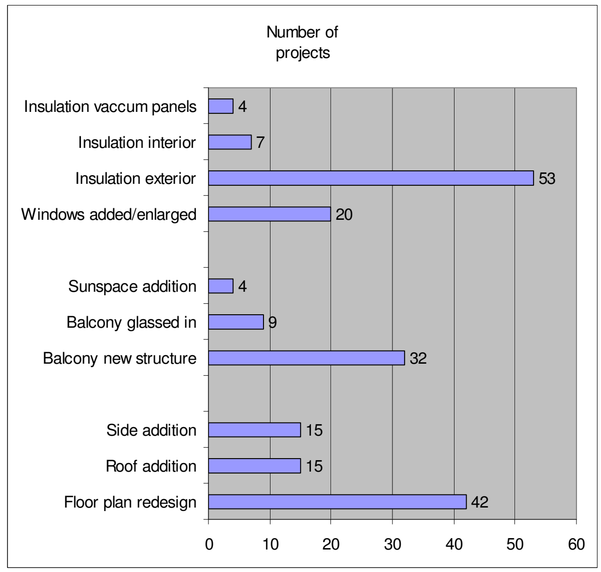
* IEA Solar Heating & Cooling Program, Task 37: Advanced Housing Renovation with Solar & Conservation, Subtask B: Advanced Projects Analyses, www.iea-shc.org

Following are observations from the 60 projects regarding architectural measures taken, U-value improvements of the building envelope, types of mechanical systems selected (including renewables) and energy savings. The graphs offer a sense of the range of properties for the building elements as well as how often building owners chose which system type.

Architectural measures:

Table 1.1 shows the numbers of projects with specific architectural changes out of the total of 60 projects. The three most frequent measures are: exterior insulation, a new balcony structure to eliminate thermal bridges and provide a more useable space, and redesigning the floor plan. Sunspaces, very popular in the 1980's, were added in only four projects. However, enclosing balconies with glass is added to the number of sunspaces, the total is 13. Noticeably small is the number of projects using interior insulation (perhaps due to risk from moisture and loss of room space) or vacuum insulation (costs and worry about longevity).

Table 1.1: Number of projects including architectural changes



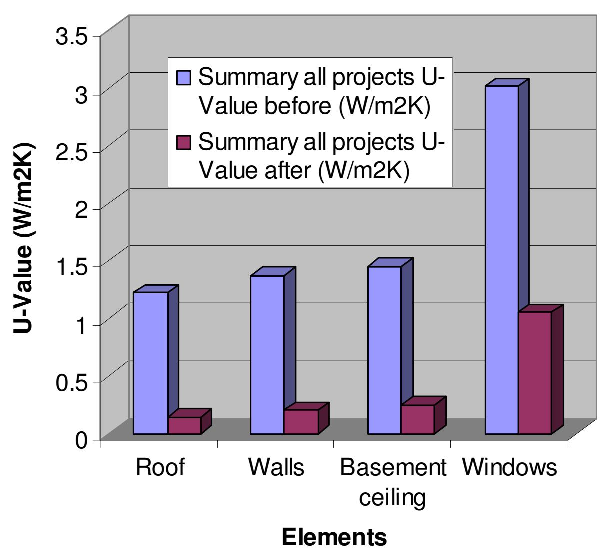
Insulation:

Table 1.2 shows how insulation values of the envelope were reduced. The biggest absolute improvement was by the windows. The U-value is reported for the frame and the glass. The low U-values indicate that the majority of the projects used triple glazing and high quality window frames. Table 1.1 showed that in 19 of the projects, now only were windows replaced but the window area was increased as well.

The walls and roof, with more surface area, lead to the greatest savings. Roof insulation is especially important for summer comfort. Basement ceiling insulation leads to better comfort on the ground floor. The U-values are slightly higher since the heat loss path is not to the outside air.

Ten projects reported to meet the Passive House Standard[2] and three almost met it.

Table 1.2: U-values of envelope elements before and after modernisation



[2] Passivhaus Standard, http://www.passiv.de

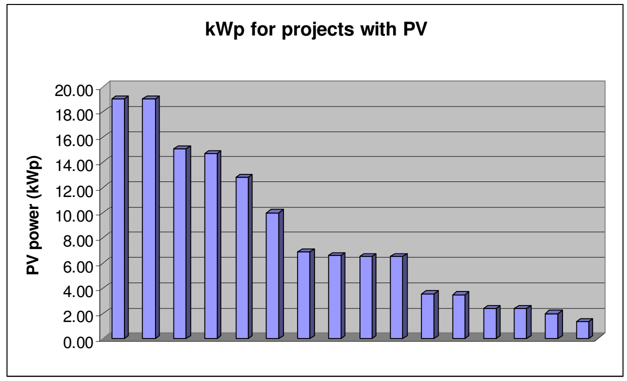
Technical Systems:

New technical systems were a major part of the modernizations (Table 1.4).

34 projects had active solar thermal systems, of which six helped meet both domestic hot water and space heating demand. Vacuum tube collectors were used in 13 projects.

PV-systems were installed in 18 projects, totaling 132 kWp. The largest systems are on the apartment buildings, with five systems between 10 and 19 kWp (Table 1.3).

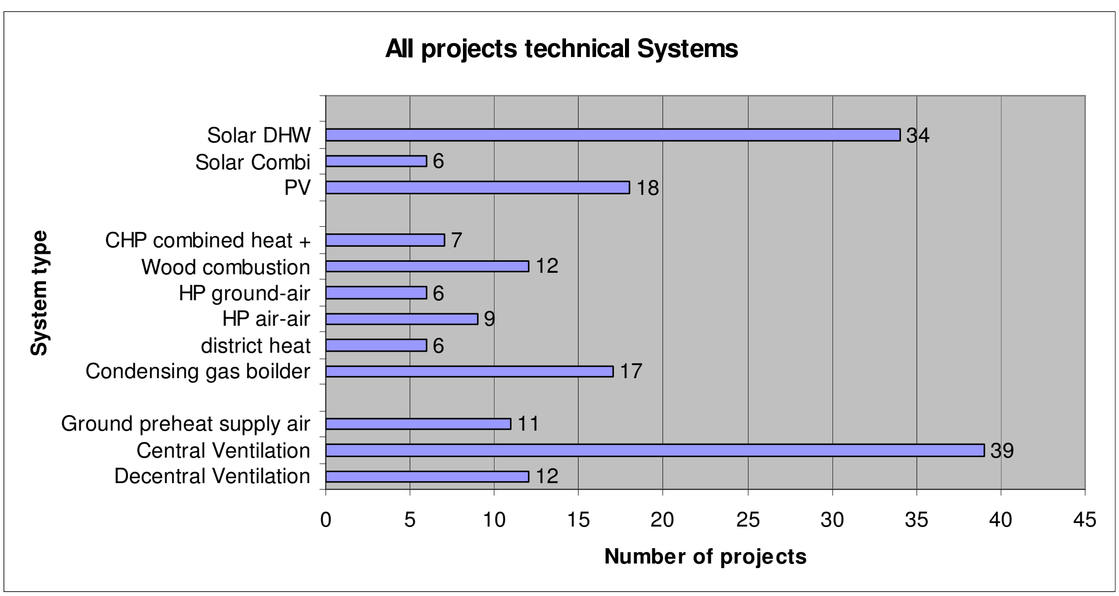
Table 1.3: PV nominal peak power of projects



Remaining heating demand was most frequently met by a condensing gas boiler installed before the renovation. Next most common were heat pumps (15 with 6 using the ground as a heat source). 12 projects used wood (pellet) combustion. Six projects incorporated combined heat and power plants (CHP), of which one used a sterling motor (521 Row houses in Manheim). Three projects still had oil fired heating; to be used scheduled replacement came due.

Of the 60 projects, 51 had mechanical ventilation with some form of heat recovery. The majority were central systems (39). Non-central systems included room ventilation units, i.e. thru-wall units or window frame slits. 11 projects preheated supply air in buried earth channels. One project used façade-mounted solar air collectors to preheat supply air entering the room behind the wall (512 APT for Elderly in Stuttgart DE). The average efficiency of the heat exchangers was 84%.

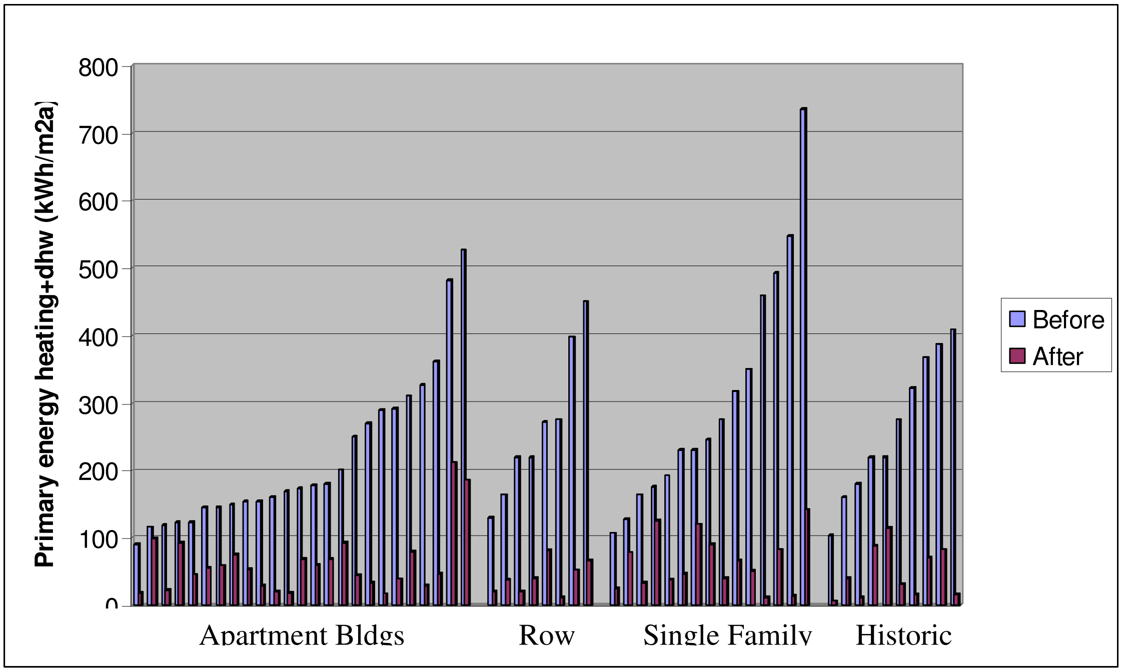
Table 1.4: Types of systems used in the projects



Performance:

On average, the 60 projects saved 76 percent, with 10 projects achieving 90 percent or more energy savings for the total demand for space heating, water heating and electricity for technical systems.

Table 1.5: Percentage energy savings of each project



It can be observed that by all housing types dramatic energy savings are possible. Not graphed are the two projects with added attica apartments, because there is no before energy consumption for comparison. All together, the 58 projects achieved on average 83 percent energy savings. The greatest savings for this collection of renovations were made by the row houses (84%) followed by the historic housing (81%). Of course, historic housing starts from the highest energy consumption levels, but it has more limitations.

The projects:

The following five sections present lessons learned for apartment buildings, row housing, single family housing, historic housing and attica add-on apartments. Each project is documented in a four to eight page brochure. A number keying system identifies the country where a project is located as well as the type of housing it is (Table 1.6). The largest number of projects are apartment buildings (25) followed by single family houses (15).

Table 1.6: Numbers of building types by country

Country	Apartment APT (10)	Row house ROW (20)	Single Family SFH (30)	Historic HIS (40)	Attic Apt ATC (50)	Total
100 Austria AT	4	0	5	2	1	**12**
200 Belgium BE	1	3	0	1	1	**6**
300 Canada CA	0	0	3	0	0	**3**
400 Switzerland CH	6	0	3	3	0	**12**
500 Germany DE	8	1	1	3	0	**13**
600 Denmark DK	2	1	0	0	0	**3**
700 Italy IT	0	0	0	1	0	**1**
800 Netherlands NL	0	2	1	0	0	**3**
900 Norway NO	2	1	2	0	0	**5**
1000 Sweden SE	2	0	0	0	0	**2**
Total	**25**	**8**	**15**	**10**	**2**	**60**

Note: the brochures are keyed by country code: (100 – 1000) and Housing type: (Apartments: 10 – 19, Row houses: 20-29, Single family: 30-39, Historic: 40-49, Attica 50).

Brochures as PDF files of these projects can be found on the website:

www.iea-shc.org. under tasks and working groups, Task 37, publications / outcomes.

2. RENOVATION OF APARTMENT BUILDINGS

Apartment buildings have many unique aspects affecting renovation:

- Because the building volume is large, the surface area is small relative to the enclosed volume. Hence, it is relatively easy to achieve low transmission losses relative to the heated floor area. However, because most apartment buildings were built as a business enterprise, construction costs were often "optimized". As a result, the enclosure is typically poorly insulated and full of thermal bridges.
- The owner may own / manage many apartment buildings with profitability being a key aspect. There are exceptions, however, where idealism influences decisions, as in the case of ownership by a family or by a corporation promoting its "green-ness".
- Failure of the heating plant or major deterioration of the building envelope may necessitate action. Simple economics suggests this to be the time for an audit of the whole building and its systems, and then plan a comprehensive renovation. The benefits become apparent in life cycle cost analysis and in the economies of correcting more conditions at the same time.
- In several examples renovation costs were completely covered by adding a story and additional apartments, increasing the rental income. This is, however, not sustainable financing. The next renovation cannot be paid in this manner.
- Design, aesthetics and living quality can be a decisive benefit for the rental market. Minimizing vacancy time can quickly offset the investment in modernization.

The most common renovation strategies used in the 25 documented projects were:

1) Add 200 to 300 mm of insulation and a new exterior to the facades of the building.
2) Eliminate the thermal break of balconies (28 projects), typically by cutting off the old, projecting balconies and constructing new, free-standing balconies. Alternatively, the balconies were glazed in. Thus the thermal bridge is within a sun-tempered space (9 projects). In one case, the balcony was fully insulated to become part of the living space.
3) Tighten the envelope and add mechanical ventilation with heat recovery by either a central unit or decentral units. The efficiency of the heat recovery was 82% with almost all projects reporting a similar nominal value. Higher reported efficiencies may be in error regarding how the efficiency was determined.
4) Add a solar system. Twelve projects invested in a solar thermal system, two of which were combi systems. Eight four projects invested in a photovoltaic system, several of which are large systems from 10 to 19 kWp.
5) Replace the back-up heating system with a renewable energy system. Many heating system types are represented here: Three projects use a heat pump of which one used the ground as a heat source. One project has a combined heat and power system. Two projects use wood pellets, and the remainder use a condensing gas boiler or are connected to district heat. The Norwegians heat using water power (hydro-electric).

The average energy consumption before and after the renovation showed a 69% reduction in primary energy consumption for space and water heating, from 220 to 63 kWh/m^{2}a.

2.2 Envelope

Table 2.1: Envelope thermal properties before and after renovation

Element	U-before (W/m^2K)	U-after (W/m^2K)	Improvement x
Roof	0.90	0.15	6.2
Walls	1.09	0.17	6.5
Basement	1.28	0.28	4.6
Windows	2.62	1.04	2.5

Insulation

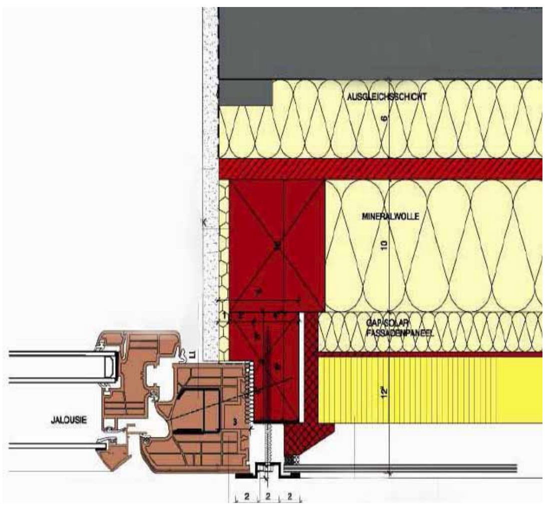


Fig. 2.1: The GAP-Solar Facade in 111 APT Linz *(Brochure: D. Meisinger, S. Gruenewald, S. Rottensteiner and Th. Mach)*

111 APT Linz AT: The walls of this urban apartment block, nearly five decades old, were still in a good condition, but the poured concrete had a terrible U-value (1.4 W/m²K). It was decided to add a solar insulation and use this mass as part of the concept. The "Gap-Solar Façade" (fig. 2.1) achieves a dynamic U-value averaged over sunshine and darkness hours of 0.16 W/m²K. The solar façade was calculated to reduce the annual heating demand from 179 kWh/m² to 14.4 kWh/m². The expected annual savings of about 444 MWh will decrease annual carbon dioxide emissions from about 160 T to 18 T. Before modernization: heating a 59 m² apartment cost € 40.80/month, after modernization only € 4.73/month!

Fig. 2.2: Eves of 514 APT Hoheloostr. Ludwigshaven DE
(Brochure author: S. Winkel & B. Kaufmann)

514 APT Hoheloogstr. Ludwigshaven DE: This project demonstrates an extreme quality of insulation, with the addition of 300 mm extruded polystyrene to the facades and careful attention to details. The eaves were framed out to avoid thermal bridges (fig. 2.2) and the foundation was insulated for the same reason, in addition to adding 120 mm of insulation to the basement ceiling. The renovation reduced annual primary energy demand from 99 to 32 kWh/m^2.

Fig. 2.3: Added wall to 1011 APT Brogården (Brochure Ulla Janson)

1011 APT Brogarden SE: This housing estate with 300 apartments built 1970 badly needed renovation. The mortar of the brick facades was falling out. Rain and subsequently ice accelerated the deterioration of the wall. The solution was to build a new metal stud wall with three layers of mineral wool insulation totaling 410 mm in front of the existing brick wall (fig. 2.3). At the same time, the existing balconies were cut off and replaced by new balconies carried by external supports. Glazing in the balconies is optional.

Fig. 2.4: Balconies of 514 APT Hohe-loostr. Ludwigs-haven DE *(Brochure: S. Winkel & B. Kaufmann)*

BALCONIES

514 APT Hoheloogstr. Ludwigshaven DE: The old, cantilevered concrete slab balconies were cut off and new, large triangular balconies added on which are supported on their own framework. They are only anchored laterally to the wall, minimizing thermal bridges. The dramatic effect and improved living quality (fig. 2.4) more than justified the cost of this measure to eliminate bad thermal bridges.

Fig. 2.5: Balconies of 211 APT Sterrenveld BE *(Brochure: Wouter Hilderson)*

211 APT Sterrenveld BE: The west side of the building was extended two meters to provide sunspace terraces on the upper floors. This was accomplished with a concrete slab and steel column construction, which also add rigidity to the building (fig. 2.5). To reduce thermal bridging, the connection between building and winter gardens has been reduced to a minimum. An almost continuous layer of hard insulation board runs between both concrete slabs. 412 APT Ostermundigen CH: The balcony depth was increased and reconfigured with half the width of the balcony glazed in as a winter garden.

Windows

Fig. 2.6: Enlarging/adding window area, 411APT Stanssted CH (*photo: Beda Bossard Büro für Baubiologie, Bauökologie & Energie)*

411 APT Stansstad CH: Here, the windows were removed and all openings increased on the SE and SW facades to increase the daylighting of the living spaces (fig. 2.6). Also, newly constructed balconies have a glass floor to admit more daylight into the windows behind the balconies.

Other examples include:

414 APT Volketswil CH: Installation of new windows, sun blinds with insulated boxes on the south façade.

416 APT Zurich-Birm. CH: To offset the tunnel effect with large insulation thickness for the walls, new bow windows were built in Larch wood.

114 Landeck Elderly Housing AT: New large frameless windows and the thermal mass of existing concrete construction provide useful passive solar gains.

2.3 Renewable Energy Use

Solar Thermal Systems

Fig. 2.7: Solar vacuum tube collector of 211 APT Sterrenveld BE *(Brochure: Wouter Hilderson)*

211 APT Sterrenveld BE: Domestic hot water production is split between pre- and post solar water heating: three 1000 l tanks each for preheating and two 300 l tanks for post-heating. 30m² vacuum tube collectors are oriented to the south-west (fig. 2.7). Total measured production the first 18 months was 9.9 MWh.

113 APT Kierling AT: 57% water and space heating demand are covered by 120 m^2 of solar collectors and a 6000 L tank.

151 APT Innsbruck AT: 85% solar coverage of annual dhw demand.

112 APT Dornbirn AT: 30 m^2 of solar roof-mounted collectors and 1500 l storage cover 60% of the demand for domestic hot water and 17% for space heating.

612 APT Engelsby DK: 80 m² of solar collectors for space and water heating.

Solar PV

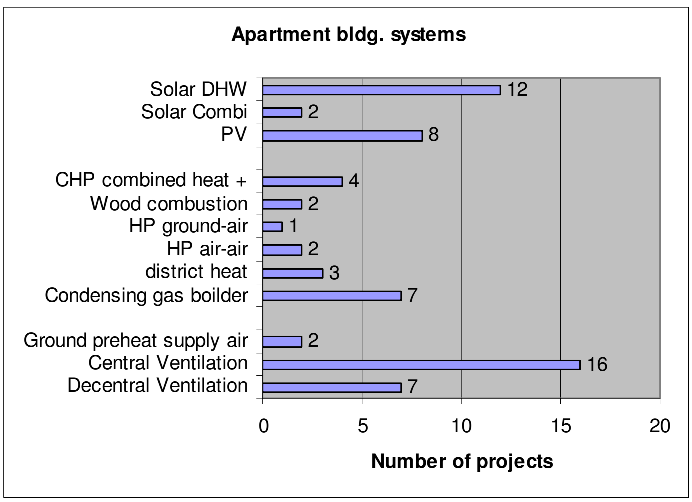
413 APT Staufen CH: The entire south roof slope of the apartment building was covered with 110 m² PV (fig. 2.8). The nominal output is 14.7 kWp. The electrical output fed into the grid in 2006 was metered at 14'300 kWh The PV installation will be amortized within 20 years.

Another example: **211 APT Sterrenveld BE:** 15m² polycrystalline PV panels, with a peak capacity of 19 kW. 2.5 MWh measured production over 17 months.

Fig. 2.8: PV Roof of 413 APT Staufen CH *(Photo AEU GmbH, Wallisellen CH)*

2.4 Technical Systems

Table 2.2 Frequency of systems in apartment projects



The most frequent means of producing heat was a condensing gas boiler (mostly the existing system). Four projects have combined heat and power systems. This is possible because of the larger absolute demand of apartment buildings compared to the other housing types.

Central ventilation systems out-number decentral systems 16 to 7.

Many project (12) have a solar thermal system, two being combi-systems. Eight have a PV system.

Mech. Ventilation with heat recovery

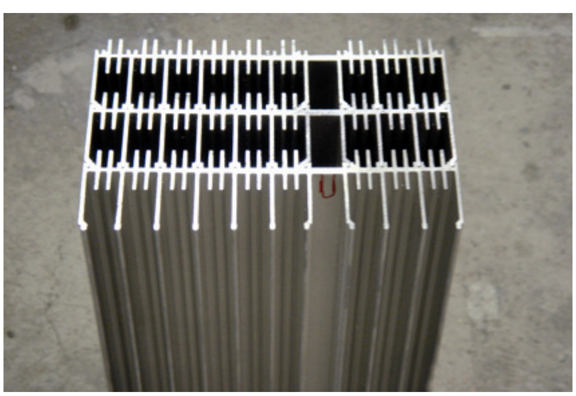


Fig. 2.98: Air-Air Ventilation heat exchanger at the project 412 APT Ostermundigen CH *(Photo: Rollimarchini*

412 APT Ostermundigen CH: The ventilation system uses a novel v heat recovery exchanger with a special profile and placed directly inside of the aluminum ducts (fig. 2.9). No additional heat exchanger is needed. Its efficiency is 80 percent. The ventilation system's electrical consumption amounts to 3.59 kWh/m²a. The fans have 54 W connected power.

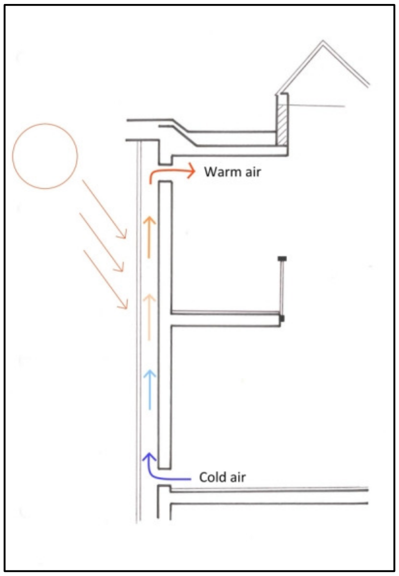


Fig. 2.10: "Trombe Wall" solar air heat of stair tower in 612 Apt Engelsby DK *(Photo: Stærmose & Isager Architects)*

612 APT Engelsby DK: The new ventilation system is demand controlled by the humidity level; the ventilation rate is high when needed, otherwise at a base level. For a 24 hour period, the ventilation typically ventilates 61% of the air compared to a traditional exhaust air system, but still the indoor climate has been improved. The energy loss is also decreased when the ventilation rate is low. The savings can be up to 40% compared to traditional ventilation. Furthermore, the ventilation air for the stair tower is heated in two-storey Trombe Walls (fig. 2.10).

Other interesting examples of mechanical ventilation with heat recovery include:

211 APT Sterrenveld BE: Due to lack the limited ceiling height, the ductwork runs vertically in six technical shafts. These are connected to four heat recovery ventilation (HRV) units. Three types of HRV units are used (in order of measured efficiency):
a rotary heat exchanger, two 2 cross flow systems and a 1 heat pipe system.

411 APT Stannstad CH: The heat exchangers for the mechanical ventilation are located in the attic. These high efficiency units supply 150 m^3/h at 50 Pa and draw only 50 W of power. Their efficiency is rated at 0.87 (Hoval Homeven RS 250). The air supply and return ducts run in the corridors and attic where the ducts are wrapped with 50 mm insulation.

414 APT Volketswil CH: A new central ventilation system was installed on top of the roof and vertical ducts were embedded in the new exterior insulation. The air is exhausted from the apartments through the existing bathroom vents.

Auxiliary Heat Production

Fig. 2.11: Drilling for heat, 251 ATC Brussels *(Brochure: J. Desmedt, J. Cre, W. Hilderson)*

251 ATC Brussels BE: Geothermal heat is supplied as the source for a heat pump (fig. 2.11). The heating system is a combination of this system, a solar thermal system and finally a back-up of a condensing gas boiler. The difficult part is to find an optimal way to integrate the operation of these different systems. The control strategy had to be flexible but not overly complicated.
The heat produced by the different systems is stored several hot water buffer tanks, totaling 1100 l.

2.5 Ecology

Fig. 2.12: Small gardens on the new graded roof terraces of 251 ATC Brussels *(Brochure by Wouter Hilderson & Johan Cre)*

251 ATC Brussels BE: Attention was given to limit demolition waste and the quantity of new materials needed in the construction. For example, the floors of the existing building were only slightly renovated and some dismantled materials were reused to build the new floors. Non treated wood was used. There are larch floors, clay wall coverings, eucalyptus window frames and insulation from wood fiber, cellulose, cork. The existing water tank was reused, a common clothes washing room was created for all the tenants. The washing machines are supplied with solar hot water. Vegetable gardens were created on the terraced roofs, accessible from the apartments and a green roof covers the lower building of the annex. The courtyard, which houses some parking spots, has a rain permeable paving and is surrounded by flowerbeds.

2.6 Redesign for Living Quality

251 APT Brussels BE: Circulation to the apartments and offices is through the carriage entrance and existing stairs. A central corridor linking the stairs on the one side to the lift on the other side leads into the apartments. To give the northern apartments a view to the south, a third level was constructed above the duplexes. The roof terraces contain small gardens (fig. 2.12). The southern façade is designed to let the sunlight enter in a controlled way. Large fixed sun visors in pergola-style contribute to creating a charming outside space, where the wooden horizontal surfaces (floor and "ceiling") dialogue together. The wood, as a contrast, softens the strong presence of the metallic elements that underline the vertical.

Fig 2.13: Joys of renovation, new floor plan layout. 416 APT Zürich *(Brochure: Nadja Grischott & Nadia Mastacchi)*

416 APT Zurich-Birm. CH: The floor plans were dysfunctional and too small for contemporary comfort standards: the three-room apartments were only 73 m2, two-room apartments 58 m2. Kitchens and bathrooms were not up to current expectations. Accordingly, the floor plan was newly laid out to provide larger, functional and modernized units (fig.2.13). To increase the apartment floor area, on the courtyard side the new façade has been moved one meter out.

511 APT Freiburg DE: Expandability of kitchen and bath in case of new occupants

513 APT Heidelberg DE: These buildings, constructed in 1951 were comprised mainly of two-room apartments. A major objective was to redesign of floor plans to fulfill modern living standards and different types of apartments ranging from two to four room units.

514 APT Ludwigshaven DE: Complete new floor plan. Conversion of two 3-room apartment per floor to one 3-room and one 2-room apartment with larger rooms and new baths /wc's and kitchens, better positioned in the floor plan.

611 APT inAlbertlund DK: The 14 buildings with 631 apartments, built in 1966-69, were too small and typically occupied only for short periods. Accordingly, the renovation included:
- Redesigning the layout of the flats, merging smaller into larger units suitable for families, elderly and physically disabled people
- Increasing the daylight penetration into the apartments
- Constructing new balconies.

Fig. 2.14: Stair tower glazing to make this a bright, daylit space. 612 APT in Engelsby *(Photos: Stærmose & Isager Architects)*

612 APT in Engelsby DK: The stair tower received new roof and side glazing to improve the quality of the space with more daylight (fig. 6.14).

113 APT Kierling AT: balconies glazed in, 3 elevators added, 6 penthouse apartments added

211 APT Sterrenveld BE: The re-layout of the apartments was done using lightweight inner walls to improve flexibility. The west façade was brought forward two meters attached to the existing construction. This accommodated the addition of large protected terraces. The old central hallway was replaced by three decentral vertical circulation shafts with generous daylighting.

412 APT Ostermundigen CH: This apartment building from 1965 needed renovation and had been vacant for 1 ½ years until the architects Rollimarchini were able to finance its purchase and renovation. The renovated apartments are now handicapped accessible, have a contemporary layout with improved daylighting and aesthetics, as well as substantially reduced energy costs. The more rentable living space was increased by creating four attica maisonettes.

411 APT Stansstad CH: The new deeper balconies were constructed with glass floors to admit more daylight into the windows. The windows on the SE and SW facades were enlarged to further increase daylighting of the living spaces. The basement walls (not ceilings as is usual) were insulated to improve the usability of the basement.

3. Row Housing

3.1 Introduction

Row houses are unique in several aspects:

- Because most units have only two facades, these have a small surface area in relation to the enclosed volume. Of special importance are roof insulation, windows, the entry door and air tightness.
- Typically, there are covenants and collective decisions are required from the owners association regarding changes to the exterior. Decisions are none-the-less, made by individuals with direct interest in the outcome. The problem is getting a consensus. Some individuals may be willing to invest in their ideals for sustainability and environment. Other owners may lack financial resources.
- Often major deterioration of the building envelope necessitates some action, so owners decide to renovate with a view to long-term return on investment. Decisive are design, aesthetics, living quality as well as investment costs.

Accordingly, the typical actions taken in these projects from BE, DE, DK, NL and NO were:

- Add insulation to the attic and/or basement ceiling
- Replace the windows and possibly entrance door
- Insulate the facades and add a new exterior finish
- Replace the boiler and hot water heater
- Add a solar system to heat hot water
- Add mechanical ventilation with a heat exchanger
- Add PV Panels for electric generation if there is public support

Looking at all eight row house projects, primary energy for heating, hot water and elec. for technical systems was reduced from 310 to 64 kWh/m^{2}a, an 84% saving!

3.2 Envelope

Table 3.1: Thermal properties of envelope components

Element	U-before (W/m^{2}K)	U-after (W/m^{2}K)	Improvement (X)
Roof	2.04	0.13	16
Walls	1.32	0.14	9.7
Basement	1.82	0.19	9.4
Windows	3.43	0.87	4

Insulation / thermal bridges

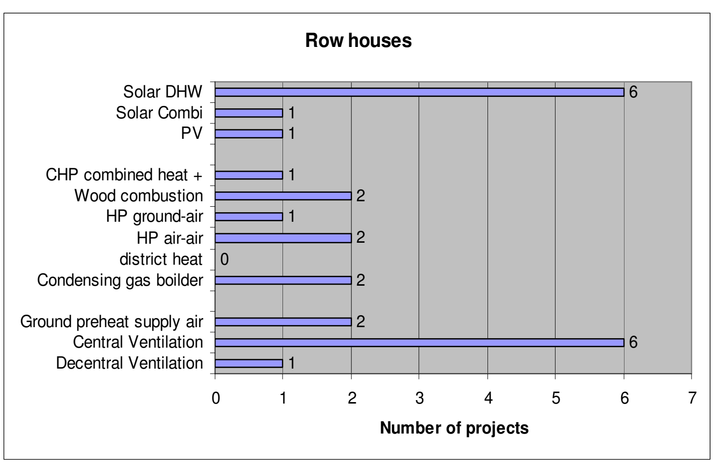
Fig. 3.1: Interior insulation of the street façade 222 ROW house in Eupen BE *(Brochure: Wouter Hilderson & Johan Cre)*

222 ROW Eupen BE: This 150 year old house needed a thorough renovation. The roof was worn out, the single-pane windows were cold and leaky and bad hygienic conditions prevailed. Also, the 130m² house was too small and needed to be enlarged to 180m². So, it was decided to do a complete renovation.

A clever system was used to insulate the street façade (fig. 3.1). The floors were cut away from the façade and a new wooden I-frame interior wall constructed and the void filled with cellulose. This allowed a continuous insulation of the entire street façade. A variable permeability vapor barrier prevents winter room humidity from passing into the wall in winter, but allows the insulation to dry out in summer. The vapor resistance depends on the relative humidity, ranging from 0.25m to 10.5m. New windows were added on the room side of the existing windows. By placing the new windows in the new interior wall it was possible to size them with a glass area almost as big as the whole existing window opening, maximizing daylighting and view. New solar collectors shade upper storey windows in summer

3.4 Renewable Energy Use

Table 3.2: Frequency of mech. systems in the eight row-house projects



Immediately evident is the popularity of solar thermal systems in 6 of the 8 row house projects, one being a combi-system for heating and dhw.

Central ventilation systems for each individual house are common, one project used room ventilators and one had no ventilation system.

There is no obvious preference for one type of heating system. Not in Table 3.2 is the one project with electric heating (223 Row Depinte BE).

3.4 Technical Systems

Auxiliary Heat Production

Fig. 3.2: 521 Row houses in Manheim. *(Brochure: Johann Reiss)*

521 ROW Mannheim DE: These rows of townhouses (fig. 3.2) share a common heat supply system which replaced the individual heating stoves of these 12 units. Heat is centrally produced by a gas-fired condensing boiler and a Stirling engine which also produces electricity. Each flat has a separate high-efficiency ventilation unit located in the attic. Diverse concepts have been implemented, including warm-air heating with various control concepts and separate systems for heating, ventilation, and cooling.

3.5 Redesign for Living Quality

223 ROW DePinte BE: To achieve ‘lofty feeling’ well daylit and an open plan this, the room layout was changed: The living space and kitchen were moved up to the first floor where there is more light, bedrooms moved to the ground floor. By raising the eaves and changing the pitch of the new roof, a large open space with a mezzanine was created. The size of the windows was optimized, with bigger windows at the back (west-side) but eliminating the skylights on the east.

Fig. 3.3: New bay windows of 621 Alberslund DK (*Photos: BoVest)*

621 ROW Albertslund DK

As part of the renovation bay windows were added to these row houses. This enlarges the indoor area and creates better daylighting of the living space (fig. 3.3).

4. Single-Family Housing

4.1 Introduction

Single-family houses are unique in several aspects:

- Because the building volume is small, the surface to volume ratio is very high. Accordingly, insulation, eliminating thermal bridges and air tightness are important.
- There is typically one owner or family so decisions are not made by a committee or corporate head quarters, but by individuals with very direct interest in the outcome.
- Often individuals are willing to invest in their ideals, so the economics of renewables are less critical than the philosophy of sustainability and environment.
- The failure of the heating system or major deterioration of the building envelope may necessitate some action, so the owners decide to renovate with a view to long term investment and performance.
- The renovation may be motivated by the decision to enlarge or strongly improve the quality of the house, i.e. after a new purchase or inheritance by a family. So, the cost of saving energy and using renewable energy is an integral part of a renewal package and must not be justified only by energy savings.
- Design, aesthetics and living quality are decisive.

Accordingly, the typical actions taken in the projects in 15 projects are reported in brochures, from AT, CA, CH, DE, NL and NO are:

- Add insulation to the attic and/or basement ceiling
- Replace the windows and possibly entrance door
- Replace the boiler and hot water heater
- Insulate the facades and add a new exterior finish
- Add a solar system to heat hot water
- Add mechanical ventilation with a heat exchanger
- Add PV Panels for electric generation if there is public support

The primary energy for heating, hot water and elec. for technical systems could be reduced from 310 to 64 kWh/m^{2}a or a 74% savings on average.

4.2 Envelope

Table 4.1: U-values of the envelope components

Element	U-before (W/m^{2}K)	U-after (W/m^{2}K)	Improvement (X)
Roof	0.75	0.12	6.1
Walls	0.89	0.15	5.8
Basement	1.24	0.30	4.1
Windows	2.75	0.96	2.9

Improving the U-values of the roof and walls had the highest priority in these row house projects. However, as can be seen in Table 4.1, also the windows and basement ceiling received attention.

Fig. 4.1: Hook-in timber wall, 133 SFH Pettenbach AT. *(Photo: W. Schwarz)*

133 SFH Pettenbach AT: Adding a storey to this house was the motivation for a complete renovation. The original walls are cantilevered on floor joists (nogging pieces) and could not take added weight. So, the addition was done with a prefabricated, load-bearing, "hook-in" timber wall construction (fig. 4.1). A new interior concrete frame carries the 120/60mm wooden rafters of the new storey. For fire protection concrete is double planked. To insulate the ground floor, without reducing limited cellar head-room, 20 mm vacuum insulation panels were laid on the ground floor and new flooring installed above it. The house with the addition has a totally new character.

Fig. 4.2: 432 SFH Ostermundingen CH *(Photo: Christian Zeyer)*

432 SFH Ostermundigen CH: Again, adding living space was the motivation for this total renovation (fig. 4.2). Existing wall insulation was stripped away and two overlapping 160 mm layers of polystropore installed as a "compact façade". Vacuum insulation was used in front of window roll blind boxes and over the on-grade floor area. A new roof was built over the existing roof. The existing roof was covered with vapor barrier glued to the wall vapor barrier. Wooden trusses with a wooden fiber deck were anchored to the old roof. Cellulose (Isofloc) was blown in the hollow. Bats nailed to the deck carry roof tiles and roof-integrated PV panels. High insulation windows were also installed.

Fig. 4.3: 932 SFH Kongsberg NO *(Brochure: Tor H. Dokka)*

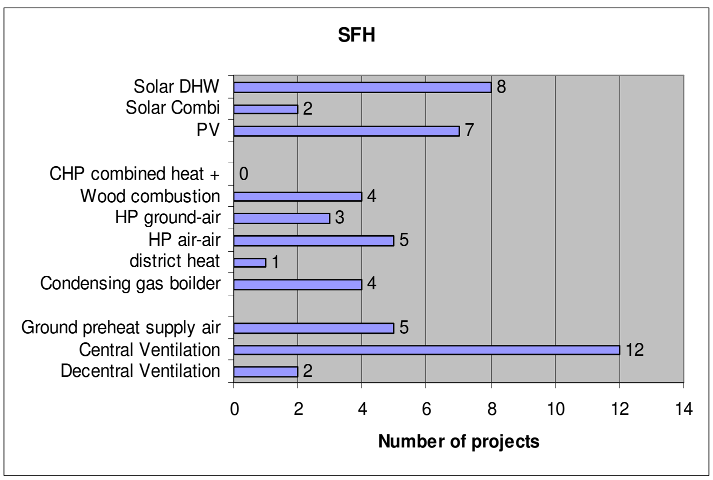
932 SFH Kongsberg NO: This log cabin, built in 1942, was completely renovated (fig. 4.3). Because the 150 mm log walls were uneven, a wooden lattice covered with OSB-panels was required to get an even surface. The facade insulation is anchored with long screws into the OSB-panels. All windows were replaced with Passive House quality windows. Under the roofing was a 50mm void space for venting and 100 mm of mineral wool. 60% of the ceiling faces an unheated attic room. The ceiling in the attic was insulated with 200mm mineral wool. The remaining 40% has an extra layer of mineral wool with variable thickness (100-400mm)). The ground of the crawl space is covered with a 0.2 mm vapor barrier and 200 mm insulation. Foundation walls are insulated with 100 mm mineral wool and 70 mm horizontal edge insulation. The crawl space is sealed from the outdoors to keep the temperature above the condensation point. Because the cottage was very draughty (estimated 15-20 ac/h by N50) attention was given to improving the air-tightness. The goal is to achieve an air tightness of 1.0 ac/h.

4.3 Renewable Energy Systems

460 EFH Ostermundigen CH To store the passive solar gains from the large new windows, an 80 mm cement floor was poured. Heat from the sun-warmed room is distributed through the house by the ventilation system with its 90% efficient heat recovery. Heat is produced by a heat pump with a 150 m deep bore hole as the heat source. A solar thermal system includes 5 m2 of collectors and 500 L storage. PV (6.6 kWp) Panels were integrated into the roof.

4.4 Technical Systems:

Table 4.2: Technical systems in the single family houses



Solar is popular among owners these single family houses owners, with 8 of the 15 projects having solar thermal systems and 7 having a PV system.

Heat pump systems are also present with 8 projects, 3 using the ground as a heat source. Wood combustion is also popular.

14 of the 15 houses have mech. Ventilation with some form of heat recovery. Five use the earth to preheat supply air.

331 SFH Toronto CA: This retrofit project, one of 12 "Equilibrium" homes being built across Canada, demonstrates sustainable design concepts and technical systems. This renovation, the "Now House", engaged the local neighborhood and general public through a series of public events during the design, planning and construction phases of the project.

Included are two sets of vacuum tube solar collectors with a 454 storage produce 1'825 kWh/a of heat. A 2 kWp grid connected PV system producing 2'410 kWh/a. Overall energy savings are 80%.

Fig. 4.4: Public awareness raising of technical systems at the 331 SFH Toronto (Brochure Lorraine Gauthier, Paul Parker & Shane ONeill

5. Historic Housing

5.1 Introduction

Historic housing is unique in several aspects:

- Because often the building facades are protected cultural heritage, it is not allowed to add exterior insulation. The only alternative is interior insulation, if indeed the room walls do not have murals or ornaments. Interior insulation requires detailing care to minimize thermal bridges, prevent room moisture from getting in or behind the insulation and avoid rot if wooden floor rafters penetrate the bearing wall.
- The walls, window and door openings, floors and ceilings are unlikely to be even or right angled, so fitting and finishing are more difficult. Several projects built a new wall inside an existing wall or installed new windows inside existing historic windows.
- Adding solar collectors or PV panels may be prohibited. Several project architects got a waiver for placing these on the non-street front facades or roof or in a court space.
- If the envelope is tightened, mechanical ventilation with heat recovery may be especially important to prevent too high humidity and mould growth on walls which could not be insulated and remain cold.
- The renovation of the building, if it remains as housing, offers special challenges to fulfill market expectations for comfort and room layout, but the result can be rich in character.
- Such renovations upon completion are particularly striking, respecting historic, cultural heritage while providing modern comfort. The resulting apartments typically have a high market appeal, so it a modernization is likely an excellent investment.

Accordingly, the typical actions taken in the projects (AT, BE, CH, DE, DK, IT) in order of carrying them out (except where an action was urgent) are:

- Add insulation to the attic and/or basement ceiling
- Add modern window sash and glazing inside existing windows
- Replace the boiler and hot water heater
- Insulate walls on the interior
- Add mechanical ventilation with a heat exchanger
- Add solar collectors and PV Panels on rear roof slopes.

Considering the constraints imposed on historic buildings the savings in primary energy for heating, hot water and elec. for technical systems are impressive:
264 to 48 kWh/m^{2}a, or an 81% reduction!

5.2 Envelope

Table 5.1: Thermal properties of envelope components

Element	U-before (W/m^2K)	U-after (W/m^2K)	Improvement (X)
Roof	1.3	0.15	8.7
Walls	1.43	0.26	5.5
Basement	1.47	0.29	5.1
Windows	3.27	1.26	2.6

Even with the limitations of historic housing, insulating the walls has a high priority, as also does the roof. Window heat losses are typically reduced by adding windows on the room side of the existing windows.

Insulation / thermal bridges

Fig. 5.1: Placing new cornices over insulation in 142 HIS Purkersdorf
(Photo: Architekturburo Reinberg)

142 HIST Purkersdorf AT: 260 mm of insulation were added to the exterior of the façade. The exterior cornices and window trim were reproduced and mounted outside the insulation to match the original façade design on the street side (Fig. 5.1).

Fig. 5.2: Rebuilt double windows (U_w reduced 2.7 to 1.35 W/m^2K) in 141 Irding.
(Photo: Hegedys & Ull/Hofer)

141 Irding AT: The fabric of the two storey 16th century building was in a very poor condition. The ground floor had water damage. The floor was totally removed, ground excavated, drainage pipes laid, and some of the foundation wall replaced. An open diffusion insulation with hygroscopic properties was installed.
The massive exterior walls were not insulated also with moisture problems. A new exterior façade was built outside the original façade and included 140 – 160 mm of mineral wool insulation. Thus, the interior wall and ceiling stucco ornamentation were preserved. To dry out the structure and keep it dry, small diameter tubes were embedded in the walls to heat the mass and provide low temperature radiant heating.
The original windows were left in place, but new window sash installed on the room-side of the original windows (fig. 5.2).

241 HIST Herselt BE: New foundations with foam glass inserted under the outer wall with new brick facade to create a 12cm cavity for mineral wool insulation. New aluminum window and door frames with thermal breaks. New electrical roller shutters for shading with additional insulation around the roller box. Size, height and external format (roof angle, window and door openings) of the construction were kept as before per local historic preservation ordinance.

442 HIST Zürich: This apartment building, constructed in 1898, was in poor condition when the owner inherited it. He wanted to renovate the units to a high living standard, drastically reduce energy consumption while preserving the historic urban character of the structure. The roof replaced with eight prefabricated modules by crane in one day, creating two new penthouse apartments. The modules incorporate 240 mm insulation. The rear walls of the building could be improved with 240 mm of insulation and a new outer plaster, the street façade had to be left in its original state.

Fig. 5.3: 543 HIST Speyer Barracks to Housing conversion. *(Brochure: Beate Schneider, Klemens Osika)*

543 HIST Speyer DE: Conversion of former military buildings erected in 1888 for a Bavarian pioneer regiment area used by French armed forces until 1997 into residential lofts (fig. 5.3) and a medical center. The buildings had old windows, no insulation and were heated with decentral coal fired furnaces. The renovation consisted of adding 100mm interior insulation with a vapor barrier to all facades, adding 24o mm of insulation to the roof and 80 mm of insulation under the first floor. (There is no basement).

Fig. 5.4: 741 HIST Modena facades had to be preserved, insulation placed inside. (Brochure: Valerio Calderaro, Stefano Agnoli)

741 HIST Modena IT: This historically protected apartment building suffered from severe thermal bridges and dampness, damaging the frescoes. The street facades are under historical protection and could not be changed (fig. 5.4). The solution was to build a new wall inside the existing wall and fill the cavity with cane, coconut and hemp strand insulation. New windows were installed on the room side of the existing windows. Finally, radiant surface heating was added to improve comfort.

5.3 Renewable Energy Use

Solar Thermal Systems

241 HIST Herselt BE: Most of the work was carried out by the owners. Of the component costs, about 12% of the renovation costs were related to sustainable options:

- +4% insulation and ventilation,
- +6% solar heat and power (net cost to the owner after capital subsidies) and
- +2% rainwater and waste water treatment in the reed pond.

442 HIST Zurich CH: The town allowed the integration of 28 m² solar flat plate collectors in the new, modular prefab roof. There is coupled with a 4000 liter central boiler tank to provide 100% solar coverage in summer and make a partial contribution to space heating in the winter. The auxiliary heating is a wood pellet furnace (32 kW) which replaced the original gas furnace (45 kW) with a backup oil tank.

Biomass / Wood

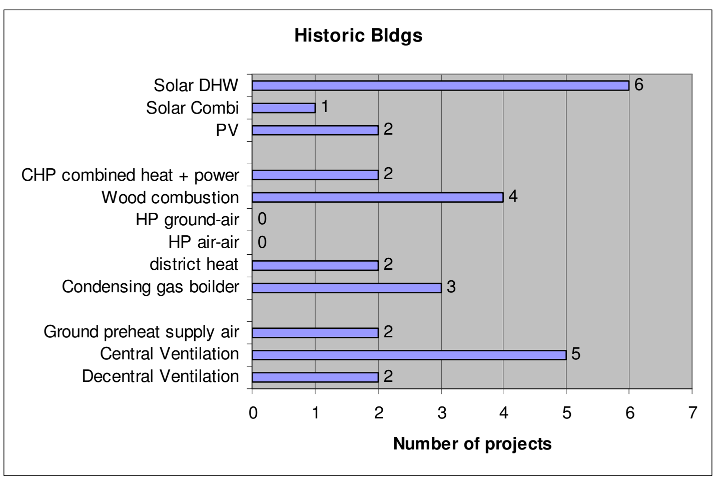
241 HIST Herselt BE: A wood stove located in the living room and intended as a means of space heating results in overheating too often.

543 HIST Speyer DE: After the renovation the heating was supplied from a central local biomass and solar plant. A decentral ventilation system with over 90% heat recovery was provided for each apartment mechanical ventilation with heat Recovery

5.4 Technical Systems

Auxiliary Heat Production

Table 5.2: Technical systems in the ten historic buildings:



Of the 10 historical buildings, six managed to get solar thermal collectors on roofs.

As passes to a historic building, wood combustion remained the most chosen heating source, besides also condensing gas furnaces.

Seven of the ten projects managed to incorporate mechanical ventilation, central systems being preferred.

543 HIST Speyer DE: Before the renovation the buildings were poorly heated by decentral stoves. After the renovation the heating was supplied from a central local biomass and solar plant. A decentral ventilation system with over 90% heat recovery was provided for each apartment mechanical ventilation with heat Recovery

5.5 Ecology

241 HIST Herselt BE: Rainwater is collected in an underground 10m³tank for toilet flushing, the washing machine and watering the garden. Waste water is naturally treated in a reed field on the property.

5.6 Redesign for Living Quality

Fig. 5.5: Elevator addition in rear courtyard of 442 HIST Zurich. *(Photo: D. Enz)*

142 HIST Purkersdorf AT: Balconies were added to the front of the building, overlooking the valley. The original floor play was reconfigured into four flats.

442 HIST Zurich CH: Comfort was greatly improved in the apartments while preserving the original aesthetics of this building:

- An elevator tower added to rear, courtyard side of the house, the street façade is under historic protection. The added attica apartment 6 storeys above the ground necessitated this convenience.

- The room ceiling with stucco ornamentation were preserved, wall paneling and doors were restored.

- Bathrooms were renovated and new kitchen layouts done.

6. Attica apartments

6.1 Introduction

Building new housing on the roof of existing apartment buildings is unique aspects:

- In order not to overload the existing apartment building structure, usually a light weight construction, for the penthouses is chosen. The most common construction is light wooden framing.
- To respect the building setback profile dictated by the street geometry (and building code) often the penthouses are set back or stepped back from the edge of the roof in the case of duplex and triples penthouses.
- The new roof of the penthouses can be geometrically so designed to optimally collect the solar energy, either for solar thermal or PV panels. Further, the solar exposure is likely optimal, being still higher and less likely to be shaded by neighboring buildings.
- The envelope is of the penthouses can easily be built to a very high energy standard, since it is essentially new construction.
- The inclusion of large window areas requires effective solar shading, especially given the lack of mass in light-weight construction.
- Such additions can be particularly striking living units, with views, better natural ventilation and less street noise. The resulting apartments have a high market value and often pay for the renovation of the building upon which they sit.

Accordingly, the typical actions taken in to achieve high performance are:

- Generous wall, and especially roof insulation
  (greatest summer overheating load)
- Large, highly insulating windows to maximize view without compromising energy and comfort performance.
- Including a solar hot water and ideally space heating system.
  Add PV if the payback price for electricity justifies the investment.
- Add mechanical ventilation with a heat exchanger

6.2 Envelope

Following are samples of these strategies selected from the Project Brochures.

Table 6.1: Thermal properties of envelope components

Element	U-attica
Roof	0.14
Walls	0.20
To bldg below	0.18
Windows	1.07

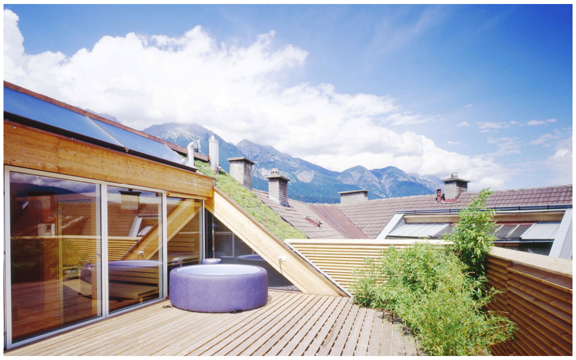


Fig. 6.1: Attica apt. Terraces of 151 ATC Innsbruck *(Photo: Lukas Schaller)*

151 ATC Innsbruck AT: To this historic building in Innsbruck two new levels were added by means of two inter-connected wooden boxes. A highly attractive interior has been achieved from the use of the laminated wooden roof construction.

Fig. 6.2: Attica apt. Terraces of 251 ATC Brussels *(Brochure: J..Desmedt, J..Cre, W. Hilderson)*

251 ATC Brussels BE: The structure of the existing roof was worn out and

roof tiles damaged so the roof had to be replaced. In stead of replacing the roof, a light wooden structure with two duplex and two triplex apartments was added. The terraced volume matches the profile of the existing pitched roofs and offers space for a terrace and small vegetable garden on each floor.

Other projects, which in addition to extensive renovation of the building, added an atica storey of apartments include:

412 APT Ostermundigen CH: This apartment building from 1965 was in need of renovation and had been vacant for 1 ½ years until the architects Rollimarchini were able to finance its purchase and renovation. To help finance the project the rentable living space was increased by adding four penthouse maisonettes.

415 APT Zurich-Seg. CH: new roof top apartments

416 APT Zurich-Birm. CH: new roof-top apartments

A Conversion factors for primary energy

Table 1: Primary energy and CO_2 conversion factors

Primary Energy and CO_2 conversion factors	**PEF**	**CO_2 eq**
	(kWh_{pe}/kWh_{end})	(g/kWh)
Oil-liter	1.13	311
Natural gas	1.14	247
Hard coal	1.08	439
Lignite	1.21	452
Wood logs	0.01	6
Wood chips	0.06	35
Wood pellets	0.14	43
EU-17 Electricity, grid	2.35	430
District heating CHP-coal cond. 70%, oil 30%	0.77	241
District heating CHP-coal cond. 35%, oil 65%	1.12	323
District heating plant; oil 100%	1.48	406
LDH CHP-coal cond. 35%, oil 65%	1.10	127
LDH Heating plant, oil 100%	1.47	323
Local solar	0.00	0
Solar heat (flat) central	0.16	51
PV (multi)	0.40	130
Wind electricity	0.04	20

B IEA, SHC, Task 37 and Subtask B

International Energy Agency (IEA)

The International Energy Agency (IEA) is an intergovernmental organization which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens. Founded during the oil crisis of 1973-74, the IEA's initial role was to co-ordinate measures in times of oil supply emergencies. As energy markets have changed, so has the IEA. Its mandate has broadened to incorporate the "Three E's" of balanced energy policy making: energy security, economic development and environmental protection. Current work focuses on climate change policies, market reform and energy technology collaboration.

Solar Heating & Cooling Program (SHC)

This program, established in 1977, carries out research through collaborative efforts of experts from member countries and the European Commission. It is headed by an Executive Committee with a representative from each Member country and Sponsor organizations. Projects, called "Tasks", are managed by an "Operating Agent". Work is coordinated with related programs: Energy Conservation in Buildings and Community Systems, PV- Power Systems, Heat Pumps and SolarPACES.

Task 37 Advanced Housing Renovation with Solar and Conservation

The Task objective was to establish a knowledge base on how to renovate housings to a very high energy standard and develop market strategies for such renovations. The Task was carried out in subtasks.

Strategies to promote energy saving renovations were developed by analyzing national building stocks and identifying building segments with greatest multiplier and energy savings potential. [Subtask A].

Exemplary renovation projects achieving large primary energy savings while creating superior living quality were analyzed and are the basis of these 60 project brochures **[Subtask B]**.

Innovative concepts and components identified from the exemplary projects were analyzed and technically and economically robust concepts were documented [Subtask C].

A tutorial on sustainability principles for renovation projects was written. It addresses environmental factors, resources, infrastructure and equipment, and health and well-being [Subtask D].

C. List of the 60 project brochures

111 APT on Makartstrase, Linz AT
112 APT in Dornbirn AT
113 APT in Kierling AT
114 APT for Elderly in Landeck AT
131 SFH in Kufstein AT
132 SFH in Mautern AT
133 SFH in Pettenbach
134 SFH in St. Martin AT
135 SFH in St.Valentin AT
141 HIS apartments in Irdning AT
142 HIS Villa in Purkersdorf AT
151 ATC Attica Innsbruck - AT

211 APT social housing Sterrenveld BE
221 ROW conversion Brussels BE
222 ROW Henz-Noirfalise, Eupen, BE
223 ROW semi-detached, De Pinte, BE
241 HIS in Herselt BE
251 ATC Attica apts in Brussels BE

331 SFH in Toronto CA
332 SFH Reep in Kitchener CA
333 SFH in Kingston House, Ontario CA

411 APT 2-family in Stansstad CH
412 APT in Ostermundigen CH
413 APT in Staufen, CH
414 APT in Volketswil1 CH
415 APT on Segantinistr Zurich,CH
416 APT in Birmensdorferstr., Zürich CH
431 SFH in Lanterswil CH
432 SFH in Ostermundigen CH
433 SFH in Walenstadt CH
441 HIS Elderly Home, Bern CH
442 HIS apartments in Zurich CH
443 HIS CAYLA in Geneva CH

511 APT Rieslerstr. Freiburg DE
512 APT for elderly in Stuttgart DE
513 APT BlaueHeimat in Heidelberg, DE
514 APT Hoheloogstr.,Ludwigshafen, DE
515 APT Schlesierstr., Ludwigshafen, DE
516 APT Teverstr., Frankfurt DE
517 APT Jean-Paul-Platz in Nürnberg DE
518 APT+Nursery in Ulm-Böfingen DE
521 ROW houses in Mannheim DE
531 SFH-Rectory, Ulm-Böfingen DE
541 HIS apts. Roter Block, Freiburg DE
542 HIS Sodastr., Ludwigshafen, DE
543 HIS Speyer DE

611 APT in Albertslund, DK
612 APT Tower in Engelsby, DK
621 ROW house in Albertslund, DK
741 HIS in Modena IT

821 ROW Kroeven-Roosendaal NL
822 ROW Roosendaal 112 NL
831 SFH PIAF® in Sint Pancras NL

911 APT cooperative Myhrerenga NO
912 APT Terrasses Husby in Stjørdal, NO
921 ROW house with annex in Oslo NO
931 SFH Wachenfeldt in Orkanger in NO
932 SFH Log home, Kongsberg NO

1011 APT bldg in Brogården, Alingsås SE
1012 APT bldgs Backa Röd, Göteborg SE

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