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smartTES

Innovation in timber construction for the modernisation of the building envelope

Book 3
Multifunctional TES

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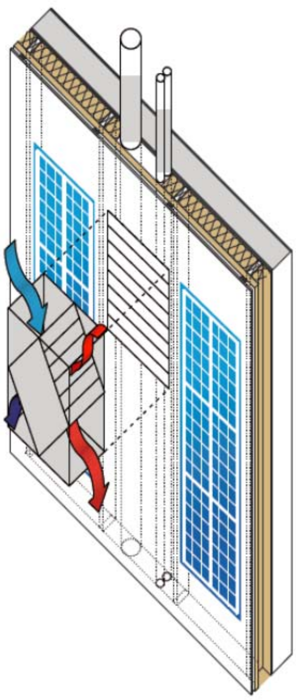

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Abbreviations, Units

Abbreviations

abe	active building envelope
AHU	Air Handling Unit
bss	building service system
DHW	Domestic Hot Water
HVAC	Heating Ventilation Air Conditioning
IAQ	Indoor Air Quality
HRU	Heat Recovery Unit
rH	Relative Humidity
ITC	Information Technology and Communication
PENR	Primary energy content not renewable
PERE	Primary energy content renewable
Q_h’	Specific heat energy demand
Q_e’	Specific end / use energy demand
Q_p’’	Annual primary energy demand
H’$_T$	specific heat transmission transfer coefficient
Re	Resource efficiency (conservation of material)
TES	TES EnergyFaçade - timber based element system for improving the energy efficiency of the building envelope
TUM	Technische Universität München
WLC	Whole Life Cost

Units

CO2 concentration	[ppm]
Q_h’	kWh
Q_e’	kWh
Q_p’’	kWh
H’$_T$	W/m²K

1. MULTIFUNCTIONAL TES

1.1 Preface

The scope is to give an overview of the capability of the *TES EnergyFacade* system as integrator of building services and to show exemplary design application for the *TES* system.
Results presented in this project report have been carried out within WP-1, Multifunctional *TES* of project "*smartTES* – Innovation in timber construction for the modernization of the building envelope".

1.2 Abstract

The work presented in this report is a joint contribution of Aalto University, HS Rosenheim, SINTEF Building & Infrastructure, and TUM concerning the integration of multifunctional building envelopes realized with SmartTES elements.

Aalto University brought in state of the art knowledge from façade solar energy systems, experience from Finnish case studies. UAS Rosenheim contributed with the evaluation of the passive wall heated envelope.
SINTEF has the focus on evaluation of mounting possibilities and the calculation of thermal losses and sound insulation.
TUM provides knowledge about building climate concepts and building service systems; defines the principles for multifunctional building envelopes and technical solutions at the system level of *TES* elements.

Energy efficiency refurbishment of buildings and building services systems retrofit are smarter with off-site production and systems integration. Optimizing a multifunctional building envelope towards a customized *smartTES* product is the main objective.
TES is equally suitable for the integration of various innovative concepts. These are examined for their applicability and integration capability in *TES* elements. This involves the integration of active components in elements, the connection of building services via *TES* elements with central devices, and reactive building envelopes as a holistic energy absorber. These solutions must be integrated as a whole system, not only to the *TES* element but also in the existing building.
Existing buildings demonstrate complex situations when retrofitting ventilation systems. It is more difficult for building services concepts to react on the as-built situation compared to new building, where it is designed in a collaborative way. With building service systems integrated in the envelope there is a higher flexibility in the development of well adapted solutions.
Holistic concepts for the multifunctional building envelope must be adapted to the particular case in detail. However an emerging standard can already be identified for the integration of HVAC. The addition of ventilation ducts in the vertical elements and the supply of each separate flat with their own ducts has already been proven by thorough investigation of constructions and in the practical implementation.
The necessary preliminary studies and the planning process are more complex, since additional constraints, as compared to basic façade renovation, are taken into account. The constraints include the building in its specific situation, existing systems, alternative new systems and service life of the components as well as sustainability of the entire concept.
All these parameters define the scope and depth of the intervention to be made in the existing substance and the related technologies and risks. Collaborative planning is the essential prerequisite to minimize risks and to ensure success.

1.3 Introduction to multifunctional smartTES (S.Ott)

1.3.1 Mission of integrated design

Due to natural decay, a great number of multiple dwelling units in Europe from the 1950's to 1980's have reached a point where renovation within the next decade is necessary. School buildings and residential buildings are building types with a huge need of modernization. *SmartTES* develops a multifunctional building envelope for the retrofit business of the timber construction sector.

1.3.2 Added value of multifunctional smartTES

SmartTES elements can do more than just add thermal insulation to the building envelope. It is possible to integrate various active and passive systems for building services.

Multifunctional SmartTES envelopes:

a) Add one or multiple technical parts or components to a timber framed TES insulation element:
   i) that are positioned in the insulation layer
   ii) or on exterior oriented surfaces of the element
b) integrate building services in the façade zone and
c) contribute added value to a façade insulation system through:
   i) reactive / responsive building elements,
   ii) an upgrade of existing building services
   iii) flexible, decentralized HVAC solutions.

„Reactive Building Elements are defined as building construction elements which are actively used for transfer of heat, light, water and air." [1].

The described quality brings the concept of reactive building skins namely advanced integrated facades from IEA Annexes 32, 35 and 37, SHC Task 23 into the refurbishment of existing buildings with *TES EnergyFacade* [1]. In order to give buildings from the 1950s to 1980s a second chance, most of the existing buildings require a deep retrofit which includes not only thermal insulation properties of the building envelope but also the technical equipment of building service systems [2]. Furthermore it is a prerequisite for improved building energy efficiency to adapt the building service systems to new thermal properties of the envelope. The improved thermal insulation of the building skin reduces the need for power of the heating system, reduces heating cost and required size of the system and shows innovation and integration potential in *TES* elements.

Figure 1-1 TES Element with integrated ventilation ductwork. The element is handled horizontally but will be turned to vertical orientation on-site. [Lylykangas]

There is a high demand of innovative solutions for the integration of technical components in the building envelope [3], [4], [5].

TES EnergyFacade is a suitable method responding to this demand and provides additional value to the client. The added value is the realization of a lean retrofit process due to the integration of several measures. Additionally, it shows the big advantage of the prefabrication concept for a multifunctional component with minimized on-site building works.

SmartTES works as a modular platform, like the conceptual design approach in the automotive sector. It has the advantage to act like a:

- carrier for building services (photovoltaic, solar thermal collectors, micro heat pumps or air handling units),
- Platform for supply piping
- Passive wall heating system (partner UAS Rosenheim).

Therefore SmartTES develops innovative and adaptive concepts for the integration of building services into TES elements.

1.4 Integrated building service systems (S.Ott)

1.4.1 Task and objectives of integration

T1.1 Production: Integrated energy supply systems (passive - active)
Starting from an investigation of existing façade systems (e.g. gap solution, lucido, Klimaaktive Hülle, etc.) the task of the work package is to explore the cutting edge potential of solar active facades.
The integration of following devices will be examined:
- Air collector, clima active façade, heat pumps
- Integration of solar active components (solar thermal or photo voltaic elements)
- Interface façade – services – room / apartment (control systems)
… systemised catalogue of requirements will give the basis for the design of elements with multifunctional properties that will be tested and monitored as mock-ups and/or in demonstration projects.

The main objectives and general principles are the:

- Combination of building envelope refurbishments with building service systems retrofits for holistic, building refurbishments
  - Evaluate design options
  - Define design principles
  - Show interrelations between envelope and technical installations
- Integration of technical installations into *TES* elements (construction and joints!)
- Generation of an added-value smart refurbishment with *TES*.

Although most of the presented concepts can be applied for buildings with different use, especially regarding HVAC systems, the results are mainly targeted at apartment buildings. HVAC for office buildings is widely spread, the necessary structural preconditions are set and the infrastructure already exists. This implies only small benefits of the integration of HVAC into the building envelope. The integration of solar energy generation systems in the façade layer could have a bigger potential for office buildings.

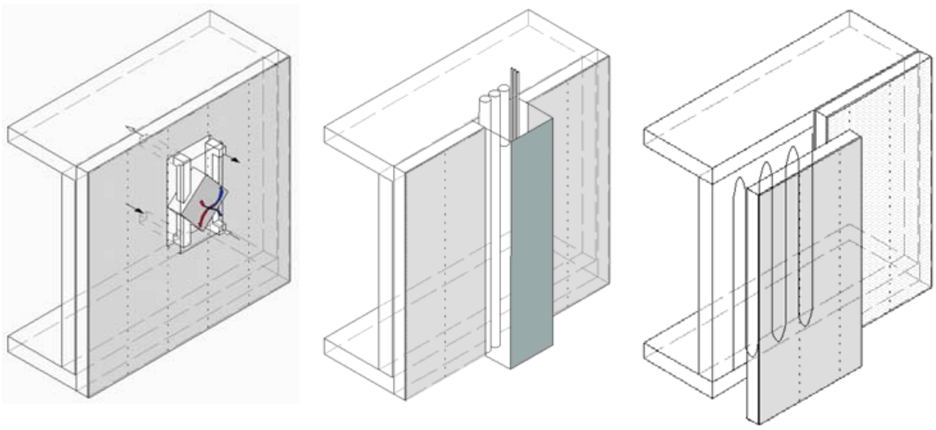


Figure 1-2 Principles of a TES-integrated (left), TES-connected (middle), TES-envelope concepts, technical installations in the building envelope.

1.4.2 Classification of design options

Hierarchy and classification of design options for the integration of building service systems is based on main components, generation components and supply or routing parts.

There are three main types of building services integration identified. They can be classified as follows:

- TES-integrated – Mechanical or electrical devices (energy generation or air handling units) in the building envelope,
- TES-connected – Routing of ventilation ductwork, water pipes (fresh water, heating, waste water), electricity and installations,
- TES-envelope concepts – Innovative concepts (passive wall heated envelope, “klimaaktive Fassade”, Gap-solution).

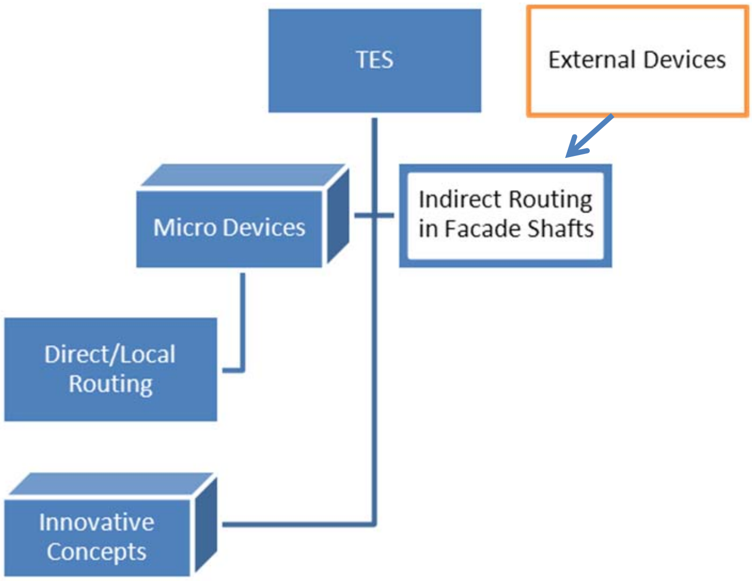


Figure 1 Micro-systems or responsive properties are integrated in TES elements (blue) and external devices (red) have only sub-systems integrated

The category of *TES-integrated* devices is limited to the area of the timber framework and the thermal insulation layers and is restricted to single elements. The integrated devices have to be small and light-weight and therefore are not able to supply entire buildings. They are dedicated to smaller units of the building like apartments. Induced by the fact of size limitations of a single *TES* element there should be no interference with joints of elements. The direct routing from the devices to the building has short length and is limited to the same element. They are close to the location of consumption. Examples are solar thermal and photovoltaic components which can be integrated on the TES level. More information about the application of solar systems in facades can be found in the Finnish report; “*smartTES*. Innovation in timber construction for the modernisation of the building envelope” [6]. More details about daylight direction systems, decentralized air handling units, micro heat pump systems can be found at website of the EU FP7 project iNSPiRe [7]. Further work is done for the application and the bordering conditions for micro heat pumps (output max. 1 kW) in refurbishment projects is done in a Master Thesis at TUM in cooperation with Chair of Building Physics, University Innsbruck [8].
The thesis aims to advance the sustainable method of energy efficient building retrofit by evaluating a building envelope integrated heat pump. In the process of building a micro heat pump of 1 to 1.2 kW nominal power, which is included in a prefabricated *smartTES* facade element, the aim is to offer a simple, functional and (cost)-efficient alternative to deep intervention in interior building services. Objective of this work is to investigate feasibility and performance and efficiency of decentralized heating systems in a case study and to compare the results with those of central systems. Thermal behavior of a condominium is simulated with TRNSYS version 17 for the purpose of generating heat load and heating demand profiles for a reference year by using the 3D input data via a SKETCHUP-plugin for TRNSYS. Those are compared in a cross-validation of the basic building model with two other thermal calculation and Simulation tools, namely MATLAB/SIMULINK with its CARNOT Toolbox and the 'Passivhaus-Projektierungs-Paket' PHPP. The obtained multi-zone-model is complemented with realistic behavior of the user in summer case. The obtained model is extended with different ventilation, heating and domestic hot water systems. Systems with air to water compressor heat pumps in combination with radiator heat distribution are analyzed. The study encompasses analyses of systems which range from

combined DHW and space heating provision to decentral systems. Electrical demands, seasonal performance factors for the system, comfort, and performance of the heat pumps are quantified and compared. In addition, tests to assess the limitations and resilience of the decentralized system have been undertaken. All systems which are analyzed serve as possible heat suppliers for the renovated house. Among the systems which are put into comparison, the system with one central heat pump and one central hot water storage has the lowest energy demand and the highest efficiency. Comparing decentralized systems, a decentralized system without storage with micro heat pumps of 1 kW has the lowest energy demand and the highest efficiency. In order to evaluate influence of storage tank size, heat pump size and supply temperatures, the performance of a sensitivity analysis of a decentralized system with storages shows that the reduction of the supply temperature is causing a strong decrease in energy demand, whereas influence of the volume of the storage is of second order. Under set-up conditions (set-temperature 20 °C and all flats heated): the power of one micro heat pump of 1 kW in each flat is sufficient. Limitations of decentralized systems are only shown in the attic flat when increasing requirements. In this case, an additional heater for the bathroom is recommended.

The category *TES-connected devices* contain only the routing as an integrated part in one or several TES elements. The routing has to be connected to external building service facilities which are far from the location of consumption. Problems arising are the dimensions of the ductwork, avoidance of collisions with joints, the TES assembly process and thermal properties of envelope. Examples of TES-connected devices are the ventilation ductwork, water supply, electric wiring etc.

TES-envelope concepts is the third category that has a status of exception. It is not purely related to the integration of sub-components from building service systems. The entire timber framed element is part of a reactive building skin influencing buildings energy consumption. Examples can be found in solar responsive envelopes that enable a dynamic thermal behaviour like a Gap-Solution facade, or the Lucido® solar facade [9], [10]. Alternative concepts combine ventilation and solar responsiveness in the German project *active building envelope* (in German: *Aktive Gebäudehülle*) [11]. It can include the improvement or support of building service systems as in the passive wall heated envelope that is presented in chapter 1.8.

1.4.3 Reduction of Impact

The refurbishment of public buildings or offices causes similar problems to users. Supply of proper working conditions is almost not possible during construction. Sometimes there is an opportunity to temporary shift users into other parts of the building or into external temporary spaces (e.g. containers). In such cases the innovative *smartTES* method can reduce the time span of renovation works and disturbance. A perfect example is the refurbishment of the Buchloe School, Germany presented in the first *TES EnergyFacade*-project [12].
A reduction of impacts of a refurbishment process is achieved by the *TES* method itself and by the integration of building services into the façade elements. Especially the computer has changed the requirements in supply and flexibility of workplaces with communication networks, electricity, light etc.

On user comfort related to services
User comfort is an important issue in working environments. The possibilities to interact with heating, natural ventilation, daylight or shadowing systems enables individual control over indoor comfort. Necessary facilities can be integrated into façade elements as well on a modular basis. Such highly integrated solutions need less maintenance than mechanical services. On the

other hand, they might have a shorter life span than less dynamic solutions. Therefore they can be replaced on a modular basis.

On building service life
Another important issue of office buildings is their short estimated service life compared to residential buildings together with a more frequent change of functional requirements. A buildings function may change earlier than the end of technical service life of separate components. The concept of modularity raises the flexibility and allows easy change without touching the substance. A benefit is to reuse and recycle components at end of life phase of the façade elements and of the integrated components.

1.4.4 Design Principles of Multifunctional Elements

Basics of Design Principles

The design principles for SmartTES construction are dependent from the task, the type and the size of components to be integrated in TES-elements. The other influence is the building itself, its condition, use, and flexibility to be transformed into a building as an integrated system with the overarching goal of a reduced energy demand and long life time (see book 5 sustainability).

The task relies on highly collaborative design which requires the know-how of a team of experts in design, engineering and technical equipment right from the beginning of the project.

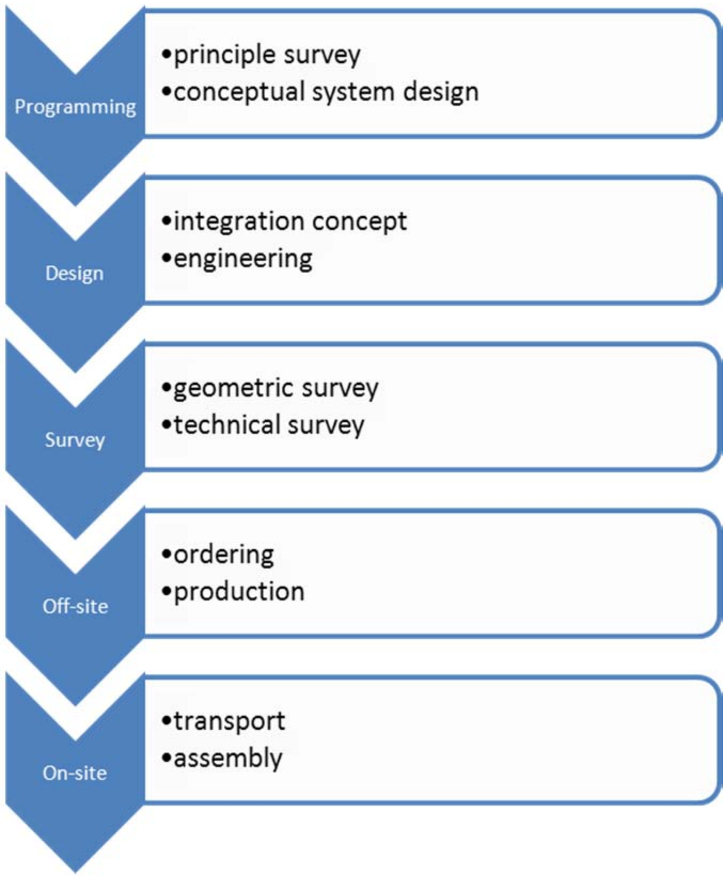


Figure 1-3 Process steps of a multifunctional SmartTES façade solution.

The individual principles are explained separately for each type of multifunctional *TES*. Additionally, there are requirements similar for all three types, the interfaces of the organisational framework (design and production process) and the geometrical connection with the existing building and its interior spaces.
The geometrically defined interfaces in planning have to be fulfilled during prefabrication and assembly to ensure the connection of technical components to interior spaces. This requirement is necessary as to ensure a high architectural quality of the interior space regardless of the integration of new equipment. For example the air inlets in living rooms have to be connected precisely to the ductwork on the exterior side of the wall within the *TES*-element. Therefore a precise survey and measurement of the height of existing floor slabs and the position of existing interior walls is the first step in planning multifunctional elements. All holes and openings through the existing exterior wall have to be put in place during planning and positioned precisely in prefabrication process.
Important milestones in the *TES* process must be considered carefully (planning, ordering, installation, transport and assembly). The protection of the integrated components during handling, transport and installation must be overseen carefully.

Table 1 Process milestones in a multifunctional TES refurbishment.

	TES-integrated	**TES-connected**	**TES-envelope**
Concept	Use of building Functionality Building as a system		
Survey	Exterior + Interior space	Exterior + Interior space	Only exterior envelope
Planning	Facilities dimension, connections, home automation, full building physics	connections, fire safety, sound protection	connections, home automation, fire safety, others depending on concept
Ordering	In-time, see planning	-	In-time, see planning
Production	Expertise, component protection	Expertise, component protection	Component protection
Transport	Element protection	Element protection	Element protection
Assembly	crane, positioning, see production, sound protection, airtightness, fire safety	see production, sound protection, fire safety	crane, see production
Interface TES / multifunctional component	airtightness, heat bridge prevention, decoupling, encapsulation and fire stops		

TES-integrated components

Components / dimension: Components and parts that are integrated in TES elements should as far as possible are compact and rectangular, for simple integration in the timber framework. The compartment depths depend on the required insulation thickness and start usually at 200 mm. The depth of the *TES* adaption layer can be added. It has a thickness of at least 30 mm. Components supply only small units due to their limits in size and power, e.g. an air micro heat pump integrated in facades has a limit of power of 1-2 kW that is only big enough for a small to medium sized apartment up to 75 square meters.

Building physics: An adequate amount of thermal insulation and heat-bridge-free installation of the integrated chassis must be ensured. A pragmatic solution for cold temperatures is a homogeneous insulation layer of approximately one-third of the total strength of the element. The insulation as well as a suitable cladding reduces the heat development of the devices during summer. The prevention of transmission of impact sound requires the decoupling of the component chassis from the timber framework. Fire and smoke transmission through the components must be avoided through fire stops or shutters, for further details see book 4 smart construction, chapter fire safety.

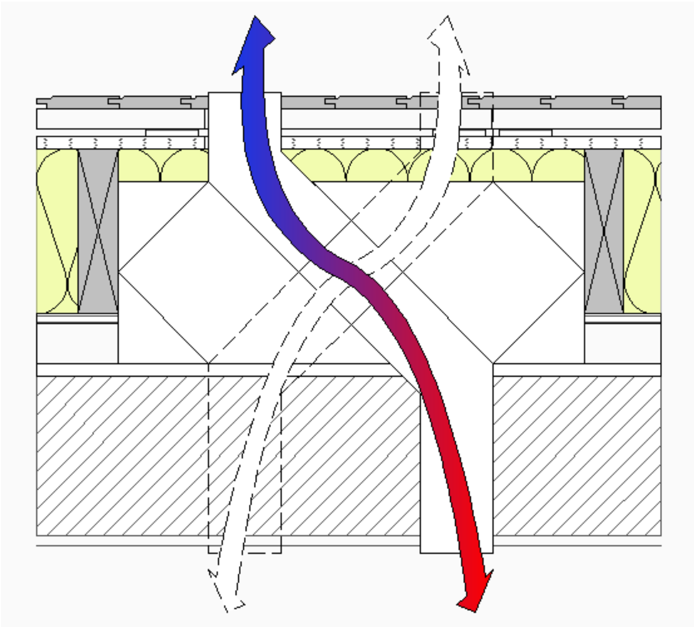


Figure 1-4 Horizontal section of TES-integrated systems. A continuous thermal insulation layer protects the chassis of devices.

Structural and constructive coincidence: The technical components are attached to the timber studs. Additional studs for fastening the technical components can be added as needed. Air tightening membranes and other the functional layers of *TES* elements must be connected to the component chassis.

Connecting cables: Connections of wires on the existing building through necessary holes in existing walls must be precisely measured. Decentralized installation of the facilities for individual apartments or units avoids additional routing.

Maintenance / repair / opening / appearance in façade: are taken into account in the planning. Maintenance intensive machines integrated in the building envelope and with regular filter replacement or similar should be accessible from the interior or easily accessible from exterior corridors, staircases, or balconies.

Photovoltaic modules are components, that can be integrated in the facade cladding or even partially or completely replace it due to their thin bodies. Photovoltaic modules release high heat loads during operation (up to 80 °C in summer) which must be removed through appropriate measures such as sufficient back side ventilation. Solar thermal panels have high thermal loads up to 120 °C running idle, particularly in the piping that must be insulated accordingly.

TES-connected devices

The conditions of the load-bearing structure and the constructive were already mentioned in the first *TES EnergyFacade* project. The routing system is described there as disconnected from *TES* elements and defined as a self-contained unit, which is located in its own shafts. This limitation is skipped in *smartTES* and necessary requirements to overcome the former concept are investigated. The advantage of the integration in elements can be clearly seen in the streamlining of processes and reduction of errors on site by higher levels of prefabrication. Hence on-site construction processes are limited in amount and duration. Components are better protected in the installed state, which improves e.g. the hygiene of ventilation ducts.

Ingredients: *TES*-elements are able to integrate and carry different routing installed within the TES, e.g. ventilation, water supply and sewage, electricity, communication.

Building physics: All media lines must be protected sufficiently against cold, they are equipped with an insulating layer of at least the thickness of the nominal diameter. An acoustic decoupling of the installations is necessary to avoid impact sound propagation. Connections to existing spaces must be airtight and insulated. Fire spread has to be limited to the area of use where the fire originates from. Routing of wires, pipes, and ductwork have to be insulated with non-combustible material.

Routing under fire safety considerations
Structure and jointing: The used parts or components are not heavy and can be integrated in the timber framework without additional effort. Connections are an important topic in *TES*-connected devices. The relation to the connections and interfaces are the most important topics in this type of elements. The positioning of the intake into the apartment is important in planning of multifunctional elements. They have to be fully solved from the design as well as the construction perspective.

Maintenance: Ventilation ductwork and sewage pipes are required to be equipped with openings for cleaning and repair.

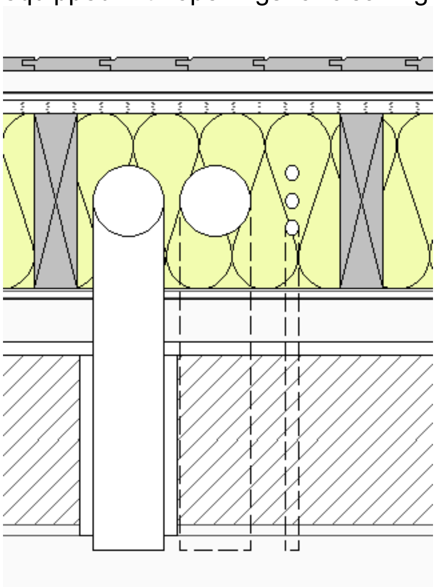


Figure 1-5 Principle image of horizontal section of TES-connected devices.

TES-envelope concepts

In *smartTES* the envelope concept of a passive heated building envelope is part of this research report. It is a new development of a responsive envelope and a result of the cooperation of the companies B&O Wohnungswirtschaft, Huber&Sohn and the University of Applied Sciences Rosenheim. The reverse flow of a solar thermal plant is used to heat up the exterior walls of a building. This is done by using thin heating pipes integrated to the back side of TES-facade elements, behind the insulation layer. A more detailed report of the passive heated building envelope is available in section 1.5.6.

The *active building envelope (abe)* and solar responsive façades like Gap-solution or Lucido® demonstrate the principles of different TES-envelope concepts. The abe façade principle is based on the ventilation of air through the open structure of porous materials into the unit of use. Air is sucked through a porous structure like insulation material made from compressed wood shavings. When air passes the insulation material, the heat; constantly brought into the micro-porous material through conduction, is exchanged with the constant airflow. Additional energy can be collected through using a transparent or -lucent cladding of the exterior side. The air sucked through the insulation is warmed up by solar heated insulation material. The climate-active facade supplies interior spaces with fresh, pre-heated air.

A solar responsive façade is using similar principles of the greenhouse effect behind glazing. The main feature of these façades is a self-shading material (surface) structure that avoids direct summer sunlight on the massive layer behind the self-shading front. This reduces the development of long wave radiation and heating of the insulation material during summer time. In winter mode, the surface structure of both façades allows sun light to go through and generate long wave radiation and heat up the insulation layer. The solar gains reduce the required thickness of the thermal insulation material.

Each of the TES-envelope concepts is very individual with solutions to provide the responsiveness. Hence the design principles cannot be generalized for them. The functionality and exemplary principles for the passive heated building envelope will be shown in chapter 1.5.6.

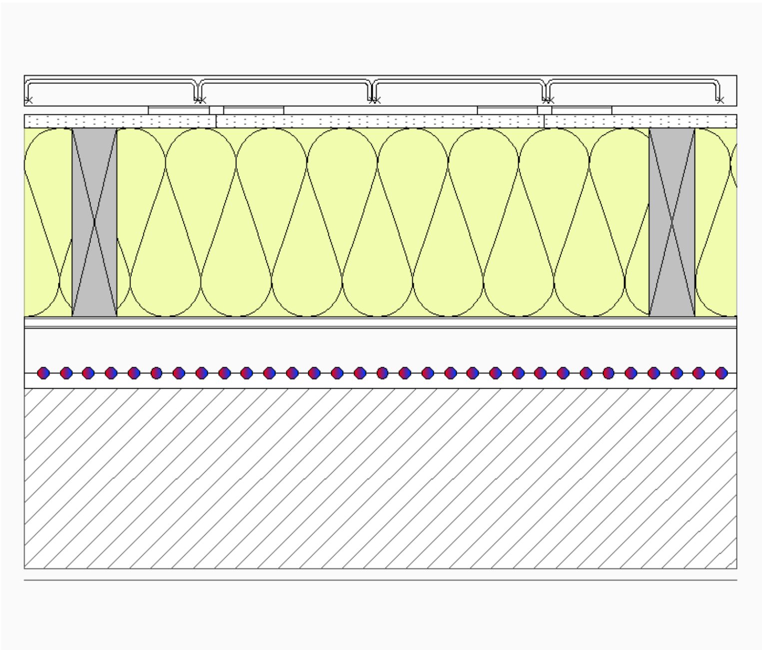
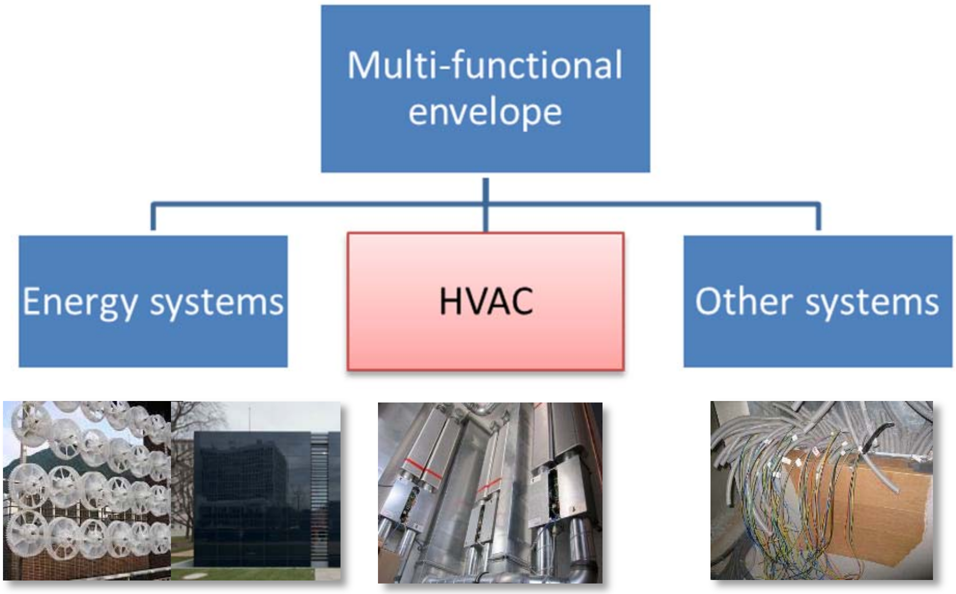


Figure 1-6 An exemplary horizontal section of a TES-envelope concept with passive heated building envelope.

1.5 Principles HVAC in existing dwellings overview (S.Ott)

Preconditions and problem description
Starting with a state of the art research an overview about the complex topic of fresh air supply and ventilation in existing dwellings is given. Focus of this chapter is on heating, ventilation and air conditioning (HVAC) concepts which can be used in *TES*-integrated or in *TES*-connected elements. Available concept and technical devices on the market or recent developments will be highlighted. New developed concepts and systems for *smartTES* multifunctional envelopes are shown in the subsequent chapter.



1.5.1 Scope of Ventilation Refurbishment or Upgrade

The presented HVAC concepts are designed for residential buildings. Dwellings have a need for a new or renewed and energy efficient ventilation system. In order to avoid high impacts on the interiors it is beneficial to utilize the possibility to integrate new ventilation systems or ducts into the new façade layer. Structural interventions and rearrangement of floor plans might not be necessary. The residents are confronted with less disturbance of living and may not even have to leave their home during the refurbishment.

1.5.2 Fresh air supply and ventilation in existing dwellings

First considerations deal with the situation of ventilation in existing and the question of indoor air quality in refurbished residential housing.

Finnish situation:
In Finland, natural gravity based ventilation was used until the 1960´s, but mechanical exhaust air systems have been installed since the mid 1950´s. The mechanical exhaust air system with a common exhaust air duct is the most usual air ventilation system of Finnish concrete element apartment buildings. Incoming fresh air is obtained through the building facade i.e. through holes in the sealing of windows or doors. When renewing or installing

new air ventilation systems, the existing exhaust air ducts can be used as a basis for renovation works [13].

Norwegian situation:
In Norway, natural gravity based ventilation was used until the 1970's, but mechanical exhaust air systems have been installed since 1960's. The most common solution until the 1980's is a common exhaust air duct in apartment buildings with incoming fresh air through the building façade. The existing exhaust air ducts is normally available for further use when renewing the air ventilation system.

German situation:
Mechanical ventilation – apart from exhaust air for interior rooms without natural ventilation – is not very common in the German building stock from the 1950´s to the 1980´s. Most of these existing exhaust air systems only demand minimal infrastructure with a single exhaust air pipe running vertically through each apartment. Big shares of them are gravity systems without any mechanical equipment. This condition brings severe technical and functional problems for existing buildings. Shafts are not always available at all. The internal routing in apartments is often limited due to low ceiling heights.
These buildings can be improved due to comfort and energy efficiency reasons with a mechanical ventilation system with supply and exhaust air combined with a high efficient heat recovery system.

Energy efficiency concepts increase the airtightness of the building envelope and its components, including the window, as to minimize heat losses. The principle solution to minimize the heat loss of the exhaust air is mechanical ventilation with efficient heat recovery unit (HRU). The air handling unit directs the supply and exhaust air flows through a heat exchanger and recovers up to 80% or higher of the heat energy from the warm exhaust air.

Improvement of IAQ
Indoor Air Quality (IAQ) is a prioritized topic in modern and refurbished buildings. The improved airtightness of the building envelope can lead to a higher concentration of air pollutants in the living areas and can cause discomfort, due to insufficient air exchange.
H armful or allergenic substances from different sources like material emissions, or e.g. volatile organic compounds (VOC) can be reduced by improved air exchange.
The most common indicator for a health risk of indoor air is the concentration of carbon dioxide (CO2) in the air, measured in parts per million (ppm). The findings on the CO2 content of the ambient air and the physiological effects, as well as the still valid limits for concentration in indoor air are defined by Pettenkofer [14]. The carbon dioxide is not only an indicator, there are also health effects such as fatigue, attention deficit disorder or reactive fault.

In principle, all odors of substances in the indoor air, indicate increased loads or concentrations which may be associated with harmful emissions. Other adverse effects of indoor air come from the fore mentioned VOCs, formaldehyde, etc. The Federal Environmental Agency in Germany (UBA) published guidelines for indoor air quality on its website [15]. The measurements of indoor air quality are carried out according to DIN ISO 16000-28 [16]. Finnish requirements for indoor air quality including concentration limits for several substances can be found in our building regulations, part D2 (2012). The Norwegian requirement for indoor air quality in apartments include a lower limit of fresh air supply of 1,2 m3/h per m2 floor area in occupied rooms.

Indoor relative humidity
The relative humidity of the ambient air is ideally set, from a physiologic health perspective, between 45 – 50 %, it should not be less than 40 % and not exceed 70 %. according to DIN EN 13779 and prEN 15251 [17], [18]. In Finnish building regulations the humidity level should be appropriate according to the use of the space (D2). At a room temperature of 20 °C the maximum moisture uptake capacity of the air is water vapour of approximately 17.5 grams.) Too high humidity levels mean a physiological deterioration of the living environment and increase the risk of the failure due to condensation. Technical issues as the lack of insulation to the exterior or thermal bridges lead to moisture damage in parts at low ambient temperatures. For this, the technical quality of the building envelope is crucial. To prevent mould growth, the temperature coefficient must in any case respect that $f_{Rsi} < 0.7$. The current thermal safety standards avoid moisture damage for the outer shell due to technical faults. Instead damage is caused by incorrect residential behaviour
Damage sensitivity of constructions can be related to high humidity levels.
On the basis of the following parameters the risk of moisture damage increases:

- residents behaviour (moisture production) → is constant
- user behaviour related to ventilation (moisture dissipation) → does not change (traditional behaviour)
- sorption of surfaces (moisture buffering) → can be changed (painting)
- indoor temperature → stable
- outdoor temperature → no influence = climate dependent
- outdoor air humidity → no influence also climate dependent.
- technical properties of the envelope (airtightness, heat brigdes) → solved by SmartTES

SmartTES can influence a construction related parameter which is critical for mould growth in the construction. The responsibility for the production of humidity is mainly on the side of the users. The outdoor conditions have an influence as well. High humidity levels can be dealt with sufficient ventilation.

Risk of different refurbishment scenarios with a focus on the ventilation:

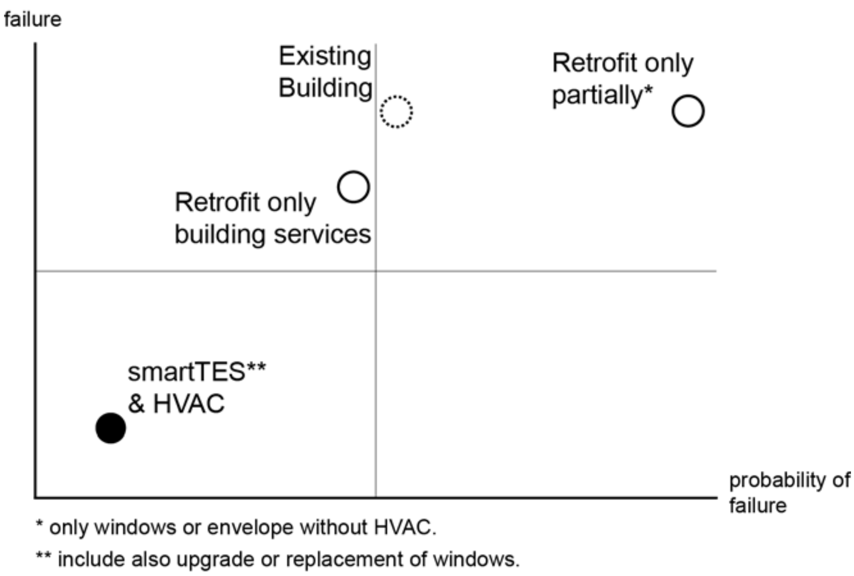


Figure 1-7 Risk of failure of the retrofit action regarding to mould and moisture in building (SO).

The risk of moisture damage after a refurbishment is shown in Figure 1-7. Namely the probability of damage depending on the extent of the damage (severe of damage) is qualitatively pointed out for several refurbishment scenarios. While different modernisation / restructuring scenarios can occur a reaction to the probability of moisture and mould damage is required. The causes of the damage can be due in unresolved constructive technical problems (thermal bridges).

1.5.3 Natural Ventilation

Modernised buildings have improved airtightness requirements and thus infiltration is minimized. Therefore, a change in user behaviour concerning the ventilation is necessary in the case of naturally ventilated buildings. Otherwise a necessary air exchange has to be solved with other ventilation concepts. E.g. a mechanical ventilation system can be retrofitted, or a controlled air flow through constant openings in window frames ensure a minimum air exchange.

Free Flow Ventilation

Natural ventilation of apartments calls for a repeat airing for sufficient moisture dissipation. The free ventilation requires a total opening of the window. Then an air flow must be ensured, which is made possible by the additional opening of a window opposite the first one, compare to cross-ventilation in Figure 1-9. An air flow is possible also with a single window fully opened. It is less effective than the cross ventilation and needs time until the fresh cold air is warmed and the exhausted warm air has escaped. However, thus obtainable moisture removal in the example maximum is between 1,700 and 1,300 g, according to [19]. An exemplary 90 m^2 apartment with four residents would have to be ventilated by airing daily at least 7 to 12 times. This is usually unrealistic; therefore, alternative ventilation concepts need to be considered.

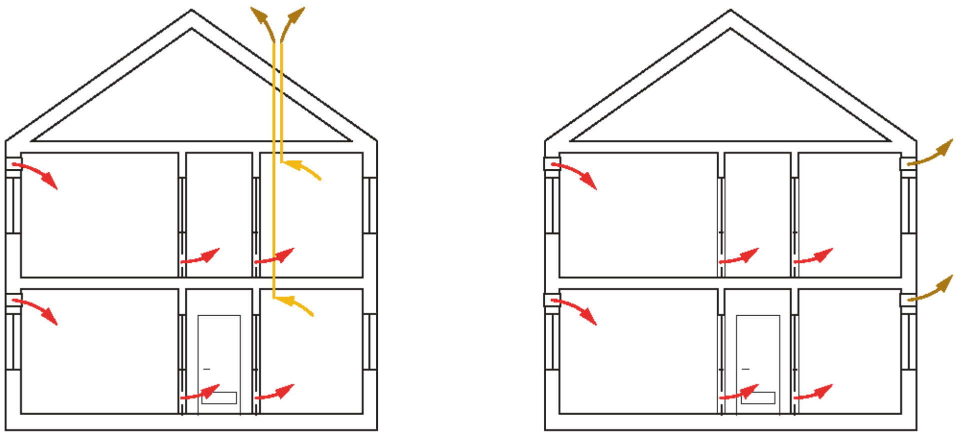


Figure 1-8 Natural ventilation concepts. Natural exhaust to the left and cross ventilation to the right [according to DIN 1946].

Natural Exhaust Ventilation

This type of natural exhaust ventilation is also called a gravity system. The duct exhausts the air by natural flow induced by different density of warm and cold air. It uses the fresh air intake from windows and combines it with a vertical central duct placed mainly in inner bathrooms etc. If no window is available openings for air cross flow are necessary either in doors or in walls. These ducts are limited in size and capacity and heat energy in warm exhaust air is lost. The benefit from these existing systems will be the reuse of the existing shafts located in the exhaust air rooms like bathrooms or kitchens. They can be integrated in holistic solutions with supply air over the *TES* envelope.

1.5.4 Mechanical Ventilation Concepts

Mechanical ventilation requires a dedicated ductwork and mechanical facilities. Both are not always available in existing buildings. Thus a deep retrofit action is a possibility to fulfill such requirements and along with the integration of considerable parts in the *smartTES* building envelope. Positive effects include minimized interventions in constructions and minimized disturbance of residents. Besides the natural ventilation types different mechanical ventilation solutions are shown in Figure 1-9.

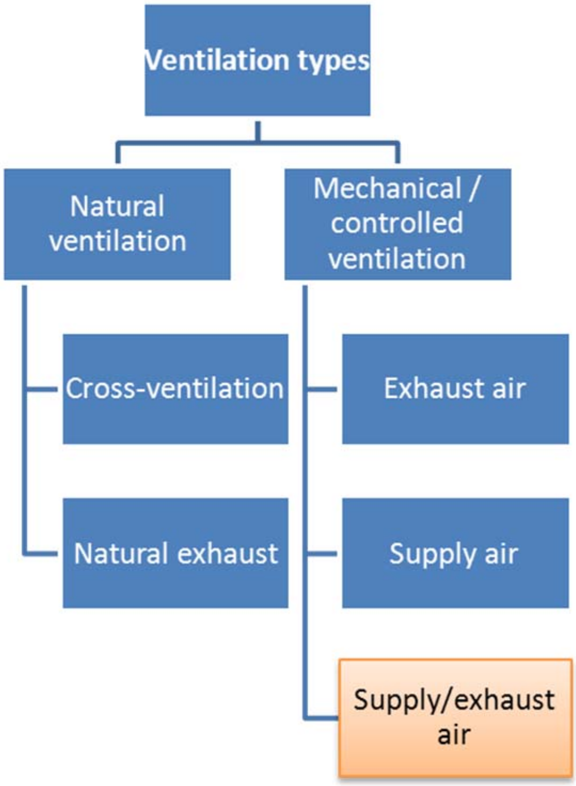


Figure 1-9 Various types of ventilation.

Controlled Gap or Exhaust Air Ventilation
The controlled gap ventilation is an example of enhanced natural ventilation concepts. The enhancement consists of an exhaust air fan and an air inlet in the exterior wall. Thus it is a modified type of natural ventilation and within the typology of ventilation belongs under controlled types. The gap ventilation consists of a (controllable) air inlet opening, which is integrated in the frame or in the fold of the sash of a window. By definition, it is mechanically improved natural ventilation but still not a comfort version. Implementation of this concept is associated with a substantive effort and has annual operating and maintenance costs. The advantage lies in a controlled air exchange and the ability to minimize the ventilation losses via a built-in heat exchanger.

Defined minimum air exchange according to German regulation e.g. in residential buildings is a minimum exchange rate of n_{50} = 0.4 according to DIN 1946-6 and DIN V 18599 for residential buildings with ventilation systems [20], [21]. Minimum requirement for Finnish residential spaces is 0.5 l/h according to national building regulations.

1.5.5 Centralized vs. decentralized concepts overview

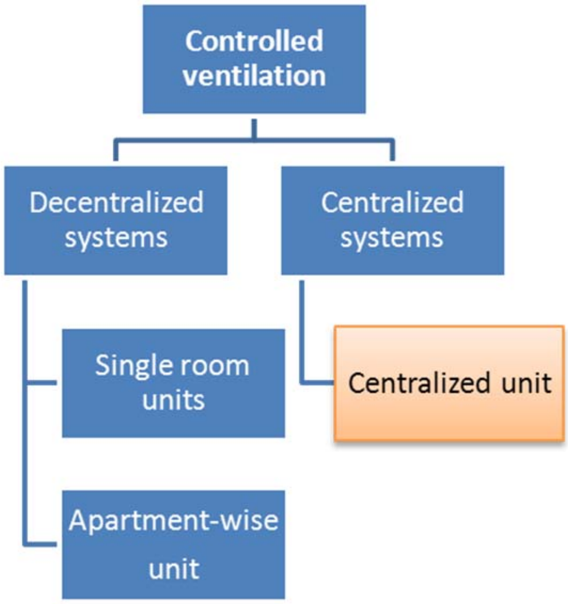


Figure 1-10 Concepts of controlled ventilation.

Decentralized ventilation concepts

Decentralized concepts are characterized by decentralized ventilation delivered by multiple air handling units. This means i.e. each apartment has an own air handling unit. It can be divided down to a room-wise supply with individual micro-AHUs, see Figure 1-11 (left).

The concept of decentralized façade AHU exists already for offices since the 1990s. In residential housing such decentralized systems are still uncommon. Although in recent years their market share has grown, especially in the retrofit market, because micro-AHU are small enough and independent to be used in existing buildings. These systems utilize compact units and technical facilities. The units contain everything from fresh air supply to heating (HRU and electrical heater), air conditioning & cooling.

Possible uses and advantages of using micro-AHU solutions in connection to a SmartTES refurbishment:

- Integration in curtain wall façade systems
- Integration in non-loadbearing walls
- Integration in suspended ceilings
- Integration in hollow floor systems.

Exemplary disadvantages of micro-AHU solutions:

- material input for each AHU,
- individual energy supply, increase technical effort,
-
- reduced efficiency in energy consumption,
- multiplied need for maintenance and repairs.

Apartment wise decentralized units do not have all these disadvantages although the problem of multiplied maintenance and energy consumption and supply networks still remains.

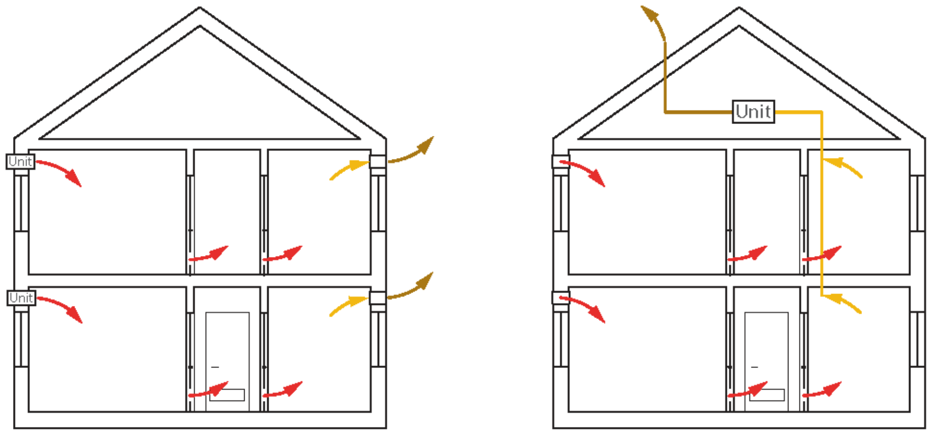


Figure 1-11 Exemplary mechanical ventilation concepts: A decentralized apartment wise system to the left , a concept based on a centralized system to the right [according to DIN 1946].

Centralized ventilation concepts

Centralized ventilation concepts are characterized by a common, single air handling unit which provides multiple apartments. This is possible as either a staircase-wise solution or by using one single unit for the entire building. See Figure 1-12.

Such systems allow centralized services and:

- reduce material input,
- have centralized maintenance and air quality control
- separation of ductwork and AHU enables later retrofit.

These centralized systems have also disavantages, such as:

- less efficiency in heat recovery
- a lack of individual control,
- high volume rates and there high energy consumption.

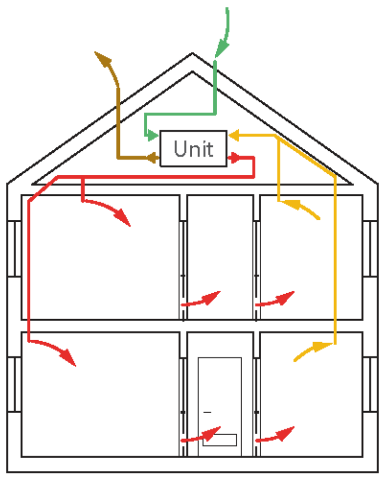


Figure 1-12 A generic example of a centralized ventilation concept with supply and exhaust air ducts [DIN 1946].

One new development is the semi-central system by *smartTES* partner Drexel&Weiss from Wolfurt, Austria. This system is based on a modular and central AHU with following individual ducts for each unit. Each pair of supply and exhaust duct has a flow rate control unit the so called v-box [22]. The v-boxes are not necessarily placed in apartments as shown in Figure 1-13. They can be connected directly after the AHU. A semi-central system allows for:

- an individual air supply by using variable flow rates,
- AHU fan power is in dependency from demanded flow rates,
- higher energy efficiency,
- allows a centralized maintenance and air quality control.

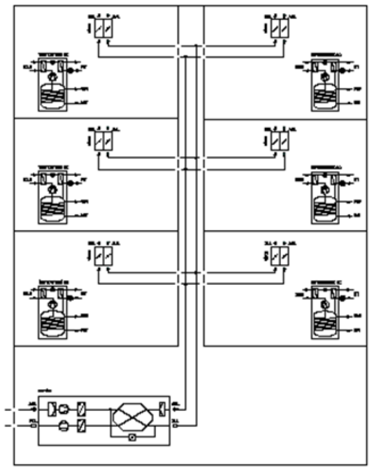


Figure 1-13 Scheme of a semi-central HVAC and domestic hot water (DHW) supply for residential houses [Drexel&Weiss].

By the variable flow rate and the individual air supply of apartments the dimensions of ducts and systems is reduced compared to central systems with common air supply and constant flow rates. The central AHU and the volume control valves can be placed on roof-top and do not have to be integrated in *TES* elements. Flexibility in future retrofit is a benefit of all centralized concepts and enabled by the integration of ductwork in *smartTES* and the separation of the AHU which has a much shorter service life.

1.5.6 Optimized integration concept in TES elements

The decision matrix is used for determining the most influential factors on the concept of multifunctional envelopes using *smartTES* elements with integrated bss. When retrofitting mechanical ventilation in residential buildings inclusion in the envelope is beneficial according to the analyses of existing situations.
Existing buildings demonstrate complex situations when retrofitting ventilation systems. It is more difficult for building services concepts to react on the as-built situation compared to new building, where it is designed in a collaborative way. With bss integrated in the envelope there is a higher flexibility in the development of sustainable solutions. Nevertheless there are restrictions caused by many parameters. Parameters are on different levels of detail. The conceptual level looks at the entire building. On the façade system level solutions are searched for the proper integration in *TES* elements. The criterion list consists of ventilation concept related parameters on the building level. On the system level of *TES* technical, functional and structural requirements set additional parameters. The parameter list is shown in Figure 1-14.

Option	Short name	Parameter description
A	element type	standard construction / composition type of TES element
B	central unit	enough and appropriate space for central unit
C	Vertical routing	simple routing with short length and no crossings
D	connection existing	reuse existing ventilation installations
E	maintenance	minimize maintenance cost, e.g. easy cleaning
F	fresh air supply	fresh air supply without effort
G	fire safety	cost-optimised, fire safe solution acc. rules
H	attic floor	enable attic floors, intervent in attic floors, location of central unit
I	extension	enable extensions
J	variable air flow	Enable technical concept in MF envelope
K	large dwelling	suitability for large dwelling (5 floors plus)
L	ventilation concept	preference of ventilation concept, e.g. decentralized, centralized
M	pipe section	minimize pipe section
N	heat bridge	minimize heat bridge
O	shafts	reuse existing shafts
P	bath retrofit	integrate bathroom retrofit
Q	energy demand	minimize energy demand of facilities
R	investment	cost-optimised investment

Figure 1-14 Criteria list for centralized ventilation concept.

Description of each criterion:

A The façade element type is based on a standardized layer composition, detailing, and jointing.
B The central unit of the HVAC system can be integrated with minimal spatial requirements or can be located on the roof top. No living space is used.
C The vertical routing is simple, with direct connections and shortest pipe length.
D Existing and new HVAC systems can be connected and old routing be reused.
E Maintenance is minimized in effort and costs. Disturbance of tenants is minimized due to long maintenance cycles and efficient maintenance procedures as well as optimal location of the maintenance openings.
F Direct fresh air supply of central unit or minimized routing.
G Fire safety is cost-efficient with a limited amount of shutters but encapsulated shafts or insulation according to regulation.
H Attic floors have to be incorporated in the HVAC solution. Different systems in parallel are difficult. Positioning of central unit in attic floor.
I (Horizontal) Extension of floor space should be possible with the centralized HVAC concept.
J Variable air flow is necessary for efficient and demand regulated HVAC units.

K Large dwellings (> 5 floors) should be provided with centralized HVAC.
L The preferred HVAC solution is based on a centralized concept.
M Pipe sections have to be minimized to avoid collisions.
N Heat bridges have to be minimized to avoid condensation.
O Existing shafts or unused chimneys are reused for the concept.
P Combination of centralized HVAC with bathroom retrofit concept.
Q Efficient HVAC components and energy savings with efficient heat recovery.
R Investment has to be cost-optimized. (Investment divided by energy savings per year = payback time)

Constant and variable parameters
Construction related parameters have to be set as constant. They cannot be changed otherwise the construction principles of the system would be changed. Additionally, there are variable parameters that are HVAC related like H (attic floor space) and L (ventilation concept), see Table 1-1. The HVAC parameters duct dimension and main direction of routing influence the construction of elements as well.

Table 1-1 Constant and variable (red) parameters which are critical according to figure 7.

A	Construction concept of TES balloon frame, linked with G, M, N
C	Vertical element
G	See A
H	Attic floor
J	Individual ducts & variable air flow rate is set as a requirement for SoA technology
L	Ventilation concept
M	Duct cross section, see A
N	Heat bridge, see A

Decision matrix
The decision matrix is a tool to evaluate the strength of the influence of different parameters on each other, see Figure 1-15. In the first round only a few assumptions are defined. Constraints are set to the evaluation of the parameters:

- TES-integrated or TES-connected solution
- Functional type of building is residential
- Mechanical ventilation system with a centralized AHU
- Controlled (mechanical) air supply and exhaust of apartments
- Variable volume flow rate is required.

These assumptions influence directly the parameters A, C, G, J, M, N and set them to fixed. This is necessary to implement compliance with the assumptions.

Option	Desciption	A element type	B central unit	C routing	D connection existing	E maintenance	F fresh air supply	G fire safety	H attic floor	I extension	J variable air flow	K large dwelling	L ventilation concept	M pipe section	N heat bridge	O shafts	P bath retrofit	Q energy demand	R investment	Goals / Objectives
A	element type		A, 0	A, 3	A, 1	A, 1	F, 0	A, 2	A, 0	A, 0	A, 1	K, 1	L, 2	M, 3	N, 1	A, 0	P, 1	A, 0	R, 3	standard type of TES element
B	central unit			C, 2	D, 1	E, 1	F, 0	G, 2	H, 1	I, 1	J, 1	M, 0	B, 1	M, 1	N, 1	O, 1	P, 1	Q, 2	R, 1	enough and appropriate space for central unit
C	routing				C, 2	C, 1	C, 1	G, 1	H, 1	C, 1	C, 1	C, 0	C, 0	M, 2	C, 1	C, 1	C, 1	C, 1	C, 1	simple routing with short length and no crossings
D	connection existing					E, 1	F, 1	G, 1	H, 1	I, 1	J, 1	K, 0	L, 1	M, 1	N, 2	O, 1	P, 1	Q, 1	R, 1	reuse existing ventilation installations
E	maintenance						E, 0	G, 1	H, 1	I, 1	J, 0	E, 1	L, 1	M, 1	N, 1	E, 1	P, 1	Q, 1	E, 2	minimize maintenance cost, e.g. easy cleaning
F	fresh air supply							F, 0	H, 1	I, 1	E, 1	K, 1	L, 1	M, 1	N, 1	F, 1	F, 0	Q, 1	R, 1	fresh air supply without effort
G	fire safety								G, 1	G, 1	G, 1	G, 2	G, 1	G, 1	G, 1	G, 1	G, 1	G, 1	R, 1	cost-optimised, fire safe solution acc. rules
H	attic floor									H, 0	H, 1	H, 0	L, 0	M, 1	N, 0	H, 1	P, 1	H, 1	H, 1	enable attic floors
I	extension										H, 1	H, 0	L, 1	M, 2	N, 2	H, 2	P, 2	H, 1	H, 1	enable extensions
J	variable air flow											J, 1	J, 0	J, 1	N, 1	J, 1	P, 1	Q, 1	R, 1	enable this technical concept
K	large dwelling												L, 2	K, 2	K, 0	K, 0	K, 0	Q, 1	R, 2	suitability for large dwelling (5 floors plus)
L	ventilation concept													L, 1	L, 0	L, 2	L, 0	L, 2	L, 3	preference of ventilation concept, e.g. decentralized
M	pipe section														M, 3	M, 1	P, 0	M, 1	M, 0	minimize pipe section
N	heat bridge															N, 0	N, 0	N, 1	N, 0	minimize heat bridge
O	shafts																O, 1	Q, 2	R, 1	reuse existing shafts
P	bath retrofit																	Q, 1	R, 1	integrate bathroom retrofit
Q	energy demand																		Q, 3	minimize energy demand of facilities
R	investment																			cost-optimised investment

Figure 1-15 Problem matrix, 0=neutral, 1-3=level of influence of the dominant criteria.

The result of the decision matrix is the sum of each parameter and shown in Figure 1-16. The score of influences is colored in results table in order to highlight the critical parameters. In consequence the parameter with the highest score has the highest interdependency with other parameters and has to be taken into consideration very carefully. Otherwise probability of conflicts in further development will increase.

Option	Weighted score	
A	8	5,80%
B	1	0,72%
C	13	9,42%
D	1	0,72%
E	7	5,07%
F	0	0,00%
G	2	1,45%
H	14	10,14%
I	4	2,90%
J	5	3,62%
K	4	2,90%
L	16	11,59%
M	17	12,32%
N	10	7,25%
O	3	2,17%
P	8	5,80%
Q	13	9,42%
R	12	8,70%

Figure 1-16 Scoring of comparison results. Dominating criteria are highlighted in red and orange color.

The first evaluation shows a strong influence of criteria C,H,L,M,N on the entire building and the detailing of *smartTES* with assumed *TES*-connected devices. The remaining parameters are variable or optional in the decision making process with regard to a multifunctional *smartTES* façade. They influence the costs and are variable, but they are not critical to the *smartTES* system itself.

Retrofit process

The cost for the planning and execution of a multifunctional building envelope is higher as compared to only insulating the building with TES elements. There are higher costs to do the initial and the detailed survey also on a geometric basis because both are necessary to prepare off-site production. The interior must be measured exactly to optimally integrate the ventilation in the architecture. The planning includes more steps and needs to be coordinated. The preparatory work in timber construction is more complex. The production must learn to deal with external components and materials. During assembly, much more connections of home automation are to perform. In pilot *TES EnergyFacade* projects only some electrical wires are implemented for e.g. roller shutters. Further craftsmanship for all technical devices is needed. On-site a further work force is needed to do demolition works. The scope of the renovation is a deep retrofit and brings the existing buildings in the vicinity of the new standards. Therefore this type of rehabilitation may not be compared to a brush renovation or simple additional insulation of the facade.

1.6 Concepts SmartTES HVAC (A. Homb)

Integration with the existing building services

Useful solutions for existing buildings
Installation of an HVAC system in an existing building may be solved in different ways. It will of course depend very much on the type of building and if one or more vertical shafts are available in the existing building. For these buildings, small to medium vertical shafts normally exist, usable for at least the outlet air of a modernized HVAC system. The *smartTES* element offers space for installing pipes for, for instance the inlet air. Further evaluation and work presented in this report is based on a new HVAC system with inlet pipes in the *smartTES* elements and outlet air in an existing shaft except the individual installation concept.

1.6.1 Individual installations

The individual installation concept is based on one installation per flat (residential building). A principal drawing of installations in three flats is presented in Figure 1-17.

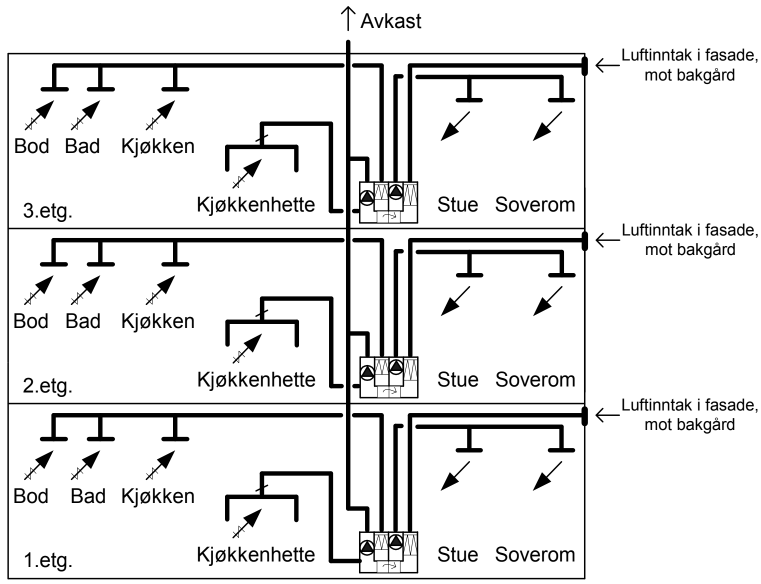


Figure 1-17 Principal drawing of a concept with individual installation of HVAC units and pipes

In this case, an individual aggregate has to be positioned in the flat. It needs space itself and of course necessary possibilities of inlet and outlet pipes from that position. Other disadvantages with this concept is that the local unit may give noise and vibration disturbances in the flat. But it is possible to make specifications ahead of an order with respect to noise and vibration properties. It is also not possible to get air inlet through the exterior wall. The *smartTES* element can of course be used in such cases for a vertical air inlet or outlet. For other cases the *smartTES* element will be free from prefabricated HVAC installations. Other possible disadvantages with this concept are the need for entrance to the unit for maintenance, and who takes care of the maintenance?

Individual installations have also advantages, for instance individual regulation of flow and temperature, and the air supply will not be affected by neighbor flats.

1.6.2 One installation per staircase

The concept with one installation per staircase is based on one central unit per vertical shaft, relevant for both school buildings and residential buildings. A principal drawing of an installation is presented in Figure 1-18.

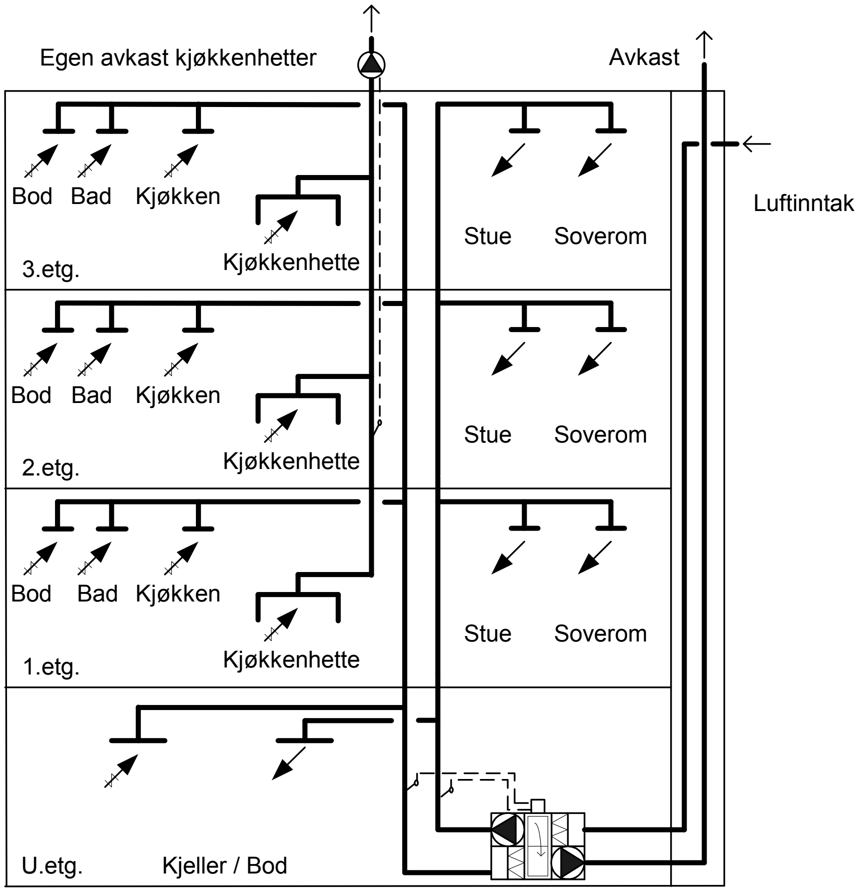


Figure 1-18 Principal drawing of a concept with one installation per staircase

In the figure, the central unit is positioned in the basement, but a position at the attic or roof is probably more common. The solution makes it possible to choose favorable positions for the inlet air, and it is often easy to get entrance to the system for maintenance. Other advantages with this concept are also a possibility of common and more professional organizing of the maintenance. It is also possible to ventilate common areas and save energy with air extract to for instance garages. Energy efficient products are available, and it is possible to compare specifications.

Disadvantages with this concept are the need for shaft for the pipes, and for some cases the space for the central units. If an existing shaft can be used for the outlet air, the *smartTES* element offers sufficient space for the air inlet pipes. Noise disturbances in the flats from the main unit may be a problem in addition to possible noise transfer between the flats, i.e. inlet/outlet device connected to the common main pipe. See book 4 for more information and tools regarding these challenges. Common main pipe may also cause transfer of odor/smell between the flats. With this concept there are also challenges regarding the necessity of central regulation of flow and temperature.

1.6.3 Central unit per building

The concept with one installation per block or building is based on several shafts coupled to one central unit. This solution is also relevant for many school buildings and residential buildings. A principal drawing of an installation is presented in Figure 1-19.

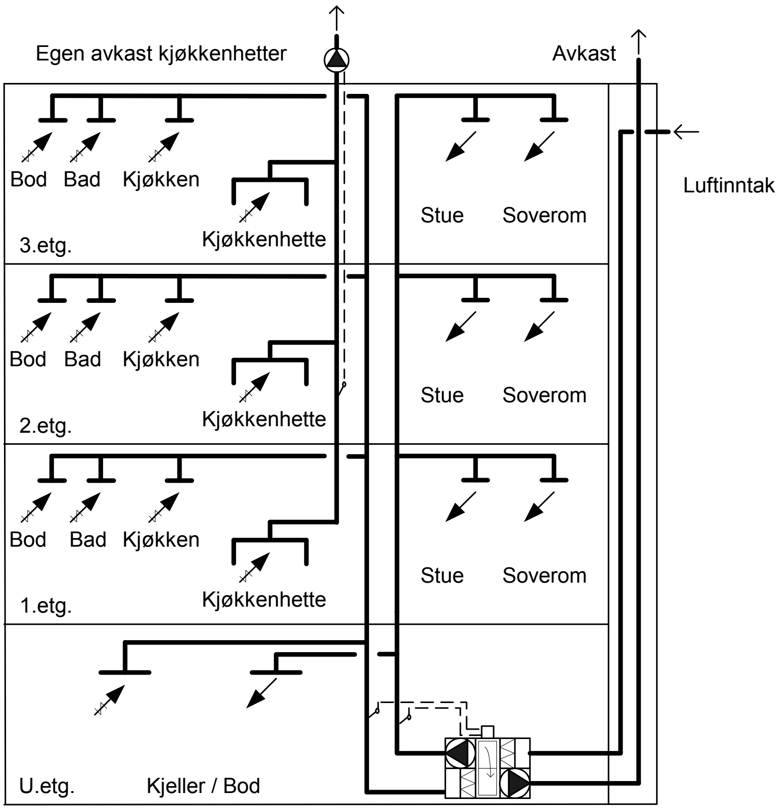


Figure 1-19 Principal drawing of a concept with one central unit per block or building

In the figure, the central unit is positioned in the basement, but a position at the attic or roof is probably more common. The advantages with this concept are much the same as the concept with one unit per vertical shaft, see chapter 5.6.2. But in this case it will be fewer installations to maintain.

The disadvantages with this concept are also much the same as the concept with one vertical unit per vertical shaft, see chapter 5.6.2. In addition, this solution will give more severe consequences for the ventilated areas if long time stop of the unit.

1.6.4 Example and evaluation

SINTEF Building & Infrastructure have contributed on several projects with upgrade of HVAC system in existing buildings, for instance three projects concerning individual installations and two projects concerning common units for one building or one vertical shaft. But so far, the SmartTES element concept has not been used for installation of new pipes. below shows a plan of one floor in a building with outlet air pipes colored red.

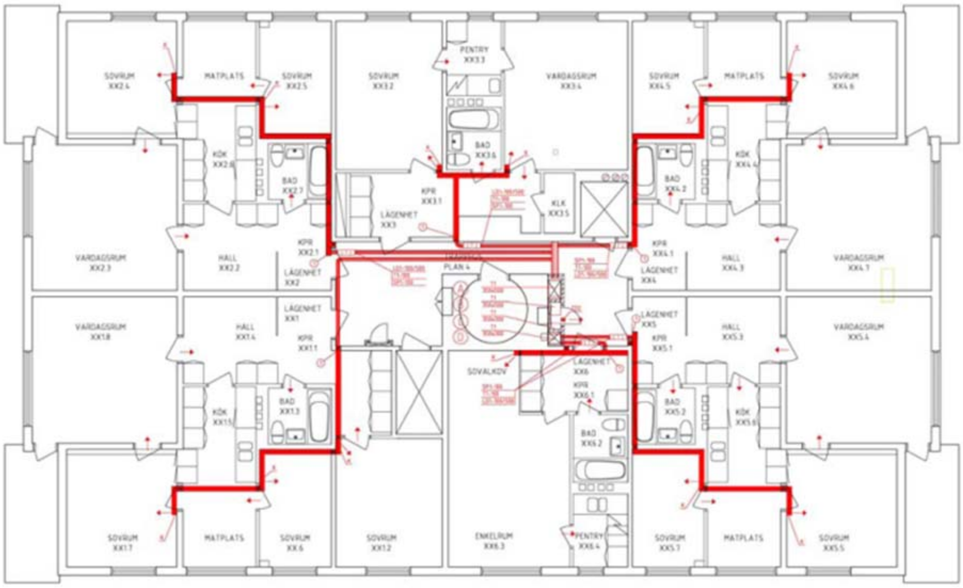


Figure 1-20 Example: Upgrade of a building with one central unit and outlet pipes colored red

In table 2 below, we present an evaluation of the different concepts with respect to type of installation and some essential properties.

Table 1-2 Evaluation of the presented concepts for HVAC upgrade of residential buildings and school buildings

Property	Individual installation	One unit per vertical shaft or per building
Air inlet position	Challenge	Preferable
Inlet transfer ducts	From SmartTES façade directly to flat	Inside new SmartTES Elements or through old garbage chute 2)
Duct positions in the flat/section	Challenge	Challenge
Air extract 1)	Existing	Existing
Kitchen air extract	Easy	Recycling device or challenge
Noise	Focus on unit, position and duct damping	Focus on central unit and transmission between flats
1) Assuming that a shaft is available for the air outlet 2) Highly insulated ducts are necessary		

Final evaluation and choice of concept has to be done for each project separately especially because it will be dependent on the available space and maintenance priorities.

1.7 Mounting smartTES HVAC (A.Homb)

The mounting of *smartTES* elements on existing buildings may be solved in different ways. For elements with HVAC ducts integrated, some more issues have to be taken into account. There will always be a need of ducts in vertical direction from the unit in the basement or at the attic/roof. Depending on the organizing of the duct installations, horizontal ducts may also been integrated into the elements. In the planning process it is also possible to choose between vertical elements, horizontal elements or a combination. A number of alternatives are therefore possible, but in practice the alternatives are limited when we integrate HVAC ducts, see chapter 5.6.1 to 5.6.4.

1.7.1 Vertical element with pipes

For the upgrading of residential buildings, it is strongly recommended to have separate ducts from the main unit to each apartment. It is therefore possible with a vertical element containing ducts for all apartments above each other Figure 1-21. The element may be in one piece if the number of floors is limited to three or four. An example of this is presented in. In this case it is necessary with a horizontal distribution of the ducts inside the apartments. An advantage with this is a limited number of duct connections between the prefabricated element and existing wall and only one hole in the existing wall for each floor. A possible solution of this is presented in chapter 5.7.4.

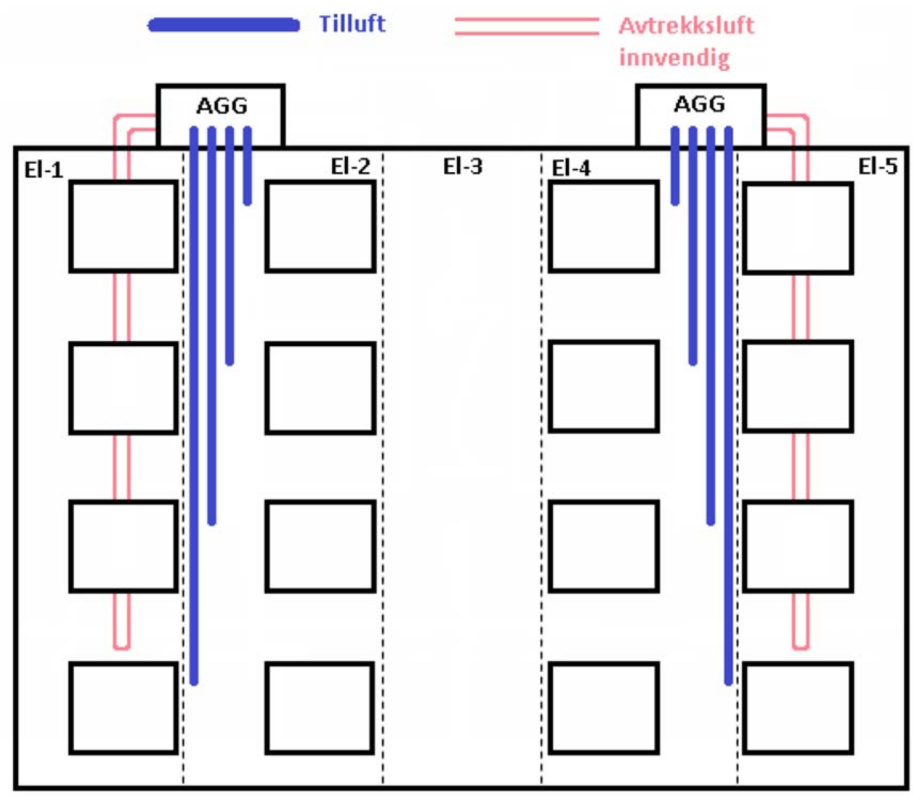


Figure 1-21 Principal solution of vertical elements with HVAC ducts integrated for the air inlet

If the building is higher, it is probably necessary to have more than one vertical element. An additional challenge to be solved then is the connection in the mounting phase between the duct from the lower and upper element.

1.7.2 Horizontal element with pipes

If only horizontal elements are planned, it will be very complicated to have separate ducts for each floor, because of the necessity of a vertical pipe to the main unit. An example of a solution with common vertical ducts is presented in Figure 1-22. To prevent sound transmission between apartments through the ducts, silencers must be placed in the channel system at each floor. High damping is necessary which means a thickness space of the silencers of at least twice the duct diameter and an increased pressure loss of the HVAC system. Such solutions are therefore difficult in practice.

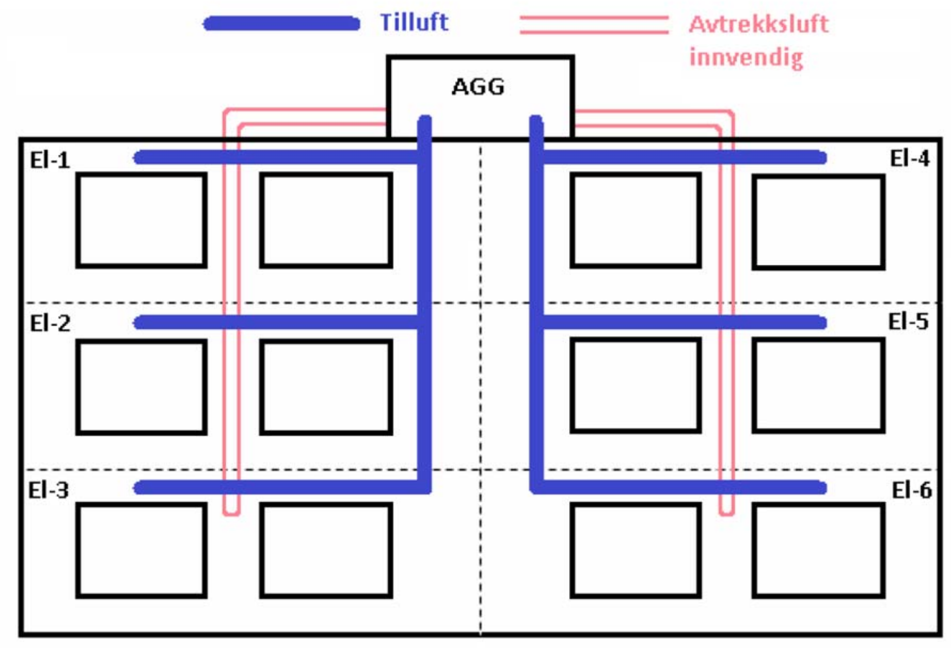


Figure 1-22 Principal solution of horizontal elements with HVAC ducts integrated for the air inlet

Another challenge is also the connection of the vertical ducts between the horizontal elements in the mounting phase. An advantage with the solution is that it is possible without horizontal ducts inside the apartments. This solution is possible in Norway assuming components in the system preventing fire spreading through the duct (fire stop valves or similar).

1.7.3 Combination of vertical and horizontal elements

With a combination of vertical and horizontal elements, several advantages are possible. All vertical ducts will be put into the vertical element and all horizontal ducts into the horizontal elements, see an example of such a mounting in Figure 1-23. Another advantage is that it is possible to integrate all horizontal ducts inside the *smartTES* elements. The vertical elements have to be positioned first. A challenge will of course bee the connection of ducts between the vertical element and each horizontal element. With only one such connection per element it should be possible to get a practical solution on this.

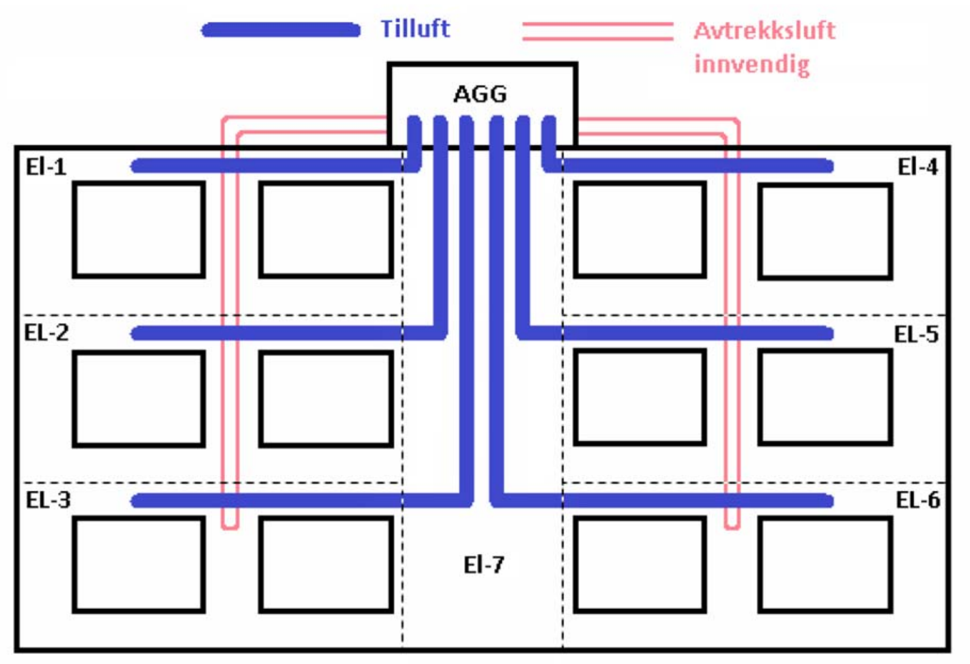


Figure 1-23 Principal solution of a combination of vertical and horizontal elements with HVAC ducts

1.7.4 Example with existing wall of masonry or concrete

Several steps have to be planned and carried out in the assembly phase. On site, existing walls have to be prepared with holes in the masonry/concrete wall. The dimension of these holes must be planned with respect to the position accuracy. The next step will be to mount the element towards the existing wall. After that, a duct piece with correct length should be attached from inside. It is important to ensure sufficient tightness of this adaption, for instance with rubber ties at one of the duct pieces. Finally, the installation has to be completed with sealing between the duct and the existing wall and finishing of the surface at inner wall. Figure 1-24a to figure 22d show suggested details of the necessary assembling steps.

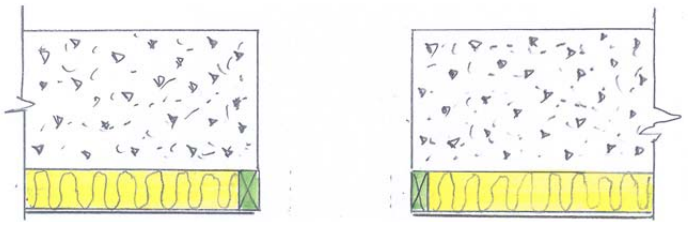
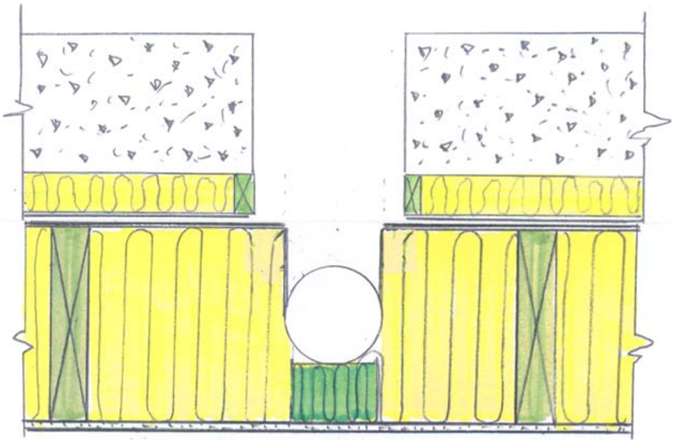
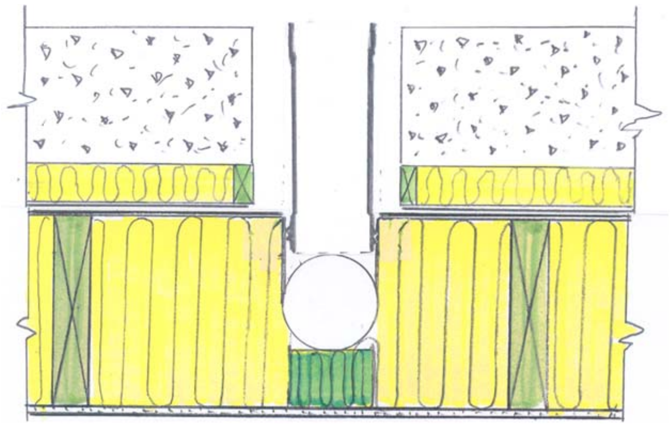


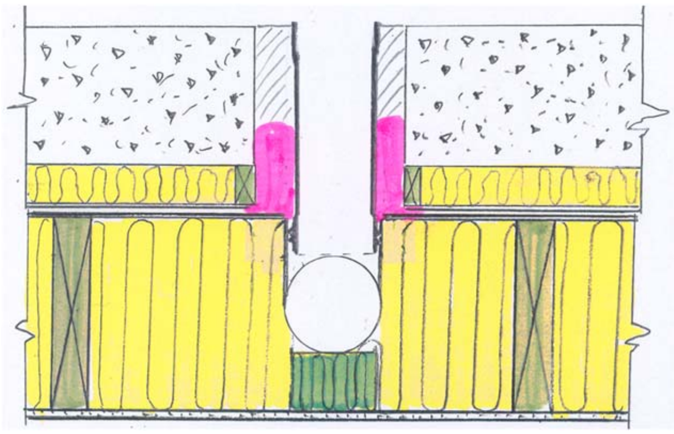
Figure 1-24a Preparing of a hole in the existing wall and if necessary an adaption layer at the exterior side



b) SmartTES element applied at the existing wall



c) Duct piece attached from inside



d) Sealing between duct and existing wall

1.7.5 Example with existing wall of wooden studs

Similar steps as mentioned in chapter 5.7.4 have to be carried out with an existing wall of wooden studs. In this case, the preparing of the hole should be easy, but of course positioned with appropriate accuracy. The next step will be to mount the element towards the existing wall and apply a duct piece similar to chapter 5.7.4. Finally, the installation has to be completed with sealing between pipe and the inner surface of the wall. A cuff foil on new studding is recommended to ensure an airtight connection. show suggested details of the necessary assembly steps.

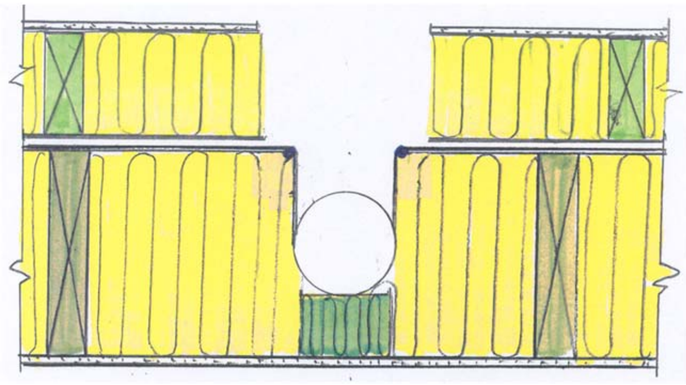
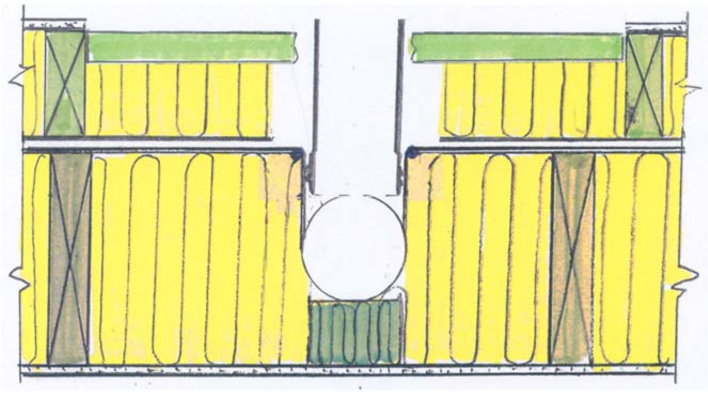
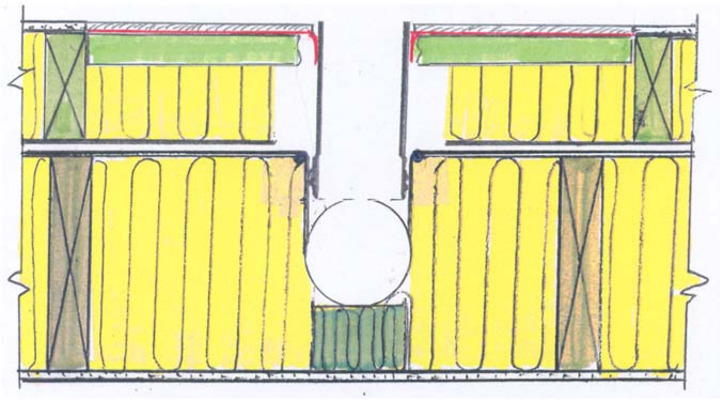


Figure 1-25 a) SmartTES element applied to the existing wall with the prepared hole



b) Duct piece and an additional studding attached from inside



c) Sealing between duct and inner wall with a cuff foil

1.7.7 Heat flow and thermal losses (B.Time/A.Homb)

Numerical simulation and calculation objects

Installation of ducts in SmartTES elements will affect the temperature distribution and the heat transfer of the wall. Simulations have been performed using 2D numerical simulation tool in "THERM" ver. 6.0. The calculations have been carried out to determine the temperature decrease in inlet air duct and increased heat losses due to the installed ducts. In table 3.1, the different calculation objects and some boundary conditions are presented.

Table 3.1 Calculation objects and some boundary conditions

	Existing wall Wood frame	Existing wall Masonry
Thickness and thermal conductivity	100 mm 0,037 W/mK	200 mm 0,5 W/mK
SmartTES element	200 mm insulation thickness	200 mm insulation thickness
External insulation cover of inlet air duct	0 mm 50 mm 100 mm	0 mm 50 mm 100 mm
Duct dimension	Ø 100 mm Ø 125 mm	Ø 100 mm Ø 125 mm
External / internal temperature	0 °C / 20 °C	0 °C / 20 °C

The simulations are also based on a heat exchanger efficiency of 80 % of the main HVAC unit and 0,5 air changes per hour in the apartments.

Temperature decrease in inlet air

In figure 3.1 and 3.1, results from calculation of temperature decrease in inlet air are given. The calculations are based on boundary conditions given in table 3.1

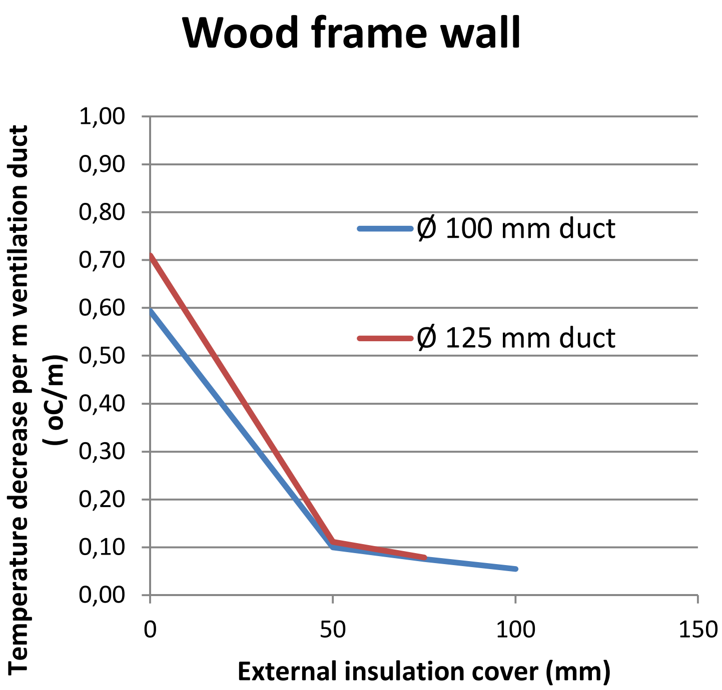


Figure 3.1 Temperature decrease per m ventilation duct in a wood frame wall

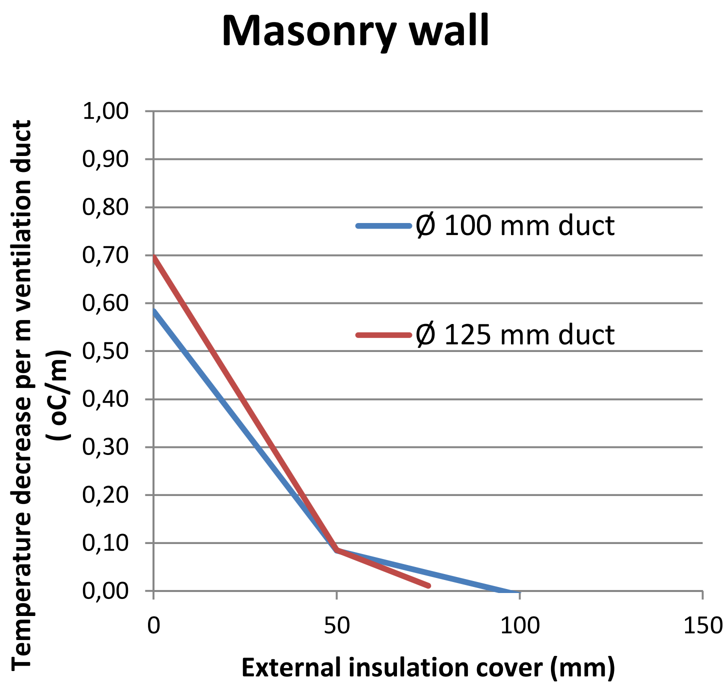


Figure 3.2 Temperature decrease per m ventilation duct in a masonry wall

Results presented in figure 3.1 and 3.2 shows a relatively high temperature decrease for the case without external insulation cover. With at least 50 mm of external insulation cover, the temperature decrease is rather low. Remember to multiply with the real length of the ducts from the main unit.

Thermal performance/U-value of wall with ducts

In figure 3.3 and 3.4, results from calculation of the additional heat loss per m ventilation duct are given. The calculations are based on boundary conditions given in table 3.1.

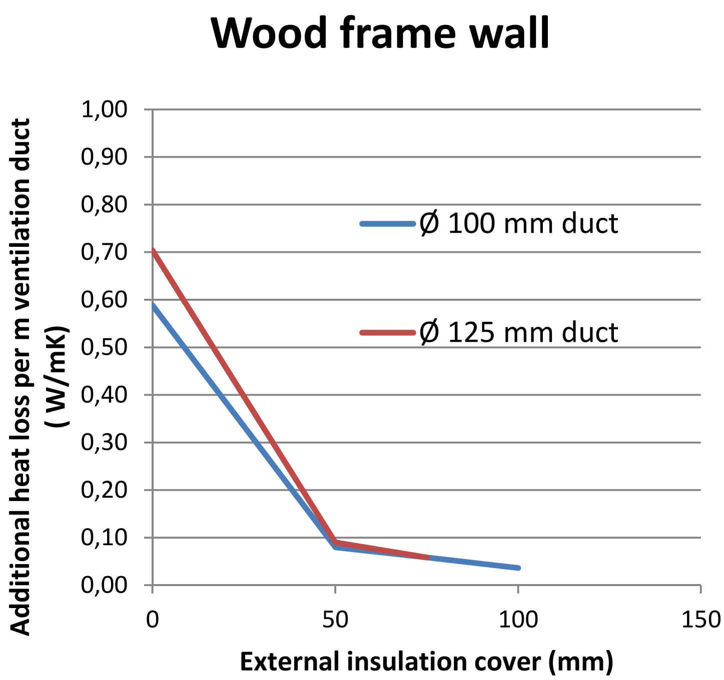


Figure 3.3 Additional heat loss per m ventilation duct in a wood frame wall

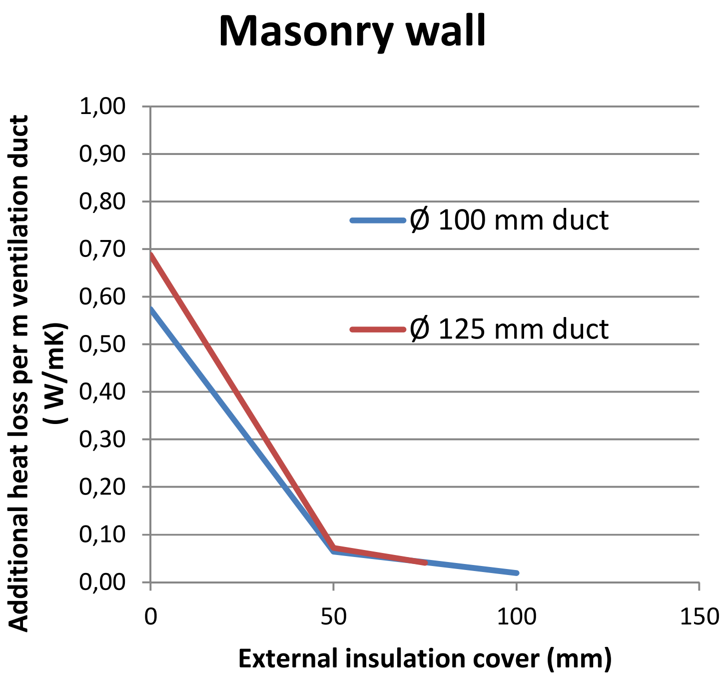


Figure 3.4 Additional heat loss per m ventilation duct in a masonry wall

Results presented in figure 3.3 and 3.4 shows a relatively high increase of the heat loss for the case without external insulation cover. With at least 50 mm of external insulation cover, the additional heat loss is rather low. For real cases remember to multiply with the length of the ducts from the main unit.

1.7.8 Noise distribution (B.Time / A.Homb)

In addition to fulfilling air conditioning requirements, an air handling system must meet acceptable noise and vibration criteria. The purpose of the following section is to give some guidelines for selecting proper criteria and some tools for designing the system. Methods for specifying and reducing noise for ducted systems will be given. The designer should therefore be aware of noise and vibration principles, since these have become a major concern in the acceptability of air handling systems. While it is not economical to over design a system for noise or vibration control, disastrous results can occur if potential problem areas are not considered in the design stage. Optimal design avoids overdesign but allows for a system that meets accepted criteria for the use of building space.

Noise from the HVAC system

Ducted systems are used to transmit air from a fan or blower to the necessary locations. Although the fan or blower is usually considered the major source of noise in such systems, the flow of air through duct elements like bends, turning vanes and flow control valves can also generate noise and vibrations. To meet the objectives mentioned above, knowledge is necessary on a number of parameters:

a) Fan noise. This data should be available from the manufacturer as octave band sound power levels in the desired operating arrangement. But predictive techniques may need to be employed in many situations.

b) Ductwork noise. Ductwork, bends, branches, flow control valves and terminations generate noise depending on the flow velocity and resistance.
c) System attenuation. The attenuation within the system provided by duct runs, bends, branches and terminations
d) Room or atmosphere corrections. The resultant sound power emerging from the ductwork system modified by corrections such as directivity, distance, room volume and room reverberation time.
e) Sound reducing techniques. If required, measures to reduce the resultant sound level by use of attenuators/silencers, duct linings, plenum chambers or modification to the system design.

The recommended method to calculate the noise from a HVAC system is to consider each noise source separately with all attenuation components to the receiving room. Then summarize all contributions and calculate the A-weighted sound pressure level in the room.

An HVAC system for 4 to 8 apartments for instance, have rather few components generating and attenuating noise when we consider each transmission path to a receiving room. In our SmartTES case we can consider only the inlet air, because the outlet air will be handled through shafts from another room. If we presuppose rather low air velocity, we can simplify the noise generation part of the system to the fan, one flow control valve and may be a termination unit. Table 5.1 presents a setup for calculation of noise from the inlet air system based on the assumptions above.

Table 5.1 Setup for calculation of noise from the air inlet system

Component	Source 1) Fan	Source 2) Control valve
Fan sound power level	From manufacturer	-
Silencer attenuation	From manufacturer	-
Branch attenuation	Volume based distribution	-
Control valve sound power level	-	From manufacturer or calculated
Bend attenuation	Tabulated values	Tabulated values
Termination unit and end reflection	From manufacturer or calculated	From manufacturer or calculated
Room corrections	Div. input	Div. input
Summarized level	Sound pressure level from source 1)	Sound pressure level from source 2)

Input values have to be given and calculations have to be carried out in 1/1-octave band from 63 Hz to 4000 Hz. Summarize these two contributions, make correction for the A-weighted levels in each 1/1-octave band and finally summarize to a single-number value. According to the Norwegian requirements for residential rooms, the $L_{pA,eqT} \leq 30$ dB and the $L_{pA,max} \leq 32$ dB, see NS 8175, sound class C. For more details on sound level calculations from HVAC systems, see SINTEF Byggforsk (1988) or Fry, A. (1988).

Transfer of noise between flats/sections

As mentioned in chapter 2, it is strongly recommended to have separate ducts from the main unit to each apartment. In such cases, the sound attenuation from one apartment to the branch after the fan/ silencer, into another duct and through this path to another room will normally be satisfactory to prevent disturbing sound transmission through the ducts.

If a concept with common duct between apartments is chosen, disturbing sound transmission is expected and we strongly recommend to conduct calculations. Such calculations will quantify the necessity of attenuation/silencer in the system between the apartments. Figure 5.1 shows a principal draw of such a system. High damping will normally be necessary which means a thickness space of the silencers positioned in the SmartTES element. Silencers or other attenuators will also give increased pressure loss of the HVAC system. A calculation method for the sound transmission through such a system is given in Vigran (2008).

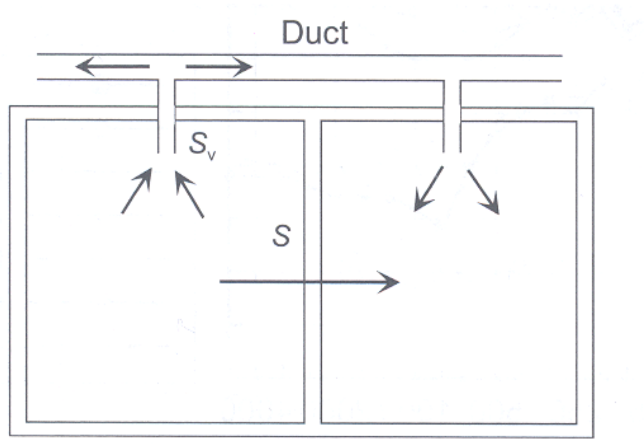


Figure 5.1 Sound transmission between rooms by way of a common duct system, from Vigran (2008)

Calculation example

In table 5.2 we present a calculation example of noise from an air inlet system. The calculations are based on sources and components from table 5.1. Input parameters for calculation of numbers in table 5.2 are not given.

Table 5.2 Calculation example of noise from an air inlet system

Component /Frequency band	63	125	250	500	1000	2000	4000
Fan sound power level, example	50	63	77	79	80	78	75
Silencer attenuation, example	-8	-15	-21	-33	-36	-31	-23
Branch attenuation	-7,2	-7,2	-7,2	-7,2	-7,2	-7,2	-7,2
Bend attenuation	0	0	0	0	0	-3	-6
Termination unit and end reflection	-21	-14	-7	-3	-4	-6	-8
Room corrections	-5,0	-5,0	-5,0	-5,0	-5,0	-5,0	-5,0
Level from fan source	8,8	21,8	36,8	30,8	27,8	25,8	25,8
Control valve sound power level, ex.	35,1	36,1	37,1	38,1	38,1	35,1	32,1
Bend attenuation	0	0	0	0	0	-3	-6
Termination unit and end reflection	-21	-14	-7	-3	-4	-6	-8
Room corrections	-5,0	-5,0	-5,0	-5,0	-5,0	-5,0	-5,0
Level from control valve	9,1	17,1	25,1	30,1	29,1	21,1	13,1
Summarized level Fan+Control Valve	12,5	23,1	37,1	33,5	31,5	27,1	26,0
Factors A-weighting	-26	-16	-9	-3	0	1	1
A-weighted level ∑ = 36 dB	0,0	7,1	28,1	30,5	31,5	28,1	27,0

The calculation example in table 5.2 shows an A-weighted level of 36 dB. This is higher than the Norwegian requirement, see chapter5.1. If relevant fan levels, control valve levels and silencer attenuation levels have been used, it will be necessary to put another silencer into the duct system. In this case it is necessary with increased attenuation especially at 500 and 1000 Hz.

1.7.9 Recommendations (B.Time, A.Homb, S.Ott, S.Loebus)

Important design principles:
Hygrothermal safety requires minimum 50 mm of exterior insulation
Sound insulation and noise protection recommends separate ductwork
Airtightness of ductwork
Fire safety and,
Connection of exterior routing with interior space,
Protection of integrated technical devices.

Hygrothermal safety (Time/Homb)

Calculation results presented in section 1.7.7 show that the temperature decrease in inlet air ducts can be kept to a minimum if substantial exterior insulation thickness is provided. We recommend at least 50 mm exterior insulation thickness. Results from calculations show that additional transmission heat losses can be kept as low as 2-6 % if a substantial exterior insulation thickness is provided.

Sound insulation (Time/Homb)

It is strongly recommended to have separate ducts from the main unit to each apartment. If a concept with one common duct between apartments is chosen, disturbing sound transmission is expected and we strongly recommend to conduct calculations.

TES HVAC element fire safety (Loebus/Ott)

Fire safety objectives
1. Separation functionality and fire resistance shall not be reduced by duct way
2. No fire, smoke or gas spread to other compartments
3. Preventing an ignition within the wall/element
4. Limiting destruction to the wall caused by thermal strain of the ducts

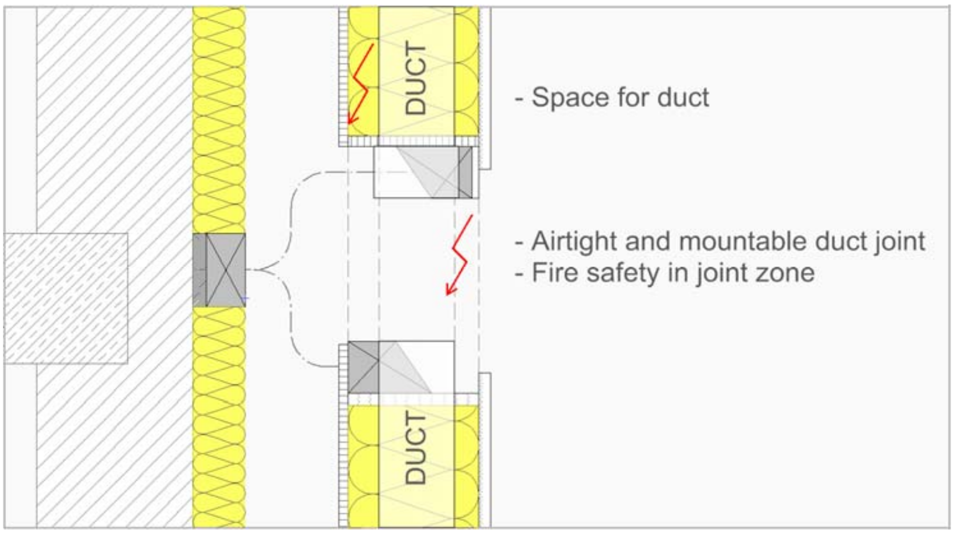


Figure 1-26 Collision of ductwork with TES joint in vertical section.

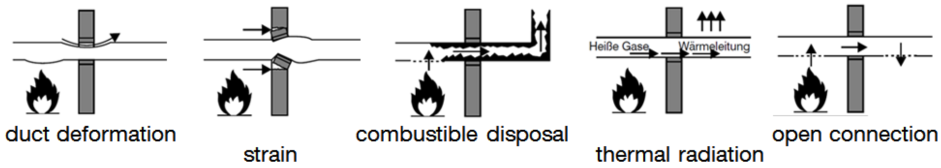


Figure 1-27 Risks in case of fire of ductwork with in walls [Source: VdS 2298:2002-06 Lüftungsanlagen im Brandschutzkonzept

Fire protection is a particularly important issue for TES-connected solutions. For lines, that pass other units of use there are strict security requirements. This is achieved by the production of non-combustible ducts with a covering equivalent to EI 30 encapsulation (≥12.5 mm gypsum fibre board shafts, or 60 mm of mineral wool with 1000 °C melting point, wrapped around the ducts) like it can be seen in the example in Figure 1-30. An alternative to the production of a shaft represents the continuous covering of cables with at least 60 mm of mineral wool. The use of molded insulating mineral wool gives benefits. See Figure 1-29. Between each line opening into another unit-of-use a fire dampershutter is obligatory.

Feasibility of Construction (Loebus/Ott)

The implementation of *TES*-integrated solutions is less expensive and has only limited influence on the neighboring units compared to on-site retrofit of building service systems. The more complex concepts are based on the principle of *TES*-connected. This can be made with very short routing distances. Compliance with the structural requirements is limited to key points, such as the transfer of the central unit, distribution and the handing over to the unit of use. Horizontal routing in *TES* elements is possible in individual cases, but that needs to be investigated in individual projects.

When the *smartTES* concept opens towards the integration of building services, the experience from timber framed TES construction has to be considered. Integration of multifunctional component is possible but there are some basic principles to respect in *smartTES* process, construction and element optimisation.

Table 1-3 General principles and optimization goals for multifunctional SmartTES.

	Objectives	Measures
Process principles	– multifunctionality – adaptation to existing struct. – off-site production – on-site assembly	– collaborative design – detailed survey – production planning – assembly planning
Construction principles	– Structural safety – Thermal + moisture safety – Sound protection – Fire safety – Wood protection	– Semi-balloon framework – airtightness and careful detailing – heat bridge prevention – decoupling + damping – encapsulation + fire stops – moisture management
Optimisation and quality	– Ecologic properties – Economic solution – Social benefit	– Renewable materials, recycling, waste management – Life time – Increased living comfort

TES element layout for integration
TES elements can be oriented vertical or horizontal. The most critical aspects are still related to manufacturing, handling in assembly and compliance with fire protection and other structural requirements.

The approach with central in regular *TES* elements integrated ducts is considered as not feasible as the necessary space for cross-sections is not available in the elements, compare Figure 1-26. Duct joints integrated in an element-joint are difficult to close in the assembly process. The airtightness of non-observable plug-and-socket connections can hardly be guaranteed. Apart from complex telescope solutions, it is recommended avoiding duct joints within the TES-Elements or providing sufficient open installation space. More problems arise with the necessary fire shutters for each units of use. The accessibility of the fire shutters for regular maintenance is to be considered.

Decentralized installations and the difficulties in accessibility are advantageous to the concept of a multifunctional building envelope. The most promising solution for the *smartTES* is to follow a concept of small ducts for the individual units, which fire shutters are located on the air handling unit. The option of the flow control by dedicated valves near central unit is also possible, see Figure 1-13. Various ways of separating and orienting elements are shown in chapter 1.7.

TES HVAC element anchoring
The anchoring of vertical TES elements goes to the horizontal coupling wood. The studs in the element must have the necessary stiffness for the transportation and the assembly process. The rigidity in the horizontal direction in the final position on the façade must also be given.

TES HVAC element prefabrication
The TES elements are produced off-site. They can be done lying what in itself is beneficial for the handling of pipes. The protection of the hygiene of all lines through measures of closure is recommended to avoid contamination. This is particularly taken into account also throughout the acquisition and transport. For installation, anti-vibration mounting and damping solutions of sound should be used.

TES HVAC element assembly
The TES elements are manufactured lying and are, of transport reasons, limited to 12 m length. Longer elements can be manufactured and transported with corresponding permission. The elements are turned into vertical position on the construction site. One example is the case Riihimäki, see section 1.9.1.

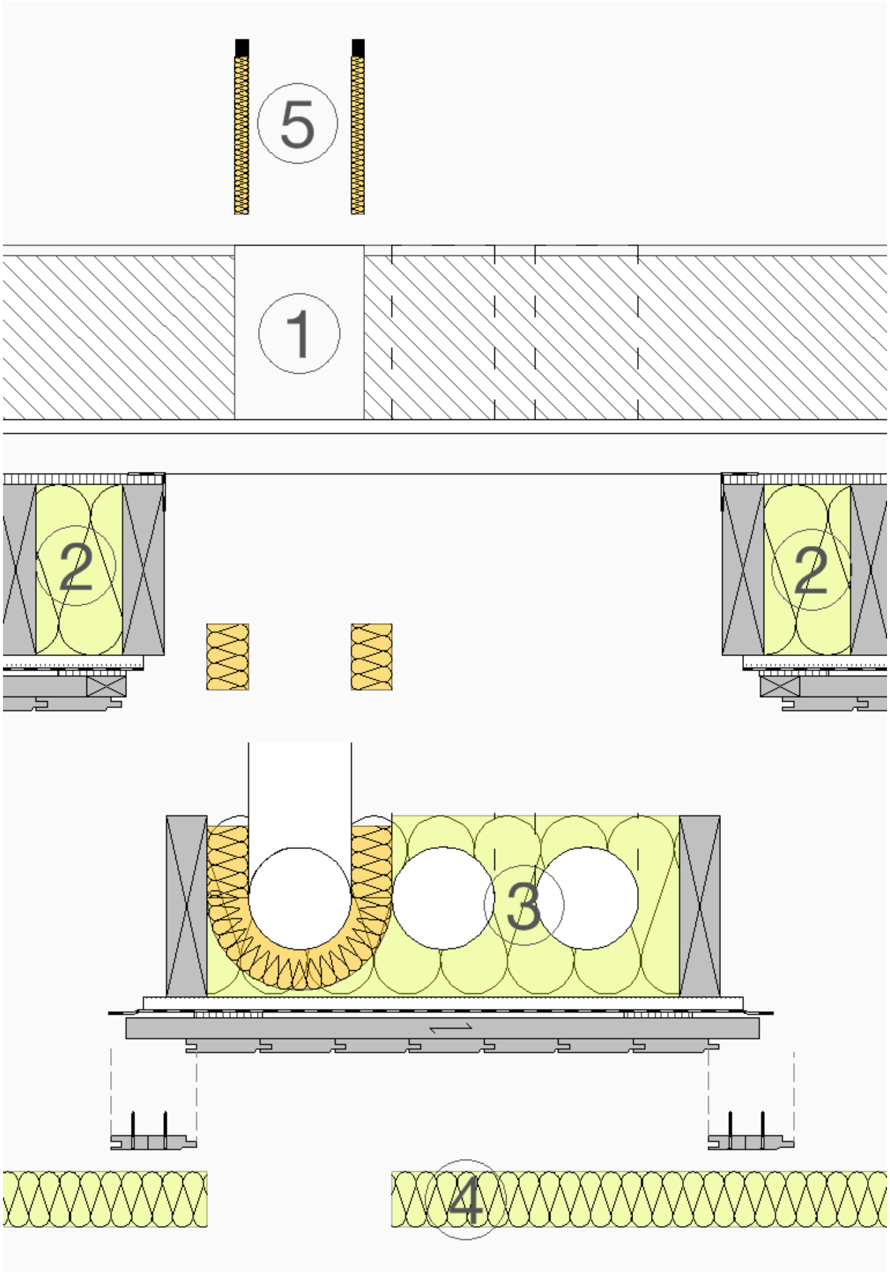


Figure 1-28 Assembly process of TES-connected element with HVAC ductwork. (1) wall opening (2) TES elements (3) TES shaft and connection (4) adaption layer blown in cellulose fibre (5) mortar filling and insulation remaining wall opening.

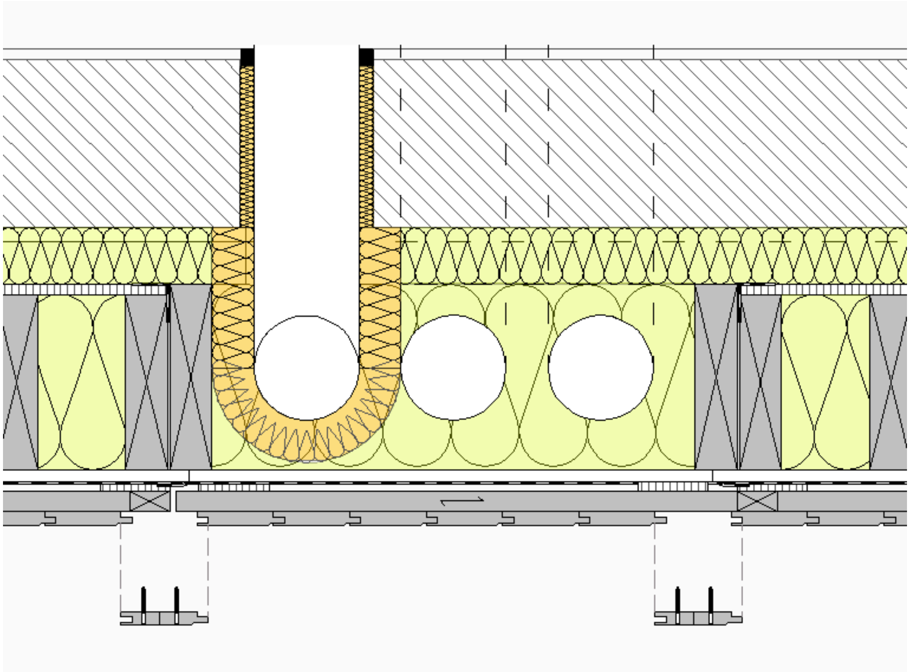


Figure 1-29 Example: Horizontal section of vertical TES module with HVAC ducts inside. Mineralwool insulation (≥ 60 mm) wrapped around ducts for fire protection.

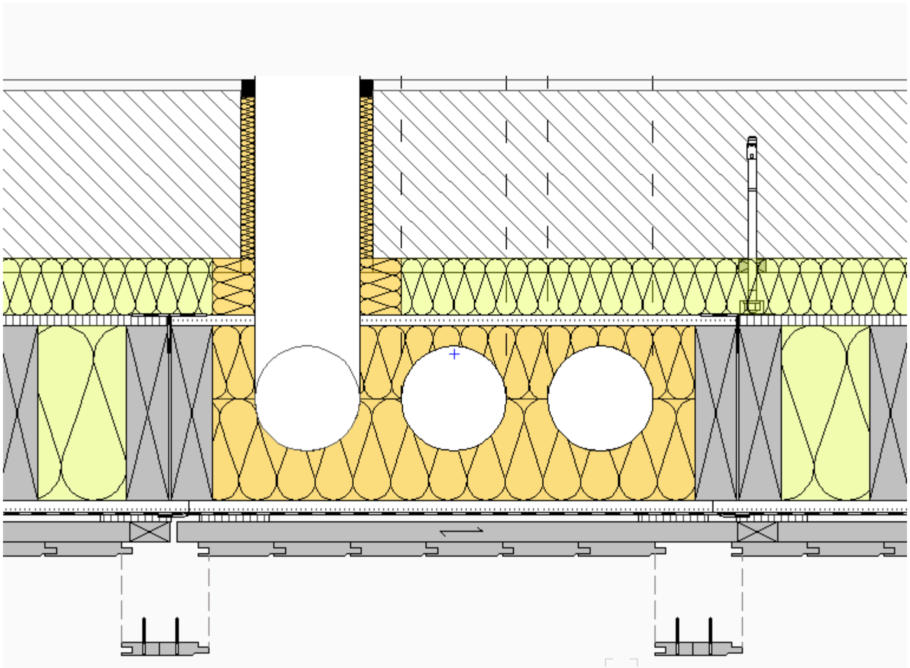


Figure 1-30 Example: Horizontal section of vertical TES module with HVAC ducts. Alternative shaft solution covered with gypsum board and precast mineral wool in lay.

1.8 Passive heated building envelope (R.Botsch)

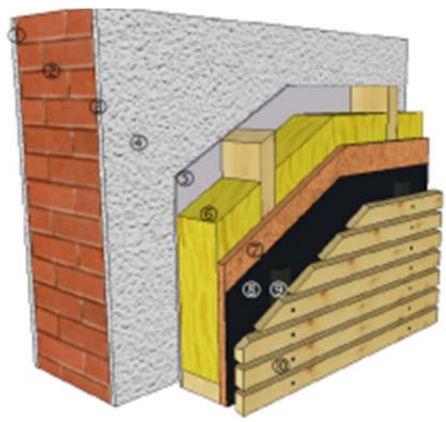
A prefabricated timber based facade for renovating the building envelope had been realized as part of the research programme "Energieeffiziente Stadt", commissioned by the German Federal Ministry of Economics and Technology. As consequence of innovations in energy efficient systems, a system for heating the building envelope had been installed; the intent was to thermally activate the existing exterior wall to reduce transmission losses.

The main objectives of the subtask “passive heated (building) envelope” are:

- Detailed evaluation of the function:
    - Thermal impact of the passive heated envelope on retrofitted buildings (thermal activation of building units in renovation)
    - Efficient use of low-energy
- Prove of sound insulation and moisture
- Evaluation of primary energy impact

1.8.1 Function of the passive heated building envelope

The idea of renovating buildings with the principle of *TES* elements is already well known. In many cases the *TES* elements are directly attached to the existing building without a gap in between. The idea of the passive heated envelope describes a differing system, where the gap between the existing, in most cases uneven, wall and the plain timber construction is used to integrate a heating system.
In the case of the passive heated envelope (PHBE) an air gap of the minimum of 30-40mm is being used in order to integrate capillary tube mats with heating water.



Layers:

1-3 Existing wall
4 Air gap with heating layer
5 Gypsum fibre board
6 Timberframe-Construction Mineral Wool Insulation 035
7 Timber soft fibre board
8 Water protection foil
9 Timber battens
10 Timber cladding

Figure 1-31: Set-up of the TES-element

This heating layer is being used as a secondary heating system. In general there are two different approaches regarding the principle of the PHBE.

The first approach is the reduction of the heating demand by lowering the effective u-value of the regarded façade. By heating up the PHBE, transmission losses (Q_e) through the external wall are reduced to a minimum. Depending on the thermal input to the PHBE, transmission losses can even be converted to energy gains (Q_i).

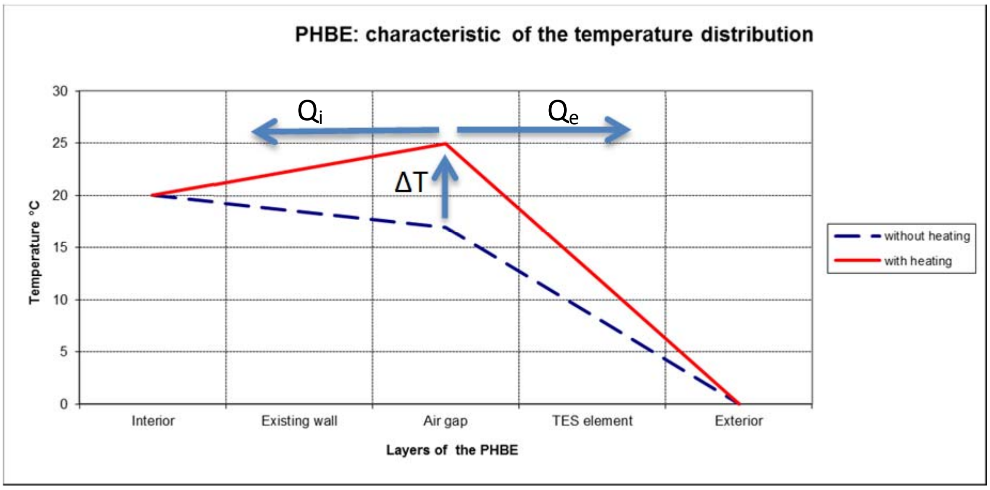


Figure 1-32: Characterization of the temperature flow of the PHBE

The second approach is to increase the efficiency of the technical building equipment, such as solar thermal systems or the primary heating. In this case the function of the PHBE can be seen in Figure 1-33.

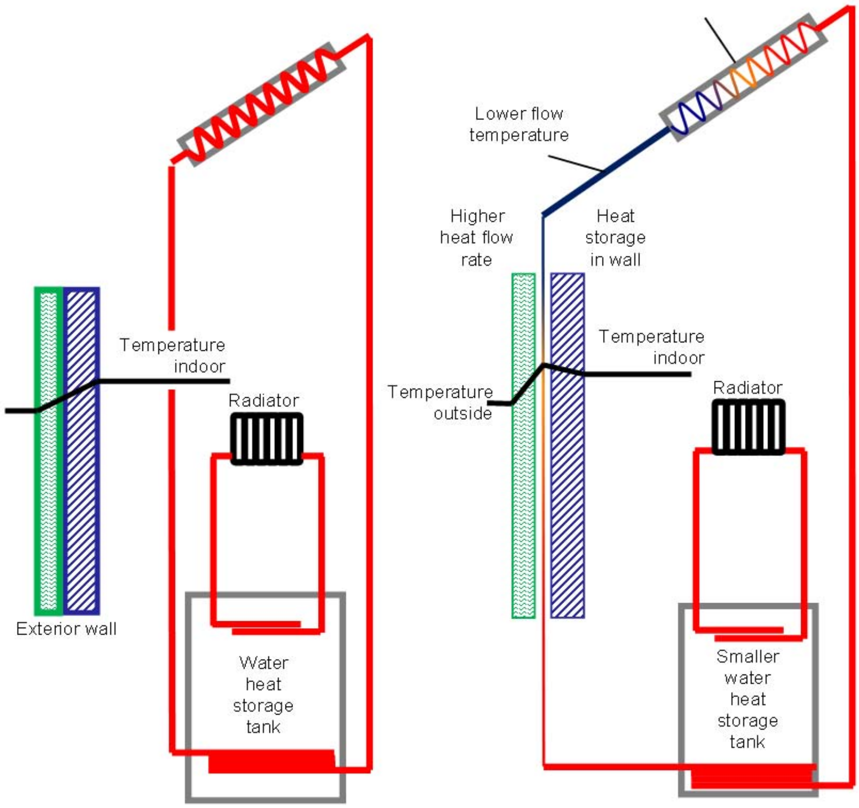


Figure 1-33: Principle of the passive heated envelope (right), usual retrofit of external walls (left)

In this approach the heating layer of the PHBE is used for storing solar thermal power into the existing wall. With decreasing flow temperatures, an increase of efficiency can be expected.

1.8.2 Examination of an existing passive heated building envelope

In order to estimate the proper function of the PHBE several tests were realized during the first project period.
The following tests were realized:

- Air-tightness of the attached TES-element to the façade
- Thermography
- Evaluation of the temperature-profile (→ heat transfer through the entire façade)
- Sound and moisture proofing

Air-tightness and thermography

Due to increasing partial pressure difference between the temperature of the heating layer and the exterior temperature, the basis of the PHBE is a very tight sealing of the TES-element. To get an idea of the additional energy losses the air-tightness of the TES-element was tested.

Two series of measurements were done in total, the results of which can be seen in Figure 1-34. The tests were performed according to the Blower-Door principle. The result is the air exchange rate at a pressure difference of 50 Pa.
Depending on the exact measures of the air gap the resulting exchange rates differ between $7h^{-1}$ and $11h^{-1}$.

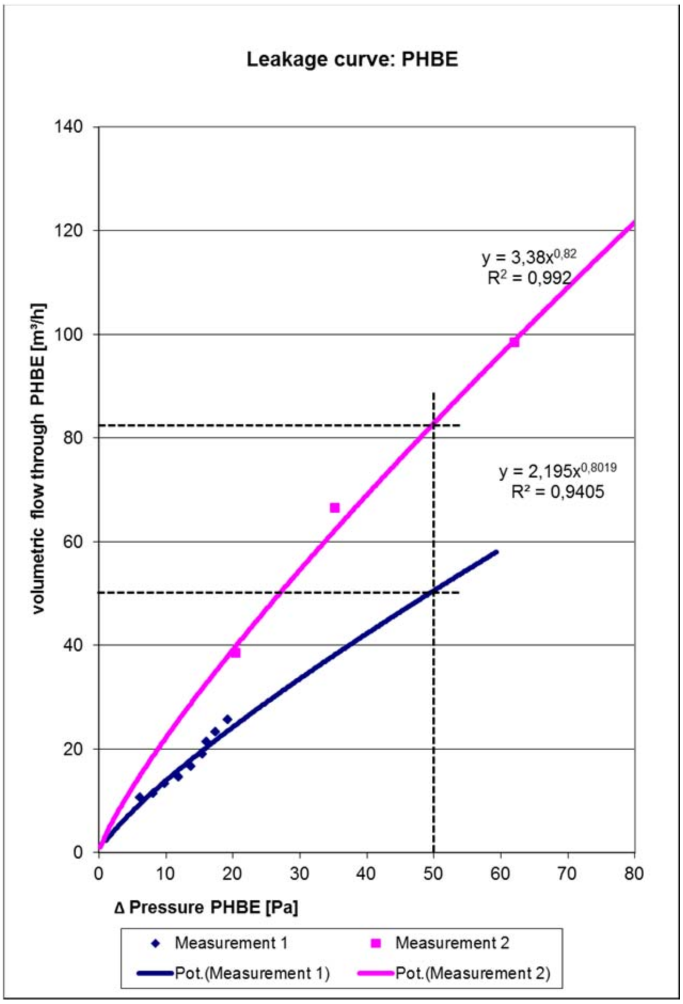


Figure 1-34: Result of the air-tightness tests

In order to find the corresponding leakages a smoke analysis was realized, leading to the identification of two critical positions:

1. The connection to the rain water pipe (to the exterior)
2. The window joints on the ground floor (to the interior)

The described problem with the window joints and the rain water pipe can also be seen in the following picture. The thermography shows quite impressing the leakages of the regarded areas.

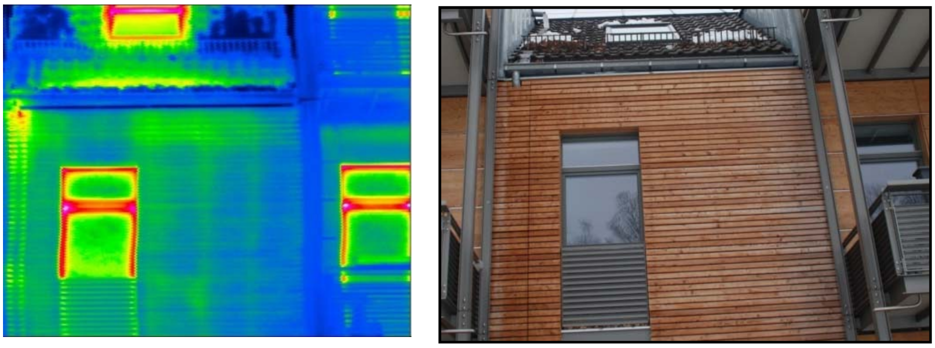


Figure 1-35: Thermography of the window joints and the rain water pipe

1.8.3 Development and realization of an optimized facade – improvement by testing a new mock-up facade

At the initial phase of the project it was known that the structure of the existing facade and the installed measurement system did not meet the requirements of an optimal PHBE. By developing an improved facade, the concept of PHBE is to be evaluated and the implementation possibilities of a usage should be shown.
Therefore a suitable structure for a new test facade was developed and installed on a neighboring building.

To define the influences of a PHBE on the rooms behind the facade, knowledge of the room parameters are mandatory. For that purpose the test facade was installed in front of a partially occupied and heated test room accessible to the University of Applied Science Rosenheim.

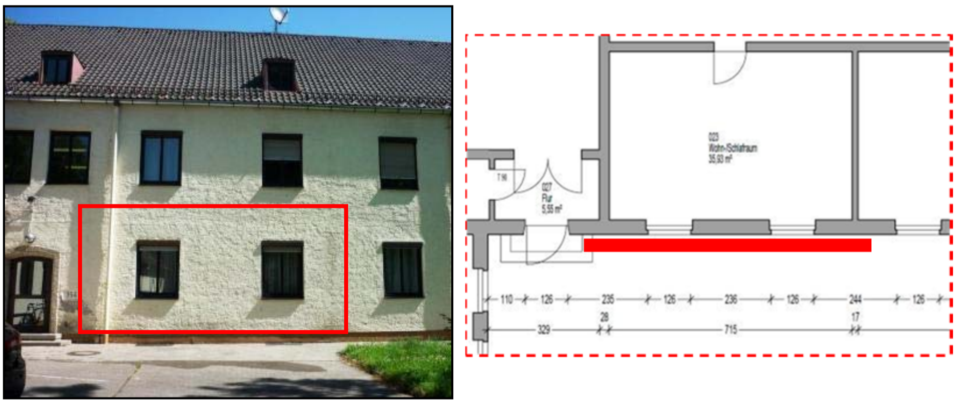


Figure 1-36: Elevation floor plan of the new mock-up facade

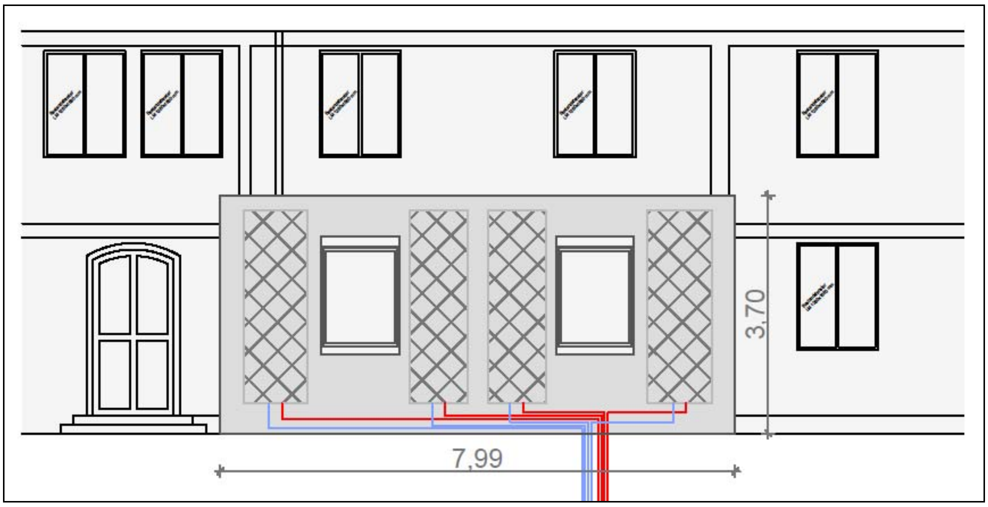


Figure 1-37: TES-Elements of the optimized construction with heating layer

Two existing windows were integrated in the new test facade. The dimensions of the test facade were selected to fit the exterior wall of the room behind. To prevent heat flow on the edges the TES-element was extended by 30 cm all around. The dimensions of the element are 8 m x 3.7 m with a surface area of 29 m². The heating surface amounts to 11.4 m² build with the same water based heating system as the existing system.

Aimed improvements of the new test facade are:

- Reduction of the air gap between TES-element and existing wall.
- Improved airtight isolation of the TES-element to the existing wall.
- Prevention of further perforation to minimize the leakage surface.

In order to guarantee the heat input of the factory-installed heating surfaces, and to make use of the strong thermal resistance of air, it is necessary to minimize the gap between the TES element and the existing wall.
In theory the amount of heat flow to the interior depends on the ratio of total thermal resistance both outwards and inwards. The following figures illustrate the issue.

By reducing the air gap from 70mm to 25mm the theoretical system is improved and the energy conversion ratio rises to 86.2%.

A particular focus was on the topic of air tightness. Therefore all sectors were sealed individually. The connection of the test facade to the building can be insured to be leak free due to the size ratio between the relatively small test facade and the existing facade on the neighboring building. The joints were connected with a special adhesive which evens out patches of the plaster. The vapour barrier of the test facade is pressed into the adhesive during assembly. Figure 1-38 shows the airtight areas of the test setup.

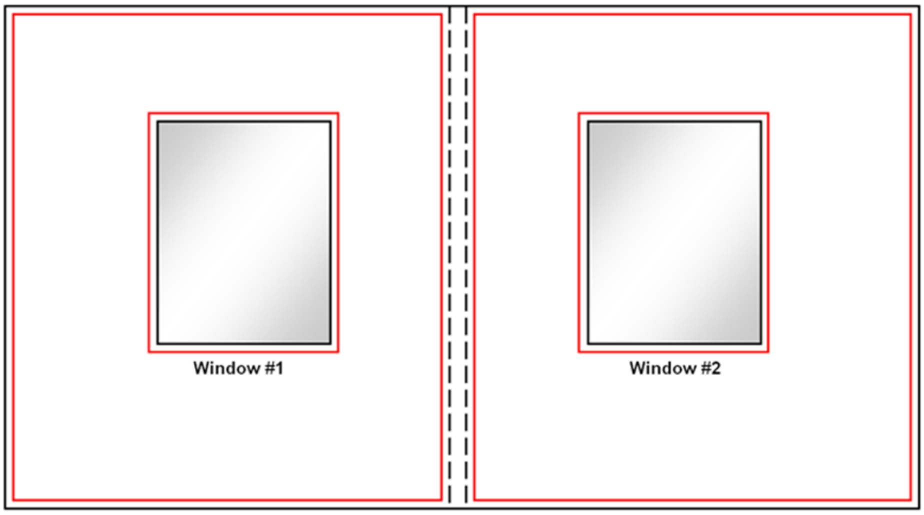


Figure 1-38: Pattern of the sealing line of the optimized elements

1.8.4 Evaluation of (primary) energy impact

The total efficiency of the PHBE depends on the energy balance of a whole building with integrated *TES* elements. As the focus of the pilot buildings in this project were laid on the functionality of the PHBE system, an overall energy balance was not feasible. In order to evaluate energy impact of the PHBE a thermal building simulation was performed.

The simulations were performed in two steps:

1. Component simulation (in order to verify the simulation model with measured data)
2. Dynamic building simulation

The interior boundary conditions of the simulations follow the condition of a zone “sleeping-room”. All other conditions and dimensions are described in the optimized mock-up façade. In order to evaluate the heating efficiency of the PHBE a time period of two cold months (December and January) were selected.

The building simulation was performed in 3 different scenarios. The first scenario (“Heating constant”) identifies the energy input of the PHBE whenever heating is needed. Looking at the cold exterior conditions this means a non-stop operation of the PHBE. In the second scenario (“Heating variable 10-16h”) the operation of the PHBE is between 10:00 and 16:00 every day regarding a theoretical condition of solar power during day time.

In the third scenario (“Heating solar use”) the control of the heating layer of the PHBE is totally linked to the supply of solar power. In this case the PHBE is activated as soon as the global irradiation exceeds 150 W/m².

In Figure 1-39 the results of the building simulations can be seen, showing the share of the PHBE energy usage (red bar). Depending on the considered scenario the contribution of the PHBE to the total energy demand is between 10% and 50%.

Figure 1-39: Results of the building simulations

1.8.5 Overall results

From the preceding results, the use of a passive heated envelope is shown to be only slightly positive. The potentials identified in the theory could not be repeated in practice. A major difficulty was identified in the poorly sealed connection of the facade elements to the existing building, causing additional thermal losses.

In the overall efficiency of the system, only a small fraction of about 10% was realized. This reasonable result can be expected using energy of a solar thermal system or any other waste energy. At this point, further research in the area of Multifunctional *TES* must be considered taking also cost efficiency into account.

1.9 Best Practice Cases

1.9.1 Case Riihimäki (Aalto / Kimmo Lylykangas)

In Innova project, a typical multi-storey house of the 1970s was renovated to meet the Finnish Passive House requirement, i.e. the heating energy demand after the renovation is maximum 25 kWh/m²a. The four-storey-high building, originally constructed in 1975, is located in the Peltosaari area in Riihimäki. The building has 33 rental apartments and a day-care centre.

The renovation included new doors and windows, balconies, additional thermal insulation and a new ventilation system with effective heat recovery. The central ventilation unit is equipped with a rotating heat exchanger. The exterior of the building was measured by laser-scanning and modelled in 3D for the dimensioning of the elements. The outer concrete panel and the thermal insulation of the old exterior walls were dismantled and replaced by vertical facade elements with a wooden frame structure. The ventilation ducts, windows and the balcony doors were installed in the elements, as the first layer of the plaster rendering of the facades.

The new renovation method reduces the duration of on-site construction work. The entire construction phase was planned in order to be ready in 5 months, which is half the time compared to respective renovations of similar multi-storey houses in the Peltosaari area. The refurbishment was additionally an opportunity for up-grading the architecture of the building [23], a more detailed description of the project is published in [6].

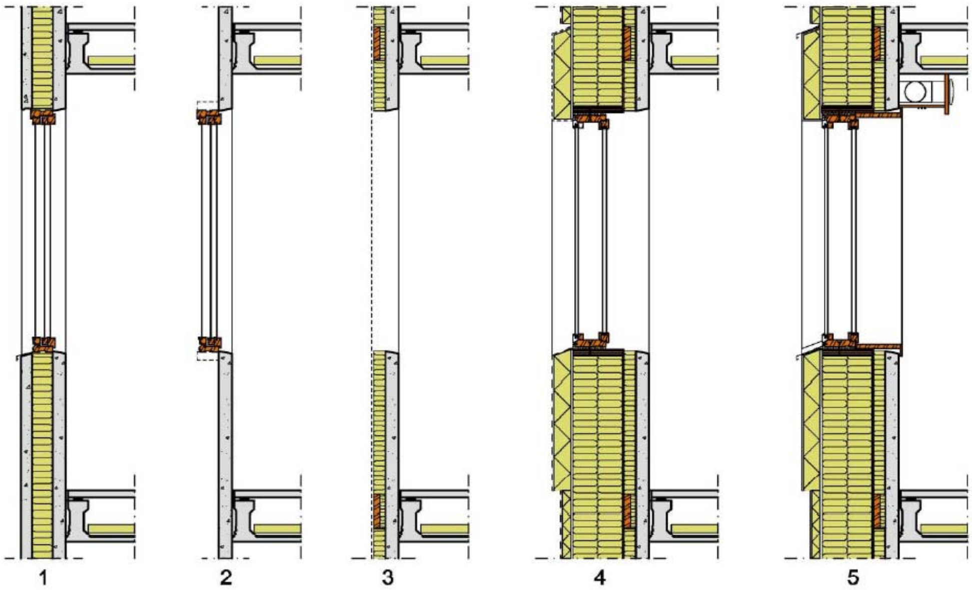


Figure 1-40 The refurbishment in five steps: from the existing concrete sandwich façade at step 1 to the final assembled and rendered TES element in step 5 [Lylykangas Architects].

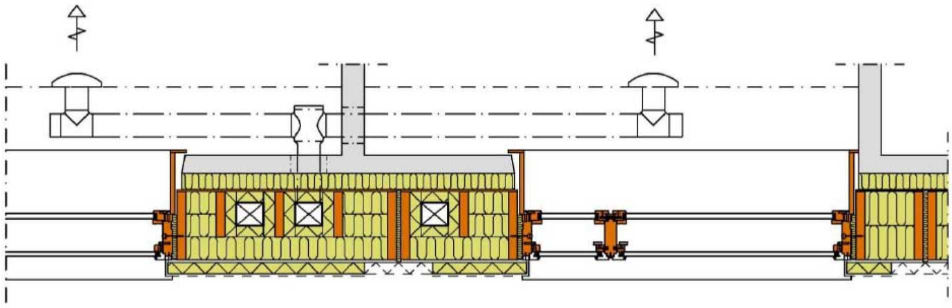


Figure 1-41 Horizontal section through the façade shows the vertical ventilation ducts and the inlet of one apartment with a fork supply for two rooms [Lylykangas Architects].

Figure 1-42 The situation prior to refurbishment. A four storey building with a facade made of concrete panels [Paroc Group Oy].

Figure 1-43 The horizontally manufactured element is turned into vertical position for assembly.

Figure 1-44 Construction site assembly of prefabricated elements with first render layer [Paroc Group Oy].

Figure 1-45 Turning of elements from truck into the vertical position for assembly [Paroc Group Oy].

Figure 1-46 The manufacturing of the element in the workshop. The top connections of the ductwork, that will be connected to the AHU, can be seen [Paroc Group Oy].

1.9.2 Case EP-A Neu-Ulm (S.Ott)

The demonstration project of a Plus Energy House in Neu-Ulm, Germany is a competition contribution of the TUM. The Plus Energy House competition was awarded by the German Federal Ministry of Construction and Urban Planning. The German partners of smartTES formed a collaborative design team and handed in a contribution for the competition. The goal was to demonstrate the possibilities and advantages of SmartTES solutions in retrofitting existing buildings towards a future requirement. All ideas and concepts from the project

proposal and the ongoing research on fusion of building services and TES elements in the facade as well as the possibilities of spatial extensions are ideally suited for such an innovative project.
The need of demonstration projects and model solutions is already emphasised in the SmartTES project proposal. The method of working with realistic case studies pursues two main goals: On the one hand the relevance and effectiveness of the strategies developed in work package 1 the multifunctional envelope can be checked; on the other hand the examples require the development of technical concepts constructions and constructions, which might be generalized and finally retroact into the formulation of design strategies. More detailed information about the architectural design and the conversion by extensions and space modules is found in book 3 chapter 1. The topic of sustainability was also part of the task and addressed in the contribution and is shown in detail in book 5.

Necessary strategy towards the goal of a Plus Energy House:

1. Reduction of the heating demand on the passive house level
2. Conversion of the energy source for electricity
3. Energy production in the building by photovoltaic
4. Technical devices efficiency in building automation and consumer products

As a further, essential measure the improvement of functional and technical aspects is taken into account, see Figure 1-47. This includes room layouts, accessibility and building physics in particular the sound insulation. Only in this way can an adequate increase in the overall quality of the building be achieved and a sustainable retrofit is guaranteed. The following notes show the limitations of the existing structure and discuss the solutions.

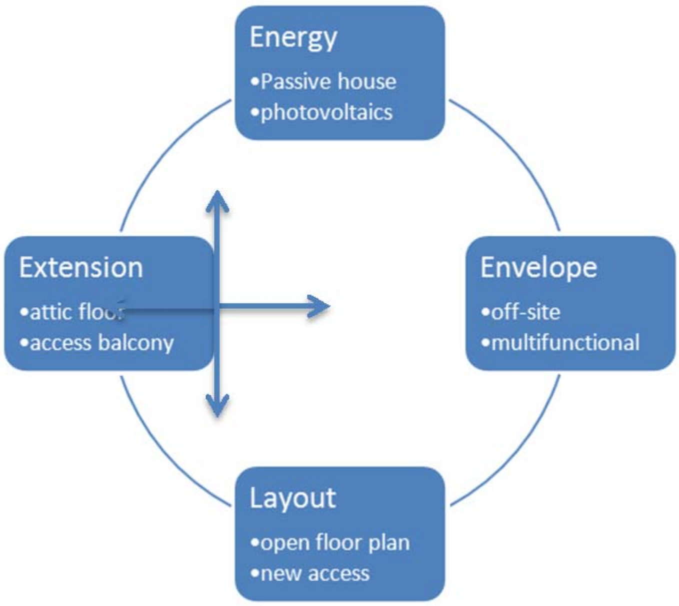


Figure 1-47 Interaction of requirements / goals in Neu-Ulm project.

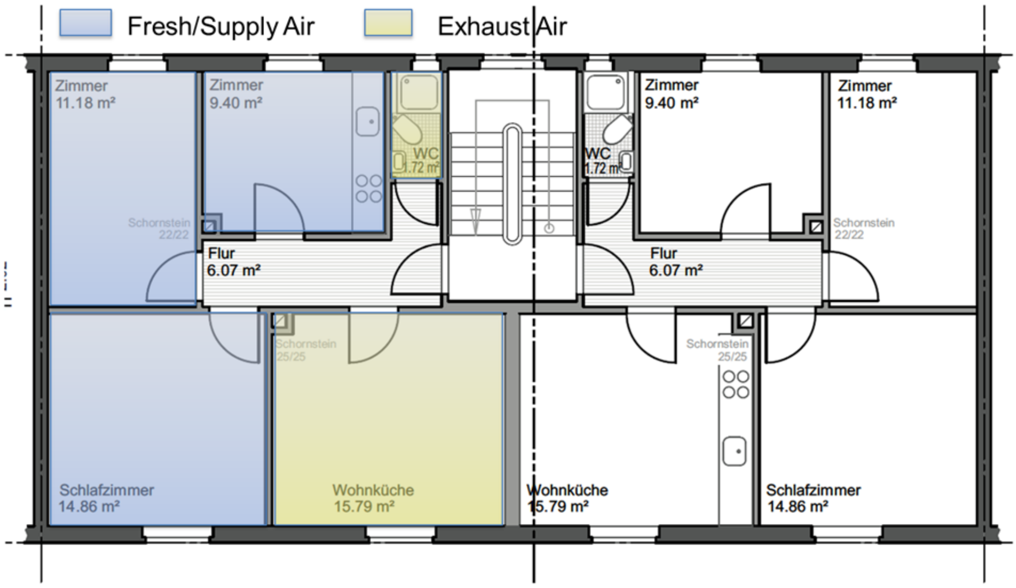


Figure 1-48 Existing floor plan with a supply and exhaust air concept.

The existing building is entirely naturally ventilated. The existing plan would require a zoning for the ventilation concept that is shared across the interior corridor. The existing and tight spaces do not allow for placement of shafts. It could be used possibly existing chimneys. But the chimneys are not large enough to supply two superimposed units. In the corridor an additional distribution zone in a suspended ceiling would be necessary. With a conventional shaft solution inside the building it is difficult to retrofit a ventilation system in the apartments.

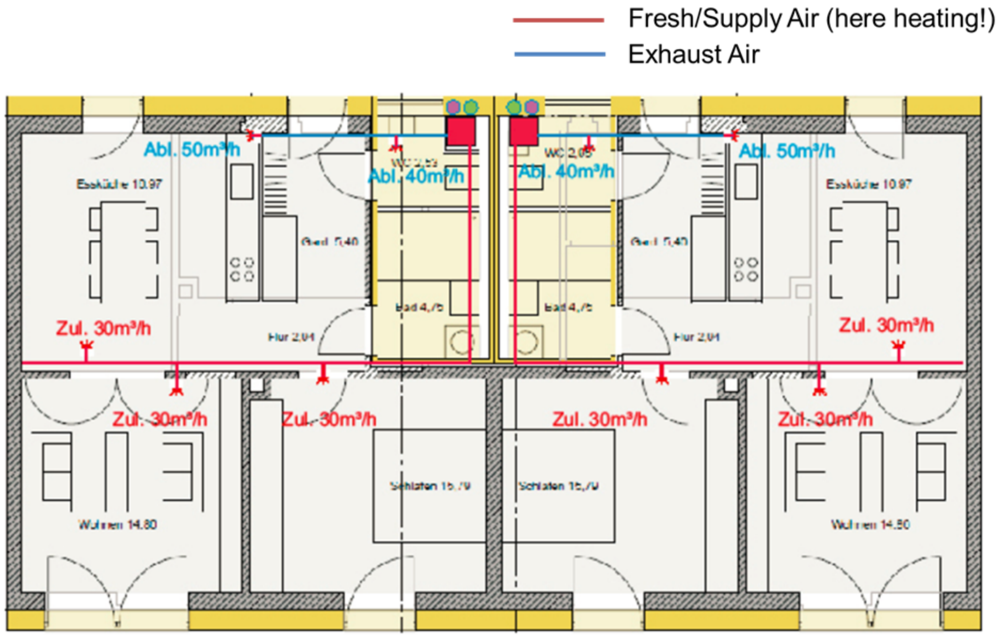


Figure 1-49 New floor plan with new bathroom, kitchen and supply and exhaust air zones.

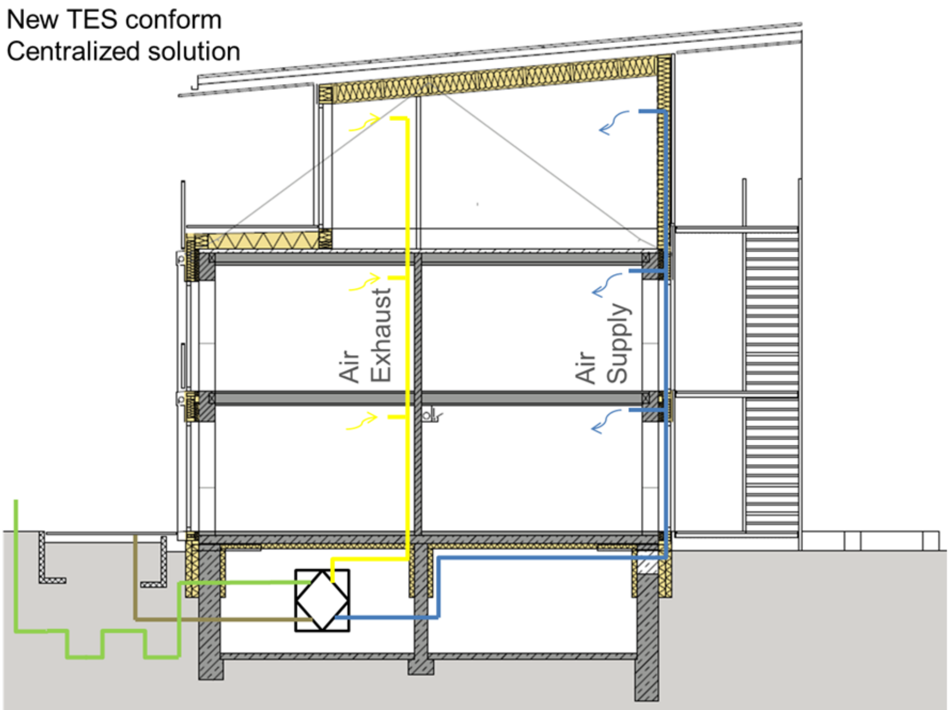


Figure 1-50 Section of the plusenergie design with roof extension.

Measures in building service systems

The measures to achieve the passive house level are mainly implemented in the building envelope and heating technology. The envelope will be refurbished with passive house components and get along with greatly reduced heating systems. However, a ventilation system must be upgraded so that ventilation heat losses are minimized and good indoor air quality is guaranteed. The heat supply of housing units is done through an air heater. The hot water supply is implemented by an air heat pump. The conversion of the energy source for electricity is also due to the large-scale use of photovoltaic on the roof.

Ventilation and Heating

The new floor plan, which is made possible by the changed access, creates clearly distinct zones for the necessary supply and exhaust. Bathrooms as prefabricated space modules integrate the central ventilation and heating unit of each apartment. The service devices are integrated as well and combines heating, hot water, and ventilation as one component, the so called *compact unit*. A *compact unit* consists of an air-to-air heat pump, air handling unit, heat exchanger, and boiler is one single device. This technology is well proven in single family passive houses. It is fully integrated into the space module and accessible for maintenance from the exterior corridor. Therefore the cleaning and maintenance of the unit can be done through an opening from the outside without entering the flat. The fresh air and exhaust air façade openings are directly connected to the compact unit behind the exterior wall, to avoid ducts and heat losses.

The compact unit has to be connected to fresh air, and interior air ducts of the apartment. The exhaust air is taken out directly within the bathroom-module and on the exterior wall of the module, in the kitchen and wardrobe space. The fresh air ducts in the first and attic floor level are routed in the dead floor in between both storeys. The linings of the air ducts in the ground floor level incorporate an indirect lighting and differentiate the internal space as well as the circulation space.

Energy demand

The plus energy home quality is achieved by robust and durable interventions. The most important step is the reduction of the heat energy demand. The building services are reduced on a few components and short distribution routes. The building envelope is highly insulated and air tight sealed with passive house components. Therefore the heat energy demand is reduced to a minimum with high thermal comfort for the tenants. A very good insulated building envelope enables the minimized heat supply by the mechanical ventilation system. The exterior walls have a U-value of 0,15 W/m2K and the windows have U-values of about 0,65 W/m2K. The average heat transmission coefficient of the entire building envelope is H'T = 0,18 W/m2K and is only 20% of the amount of the reference building.

Ventilation, heating and domestic hot water supply is decentralized in each apartment.

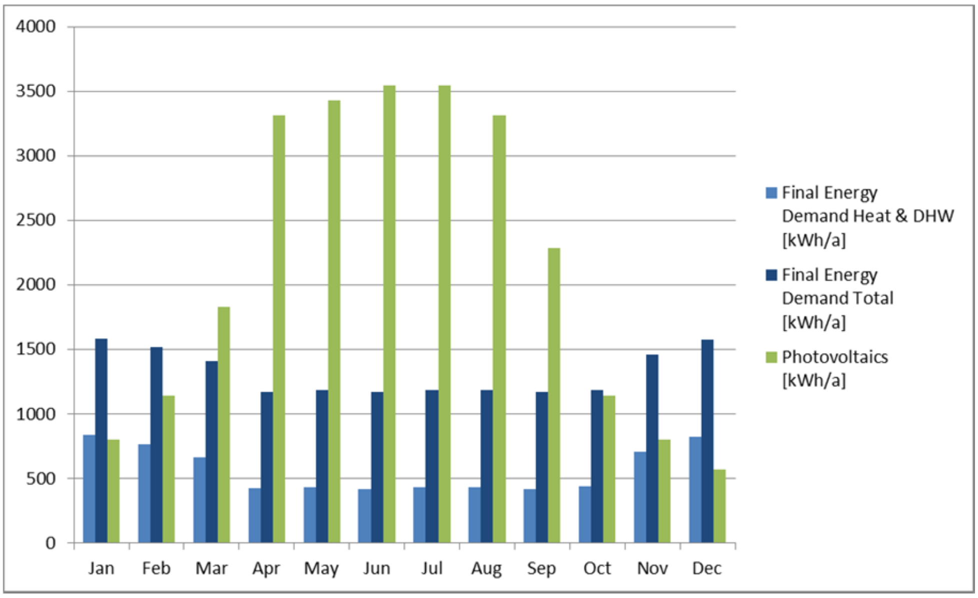


Figure 1-51 Energy harvesting and energy demand during the course of the year.

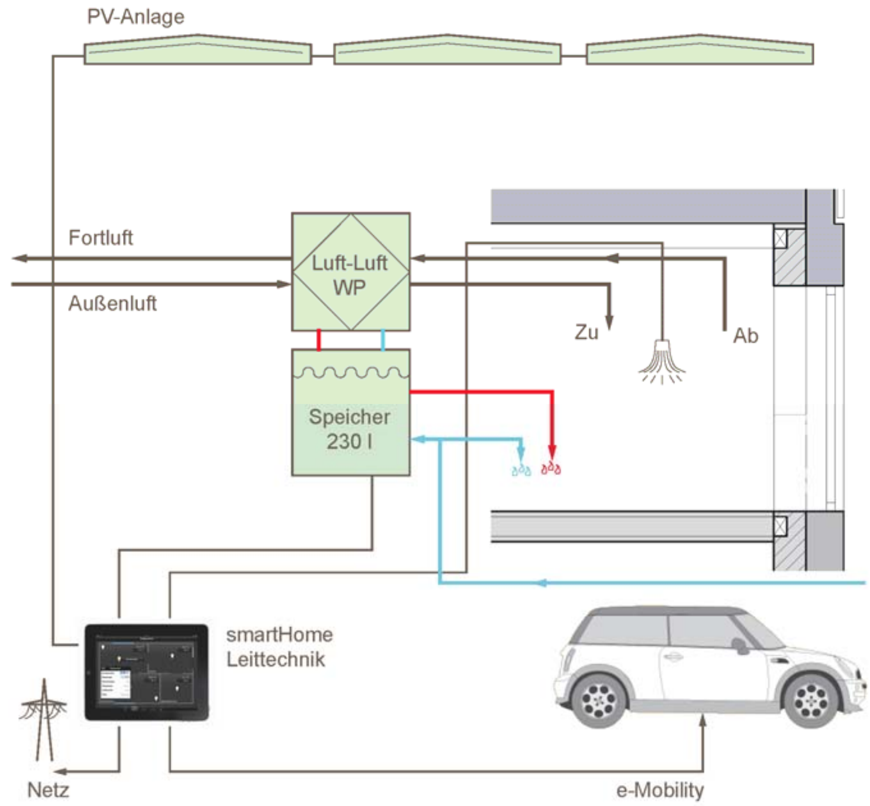


Figure 1-52 Building services and energy supply design.

Energy generation

The entire area of the roof is filled with 112 poly-crystalline photovoltaic modules. The size of the roof is about 200 m2 with an inclination of 5° facing south. The equipment with a peak performance of 27 kWp, produces roughly 163% of the energy demand of the entire building and the household electricity of all apartments. The excess energy is sold to the grid or can be used for charging the designated electric vehicles. Inverter modules, meters, wiring and connections /links to the public grid are in the basement of the building. The energy demand of users can be separated directly from the main meter to individual apartments. A separate meter of each apartment by the public utility is not necessary. The generated energy is directly used by the tenants. The billing can be centralized by the housing company. The energy generation is limited to the photovoltaic and the energy demand of the apartments is supplied only by electricity. This is a reduction of a few components for energy exchange and raises the flexibility of the energy balance and reduces the effort for maintenance, repair, administration and billing. Additionally the energy balance of the building itself and the tenants own consumption will be transparent and easy to understand. The plus energy home produces a surplus of 9902 kWh of final energy. Rated with a primary energy factor for renewable electricity, which avoids not renewable energy generation, the primary energy surplus is 27725 kWh.

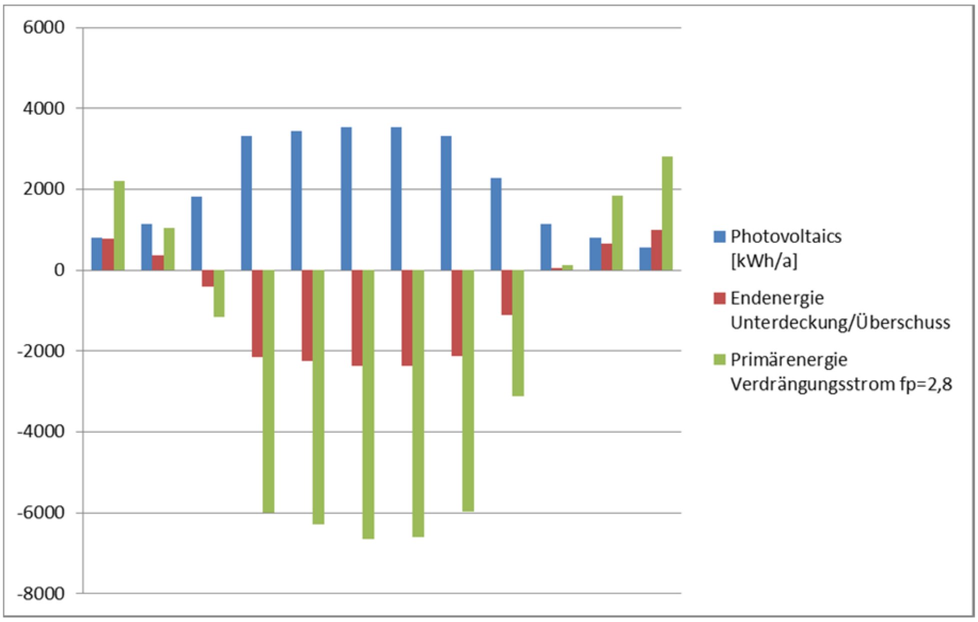


Figure 1-53 Primary energy balance indicating the solar generated electricity replacement with a factor of 2.8.

Figure 1-54 Integration of home automation for efficiency, indoor climate and monitoring.

Integrated Smart Home / Home Automation concept is planned together with the monitoring. The necessity of repair, retrofitting and addition of existing electric and electronic equipment allows the integration of a new measuring and control system based on wireless system. Therefore the enocean® radio technology is installed, with wireless sensors, controls and wireless switches for everyday building services (lighting, plugs, thermostat). The enocean® technology uses energy harvesting, in order to produce a small amount of electric energy from pressure, movement and luminance to send the wireless signals to the main unit or single switches. An additional cost and resource intensive wiring of switches and sensors is not necessary. The Smart Home Automation system uses the network of all controls, sensors and switches for the collection of data for the monitoring and the analysis and helps to reduce the costs for the monitoring as well as to integrate the home into future smart grid technology. By an integrated smart metering, down to the single appliance level, it is possible to give feedback to tenants on their energy consumption and the energy generation of the house as well as the charging status of the designated electric vehicles.

Summary

In the critical reflection of the result, a comparison of design options with the measures actually chosen is necessary, see Table 1-1. Some options that actually belong to the principles of SmartTES were not chosen for technical considerations and cost reasons. This includes the installation of ventilation ducts in the TES elements. Instead, a good alternative is selected with the space modules. It enables decentral supply of each unit and combines the equipment at a point together.

The roof extension has been decided on the basis of the need for large photovoltaic surfaces and a necessary renewal of the roof structure. The solar technology should not be shown in the facade. By choice for the roof, the yield of renewable solar energy can be maximized. The changes to the floor plans are an integral part of the overall concept including building service systems.

Table 1-4 Overview on the design options and the chosen measures for the final result.

Design options	Result
– Photovoltaic integrated in façade or roof – HVAC ductwork integrated in façade or interior – HVAC facilities integrated in façade or interior – Access situation rearrangement – Roof extension	– Highly insulated envelope produced off-site – Decentralized air heat pump and ventilation unit with heat recovery – Roof extension with PV – Annual plus energy balance – Open floor plan with new access and bathroom module

1.10 Recommendations (S.Ott)

A holistic refurbishment process including the improvement of the thermal properties of the building envelope should include a review of the adequacy of existing building services concepts and systems. Due to the reduced heat losses, the heating system must be adjusted in size and power and the higher airtightness of the envelope requires an approach to ensuring the quality of indoor air quality.

Method level

The *TES* method allows for the integration of additional non-system components that go beyond the actual task of the heat and moisture protection as well as the appearance of the facade. The timber frame components themselves provide space and structural conditions for a safe delivery of additional components. As a result, beyond the pure insulation and cladding task, multifunctionality of *TES* elements is obtained. The integration of windows as an essential component in facade projects was demonstrated in in the earlier *TES Energy Facade* – project.

Instead of retrofitting or renewing building service systems using the floor space, components can be placed right in the building envelope, by this type of application. This will improve the conditions for the use of integrated energy concepts.

An integrated approach means, in this context, the coordinated use of building services components in the context of the existing building. Building services components are defined by their active involvement in the transfer of heat, water, light, and air.

Through the feasibility within a reasonable budget of integrated concepts in higher-value solutions of the real estate value can be increased.

Feasibility of integrated concepts within a reasonable budget generate added value. The owner can go for a higher-value solution and increase the value of the real estate.

The necessary preliminary studies and the planning process is more complex, since additional constraints, as compared to a simple façade renovation, are taken into account. Such constraints include for example:

- Total building orientation and use
- existing systems and structural parts (shafts)
- alternative systems and structural changes (additions and demolition)
- service life, quality level

These parameters define the scope and depth of the intervention to be made in the existing substance and the related technologies and risks. Collaborative planning is the essential prerequisite to minimize risks and to ensure success.

Marketing and added value

- Improved living comfort – higher standard
- Advantages of refurbishing the building service systems (reducing heating system, pipes, etc.) = a substantial increase in energy efficiency
- Deep intervention which costs, construction time and restriction of users can be reduced
- Saved interior and floor space as compared to integrating ductwork inside the apartment

Construction level
Installation of various components from micro devices such as micro heat pumps, photovoltaic or solar thermal panels, to ventilation ducts.
Structural and buildings physics requirements of the *TES* construction principles have to be considered.

Sustainability
Effects on the environment during the operational phase, the use of the building, are positively influenced by integrated approaches and reactive components, making substantial improvements of energy efficiency even up to Passive House level possible.
The core substance of the existing building is protected by multifunctional building envelopes (despite deep retrofit), because large parts of the interventions happen in the envelope and this allows for a minimally invasive procedures on interiors.
Effect on society - the level of innovation of multifunctional envelopes and the holistic solution speaks of the sustainable investment because the extended life of the property delays next phase of obsolescence.
Effects on the user by *smartTES* multifunctional envelopes could be positive, since the interventions are reduced and yet simultaneously creating a higher quality of living (higher building quality).

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