RENOWAVE
DECARBONIZATION OF THE BUILDINGSTOCK

Innovationsprojekt unterstützt von

Schweizerische Eidgenossenschaft
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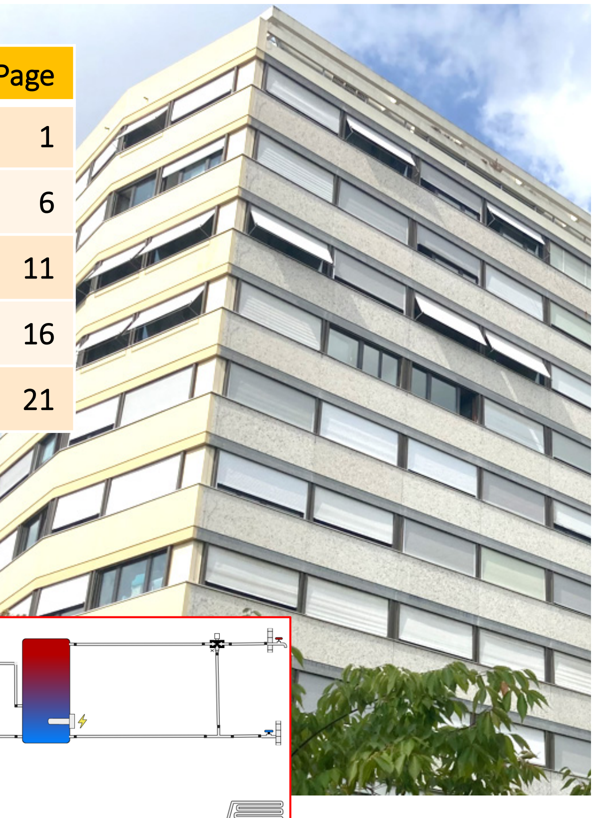
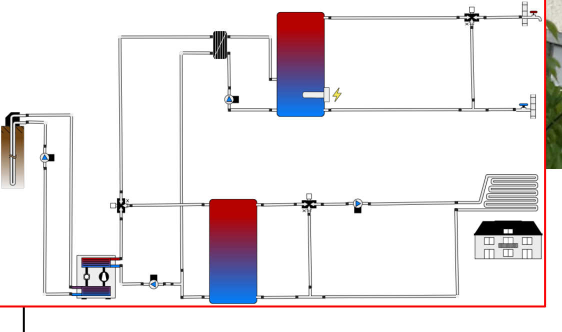
Innosuisse – Schweizerische Agentur für Innovationsförderung

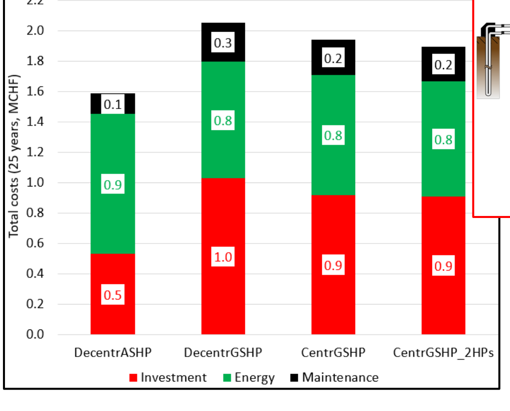
Heat pump solutions for the decarbonization of existing buildings - Five case studies

Five real and archetypal buildings across Switzerland have been selected and analyzed with the goal to compare different heat pump-based solutions for the replacement of fossil heating system. With the collaboration of implementation partner Scheco AG, the results have been summarized in factsheets. The factsheets can help building owners, planners, and public authorities with the selection of variants.

Factsheet	Page
Factsheet 1 - Old building from the 1940s	1
Factsheet 2 - Multi storey building from the 1960s	6
Factsheet 3 - High-rise building from the 1960s	11
Factsheet 4 - Apartment block from the 1970s	16
Factsheet 5 - Building complex of five MFHs	21







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Heat pump systems for existing multifamily buildings
Case Study 1 - Old building from the 1940s

CHARACTERISTICS

Located in the city center of Lausanne, this Multi-Family-House is characterized by a mixed use (shops on the ground floor and apartments on the other floors). It has five residential floors and a recessed attic for a total of 24 apartments. Under the flat hipped tiled roof there is an unheated attic. The ground floor elevation is clad in artificial stone panels. The windows have been replaced. Only the window frames of the ground floor shops are completely intact. The windows are framed with textured artificial stone elements. The cement slabs of the loggias rest on the solid external walls. The parapets are bricked and plastered with iron railings.
The actual heating system, installed in the basement of the building, consists of an oil boiler which produce energy for space heating and domestic hot water. The energy for space heating is delivered to the heated rooms through radiators. The building is located near an existing district heating network.

OVERVIEW

Year of construction	1939
Location	Lausanne (canton Vaud)
Energy Reference Area	2445 m^2
Building category (SIA 380/1)	Residential (85%), Commercial (15%)
Calculated space heating demand	230 MWh/a (94 kWh/m^{2}a)
Calculated domestic hot water demand	66 MWh/a (27 kWh/m^{2}a)
Heating system	Oil boiler
Heat delivery	Radiators

Attic/Roof
Four attic apartments with flat hipped roof

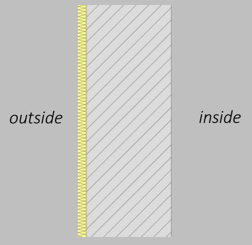
External wall
Plastered hollow concrete blocks (approx. 35 cm)

Exterior
Recessed loggia, concrete ceiling, solid plastered masonry balustrade with iron handrail

Apartments
Five floors are allocated to flats (20 apartments)

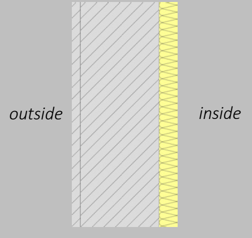
Commercial floor
Ground floor occupied by shops

External wall (apartments)
U before renovation: 1.22 W/m^2K
U after renovation: 0.65 W/m^2K



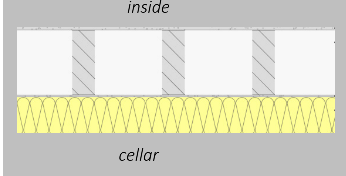
Mineral insulating plaster (40 mm)
Cement hollow blocks (340 mm)
Gypsum Plaster (7 mm)

External wall (plinth)
U before renovation: 1.19 W/m^2K
U after renovation: 0.26 W/m^2K



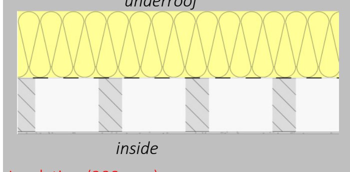
Artificial stone slab (40 mm)
Cement hollow blocks (340 mm)
Insulation (90 mm)
Vapor barrier

Cellar ceiling
U before renovation: 0.98 W/m^2K
U after renovation: 0.22 W/m^2K



Tiles (12 mm)
Hourdis ceiling (210 mm)
Gypsum plaster (7 mm)
Insulation (120 mm)

Underroof
U before renovation: 1.01 W/m^2K
U after renovation: 0.14 W/m^2K



Insulation (200 mm)
Vapor barrier
Hourdis ceiling (160 mm)
Gypsum plaster (7 mm)

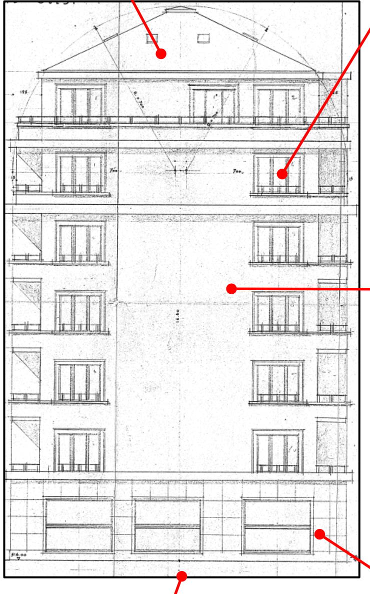
Window of the apartments
U_g before renovation: 1.1 W/m^2K
U_f before renovation: 2.0 W/m^2K
g before renovation: 0.55
U_g after renovation: 0.6 W/m^2K
U_f after renovation: 1.1 W/m^2K
g after renovation: 0.67

BUILDING ENVELOPE - Refurbishment strategy

The architectural features of the façade, the loggias, the open corner of the building, and the recessed attic make it difficult to install external insulation without architectural losses. The chosen refurbishment strategy for the external walls in the form of an insulating plaster makes it possible to preserve the architectural qualities. To compensate for this, the underroof and the cellar ceiling are insulated to the maximum and the windows are replaced.
The existing structure of the underroof will be insulated with 200 mm of insulation for a total U-value after renovation of 0.14 W/m^2K. The cellar ceiling will be insulated (layer of 120 mm) in order to reach an U-value of 0.22 W/m^2K.
The external wall of the apartments will be equipped with an additional mineral insulation plaster of 40 mm on the outside, while the external walls of the plinth will be internally insulated (90 mm). All the windows will be replaced with three panes windows with wood frame.

Underroof*

Windows of the apartments*



External wall of the apartments*

Ceiling against unheated*

External wall plinth*

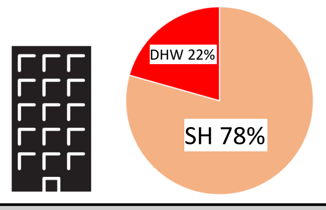
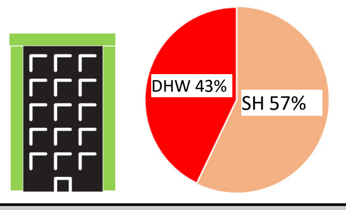
*actual status (before renovation)

HEATING CONCEPT - Definition of heating variants

To reduce the direct CO_2-emissions of the existing heating system for space heating (SH) and domestic hot water (DHW) preparation, two variants have been investigated:

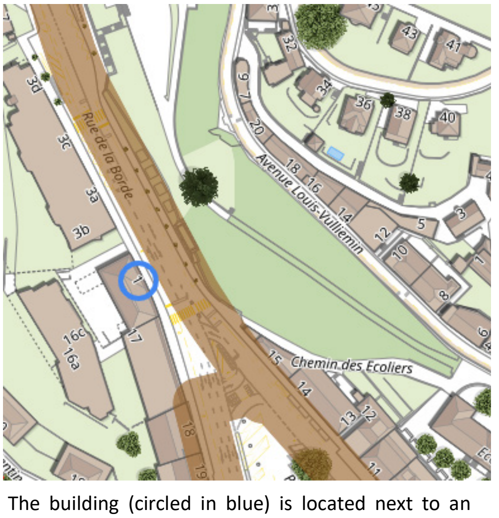
- District heating (DH): the existing district heating network is used to provide energy to the building for SH and DHW preparation;
- Air to Water Heat Pump (ASHP): SH and DHW are covered with an air-to-water heat pump.

The variant "ASHP" has been considered only in case the building envelope is refurbished. In all variants the replacement of the existing radiators with new radiators is considered. The supply water temperature has been set depending on the building envelope status. Since ground probes drilling is not permitted in this area, ground source heat pumps was not considered as heating variant in this analysis. Details about the different heating variants are described in the Annex. The choice of the heating variants is the result of a preliminary discussion with the HVAC partners.

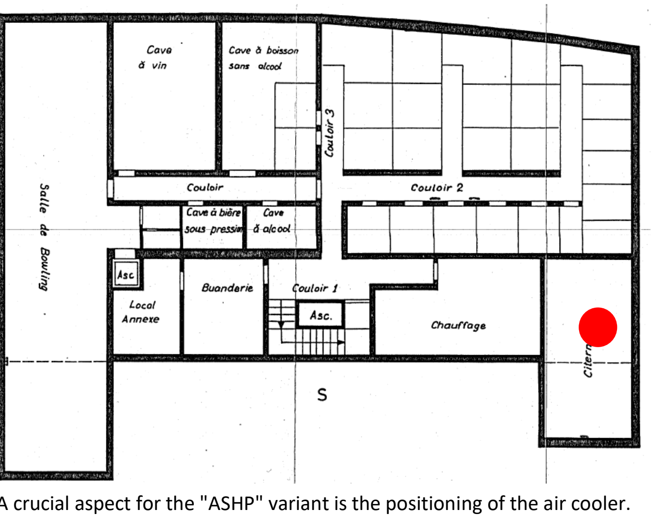
	Building envelope non-refurbished SH / DHW [kWh/m²a]: 94 / 27 	**Building envelope refurbished** SH / DHW [kWh/m²a]: 36 / 27 	
Heating variant	**DH**	**ASHP**	**DH**
COP_{nom}/Capacity HP_{max} (at A2/W35)*	-	3.9 / 93 kW (38 W/m²)	-
District heating power	150 kW (61 W/m²)	-	70 kW (29 W/m²)
Volume storage for DHW/SH	2500 l / -	2500 l / 3500 l	2500 l / -
Electricity demand (kWh/m²a)**	-	19	-
Energy demand from DH network (kWh/m²a)	122	-	65

*data from datasheets of real HPs products

**Electricity demand of the heating system (heat pumps + circulating pumps)



The building (circled in blue) is located next to an existing district heating network. For that reason, it was decided to consider the district heating as possible heating variant for the building under analysis. All the assumptions (e.g. temperatures, tariffs and so on) are based on data available on the website of the energy provider



A crucial aspect for the "ASHP" variant is the positioning of the air cooler. Because of the roof structure and position of the building, the external installation or the positioning of the unit on the roof is not possible. Together with HVAC partners, it was decided for an internal installation of the component in the room of the cellar where the oil tank is installed (see red point). Such a solution was already installed in similar buildings and represents the best option for the building under analysis.

Assumptions

- Financial subsidies not considered;
- The costs for replacement of existing radiators not included;
- Only electricity consumption of the heating system is included in the electricity costs;
- Constant electricity price of 0.25 CHF/kWh;
- Maintenance of 1%/a of investment costs;
- Time analysis of 25 years.

Investment costs

Building envelope non-refurbished (only heating system)

- DH: 140 kCHF (57 CHF/m^2)

Building envelope refurbished (heating system plus building envelope)

- ASHP: 2.7 MCHF (1092 CHF/m^2)
- DH: 2.3 MCHF (956 CHF/m^2)

Electricity / Energy costs (per year)

Building envelope non-refurbished

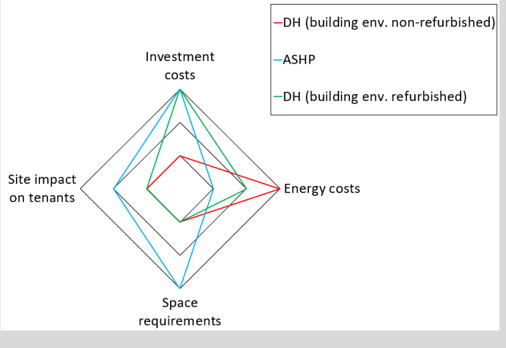
- DH: 41.8 kCHF (17 CHF/m^2)

Building envelope refurbished

- ASHP: 11.5 kCHF (5 CHF/m^2)
- DH: 22.2 kCHF (9 CHF/m^2)

Radar chart for comparison of the heating variants:

The "DH" variant is the variant with the lowest initial investment costs (140 kCHF) and the highest energy costs (approx. 42 kCHF). Since the "DH" variant needs only the installation of a heat exchanger in the heating room, space requirement is much lower compared to the "ASHP" variant, where additional components are needed (i.e., storages, heat pump, air cooler and so on).

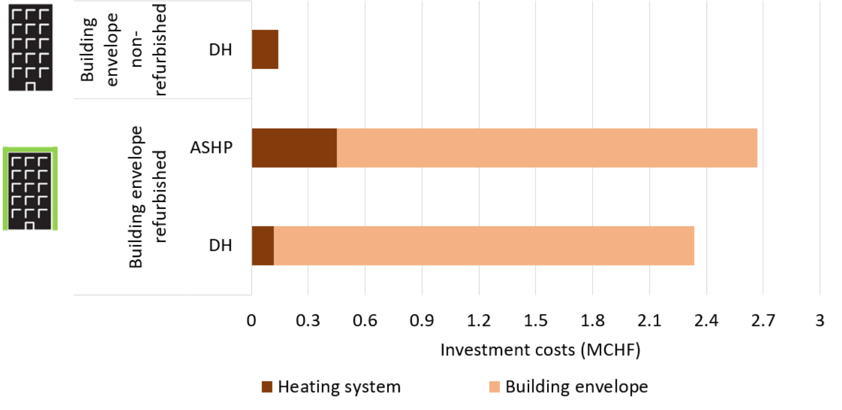


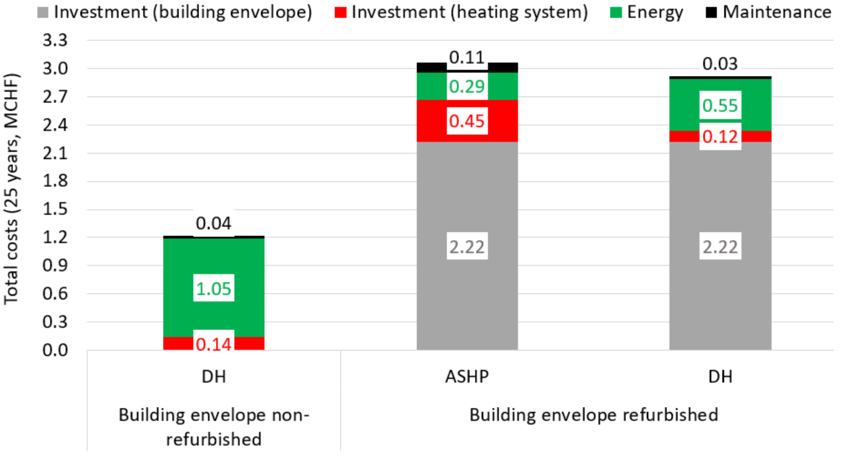
ECONOMIC ANALYSIS

To compare all the analyzed variants, an economic analysis over 25 years was performed. The first diagram below shows for each variant the total investment costs, while the second diagram shows the total costs (over 25 years) for investment, energy and maintenance.

If the "DH" variant is considered, the investment costs for the heating system are slightly higher (+16%) in case the building envelope is not refurbished. In case of refurbished building envelope, investment costs for building envelope renovation represent approx. 85-95 % of the total investment costs. It is important to highlight that here the investment costs for the building envelope refurbishment are based on rough assumptions and are subject to large uncertainties.

Over 25 years, the two variants "ASHP" and "DH" (in case of refurbished building envelope) have similar total costs with approx. 3 MCHF.





RECOMMENDATION

At the location of the building that was analyzed in this case study, for the non-refurbished case, only the connection to a district heating was considered when the heat production is changed from fossil to renewable energy.

In case an energy refurbishment of the building envelope is carried out, the heating demand of the building and the energy costs of the heating system are reduced, even though the total costs are higher. Additional advantage of the refurbishment of the building envelope will be an increased thermal comfort for the inhabitants. The higher investment costs of the ASHP variant are partly evened out by its lower energy costs compared to the DH variant with total costs that are comparable for both variants. The district heating is characterized by lower space requirements and low system complexity compared to heating system based on heat pumps. In addition, the room where the actual oil tank is installed could be made free for other uses.

It is important to highlight that the cost assessments are based on rough assumptions that are subject to larger uncertainties.

Annex

Building simulation – Inputs and assumptions

In order to evaluate the annual space heating demand of the building, the dynamic multi-zone simulation tool IDA ICE (Indoor Climate and Energy) has been used. Both cases (i.e., with and w/o building envelope refurbishment) have been modelled and simulated. Climate data of Pully (SIA 2028) has been selected, while data from the national norm SIA 2024 has been used for the modelling of the internal heat gains of the building (people, light and appliances). A set point temperature of 22 °C with "ideal" heating system has been chosen. A constant air infiltration rate of 0.5 h^{-1} has been assumed for the entire building. Since detailed information about DHW demand of the building is not available, assumptions have been done based on national norms and experience.

Economic analysis – Inputs and assumptions

To compare the different variants, an economical analysis has been performed. The evaluation of the investment costs (for each heating variants and for the building envelope refurbishment) has been done with the inputs from HVAC partners and architects. Within the investment costs for the heating system, the cost for radiators replacement was not considered. The economical analysis has been performed assuming a lifetime of 25 years. A constant electricity price of 0.25 CHF/kWh and a cost for maintenance of 1%/y of the investment costs have been considered. In the evaluation of electricity costs, the electricity consumption for light and appliances of the building have not been taken into account. Financial subsidies (for building envelope refurbishment or installation of heat pump systems) were not considered.

Heating variants simulation – Description and controls

The different heating variants have been modelled with the help of the software POLYSUN. The different heating variants, defined and modelled together with HVAC partners, are schematically represented on the right.

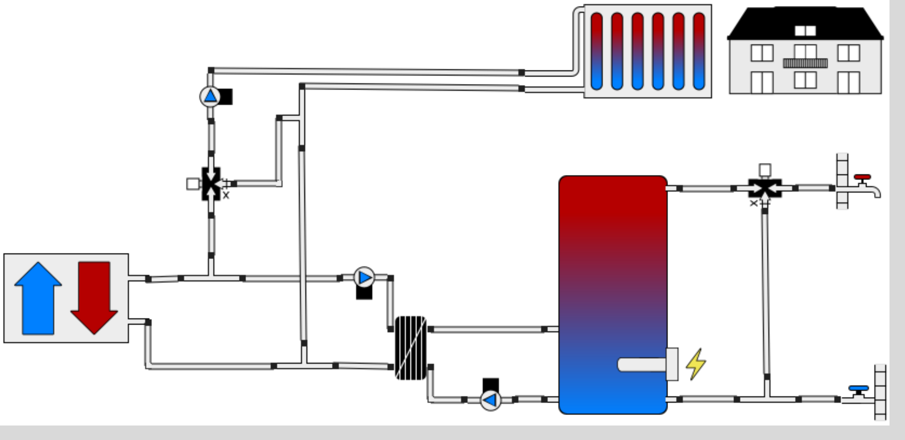
The variant "ASHP" is equipped with two storages for DHW (2500 l) and space heating (3500 l). The heating system is equipped with a three-way valve in order to activate the heat pump for space heating or preparation of DHW (DHW has always priority to space heating).

Set point temperature for space heating is based on a heating curve (55°C with an outside temperature of -8 °C) as function of the ambient temperature.

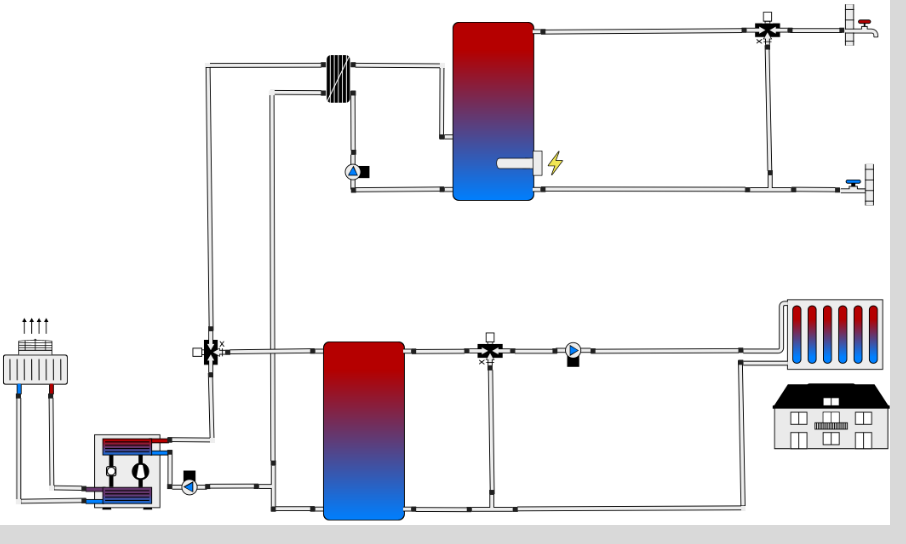
The variant "DH" has only a storage for DHW with a volume of 2500 l.

Schemes of the heating variants

Variant "DH" (district heating)



Variant "ASHP" (Air to water heat pump)



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Heat pump systems for existing multifamily buildings

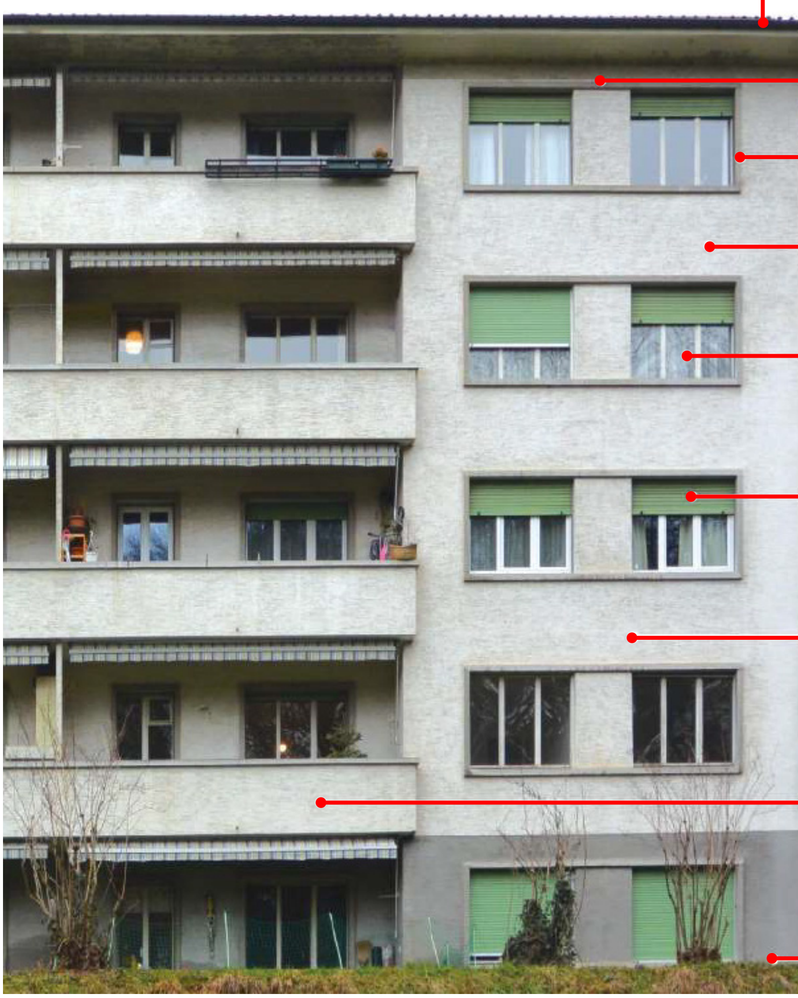
Case Study 2 - Multi storey building from the 1960s

CHARACTERISTICS

The detached Multi-Family-House is located in the suburbs of Lausanne, in a large green area, and it is part of an ensemble of residential buildings from the post-war years. The building has eighteen apartments (four flats for each storey) with two flats located on the ground floor.
The staircase is on the north-east side and is extensively glazed with single glazing in metal frames. The attic space under the flat hipped roof is unused and unheated.
The 30 cm thick, plastered external walls consist of a load-bearing, external masonry stand, an air layer and an inner facing shell made of masonry.
Some of the windows from the time of construction have been preserved and consist of wooden frames with double single glazing. Roller blinds with internal blind boxes serve as sun protection.
The actual heating system consists of an oil boiler which produces heat for space heating and domestic hot water. The energy for space heating is delivered to the heated rooms through radiators.

OVERVIEW

Year of construction	1960
Location	Lausanne (canton Vaud)
Energy Reference Area	1475 m^2
Building category (SIA 380/1)	Residential
Calculated space heating demand	133 MWh/a (90 kWh/m^{2}a)
Calculated domestic hot water demand	40 MWh/a (27 kWh/m^{2}a)
Heating system	Oil boiler
Heat delivery	Radiators



Roof
Flat hipped roof with tiled covering and roof overhang

Upper storey ceiling
Hourdis ceiling

Window surround
Cast stone

Storey ceiling
Hourdis ceiling

Window
Wooden frame, double glazing

Sun protection
Roller blinds with internal blind box

External wall
Brick masonry plastered with air layer and inner facing shell (approx. 30 cm thick)

Outdoor area
Loggia, concrete slab resting on exterior walls, plastered masonry parapet

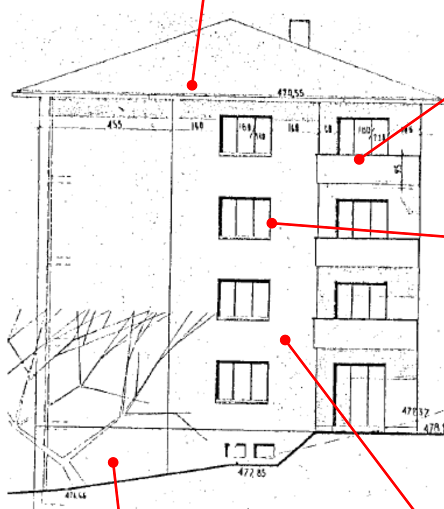
Cellar ceiling
Hourdis ceiling

BUILDING ENVELOPE - Refurbishment strategy

The simple cubature of the building allows for external insulation while retaining the characteristic features. The characteristic artificial stone frames of the windows are replaced by insulated glass fiber concrete elements.
The existing insulation layer of the roof will be removed and replaced with a new insulation layer of 260 mm for a total U-value after renovation of 0.11 W/m²K.
The external wall of the apartments will be equipped with an additional insulation layer of 160 mm on the outside, while the external walls of the balconies will be externally insulated with a layer of 100 mm. All the windows will be replaced with two panes windows with wood frame.
Since the ground floor of the building is occupied by technical rooms and apartments, the cellar ceiling will be insulated with a layer of 120 mm to reach an U-value of 0.31 W/m²K.

Underroof*

Balconies*



Window of the apartments*

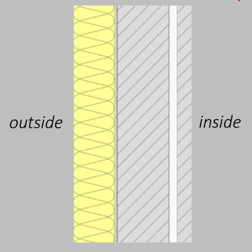
Floor cellar / apartments on the ground floor*

External wall*

*actual status (before renovation)

External wall (apartments)

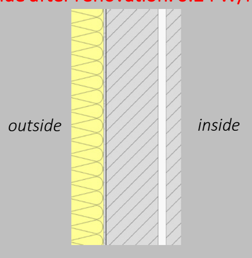
U-value before renovation: 0.65 W/m²K
U-value after renovation: 0.16 W/m²K



Insulation layer (160 mm)
Plaster (10 mm)
Hollow brick masonry (200 mm)
Air layer (30 mm)
Brick masonry (60 mm)
Gypsum plaster (7 mm)

External wall (balconies)

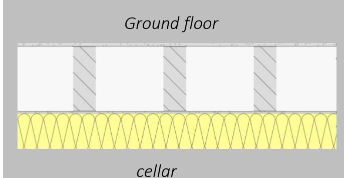
U-value before renovation: 0.65 W/m²K
U-value after renovation: 0.24 W/m²K



Insulation layer (100 mm)
Plaster (10 mm)
Hollow brick masonry (200 mm)
Air layer (30 mm)
Brick masonry (60 mm)
Gypsum plaster (7 mm)

Cellar ceiling

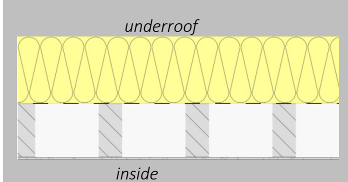
U-value before renovation: 1.06 W/m²K
U-value after renovation: 0.31 W/m²K



Insulation (120 mm)
Hourdis ceiling with concrete beams (250 mm)

Underroof

U-value before renovation: 0.3 W/m²K
U-value after renovation: 0.11 W/m²K



Insulation (260 mm)
Vapor barrier
Insulation 100 mm (removed)
Hourdis ceiling with concrete beams (210 mm)
Gypsum plaster (7 mm)

Window of the apartments

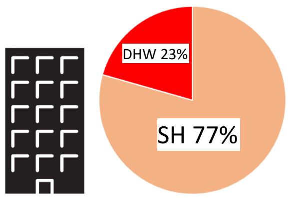
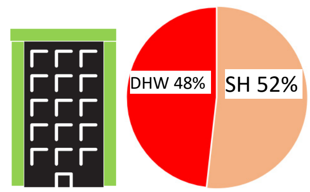
U_g-value before renovation: 1.1 W/m²K
U_f-value before renovation: 1.9 W/m²K
g before renovation: 0.75
U_g-value after renovation: 1.0 W/m²K
U_f-value after renovation: 1.1 W/m²K
g after renovation: 0.6

HEATING CONCEPT - Definition of heating variants

To reduce the direct CO_2-emissions of the existing heating system for space heating (SH) and domestic hot water (DHW) preparation, two variants have been investigated:

- Air to Water Heat Pump (ASHP): SH and DHW preparation is covered with an air-to-water heat pump;
- Ground to Water Heat Pump (GSHP): SH and DHW preparation is covered with a ground-to-water heat pump.

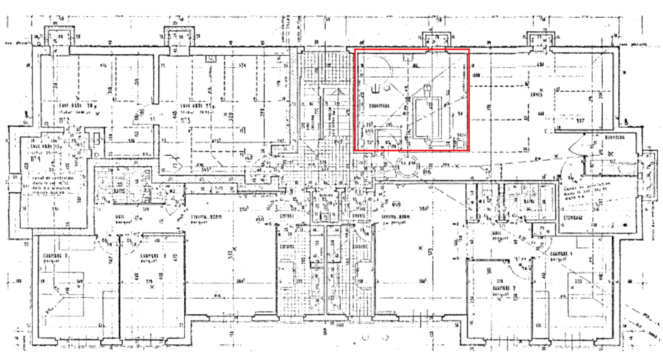
The two variants were considered for both building envelope statuses (i.e., not refurbished and refurbished).
For all variants, the replacement of the existing radiators with new radiators is considered and the supply water temperature for the heating has been set depending on the building envelope status.
Since district heating network is not present in this area, this option was not considered as heating variant in this analysis.
Details about the different heating variants are described in the Annex. The choice of the heating variants is the result of a preliminary discussion with the HVAC partners.

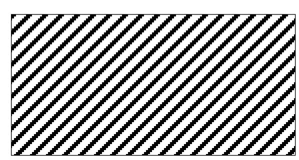
	Building envelope non-refurbished SH / DHW [kWh/m²a]: 90 / 27  		**Building envelope refurbished** SH / DHW [kWh/m²a]: 29 / 27  	
Heating variant	**ASHP**	**GSHP**	**ASHP**	**GSHP**
$COP_{nom}/Capacity_{nom}$ heat pump*	4.2 / 2 x 39 kW (at A2/W35)	4.3 / 67 kW (at B0/W35)	4.2 / 30 kW (at A2/W35)	4.3 / 36 kW (at B0/W35)
Number and length of ground probes	-	8 x 240 m	-	4 x 240 m
Volume storage for DHW/SH	1000 l / 2000 l	1000 l / 2000 l	1000 l / 1500 l	1000 l / 1500 l
Electricity demand (kWh/m²a)**	43	36	18	14

*data from datasheets of real HPs products proposed by HVAC partner

**Electricity demand of the heating system (heat pumps + circulating pumps)

The building (black point) is located in an area (green area in the picture) where ground drilling is permitted. For that reason, it was decided to consider the ground source heat pumps as possible heating variant for the building under analysis.





A crucial aspect for the "ASHP" and "GSHP" variants is the positioning of the air cooler (for "ASHP") and ground probes (for "GSHP"). Together with HVAC partner, it was decided to install these components externally (see patterned area) in a green area where enough space is available for such components. In this way the external units will be next the technical room where the internal units will be installed (see red box) in the cellar.

Assumptions

- Financial subsidies not considered;
- The costs for replacement of existing radiators not included;
- Only electricity consumption of the heating system is included in the electricity costs;
- Constant electricity price of 0.25 CHF/kWh;
- Maintenance of 1%/a of investment costs;
- Heat pump lifespan: 25 years;
- Time analysis of 25 years.

Investment costs

Building envelope non-refurbished (only heating system)

- ASHP: 270 kCHF (183 CHF/m^2)
- GSHP: 390 kCHF (264 CHF/m^2)

Building envelope refurbished (heating system plus building envelope)

- ASHP: 1.52 MCHF (1030 CHF/m^2)
- GSHP: 1.60 MCHF (1085 CHF/m^2)

Electricity / Energy costs (per year)

Building envelope non-refurbished

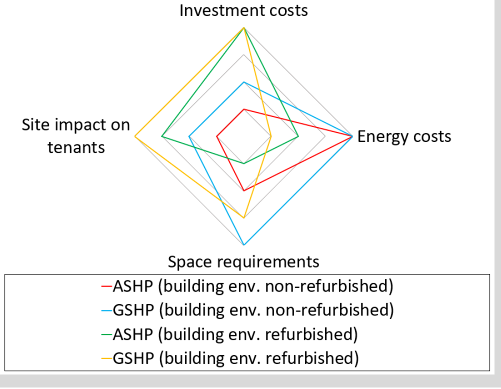
- ASHP: 16 kCHF (11 CHF/m^2)
- GSHP: 13 kCHF (9 CHF/m^2)

Building envelope refurbished

- ASHP: 6 kCHF (4 CHF/m^2)
- GSHP: 5 kCHF (3 CHF/m^2)

Radar chart for comparison of the heating variants:

The "ASHP" variant (for building envelope non-refurbished) is the variant with the lowest initial investment costs and the highest energy costs. Since the "ASHP" variants need only the installation of the external units outside the building, space requirement is lower compared to the "GSHP" variant, where ground probes are needed.

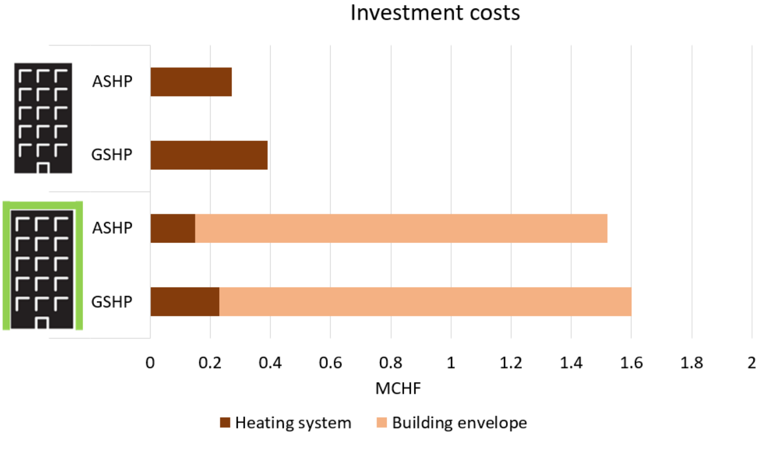


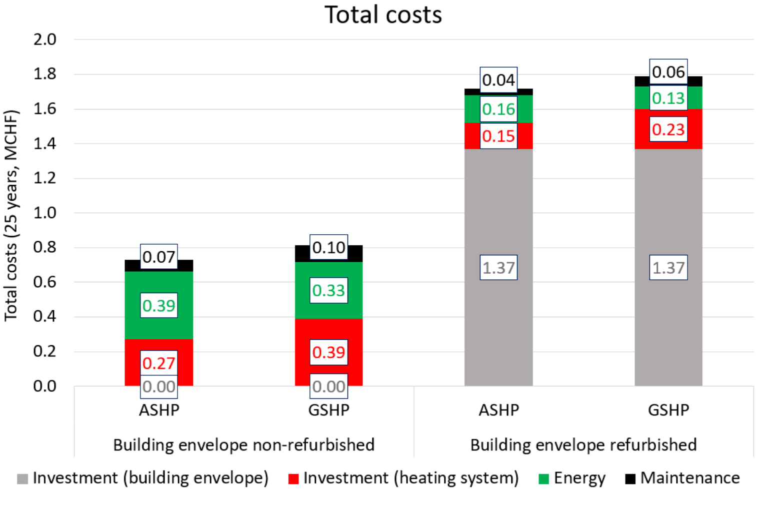
ECONOMIC ANALYSIS

To compare all the analyzed variants, an economic analysis over 25 years was performed. The first diagram below shows for each variant the total investment costs, while the second diagram shows the total costs (over 25 years) for investment, energy and maintenance.

If the building envelope is not refurbished, the investment costs for the heating system are higher (approx. 40 % higher) compared to the case in which the building envelope is refurbished. In case of refurbished building envelope, investment costs for building envelope renovation represent approx. 85 - 90 % of the total investment costs. The investment costs for the building envelope refurbishment are based on rough assumptions and are subject to large uncertainties.

Over 25 years the variants "ASHP“ and “GSHP” have comparable total costs with approximately 0.8 MCHF (if building envelope is not refurbished) and 1.8 MCHF (in case of renovated building envelope).





RECOMMENDATION

Regardless of whether the building envelope is refurbished, the total costs show that the ASHP and the GSHP variants have comparable total costs. In case an energy refurbishment of the building envelope is carried out, the heating demand of the building and the energy costs of the heating system are reduced, even though the total costs are higher. Additional advantages of the refurbishment of the building envelope will be an increased thermal comfort for the inhabitants and a decreased electricity demand of the heat pump during wintertime when electricity prices are expected to be higher in future.

The higher investment costs of the GSHP variant are partly evened out by its lower energy costs compared to the ASHP variant with total costs that are comparable for both variants. If the electricity grid load and the costs for purchased electricity are considered, the higher COP of the GSHP brings further advantages compared to the ASHP variant, as it has lower electricity demands during wintertime. On the other hand, the ASHP variant is characterized by lower space requirements and low system complexity compared to heating system based on ground source heat pumps. It is important to highlight that the cost assessments are based on rough assumptions that are subject to larger uncertainties.

Annex

Building simulation – Inputs and assumptions

To evaluate the annual space heating demand of the building, the dynamic multi-zone simulation tool IDA ICE (Indoor Climate and Energy) has been used. Both cases (i.e., with and w/o building envelope refurbishment) have been modelled and simulated. Climate data of Pully (SIA 2028) has been selected, while data from the national norm SIA 2024 has been used for the modelling of the internal heat gains of the building (people, light and appliances). A set point temperature of 22 °C with "ideal" heating system has been chosen. A constant air infiltration rate of 0.5 h^{-1} has been assumed for the entire building. Since detailed information about DHW demand of the building is not available, assumptions have been done based on national norms and experience.

Economic analysis – Inputs and assumptions

To compare the different variants, an economical analysis has been performed. The evaluation of the investment costs (for each heating variants and for the building envelope refurbishment) has been done with the inputs from HVAC partners and architects. In the investment costs for the heating system, the cost for radiators replacement was not considered. The economical analysis has been performed assuming a lifetime of 25 years. A constant electricity price of 0.25 CHF/kWh and a cost for maintenance of 1%/y of the investment costs have been considered. In the evaluation of electricity costs, the electricity consumption for light and appliances of the building have not been considered. Financial subsidies (for building envelope refurbishment or installation of heat pump systems) were not considered.

Heating variants simulation – Description and controls

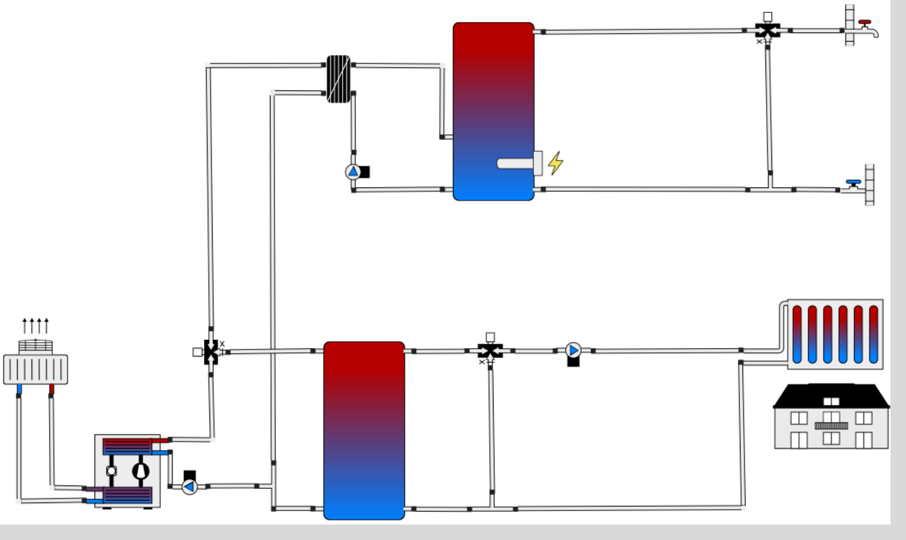
The different heating variants have been modelled in the software POLYSUN. The different heating variants, defined and modelled together with HVAC partners, are schematically represented on the right.

The system is equipped with a storage for DHW of 1000 l and a second storage for space heating of 2000 l (1500 l in case of renovated building envelope). The heating system is equipped with a three-way valve to activate the heat pump for space heating or preparation of DHW (DHW has always priority to space heating).

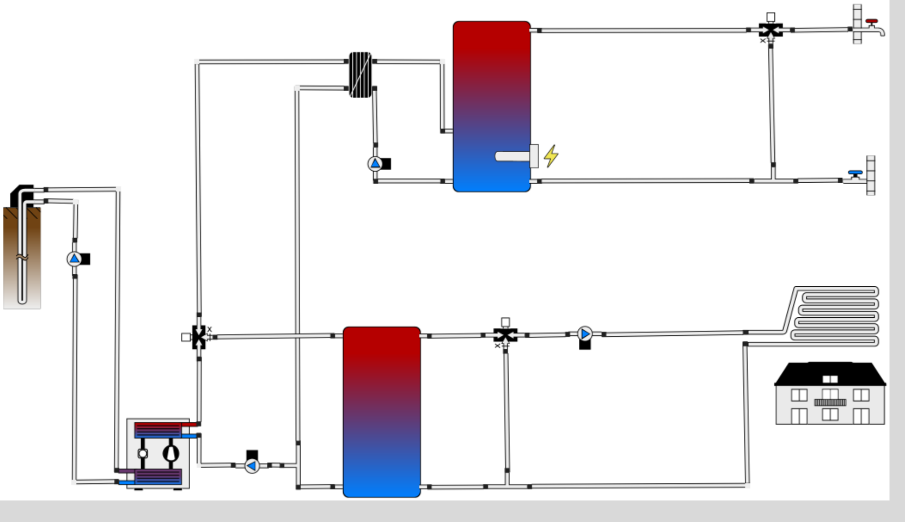
Set point temperature for space heating is based on a heating curve (40°C with an outside temperature of -8 °C in case of renovated building envelope) as function of the ambient temperature. The supply water temperature is increased of 20 K in case of non-renovated building envelope.

Schemes of the heating variants

Variant "ASHP" (Air to water heat pump)



Variant "GSHP" (Ground to water heat pump)



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Heat pump systems for existing multifamily buildings

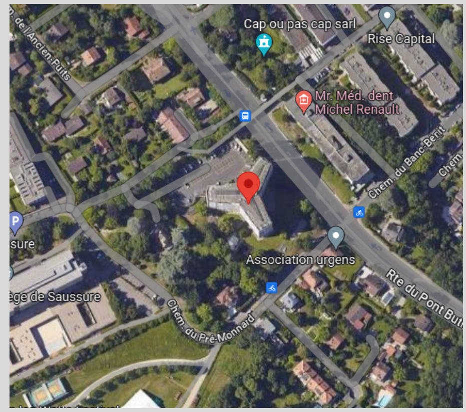
Case Study 3 - High-rise building from the 1960s

CHARACTERISTICS

The building, located in the municipality of Lancy (in the canton Geneva), is a high-rise construction of the 1960s. It is characterized by an atypical shape and mixed use (offices on the first two floors and apartments on the other eight floors). The building, 41 m high, has 105 apartments and 14 offices. A public library is located on the ground floor. The curtain walls (windows and parapets) in metal construction of the first and second floor have been already replaced in recent years, as well as the glass façade of the library.

The actual heating system, installed in the basement of the building, consists of two condensing gas boilers (2 x 609 kW) which produce energy for space heating and domestic hot water. Both boilers are connected to a large storage tank. From the storage tank, the heat is distributed to the whole building through three main distributors. The system is equipped with two additional tanks for domestic hot water (each with a volume of 1 m³). The energy for space heating is delivered to the heated rooms through monotube radiators installed under the windows.

OVERVIEW



Year of construction	1963
Location	Lancy (canton Geneva)
Energy Reference Area	13860 m²
Building category (SIA 380/1)	Residential (86%), Administration (14%)
Calculated space heating demand	1005 MWh/a (72 kWh/m²a)
Calculated domestic hot water demand	261 MWh/a (19 kWh/m²a)
Heating system	Condensing gas boiler
Heat delivery	Radiators

Roof
Flat roof made of concrete with insulation, bitumen waterproofing, and covered with gravel

Attic

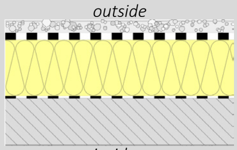
External wall
Wood-metal windows and prefabricated concrete window parapets

Apartments
Eight floors are allocated to flats

Offices
First and second floor occupied by offices

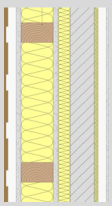
Mixed use
Public library located on the ground floor

Roof
U before renovation: 0.72 W/m²K
U after renovation: 0.14 W/m²K



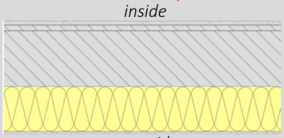
Gravel (50 mm)
Waterproofing (30 mm)
Insulation EPS (240 mm)
Vapor barrier (10 mm)
Concrete (200 mm)
Plaster (5 mm)

External wall
U before renovation: 0.98 W/m²K
U after renovation: 0.14 W/m²K



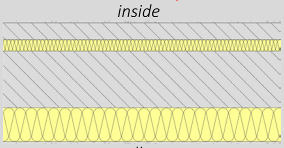
Cladding (20 mm)
Understructure (40 mm)
Wind barrier (0 mm)
Fermacell (25 mm)
Insul. mineral wool / wood structure (160 mm)
Fermacell (25 mm)
Insul. mineral wool (60 mm)
Concrete (120 mm)
Insul. mineral wool (20 mm)
Air (40 mm)
Plaster (15 mm)

Floor against ambient
U before renovation: 2.10 W/m²K
U after renovation: 0.18 W/m²K



Parquet (15 mm)
Cement screed (20 mm)
Concrete (200 mm)
Insul. mineral wool (160 mm)
Plaster (10 mm)

Floor against unheated
U before renovation: 2.10 W/m²K
U after renovation: 0.18 W/m²K



Carpet (10 mm)
Cement screed (60 mm)
Insulat. EPS (40 mm)
Concrete (200 mm)
Insul. mineral wool (120 mm)
Plaster (10 mm)

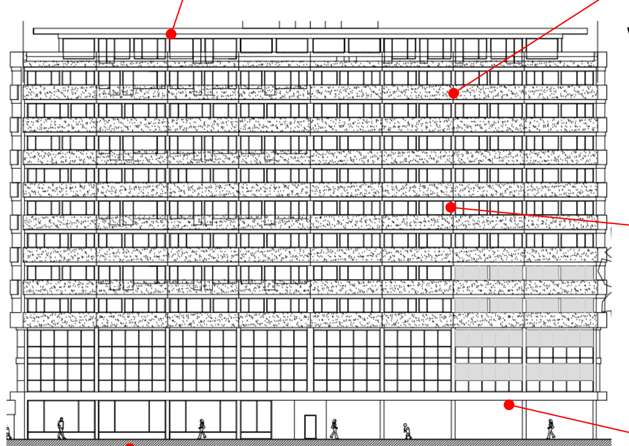
Window of the apartments
U_w before renovation: 2.9 W/m²K
g before renovation: 0.8
U_w after renovation: 1.1 W/m²K
g after renovation: 0.5

BUILDING ENVELOPE - Refurbishment strategy

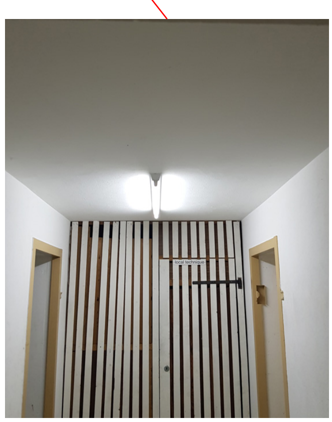
In the past years, only the first two floors have been renovated with the replacement of the curtain wall cladding. In order to reduce the energy demand of the building, the roof, the window parapets and walls of the levels 3 to 8 and the floors against ambient or non heated rooms need to be refurbished. The existing structure of the roof will be additional insulated with 240 mm of EPS (protected by a waterproofing layer) and covered with gravel for a total U-value after renovation of 0.14 W/m²K. The external wall will be improved with an additional prefabricated module consisting of a wood structure and a total insulation of approx. 220 mm of mineral wool, encapsulated in Fermacell gypsum fiber board for fireproofing, and integrating new windows with a U-value of 1.1 W/m²K. The floors against ambient or against non heated rooms will be additionally insulated with mineral wool (160 mm and 120 mm, respectively) to reach a U-value of 0.18 W/m²K.
The envelope constructions before (only layers in black) and after renovation (all layers) are showed in the column on the left.

Roof*

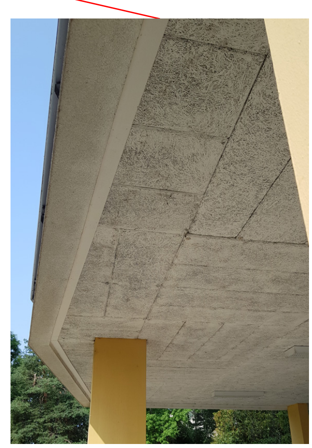
External wall of the apartments*



Windows of the apartments*



Ceiling against unheated*



Floor against ambient*

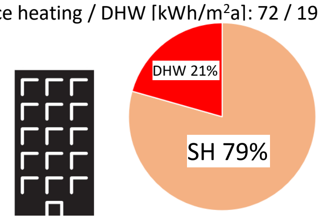
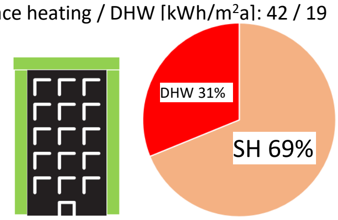
*actual status (before renovation)

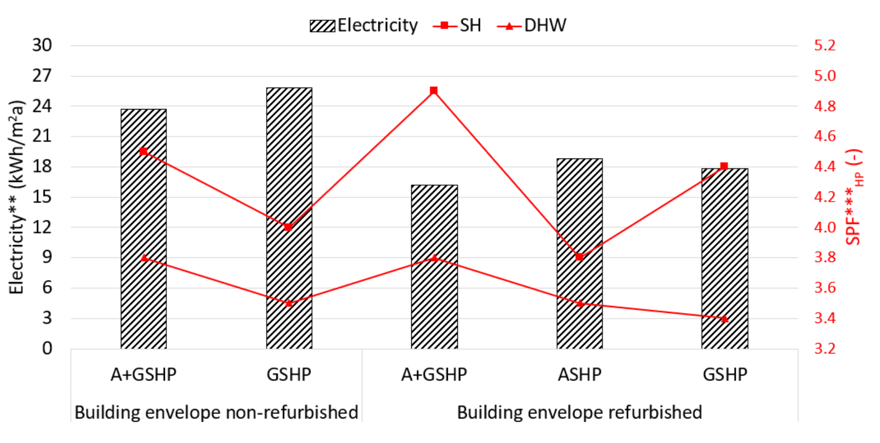
HEATING CONCEPT - Definition of heating variants

To reduce the direct CO_2-emissions of the existing heating system for space heating (SH) and domestic hot water (DHW) preparation, three variants have been investigated:

- Air + Ground to Water Heat Pump (A+GSHP): SH and DHW are covered with two separate heat pumps. As heat source, an air cooler is installed in series with the ground probes. The air cooler can be used in summer for the regeneration of ground probes;
- Air to Water Heat Pump (ASHP): SH and DHW are covered with two air-to-water heat pumps;
- Ground to Water Heat Pump (GSHP): SH and DHW are covered with two ground-to-water heat pumps.

The two heating variants "A+GSHP" and "GSHP" have been defined for two cases: building envelope non-refurbished and refurbished according to the refurbishment strategy. The variant "ASHP" has been considered only in case the building envelope is refurbished. In all the variants the replacement of the existing radiators with new radiators was considered and the supply water temperature has been set depending on the building envelope status.
For all the variants a heat pump that use CO_2 (R744) as refrigerant was considered. This refrigerant has many positive aspects (low toxicity, natural refrigerant, GWP = 1), but the return temperature (i.e., inlet temperature in the condenser) must be low enough (equal or lower than 35°C) in order that the heat pump can work efficiently.
District heating was not considered as heating variant in this analysis, out of the scope of the project. Details about the different heating variants are described in the Annex.

	Building envelope non-refurbished Space heating / DHW [kWh/m²a]: 72 / 19 		**Building envelope refurbished** Space heating / DHW [kWh/m²a]: 42 / 19 		
Heating variant	**A+GSHP**	**GSHP**	**A+GSHP**	**ASHP**	**GSHP**
COP HP*	3.0 (at B0/W60)	3.0 (at B0/W60)	3.3 (at B0/W55)	2.2 (at A-4/W55)	3.3 (at B0/W55)
Capacity of HP*	2 x 260 kW (37 W/m²)	2 x 260 kW (37 W/m²)	2 x 175 kW (25 W/m²)	2 x 175 kW (25 W/m²)	2 x 175 kW (25 W/m²)
Ground probes	40 x 300 m (0.9 m/m²)	100 x 300m (2.2 m/m²)	30 x 300 m (0.6 m/m²)	-	50 x 300 m (1.1 m/m²)
Air cooling unit	500 kW (36 W/m²)	-	240 kW (17 W/m²)	240 kW (17 W/m²)	-
Electricity demand (kWh/m²a)**	24	26	16	19	18



* data from datasheets of real HPs products
** Electricity demand of the heating system (heat pumps + circulating pumps)
*** Seasonal Performance Factor of the heat pump (Q_{cond} / $Q_{el,compr}$)

Assumptions
- Financial subsidies not considered;
- The costs for replacement of existing radiators are included in the analysis (541 kCHF);
- Only electricity consumption of the heating system is included in the electricity costs;
- Heat pump lifespan: 25 years
- Constant electricity price of 0.25 CHF/kWh;
- Maintenance of 1%/a of investment costs;
- Time analysis of 25 years.

Investment costs of the variants

Building envelope non-refurbished (only heating system)
- A+GSHP: 2.9 MCHF (212 CHF/m^2)
- GSHP: 4.2 MCHF (306 CHF/m^2)

Building envelope refurbished (heating system plus building envelope)
- A+GSHP: 13.3 MCHF (962 CHF/m^2)
- ASHP: 12.7 MCHF (919 CHF/m^2)
- GSHP: 13.6 MCHF (984 CHF/m^2)

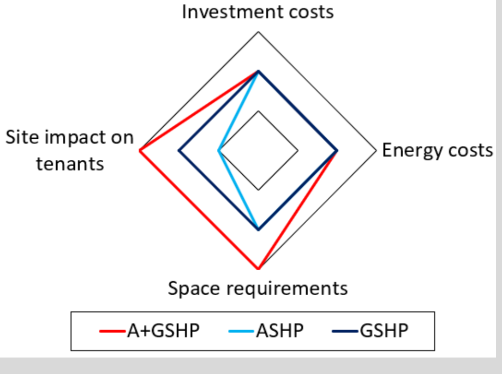
Electricity costs (per year)

Building envelope non-refurbished
- A+GSHP: 82 kCHF (5.9 CHF/m^2)
- GSHP: 89 kCHF (6.4 CHF/m^2)

Building envelope refurbished
- A+GSHP: 56 kCHF (4.1 CHF/m^2)
- ASHP: 65 kCHF (4.7 CHF/m^2)
- GSHP: 62 kCHF (4.4 CHF/m^2)

Radar chart for comparison of the heating variants (Case: building envelope refurbished):

Since the costs are subject to large uncertainties and the difference of costs is below 15%, the three variants have the same point-scale in the radar chart. Since drilling for ground probes is not needed, the variant "ASHP" has the lowest site impact on tenants compared to the other two variants.

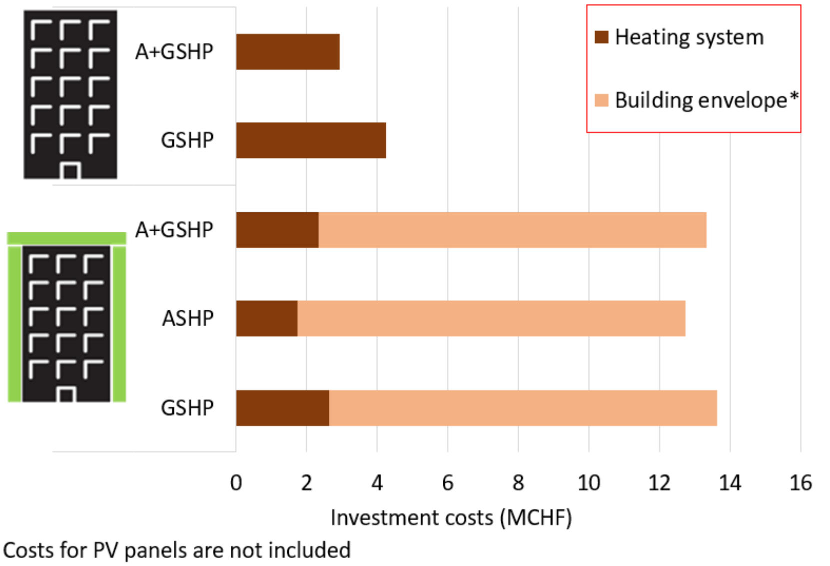


ECONOMIC ANALYSIS

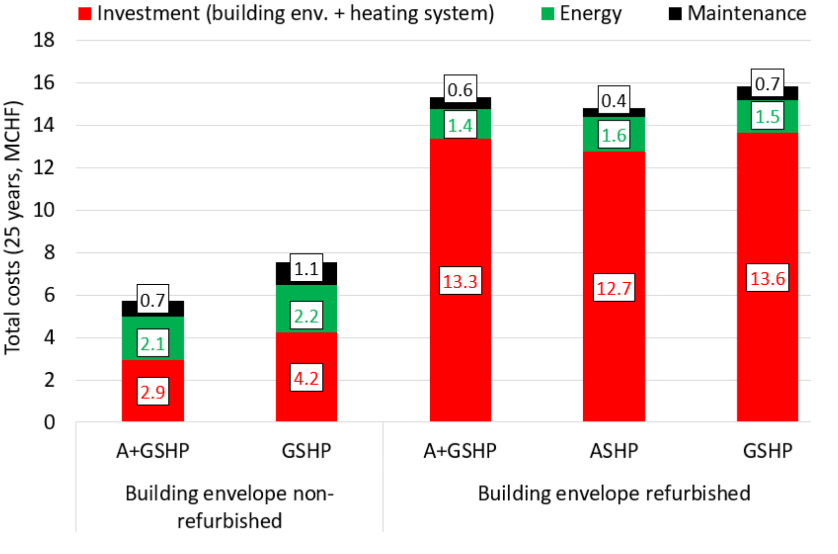
In order to compare all analyzed variants, an economic analysis over 25 years was performed. The first diagram below shows the total investment costs for each variant, while the second diagram shows the total costs (over 25 years) for investment, energy and maintenance.

As expected, if the building envelope is not refurbished, the investment costs for the heating system are higher because of the bigger heat pumps and more ground probes. In case of the refurbished building envelope, investment costs for the building envelope renovation represent approx. 80 - 85% of the total investment costs. It is important to highlight that here, the investment costs for the building envelope refurbishment are based on rough assumptions and are subject to large uncertainties.

Over 25 years the variant "A+GSHP" (in case of non-refurbished building envelope) has the lowest total costs with 5.7 MCHF.



* Costs for PV panels are not included



RECOMMENDATION

In case the building envelope is not refurbished, the A+GSHP variant represents the most attractive financial option as the diagrams above show. In case the building envelope is refurbished, the estimated total costs over 25 years are very similar for the three variants analyzed. In case an energy refurbishment of the building envelope is carried out, the heating demand of the building and the energy costs of the heating system are reduced, even though the total costs are higher. Additional advantages of the refurbishment of the building envelope will be an increased thermal comfort for the inhabitants and a decreased electricity demand of the heat pump during wintertime when electricity prices are expected to be higher in future. It is important to highlight that the cost assessments are based on rough assumptions that are subject to larger uncertainties.

Annex

Building simulation – Inputs and assumptions

To evaluate the annual space heating demand of the building, the dynamic multi-zone simulation tool IDA ICE (Indoor Climate and Energy) has been used. Both cases (i.e., with and w/o building envelope refurbishment) have been modelled and simulated. Climate data of Geneve-Cointrin (SIA 2028) has been selected, while data from the national norm SIA 2024 has been used for the modelling of the internal heat gains of the building (people, light and appliances). A set point temperature of 22 °C with "ideal" heating system has been chosen. A constant air infiltration rate of 0.5 h^{-1} has been assumed for the entire building. Since detailed information about DHW demand of the building is not available, assumptions have been done based on national norms and experience.

Heating variants simulation – Description and controls

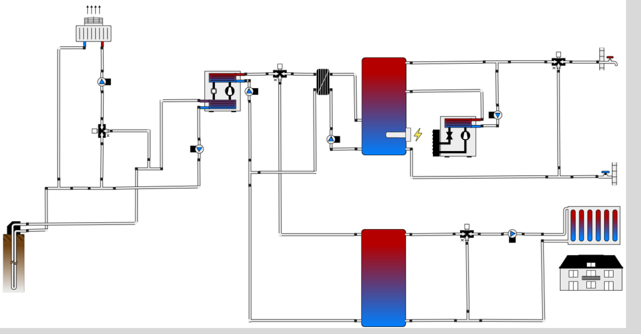
The different heating variants have been modelled with the help of the software POLYSUN. The different heating variants, defined and modelled together with HVAC partners, are schematically represented on the right. It is important to note that, due to limitations in the modelling of the simulation tool, simplifications were necessary in order to model the proposed variants. This means that there are some difference between the models in POLYSUN and the HVAC schemes defined together with the HVAC planners. Simplifications concern, for example, the number of the heat pumps (two in parallel in reality, one in the models), the number of storages for DHW (two in reality, one in the models), but also the modelling of the heat pumps with CO_2 as refrigerant. In all three simulated variants, one heat pump provides energy for space heating and DHW preparation. A circulation heat pump (always activated) of 10 kW is able to cover the circulation losses of the system. The heating system is equipped with two storages for DHW (8 m^3) and space heating (6 m^3). Unlike variants "ASHP" and "GSHP" (that use only one heat source), the variant "A+GSHP" is equipped with an air cooler that can be used also for the regeneration of the ground probes. Each storage is equipped with temperature sensors to control the switching on and off of the two heat pumps. Set point temperature for space heating is based on a heating curve (55°C with an outside temperature of -5 °C) as a function of the ambient temperature. The setpoint is increased by 10 K in case the building envelope is not refurbished.

Economic analysis – Inputs and assumptions

To compare the different variants, an economical analysis has been performed. The evaluation of the investment costs (for each heating variants and for the building envelope refurbishment) has been done with the inputs from HVAC partners and architects. The economical analysis has been performed assuming a lifetime of 25 years. A constant electricity price of 0.25 CHF/kWh and a cost for maintenance of 1%/a of the investment costs have been considered. In the evaluation of electricity costs, the electricity consumption for light and appliances of the building have not been taken into account. Financial subsidies (for building envelope refurbishment or installation of heat pump systems) were not considered.

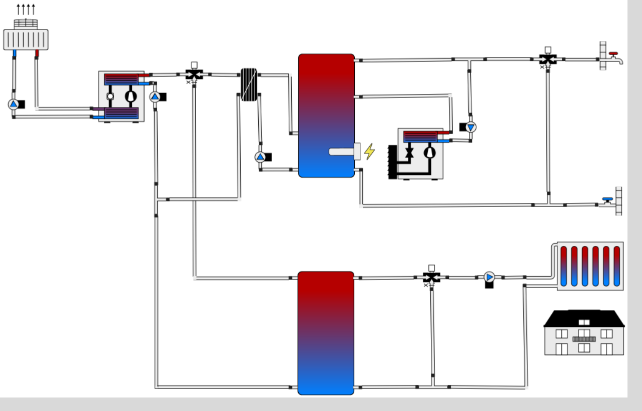
Schemes heating variants

Variant "A+GSHP" (Air+Ground to water heat pump)

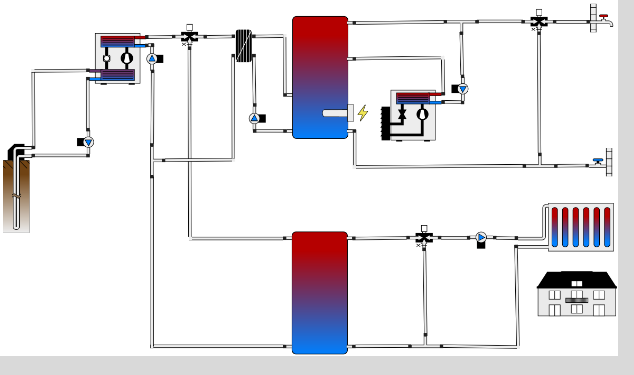


In this variant, heat can be extracted from the ambient air (with an air cooler) and/or from the ground. The two main advantages of such a system is the reduction of investment costs for the ground probes and the possibility to use the ambient air as heat source, especially in summer when outside temperature is higher. In addition, the air cooler can be used to regenerate the ground probes. When the ambient temperature is higher than the brine outlet temperature from the ground probe field, the regeneration loop can be activated and heat from the air can be released in the ground probes.

Variant "ASHP" (Air to water heat pump)



Variant "GSHP" (Ground to water heat pump)



Because of heat extraction during the winter season, the ground temperature decreases over the years. According to the national norm SIA 384/6, a simulation of 50 years is necessary to calculate the average minimum heat transfer fluid temperature (that must be higher than -1.5 °C). Through the software POLYSUN, it was possible to dimension the length and number of ground probes for the variants "A+GSHP" and "GSHP" to comply the requirements of the norms.

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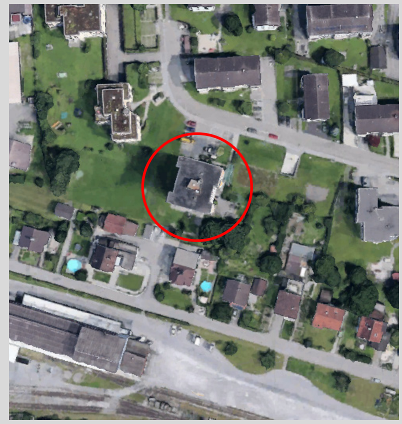
Heat pump systems for existing multifamily buildings

Case Study 4 - Apartment block from the 1970s

CHARACTERISTICS

The building is located in the countryside of canton St. Gallen and, with its ten floors, represents a typical high-rise building from the 1970s. The building has thirty apartments (three flats for each storey) with balconies on the East and West side.
The roof and the external walls are made of reinforced concrete with an insulation layer of 6 cm and 2 cm, respectively. The windows consist of wooden frames with double glazing for a total U-value of 1.4 W/m^{2}K. Roller blinds with internal blind boxes serve as sun protection.
The actual heating system consists of an oil boiler with a power of 240 kW which produces heat for space heating and domestic hot water. The energy for space heating is delivered through radiators.

OVERVIEW



Year of construction	1971
Location	Uznach (canton St. Gallen)
Energy Reference Area	3150 m^2
Building category (SIA 380/1)	Residential
Calculated space heating demand	276 MWh/a (88 kWh/m^{2}a)
Calculated domestic hot water demand	60 MWh/a (19 kWh/m^{2}a)
Heating system	Oil boiler
Heat delivery	Radiators

Roof
Concrete flat roof with 6 cm of insulation with a PVC foil as roof cladding

Window
Wooden frame, double glazing

Sun protection
Roller blinds with internal blind box

External wall
Construction in reinforced concrete with 2 cm of insulation

Outdoor area
Loggia on the East and West side

BUILDING ENVELOPE - Refurbishment strategy

In order to decrease the heating demand of the building, the existing external surfaces (i.e., roof, walls and windows) need to be refurbished. The simple cubature of the building allows for external insulation while retaining the characteristic features.

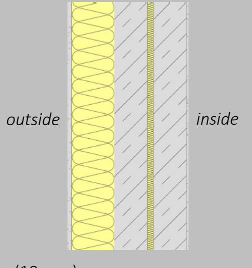
On the external roof, the existing insulation layer (of 60 mm) will be removed and replaced with a thicker insulation layer of 100 mm to decrease the U-value of the construction.

As the external walls are built with a sandwich structure (concrete/insulation/concrete), the existing insulation layer will be maintained. In addition, a new insulation layer of 120 mm will be placed on the outside of the wall to reach an U-value of 0.28 W/m²K. All windows will be replaced with two panes windows with wood frame with an U-value that will decrease from 1.4 W/m²K to 0.9 W/m²K.

External wall

U before renovation: 1.32 W/m²K

U after renovation: 0.28 W/m²K

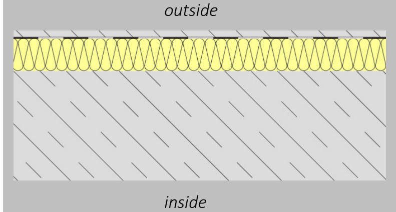


Plaster (10 mm)
Insulation (120 mm)
Reinforced concrete (100 mm)
Insulation (20 mm)
Reinforced concrete (100 mm)
Plaster (10 mm)

External roof

U before renovation: 0.46 W/m²K

U after renovation: 0.19 W/m²K



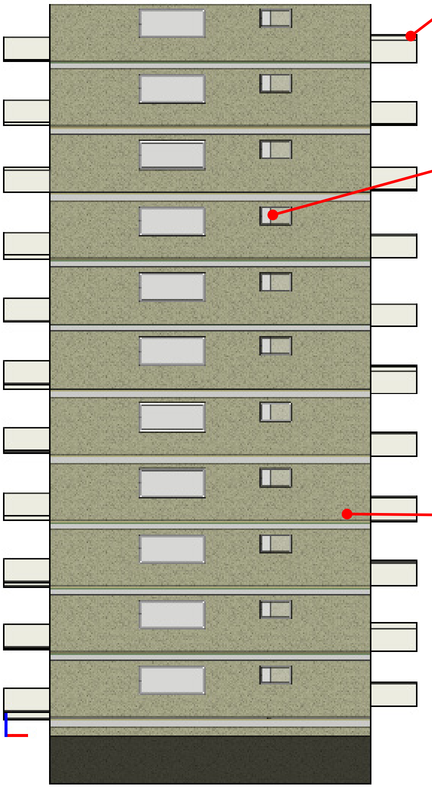
Roof tiles
PVC film
Insulation (60 mm) (removed)
Insulation (100 mm)
Reinforced concrete (250 mm)

Window

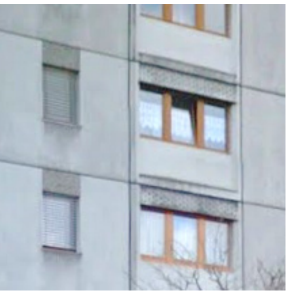
U_g before renovation: 1.5 W/m²K
U_f before renovation: 1.2 W/m²K
g before renovation: 0.80
U_g after renovation: 0.7 W/m²K
U_f after renovation: 2.0 W/m²K
g after renovation: 0.45

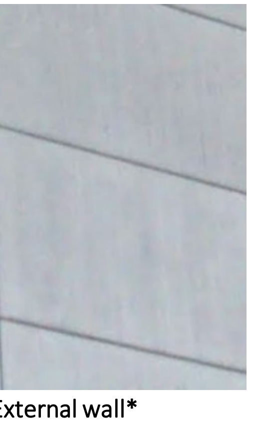
Roof*

Loggia*



Window of the apartments*





External wall*

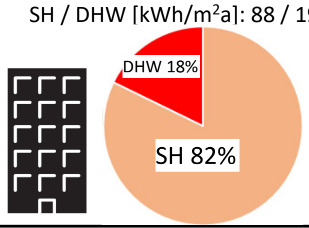
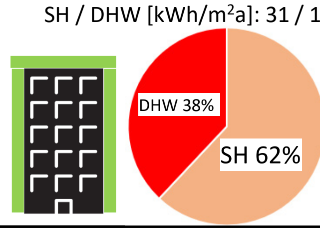
*actual status (before renovation)

HEATING CONCEPT - Definition of heating variants

To reduce the direct CO_2-emissions of the existing heating system for space heating (SH) and domestic hot water (DHW) preparation, two variants have been investigated:

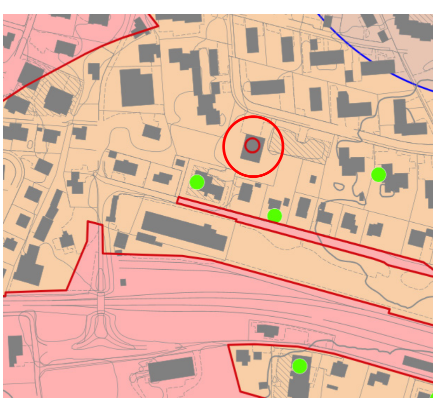
- Air to Water Heat Pump (ASHP): SH and DHW are covered with an air-to-water heat pump;
- Ground to Water Heat Pump (GSHP): SH and DHW are covered with a ground-to-water heat pump.

The "ASHP" has been considered only in case the building envelope is refurbished, while the "GSHP" variant was considered for both building envelope status (i.e., not refurbished and refurbished).
In all variants, the existing radiators are replaced with new radiators, and the supply water temperature is set depending on the building envelope status. Since a district heating network is not present in this area, this option was not considered as heating variant in this analysis. Details about the different heating variants are described in the Annex. The choice of the heating variants is the result of a preliminary discussion with the HVAC partners.

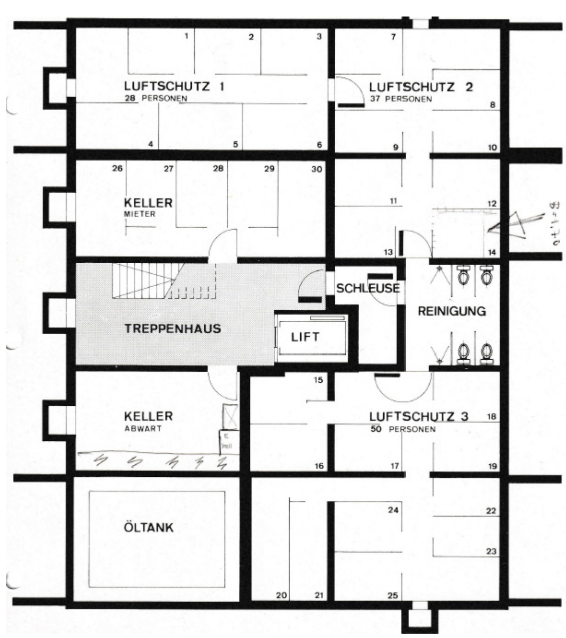
	Building envelope non-refurbished SH / DHW [kWh/m²a]: 88 / 19  	**Building envelope refurbished** SH / DHW [kWh/m²a]: 31 / 19  	
Heating variant	**GSHP**	**GSHP**	**ASHP**
COP_{nom}/$Capacity_{nom}$ heat pump*	4.7 / 100 kW (at B0/W35)	4.7 / 64 kW (at B0/W35)	4.2 / 71 kW (at A2/W35)
Number and length of ground probes	18 x 200 m	9 x 200 m	-
Volume storage for DHW/SH	2000 l / 3500 l	2000 l / 3500 l	2000 l / 3500 l
Electricity demand (kWh/m²a)**	33.5	13.3	14.2

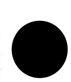
* data from datasheets of real HPs products proposed by HVAC partner

** Electricity demand of the heating system (heat pumps + circulating pumps)



The building (circled in red) is located in an area (orange area in the picture) where ground drilling is basically permitted with a hydrogeological preliminary clarification. Existing ground probes (green points) are already present in the area. For that reason, it was decided to consider the ground source heat pumps as possible heating variant for the building under analysis.





A crucial aspect for the "ASHP" is the positioning of the air cooler, which is installed outside the building. Together with HVAC partner, it was decided to install this component in a green area where enough space is available for such components (see black point) . In this way the external units will be next the technical room where the internal heat pump units will be installed.

Assumptions

- Financial subsidies not considered;
- The costs for replacement of existing radiators not included;
- Only electricity consumption of the heating system is included in the electricity costs;
- Constant electricity price of 0.25 CHF/kWh;
- Maintenance of 1%/a of investment costs;
- Heat pump lifespan: 25 years;
- Time analysis of 25 years.

Investment costs of the variants

Building envelope non-refurbished (only heating system)

- GSHP: 540 kCHF (171 CHF/m^2)

Building envelope refurbished (heating system plus building envelope)

- GSHP: 3.5 MCHF (1108 CHF/m^2)
- ASHP: 3.3 MCHF (1063 CHF/m^2)

Electricity / Energy costs (per year)

Building envelope non-refurbished

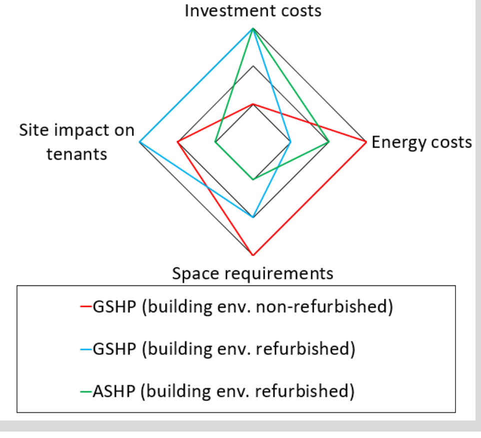
- GSHP: 26 kCHF (8 CHF/m^2)

Building envelope refurbished

- GSHP: 10 kCHF (3 CHF/m^2)
- ASHP: 11 kCHF (4 CHF/m^2)

Radar chart for comparison of the heating variants:

The "GSHP" variant for building envelope non-refurbished is the variant with the lowest initial investment costs and the highest energy costs. Since the "ASHP" variants need only the installation of the external units outside the building, space requirement is lower compared to the "GSHP" variants, where ground probes are needed.

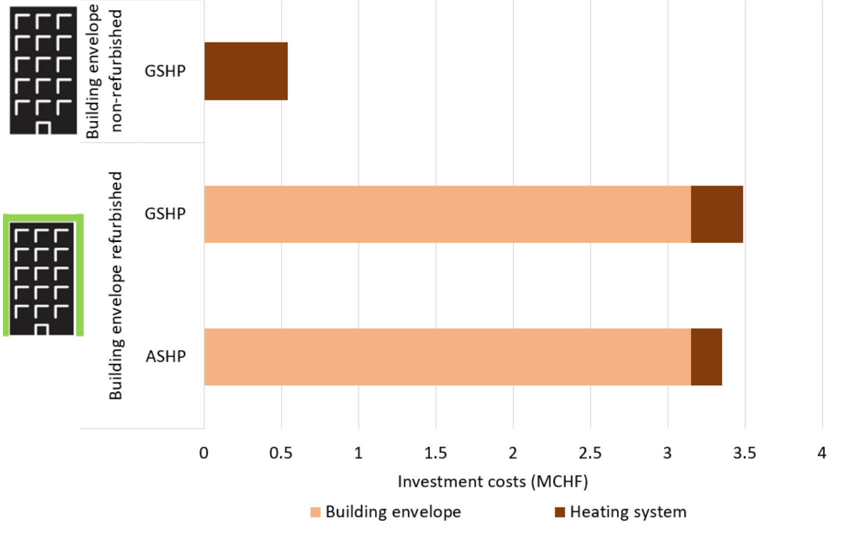


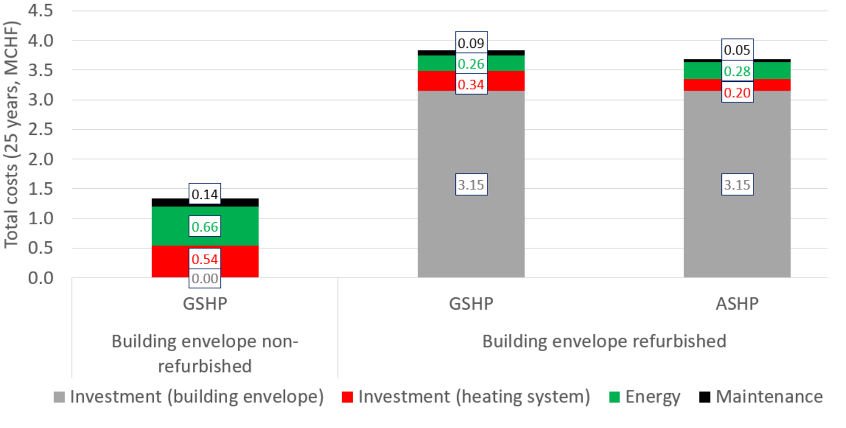
ECONOMIC ANALYSIS

An economic analysis over 25 years was performed for all variants. The first diagram below shows for each variant the total investment costs, while the second diagram shows the total costs (over 25 years) for investment, energy and maintenance.

If the building envelope is not refurbished, the investment costs for the heating system are higher compared to the case in which the building envelope is refurbished. In case of refurbished building envelope, investment costs for building envelope renovation represent approx. 90-95% of the total investment costs. It is important to highlight that here, the investment costs for the building envelope refurbishment are based on rough assumptions and are subject to large uncertainties.

Over 25 years the variants "ASHP" and "GSHP" have similar total costs (approx. 3.8 MCHF) in case the building envelope is refurbished.





RECOMMENDATION

At the location of the building that was analyzed in this case study, for the non-refurbished case, only a GSHP system is technically feasible when the heat production is changed from fossil to renewable energy. In case an energy refurbishment of the building envelope is carried out, the heating demand of the building and the energy costs of the heating system are reduced, even though the total costs are higher. Additional advantages of the refurbishment of the building envelope will be an increased thermal comfort for the inhabitants and a decreased electricity demand of the heat pump during wintertime when electricity prices are expected to be higher in future. The higher investment costs of the GSHP variant are partly evened out by its lower energy costs compared to the ASHP variant with total costs that are comparable for both variants. If the electricity grid load and the costs for purchased electricity are considered, the higher COP of the GSHP brings further advantages compared to the ASHP variant, as it has lower electricity demands during wintertime. It is important to highlight that the cost assessments are based on rough assumptions that are subject to larger uncertainties.

Annex

Building simulation – Inputs and assumptions

To evaluate the annual space heating demand of the building, the dynamic multi-zone simulation tool IDA ICE (Indoor Climate and Energy) has been used. Both cases (i.e., with and w/o building envelope refurbishment) have been modelled and simulated. Climate data of Zürich (SIA 2028) has been selected, while data from the national norm SIA 2024 has been used for the modelling of the internal heat gains of the building (people, light and appliances). A set point temperature of 22 °C with "ideal" heating system has been chosen. A constant air infiltration rate of 0.5 h^{-1} has been assumed for the entire building. Since detailed information about DHW demand of the building is not available, assumptions have been done based on national norms and experience.

Economic analysis – Inputs and assumptions

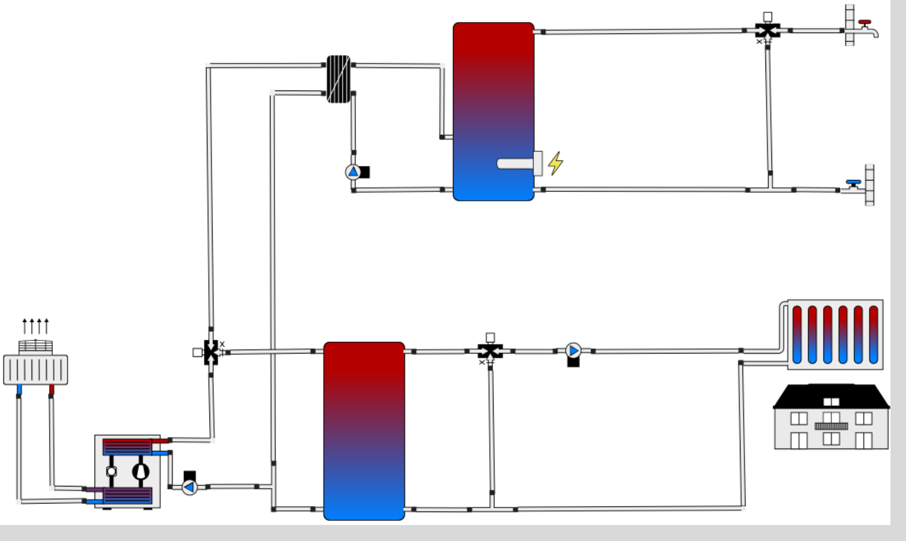
The evaluation of the investment costs for each heating variant and for the building envelope refurbishment has been done with the inputs from HVAC partners and architects. Within the investment costs for the heating system, the cost for radiators replacement was not considered. The economical analysis has been performed assuming a lifetime of 25 years. A constant electricity price of 0.25 CHF/kWh and a cost for maintenance of 1%/y of the investment costs have been considered. In the evaluation of electricity costs, the electricity consumption for light and appliances of the building have not been considered.
Financial subsidies (for building envelope refurbishment or installation of heat pump systems) were not considered.

Heating variants simulation – Description and controls

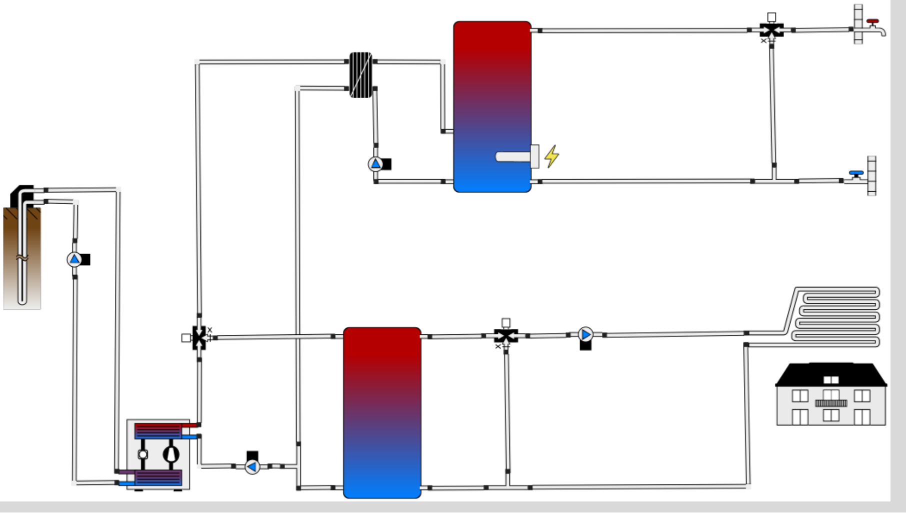
The different heating variants have been modelled with the software POLYSUN. The different heating variants, defined and modelled together with HVAC partners, are schematically represented on the right.
The system is equipped with a storage for DHW of 2000 l and a second storage for space heating of 3500 l. Each storage is equipped with temperature sensors to control the switching on and off of the heat pump. The heating system is equipped with a three-way valve to activate the heat pump for space heating or preparation of DHW (DHW has always priority to space heating).
Set point temperature for space heating is based on a heating curve (40°C for an outside temperature of -8 °C in case of renovated building envelope) as function of the ambient temperature. The supply water temperature is increased by 20 K in case of non-renovated building envelope.

Schemes of the heating variants

Variant "ASHP" (Air to water heat pump)



Variant "GSHP" (Ground to water heat pump)



Innovation project supported by

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Confederaziun svizra

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Heat pump systems for existing multifamily buildings

Case Study 5 - Building complex of five MFHs

CHARACTERISTICS

The building complex of five Multi-Family-Houses (MFHs), located in the municipality of Stäfa (in canton Zurich), is a residential construction of the yearly 2000s. Each of the five buildings is characterized by three floors plus an attic for a total of seven apartments (35 for the whole complex). Each building has a glazed seating area on the south-side. The building envelope is on a good status with external walls insulated with 14 cm of EPS and double-glazed windows with external venetian blinds.
The building complex is heated with decentralized systems (installed in the basement of each of the five buildings), each consisting of a gas boiler (41 kW) which produce energy for space heating and domestic hot water. The energy for space heating is delivered to the heated rooms through floor heating. Each technical room is equipped with a storage tank of 400 l for domestic hot water.

Attic

External wall
Brick masonry walls with external insulation

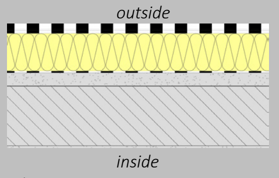
External windows
Double glazed windows with external venetian blinds

Apartments
Two apartments for each floor (seven apartments for each building)

OVERVIEW

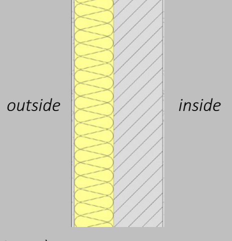
Year of construction	2006
Location	Stäfa (canton Zürich)
Energy Reference Area	6285 m^2
Building category (SIA 380/1)	Residential
Calculated space heating (SH) demand	220 MWh/a (35 kWh/m^2a)
Calculated domestic hot water (DHW) demand	119 MWh/a (19 kWh/m^2a)
Heating system	Gas boiler
Heat delivery	Floor heating

Roof
U-value: 0.19 W/m²K



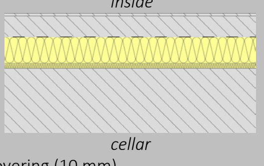
Drainage layer
Separating layer
Bituminous waterproofing (10 mm)
PU rigid foam board (140 mm)
Vapor barrier (5 mm)
Slope cover (50 mm)
Reinforce concrete (220 mm)
Interior plaster (10 mm)

External wall
U value: 0.23 W/m²K



Plaster (10 mm)
Insulation EPS (140 mm)
Brick masonry (175 mm)
Plaster (10 mm)

Floor against unheated
U value: 0.20 W/m²K



Floor covering (10 mm)
Cement screed (80 mm)
PE-film
Hard foam PUR (100 mm)
Mineral fiber board (20 mm)
Reinforced concrete (250 mm)

Window of the apartments
U_g value: 1.0 W/m²K
U_f value: 3.0 W/m²K
Frame ratio: 11%
g value: 0.62

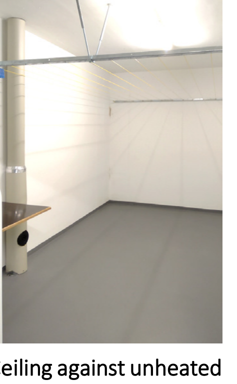
BUILDING ENVELOPE

This complex of five MFHs of this case study has been built in 2006 and thus, is relatively new. Since the building envelope is on a good status and energetically efficient, refurbishment strategy of the building envelope was not considered.
Each of the five MFH consists of three floors and an attic for a total of seven apartments. On the south side, each apartment has a large glazed seating area.
The flat roof is made of reinforced concrete and is insulated with 14 cm of PU rigid foam board with an U-value of 0.19 W/m²K. The external walls, with an U-value of 0.23 W/m²K, are externally insulated with 14 cm of EPS and made of brick masonry.
The floor against unheated rooms, in reinforced concrete, are insulated with PUR and mineral fiber board (100 mm and 20 mm, respectively) with an U-value of 0.20 W/m²K. All the main constructions are described on the left. The double-glazed windows of the apartments, equipped with external venetian blinds, present an U-value of 1.22 W/m²K.

Windows of the apartments

Glazed seating area

Staircase and external wall



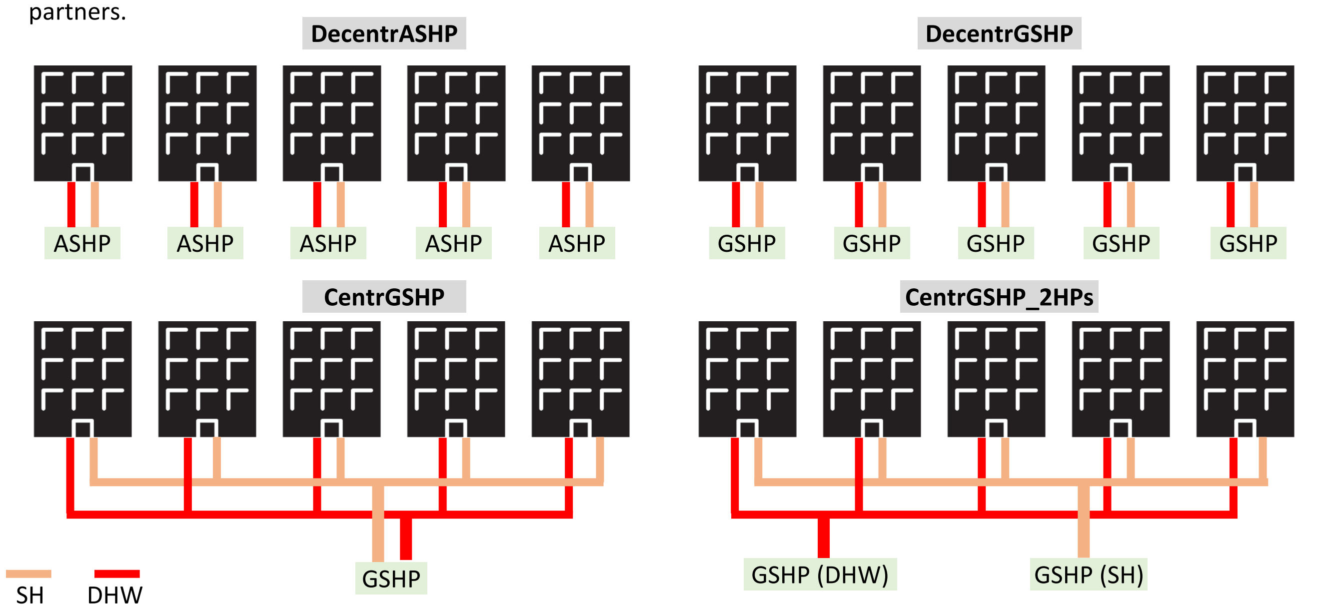
Ceiling against unheated

HEATING CONCEPT - Definition of heating variants

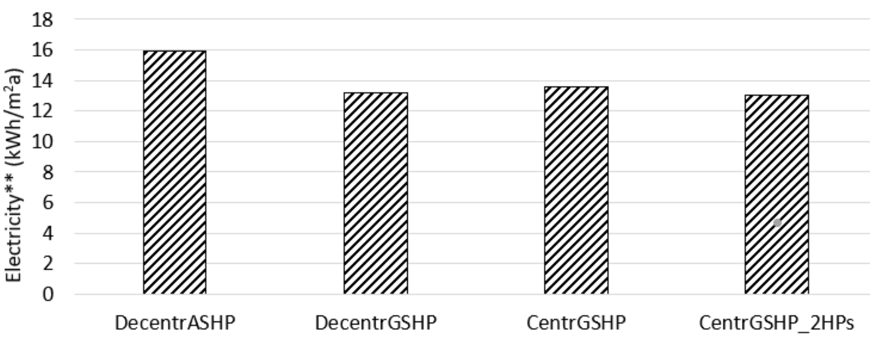
To reduce the direct CO_2-emissions of the existing heating system for space heating (SH) and domestic hot water (DHW) preparation, four variants have been investigated:

- Decentralized Air to Water Heat Pump (DecentrASHP): SH and DHW for each building are covered with a single heat pump. Since the building complex consists of five MFHs, five separate heat pumps are considered;
- Decentralized Ground to Water Heat Pump (DecentrGSHP): SH and DHW for each building are covered with a single heat pump. Since the building complex consists of five MFHs, each building will be equipped with a separate heat pump and ground probe field;
- Centralized Ground to Water Heat Pump (CentrGSHP): SH and DHW of all the five MFHs are covered with a single heat pump. In this case, only one heat pump and one ground probe field will be installed for the whole complex;
- Centralized Ground to Water Heat Pump with two heat pumps (CentrGSHP_2HPs): this variant represents a variation of the third variant in which two heat pumps (one for space heating and one for domestic hot water) will be installed.

In all the variants the actual heat delivery (i.e., floor heating) was considered. Since district heating is not planned in the next future, it was not considered as heating variant in this analysis. Details about the different heating variants are described in the Annex. The choice of the heating variants is the result of a preliminary discussion with the HVAC partners.



Heating variant	DecentrASHP	DecentrGSHP	CentrGSHP	CentrGSHP_2HPs
COP HP*	3.4 (at A2/W35)	4.2 (at B0/W35)	4.0 (at B0/W35)	SH: 3.9 (at B0/W35) DHW: 3.9 (at B0/W35)
Total capacity of HP*	5 x 43 kW (34 W/m²)	5 x 43 kW (34 W/m²)	2 x 112 kW (36 W/m²)	SH: 177 kW (28 W/m²) DHW: 47 kW (7 W/m²)
Ground probes (total)	-	30 x 200 m (0.9 m/m²)	30 x 200 m (0.9 m/m²)	30 x 200 m (0.9 m/m²)
SPF_{hp}	3.5	4.3	4.1	SH: 4.7 DHW: 3.6
Electricity demand (kWh/m²a)**	16	13	14	13



*data from datasheets of real HPs products

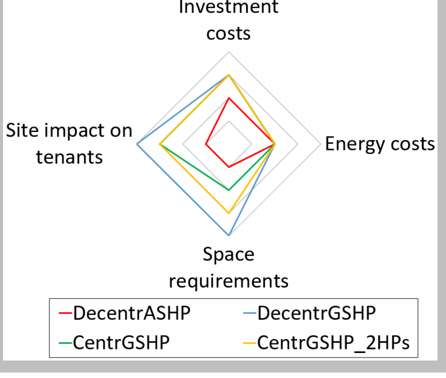
** Electricity demand of the heating system (heat pumps + circulating pumps) for the five MFHs

Assumptions
- Financial subsidies not considered;
- Only electricity consumption of the heating system is included in the electricity costs;
- Constant electricity price of 0.37 CHF/kWh;
- Maintenance of 1%/a of investment costs;
- Time analysis of 25 years.

Investment costs
Building envelope non-refurbished (only heating system)
- DecentrASHP: 530 kCHF (84 CHF/m²)
- DecentrGSHP: 1030 kCHF (164 CHF/m²)
- CentrGSHP: 920 kCHF (146 CHF/m²)
- CentrGSHP_2HPs: 910 kCHF (145 CHF/m²)

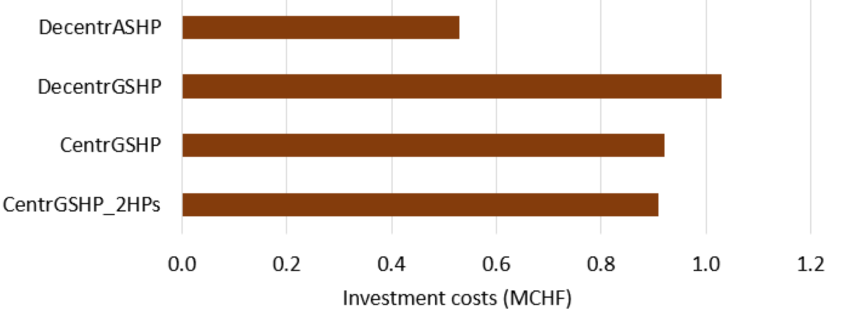
Electricity costs (per year)
- DecentrASHP: 37 kCHF (6 CHF/m²)
- DecentrGSHP: 31 kCHF (5 CHF/m²)
- CentrGSHP: 32 kCHF (5 CHF/m²)
- CentrGSHP_2HPs: 30 kCHF (5 CHF/m²)

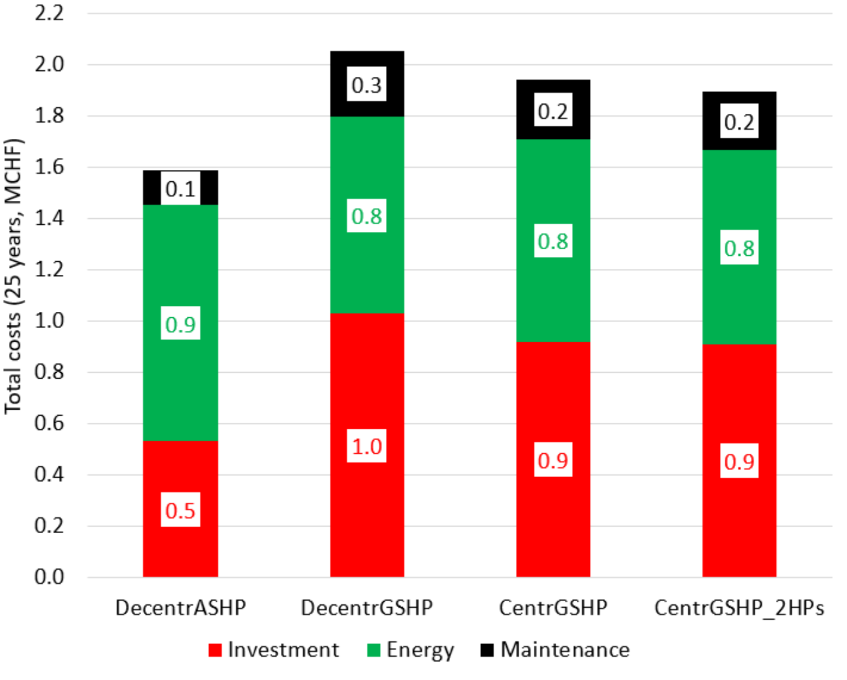
Radar chart for comparison of the heating variants:
The "DecentrASHP" variant is the variant with the lowest initial investment costs (84 CHF/m²) and the highest energy costs (6 CHF/m²). Since drilling for ground probes is not needed, the variant "DecentrASHP" has the lowest site impact on tenants compared to the other two variants. For the qualitative evaluation of the space requirement, it was considered the space required in the garden (for the ground probes) and in the cellar for the heating equipment. Because of the five ground probe fields and five heat pumps installed in the cellars of the buildings, the "DecentrGSHP" presents the highest space requirements.



ECONOMIC ANALYSIS

In order to compare all analyzed variants, an economic analysis over 25 years was performed. The first diagram below shows for each variant the total investment costs, while the second diagram shows the total costs (over 25 years) for investment, energy and maintenance. It is important to highlight that the investment costs are based on rough assumptions and are subject to large uncertainties. The variant "DecentrGSHP", with a total investment costs of approx. 1 MCHF, presents the highest investment costs, while the two variants with centralized solutions have a total investment costs slightly lower (approx. 900 kCHF).
Over 25 years, the variant "DecentrASHP" has the lowest total costs with 1.6 MCHF, 23% lower compared to the variant "DecentrGSHP" (2.1 MCHF).





RECOMMENDATION

The diagrams above show that the decentral air source heat pump (DecentrASHP) variant represents the most attractive financial option compared to the other three variants analyzed. As reported in the radar chart, the variant DecentrASHP has the lowest investment costs and site impact on tenants because, compared to the other variants, drilling for ground probes is not needed. The external units of the heat pumps could be placed on the side of each building in order to maintain the roof surface available for (eventual) installation of PV panels. On the other hand, a ground source heat pump would decrease the electricity peaks of the heat pump during the wintertime and this aspect would represent a beneficial for the electricity grid load and the electricity costs. It can be expected that in future, during wintertime, electricity prices will be higher. Comparing the GSHP variants, it can be stated that the centralized solution with ground probes is financially more attractive (compared to the variant DecentrGSHP), but the placement of the big heat pumps in the basement of the building complex could represent an obstacle to be considered. It is important to highlight that the cost assessments are based on rough assumptions that are subject to larger uncertainties.

Assumptions

- Financial subsidies not considered;
- Electricity consumption of the heating system (Variant "DecentrASHP") and households is included in the electricity demand;
- Annual electricity demand: 222 MWh/a (heating system: 100 MWh/a, households: 122 MWh/a);
- Constant electricity price (0.37 CHF/kWh) and PV feed-in tariff (0.17 CHF/kWh) was assumed;
- Maintenance of 1%/a of investment costs;
- Time analysis of 25 years;
- Time step simulation: 1 hour;
- Investment costs of 1700 CHF/kW$_p$ was assumed in all variants;
- PV panels installed only on the attic roof of the five buildings (orientation: south, inclination: 30°) in all the variants.

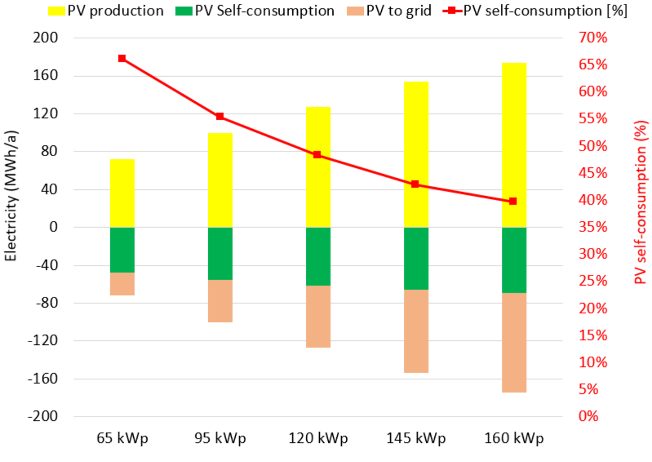
PV variant	Total PV area [m²]	Number of modules
w/o PV	-	-
65 kW$_p$	92	54
95 kW$_p$	128	75
120 kW$_p$	162	95
145 kW$_p$	197	115
160 kW$_p$	223	130

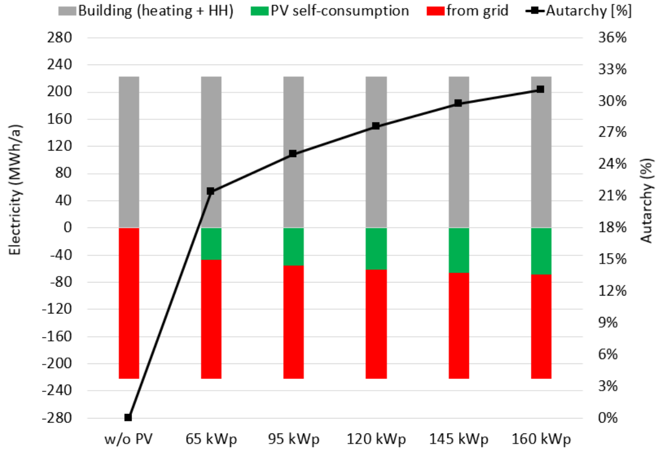
PV STUDY - Definition of variants and analysis

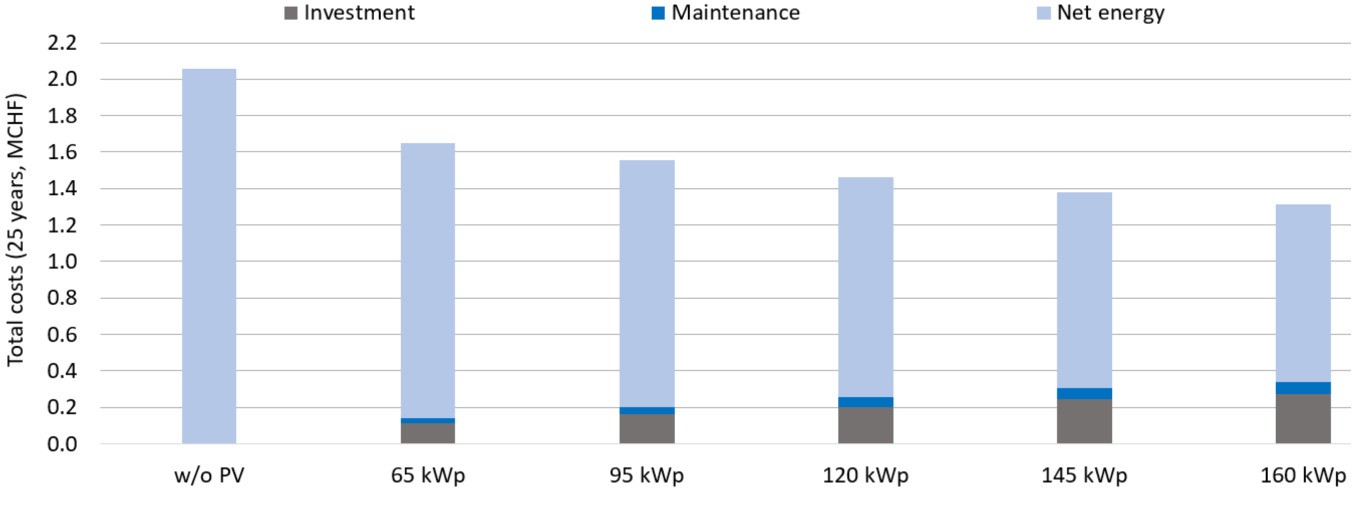
Different PV variants were defined and compared in order to find out the most attractive financial option for the building complex under analysis. All the main assumptions of the study are listed on the left. In all PV variants analyzed, the heating variant "DecentrASHP" was considered. Five different PV variants (from 65 kW$_p$ to 160 kW$_p$ of total PV power installed) were defined and compared with the case without PV system. The variant "160 kW$_p$" represents the case in which the whole surface of the five attic roofs is equipped with PV panels.

The two diagrams below show for each variant the electricity balance of the PV system and of the building. With the variant "160 kW$_p$" the PV system produces approx. 170 MWh/a, that is 23% lower than the annual total electricity demand of the building (i.e., 222 MWh/a). With the increase of the PV system size, there is a reduction of the electricity demand from the grid (until a value of 150 MWh/a in case of "160 kW$_p$") and an increase of the grade of autarchy until the maximum value of 31 %. The variant "65 kW$_p$" has a PV self-consumption of 66 %. This value decreases to 40 % in case of "160 kW$_p$" variant.

In order to compare economically the different variants, a constant electricity price and a constant PV feed-in tariff (0.37 CHF/kWh and 0.17 CHF/kWh, respectively) were assumed to calculate the net energy (i.e. the difference between the cost of purchased electricity and the gain of fed electricity to the grid). The last diagram below shows that the most attractive financial option is the "160 kW$_p$“ variant, where a reduction of total costs of 36% (compared to the option without PV) can be reached.







Annex

Building simulation – Inputs and assumptions

In order to evaluate the annual space heating demand of the building, the dynamic multi-zone simulation tool IDA ICE (Indoor Climate and Energy) has been used.
Climate data of Zürich (SIA 2028) has been selected, while data from the national norm SIA 2024 has been used for the modelling of the internal heat gains of the building (people, light and appliances). A set point temperature of 22 °C with "ideal" heating system has been chosen. A constant air infiltration rate of 0.5 h^{-1} has been assumed for the entire building.
Since detailed information about DHW demand of the building is not available, assumptions have been done based on national norms and experience.

Heating variants simulation – Description and controls

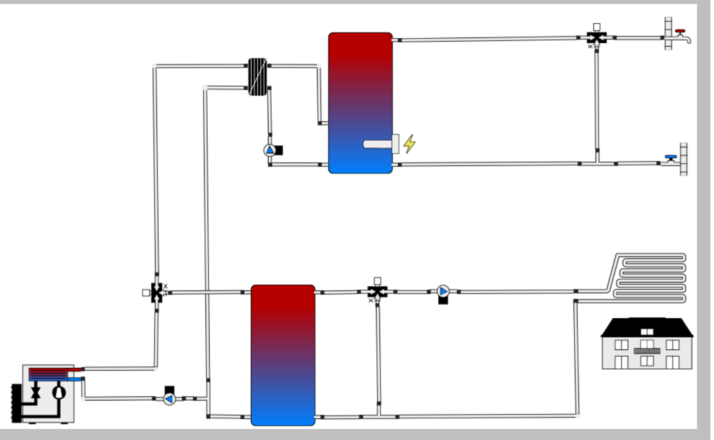
The different heating variants have been modelled with the help of the software POLYSUN. The different heating variants, defined and modelled together with HVAC partners, are schematically represented on the right. It is important to evidence that, due to limitations in the modelling of the used tool, simplifications were necessary in order to model all the proposed variants.
In the first two variants (i.e., "DecentrASHP" and "DecentrGSHP"), the heating system is equipped with one storage for DHW (1000 l) and space heating (2000 l), while in the other two variants, the storages are bigger (5 m^3 for DHW and 10 m^3 for SH) because the system serves the whole building complex.
Set point temperature for space heating is based on a heating curve (40°C with an outside temperature of -8 °C) as function of the ambient temperature.
Unlike the first three variants, the last variant (i.e., "CentrGSHP_2HPs") is the only one in which two separate HPs are used for DHW and space heating.
The variants with ground probes were dimensioned (length and number of probes) in order to comply the requirements of the SIA 384/6.

Economic analysis – Inputs and assumptions

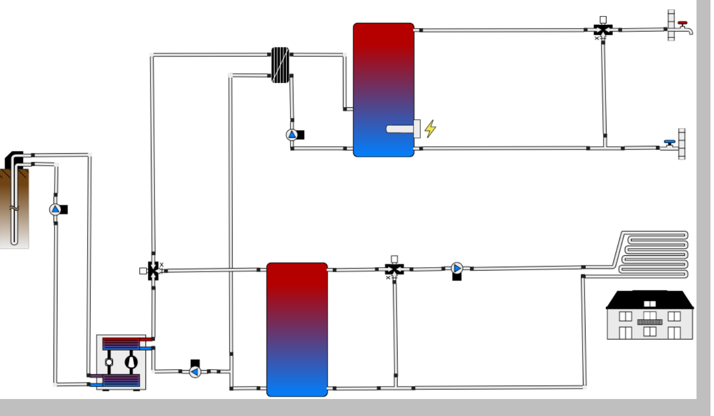
In order to compare the different variants, an economical analysis has been performed. The evaluation of the investment costs has been done with the inputs from HVAC partners and architects.
The economical analysis has been performed assuming a lifetime of 25 years. A constant electricity price of 0.37 CHF/kWh and a cost for maintenance of 1%/y of the investment costs have been considered. In the evaluation of electricity costs, the electricity consumption for light and appliances of the building was taken into account only in the PV study.
Financial subsidies (for PV or installation of heat pump systems) were not considered.

Schemes heating variants

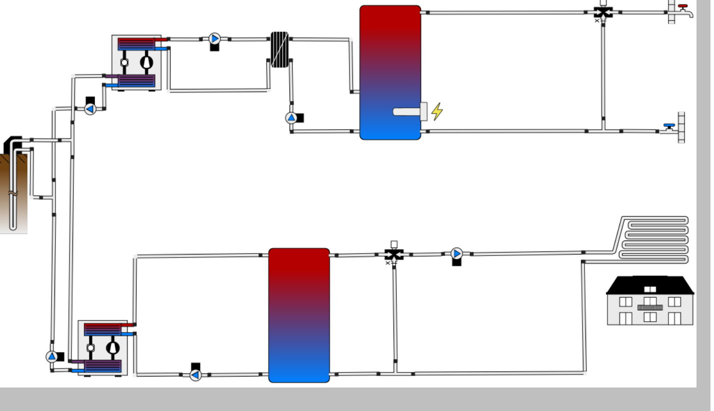
Variant "DecentrASHP"*



Variant "DecentrGSHP"**



Variant "CentrGSHP_2HPs"



* *In this variant, each heating system serves a single building. This means that, in order to simulate the system for the whole building complex, five of these systems need to be considered. The same condition applies to the second variant "DecentrGSHP".*

** *This model could be used also for the simulation of the variant "CentrGSHP" (not represented here) since the layout is similar. In this case, the model was readapted (i.e., length of pipes, heating/dhw demand, storages volumes, power of HPs and so on) in order to take into account that the system serves the whole building complex.*