Modular prefab integrated HVAC units: description and development of demonstration units

(D2.3)

Development and advanced prefabrication of innovative, multifunctional building envelope elements for MOdular REtrofitting and CONNECTions (MORE-CONNECT)

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1 Introduction

Technology innovations for deep renovation focus particularly on prefabrication of components for the building envelope (for example prefab multifunctional facades, roofs with BIPV etc.). Several products and concepts have been developed now (see also MORE-CONNECT report D2.2: A set of basic modular façade and roof elements) and a number is available as prototype or available on the market already. One of the main objectives for these innovations is to come to a substantial price reduction, by mass production and prefabrication. Currently, still a relatively large part of the renovation costs is determined by building services. This is mainly due to the fact that building services are still not fully integrated in the overall constructional renovation concept. One of the proposed ways to come to a substantial cost reduction for the building services in deep renovation is the development of compact prefabricated platforms in which the most essential components for heating, (cooling if applicable), ventilation, DHW, storage and others are combined. These so called 'engines' should also be *modular*, i.e. adjustable to the specific needs of apartments and dwellings or more, particularly of households.

The proposed *modularity* can be developed along three directions:

Modularity of the prefab engines can be developed along three different lines:

a. Modularity in place:
The most optimal place for an engine will depend to a large extent on the design and morphology of the dwelling or building. Engines can also be developed as central or as decentral units.
Central: For example as a compact complete unit which can be placed to a façade, on the roof, in the attic or basement etc.
Decentral: in a number of cases it can be convenient to split an engine into (two) parts.

b. Modularity in medium of heat transfer:
Several mediums of heat (and cold) transfer are possible like water, air (combination ventilation with air heating), all-electric or hybrid systems.

c. Modularity in phased composition of the 'engine' in time
The functionalities of this way of modularity are:

- To start with (cheaper) basic options that can be upgraded if more budget is available, (e.g. adding heat recovery to ventilation or extra PV).
- To change the engines to the needs of households, (e.g. with an expanding family adding more capacity for DHW and storage and vice versa).
- To add new technologies when available (e.g. new compact storage options).

This proposed way of modularity leads so called no-regret options, both to individual owners as for housing companies as well as single family dwellings as multifamily buildings.

The primary objective of this report is to evaluate possible heating, ventilation and air-conditioning solutions for nZEB for deep renovation of multi apartment and single family buildings and how these solutions can be applied in prefab modular installation platforms or so called 'engines'.

This task (2.3) starts with a technology inventory and review of all necessary components that is necessary to climatize the buildings. This includes heating, cooling (optional; for residential buildings: mainly buildings passive cooling with solar shading and ventilative cooling), ventilation, domestic hot water. A selection is made of the most favorable technologies, following the criteria in task 2.1. The concepts will be preferably all-electric, using demand controlled technologies for ventilation and heating, and low temperature emission systems. The HVAC components will be combined in very compact frames, preinstalled in compact units, with possibilities to mount it as a box to facades (in an integrated aesthetic and architectural appearance with the facade) or as a compact unit in attics etc. This unit is called the MORE-CONNECT engine.

For this chapter the same building as described in written material D2.1 is evaluated for each geo-cluster in order to calculate HVAC installed capacities for multi apartment buildings.

Main outputs of this document is obtaining information on HVAC installed capacities before and after renovation and sizing of systems elements. Gathered information will provide data for HVAC elements integrations specifics into prefabricated elements.

To compare the actual necessary ventilation air volumes from country to country a case building has been chosen. The building type is multi-apartment and the ceiling height should be assumed to be 2.5 m.

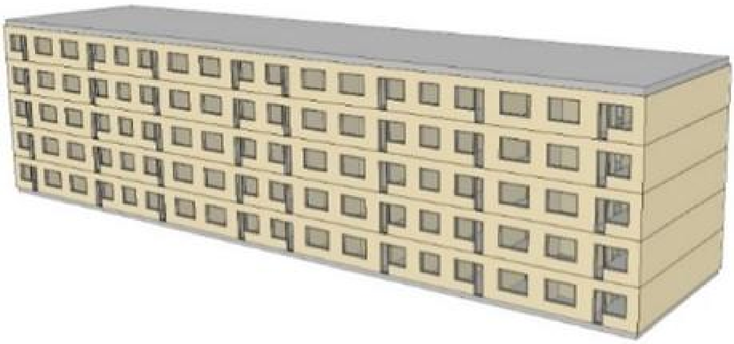


Figure 1 Image of case study building

2 Terms and definitions

additional energy – electrical energy that is used in heating, hot water supply, air conditioning and lighting systems to produce and transform supplied energy into useful energy, for example, for ventilators, pumps, electronics. Energy that is produced is not additional energy;

almost zero energy building – building with very high energy efficiency. Almost zero or very small amount necessary energy should be to big extent covered from renewable energy sources, including energy produced on the site or nearby from renewable sources;

building's energy consumption – amount of energy that describes energy consumption necessary for heating, ventilation, cooling, lighting and hot water supply of exact building;

building's energy efficiency – comparison of buildings' energy consumption amongst similar type building in the area with similar climatic conditions;

conditioned room – part of building where all year round desired temperature and relative humidity is maintained;

district heating networks – heating networks that connect heating source to heating points of users' buildings;

energy necessary for heating – calculated energy that should be supplied to heating system to maintain desirable temperature in defined period of time, not considering technical systems of the building;

heat pump – facility that relocate heat from colder place to warmer. This process consumes energy as heat arbitrarily flows in opposite direction. Depending from heat source there are ground, air or water heat pumps;

heat pump energy efficiency index (COP) – relation between discharged heat or cold energy and consumed electrical energy;

heated space – space where defined temperature is maintained with heating system;

heating area – area of heated space;

heating boiler – facility that produces energy by burning fuel and forwards it to heat carrier that provides heat energy to the building;

heating degree days – difference in degrees between room air temperature and average daily outside air temperature summed for all heating season days;

heating network net efficiency factor – relation between supplied heating energy amount to centralized heating system users in defined time interval and received heating energy in the same time period from heat source;

heating season – period of year in days when heating system operates;

internal heat energy gains – heating energy that is produced by building's residents (metabolic heat) and facilities, for example lighting, household devices, office equipment;

low energy consumption building – building whose necessary energy consumption for heating is below some defined value;

ME – mechanical exhaust ventilation

MVHR – mechanical ventilation with heat recovery passive building – building with low energy consumption where for the most part of year heating system for room temperature provision is not necessary. Necessary heat is provided using existing internal heat sources and sun energy;

primary energy – energy from renewable and non-renewable energy sources that is not recycled or transformed;

renewable energy sources integrated in the building – renewable energy sources that are only related to engineering systems of exact building;

self renewable energy sources – resources that are supplemented in natural processes but their supplement is limited. Renewable energy resources include wind, sun, aero-thermal, geo-thermal, hydro-thermal and sea energy, hydro-energy;

solar energy – energy obtained from the sun and transformed into usable energy using photovoltaic elements to produce electricity;

solar gains – heating energy provided by solar radiation entering the building through the windows directly or indirectly (after absorbing in building elements), through opaque walls and roofs or passive sun utilization for structures (for example, conservatory, transparent isolation). Active sun utilization facilities (for example, sun collectors) are part of building's technical system;

solar heating – heating energy obtained from the sun using sun collectors;

system boundary – boundary that includes all spaces (inside the building and outside) related to building where energy is consumed or produced;

system heating energy losses – heating energy losses caused by building's technical system that is not participating in system's effective output. System losses can become building's internal heating energy gains if they are recoverable. Heating energy that is recovered in the system is not heating energy loss, but heating energy gain;

wind energy – energy obtained from wind and transformed into usable energy, for example using wind generators to produce electricity or using windmill to produce mechanical energy;

zero energy building – building with Zero Net energy consumption and zero carbon emission in year's period. Zero energy buildings can be operated autonomously from energy supply network, if energy is obtained in sufficient amount on the spot.

3 Principle solutions for modular installation of HVAC systems "house engine"

Nowadays all multi apartment buildings as well as single family houses have such vitally important HVAC components as heating system, domestic hot water system, ventilation and cooling system in case of higher indoor comfort level required during the summer. Use of renewable and sustainable energy is one of the EU top priorities in order to ensure significant reduction of greenhouse gas emission caused by building sector. PV panels, solar thermal panels and heat pump energy are the most realistic sources to be widely implemented in building sector.

Usually heating systems, ventilation systems and cooling equipment are installed separately in different technical rooms and in some cases even floors or ceilings. Additional installation of renewable energy sources in later stages may require significant reconstruction of existing HVAC system. Until now, the costs of building services (HVAC systems) are a relatively large part in the total costs of deep renovation. This is due to the fact that building services are still not fully integrated in the overall constructional renovation concept. One of the proposed ways to come to a substantial cost reduction for the building services in deep renovation is the development of compact prefabricated platforms in which the most essential components for heating, (cooling if applicable), ventilation, DHW, storage and others are combined. These so called 'engines' should also be modular, i.e. adjustable to the specific needs of dwellings or more particularly of households. These so called "house engines" aim to minimize installation costs and installation time and at the same time to ensure installation quality and simple modernization during lifetime.

There are already modular solutions available on the market, especially for single family dwellings. Figures 2 and 3 presents some examples of modular HVAC installation units in Netherlands.

Figure 2 Example of modular HVAC unit developed by BAM (left), modular HVAC unit with heat pump and ventilation heat exchanger (middle), and gas boiler installation (right)

Figure 3 Engine in portal next to front door developed by Volker Wessels

A first generation of these engines have been developed and applied in a number of deep renovation projects but there are still a number of steps to take in optimization and to come to further price reduction. These presented solutions have shown good results during first years of operation in moderate climates. However, further development is necessary in order to prevent unit freezing in cold climate. Also more unified solution will ensure simple integration and combination of different energy sources i.e. renewable energy. However there are also some drawbacks that prevent the modular house engine to be easily implemented. Some of them to mention are the unique situation for each renovated building, different approaches of design solutions as well as local legislation. Nevertheless all this can be solved with the right approach and detailed approach during design process.

Typical components of modular HVAC unit are:

- ✓ Heat exchanger for heating loop;
- ✓ Hot water heat exchanger;
- ✓ Local energy source (gas boiler, heat pump, connection to external energy sources);
- ✓ Expansion tank;
- ✓ Air handling unit including ventilation heat recovery;
- ✓ In rarer case also cooling source.

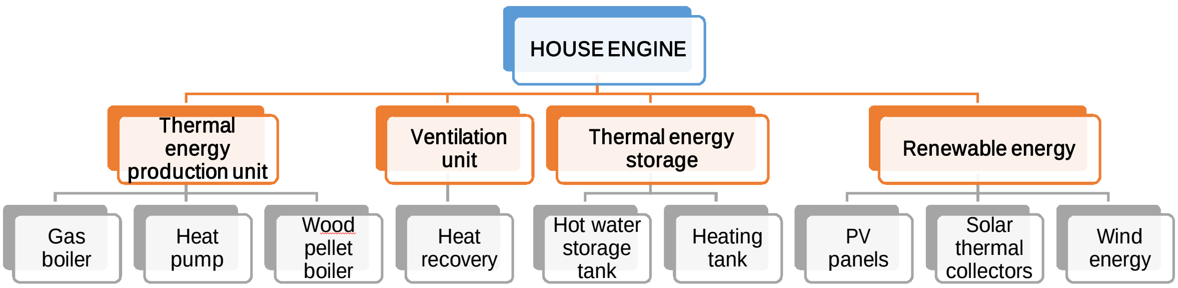


Figure 4 HVAC systems “house engine” optional component

In order to make correct sizing of modular HVAC unit the maximal capacity of all elements should be correctly calculated. The main HVAC system parameters such as duct and pipe diameters, maximal airflow of ventilation unit and maximal capacity of heating/cooling equipment affects overall size of modular HVAC unit.

To investigate the potential application of such device in the further part of the text detailed analysis is performed regarding different ventilation principles, heating and cooling calculations as well as possibility's to integrate the solution in existing houses. The calculations are dived in between not only comparing different engineering principles but also regarding different needs and legislation rules between involved countries.

4 Ventilation and air-conditioning

4.1 Introduction

Ventilation is of major importance for the well-being of people in their homes. The two main purposes of ventilation are to obtain an acceptable indoor air quality and to avoid degradation of the building fabric (e.g. rot in wood, mold, rust on steel). Improving the indoor air quality and well-being in homes is often one of most important reasons for (deep) renovation. A good ventilation strategy and selection of ventilation systems is therefore one of the most important challenges in deep renovation processes. As to indoor air quality the occupants' sensitivity can vary across a wide range from an allergic infant to a well-trained sportsman, from an active person spending most of the time outdoors to an elderly person confined to a life indoors. During the lifetime of a building, its occupancy pattern also varies.

Today there are a wide variety of different ventilation strategies in the different European countries. In some countries the only ventilation is uncontrolled air infiltration and window airing, while in others passive stack ventilation systems are more or less in common use. In countries with colder climates, mechanical systems have been installed in new buildings since the seventies, in particular in the Nordic countries. The systems are either exhaust only or balanced, with or without heat recovery units. Apart from northern Europe the dominating European ventilation system is natural ventilation.

The natural ventilation systems are driven by wind and thermally (stack) generated pressures. Designing for natural ventilation is concerned with harnessing these forces by the careful sizing and positioning of openings

4.2 Classification of ventilation systems

The ventilation systems can be dived in following groups according to the driving forces for supply and exhaust:

- natural ventilation,
- mechanical exhaust ventilation with natural supply,
- mechanical supply-exhaust ventilation
    - ✓ apartment or dwelling based ventilation system (individual)
        - central units
        - decentral units
    - ✓ building based ventilation system (central)
- hybrid ventilation

Each of these types of ventilation systems have their advantages and drawbacks.

4.2.1 Natural ventilation

The natural ventilation is obtained only through natural forces including wind pressure and stack effect. These forces are dependent on the location, surrounding, and height of the building as well as temperature gradient between indoors and outside. It must be noted that the lower floors of buildings have less effect due to wind but higher because of stack effect, while the upper floors have vice versa. The pros of this kind of ventilation system is the lack of extra energy needed to power the system but the cons of it are the uncontrollable nature of it and also the lack of possibility to regain heat or cold from exhaust air and filtrate the intake air.

This type of system was often used in older time Soviet buildings that were designed to have natural air intake through gaps in building construction and exhaust through ventilation shafts located in kitchen and bathrooms. However in colder climates, the natural ventilation system cannot be used as a ventilation system for modern newly built buildings or renovated ones as this system does not guarantee the necessary air change rate for achieving the required indoor climate conditions and does not provide opportunity to recover energy from exhaust air therefore cannot be applied in case of designing nZEB type buildings. Natural ventilation system is usable only in warmer climate where widows are often open.

4.2.2 Mechanical exhaust ventilation with natural supply

The system is a mix between natural supply and mechanical exhaust ventilation systems. It usually has natural air inlets for air supply in the façade and mechanical exhaust fans. These fans can be located either inside the apartments or on the roof of exhaust ducts. The fans help to drive the ventilation systems at times when the natural forces are not enough. If special fans are applied, they can even the suction pressure through the whole height of building therefore providing opportunity to achieve designed ventilation rates at any given moment. This system can also be equipped with temperature and moisture sensitive air inlets as well as moisture sensitive exhaust fans.

The benefits of this type of system is its relatively easy installation both for new and renovated buildings as it does not take up so much space and the exhaust fans can be applied to existing shafts in case of retrofitting. This is the reason why this kind of ventilation system is often applied in case of renovation. In addition, hybrid type system consumes very low amount of excess electricity for fan powering. At the same time, this system most often does not utilize the heat from exhaust air. Although in some case, heat recovery from exhaust air is achieved by using air to water heat pump.

4.2.3 Mechanical supply-exhaust ventilation with heat recovery

The most advanced type of ventilation system is fully mechanical with both air supply and exhaust operated by a single air-handling unit with additional elements according to needs. The most common elements of air handling unit includes dampers, filters, fans, silencers, post/preheating, cooling and heat exchanger.

The most important benefits of such a system are the possibility to precisely ensure the designed air volume for each of the room, possibility to automate the working regime of the ventilation unit depending on the needs and possibility to regenerate the heat form exhaust air which saves a huge amount of heating energy in cold climates. For example to reach nZEB status in Latvia, the ventilation system must be equipped with heat recovery unit and it must have at least 75 % thermal efficiency.

At the same time the cons of such a system are the necessity of space to place the air handling units (AHU) and ducts, need for silencers to reduce the noise, expensiveness for installation, the largest amount of consumed electrical energy for operating if compared to other types of ventilation systems. This type of systems can be further divided into two subgroups – central and dwelling/apartment (decentral) based ventilation systems. The central AHU's serves the whole building or for each staircase and could possibly be placed at in most cases can be positioned in the attic or basement. However, in cases of refurbishment the problem to locate the necessary air ducts often serves as purpose against installing such a system. To solve this, the prefabricated building envelope elements should have a dedicated place left for the ducts.

The dwelling/apartment based systems can be subdivided in two types:

- central units
- decentral units

Central units work with a system of supply ducts to habitable rooms and exhaust ducts to services rooms (kitchen, bath, toilet, storage room). In modern units laminar cross flow heat exchangers are applied with a typical efficiency of 75 – 90%.

Figure 5: Central mechanical ventilation with heat recovery

Decentral units are local units with mechanical supply and exhaust on room level, combined with heat recovery and in most cases CO_2 controlled. Sometimes these units are combined with a radiator or convector. These combined heating and ventilation solutions are very are attractive for renovation as no supply ducts are necessary. Yet these decentral units still need mechanical exhaust in services rooms

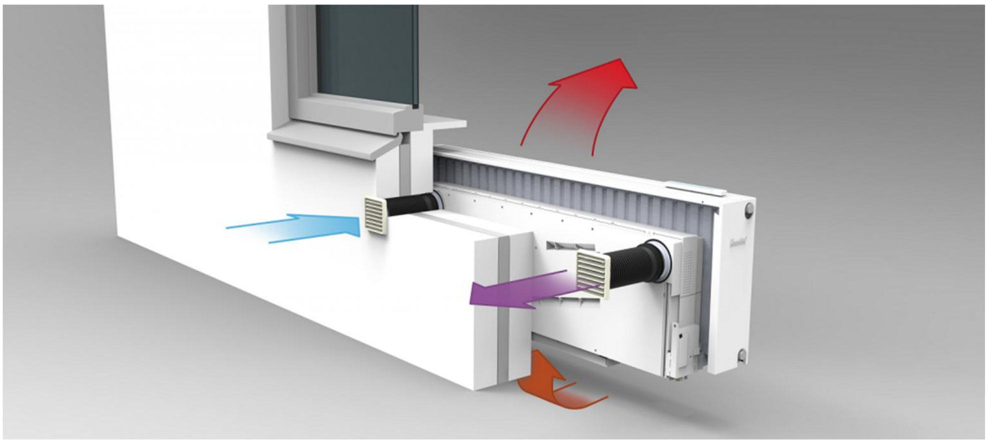


Figure 6: Decentral mechanical ventilation with heat recovery, CO2 controlled, integrated with a radiator

Figure 7 Prototype of decentral MVHR and heating element, integrated in a prefab facade. RLLL pilot dwelling Heerlen the Netherlands

4.2.4 Hybrid ventilation

Hybrid Ventilation is a two-mode system, which is controlled to minimise the energy consumption while maintaining acceptable indoor air quality and thermal comfort. The two modes refer to natural and mechanical driving forces.

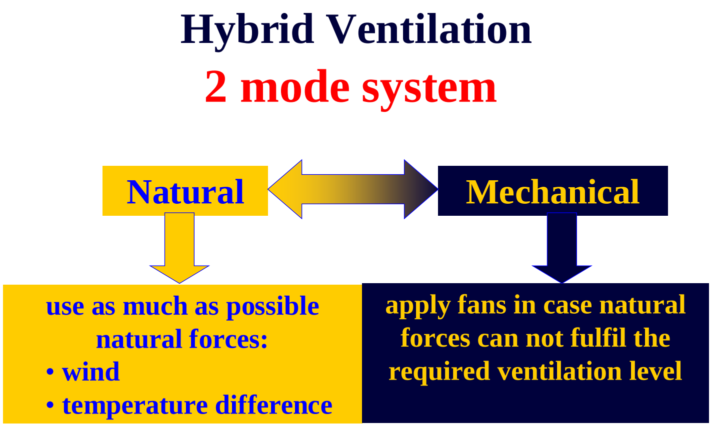


Figure 8: Schematic picture of hybrid ventilation

Three hybrid ventilation concepts can be defined:

- alternate use of natural and mechanical ventilation
- fan assisted natural ventilation
- stack and wind supported mechanical ventilation.

All buildings with hybrid systems up till now are far from what might be the optimum solution. There is a knowledge gap especially on dimensioning and control of hybrid ventilation systems.

4.3 Overview of components used in ventilation systems

The natural ventilation components used in Europe are:

- Openable windows and louvers, which in many buildings are the main component of natural ventilation. They permit the passage of large air flows for purging or summer cooling, but might cause energy waste during the heating season.
- Air vents and “trickle” ventilators, which can ensure that unnecessary ventilation can be avoided during winter. One vent per room is typically recommended. They are often located above the window or integrated into the window frame. Sometimes ventilators are located directly behind wall mounted radiators in order to avoid draft during winter.
- Automatic (variable area) inlets, which respond automatically to various air quality and climate parameters. They are not yet widely used, due to high costs.
- Passive stacks, which are vertical ducts from e.g. bathrooms and kitchens to above roof level. The purpose is to enhance temperature difference or stack driven air flow.
- Air vents for combustion appliances, which secure combustion supply air to an open combustion appliance.

Mechanical ventilation can provide controlled ventilation to a space. Mechanical ventilation components used in Europe are:

- Fans, which provide the motivating force for mechanical ventilation.
- Ducts, which transfer air. Ducts impose a resistance to air flow, thus influencing performance and energy use.
- Diffusers, which discharge mechanically supplied air into ventilated spaces.
- Air intakes, which are the openings where outdoor air is ducted to a ventilation system.
- Air inlets, which are passive openings for providing air to a space.
- Air grilles, which capture exhaust air from a space.
- Silencers (noise attenuators), which dampen the noise from the ventilation system and noise being transferred through the ventilation system.

Additionally, in the design of hybrid systems the following components and aspects may play an important role:

- local exhaust versus central exhaust
- tuning supply and exhaust
- self-controlled air inlets
- low pressure ducting supported by wind and buoyancy
- demand control
- optimal dimensioning

4.4 Existing situation in MORE-CONNECT geoclusters

4.4.1 Latvia

The existing old building stock mostly consists of the typical series buildings built during 1970ies. The ventilation system for these buildings were designed to be natural type with air supply through constructive imperfections of building envelope and exhaust through ventilation channels located in the kitchen and bathrooms. Although this system does not consume any additional energy, it is bad due to reasons like uncontrollability, lack of ventilation during summer time as well as noise and smell transfer from one flat to another. The ventilation airflows were calculated according to Soviet SNiP.

During the last 10 years, a large number of occupants of these buildings have changed the old wooden frame windows with new PVC type. This has led to reduced infiltration rate and caused problems like mold inside the bathrooms and sweaty windows in kitchen. Another problem is caused by the fact that many flats have been equipped with mechanical exhaust fans for bathrooms or kitchen hoods with connection to the existing shafts. They were not originally designed for this and therefor the smell travels between the apartments as well as causing problems for the other occupants who still have the original system.

4.4.2 Estonia

Only very old dwellings were built without stack for ventilation. In buildings without central heating system, the stove operated as a part of ventilation system (extract air), since air is needed for burning wood. Window airing was prevalent solution for outdoor air intake in that case. Before year 1991 almost all residential buildings were built without mechanical ventilation systems. Even if mechanical exhaust was designed, it made a loud noise while working and was therefore not used in practice. Supply air was designed to intake air from leakages, mostly through the windows. Fresh air inlets were also sometimes used in case of apartment buildings (Mikola et al., 2013). The ventilation systems of dwellings that were built before 1990 were designed according to SNiP II-3-71 (1972) (later SNiP 2.08.01-85, 1986).

Table 1 Ventilation airflows according to SNiP

		Supply air		Exhaust air	
Standard	Living room	Bedroom	Kitchen	Bathroom	WC
SNiP II-3-71 SNiP 2.08.01-85	1 h^{-1} (earlier) 0.8 $l/(s \cdot m^2)$	1 h^{-1} (earlier) 0.8 $l/(s \cdot m^2)$	20 l/s (75 m^3/h)	7 l/s (25 m^3/h)	7 l/s (25 m^3/h)

4.4.3 Denmark

Most single family houses and the oldest apartment blocks have natural ventilation. In the apartment blocks this functions through “chimneys” from kitchen and bathrooms with stack effect supported by wind pressure. In newer or renovated apartment blocks the ventilation capacity of these systems have been improved by exhaust air ventilation systems.

In newer low-energy single family houses and newly built or renovated apartment blocks with focus on energy saving balanced mechanical ventilation systems with heat recovery is used. The heat recovery efficiency of these systems are in the range of 75-90%.

4.4.4 Czech Republic

Important part of the national residential building stock in the Czech Republic is represented by multi-family housing with more than two million flats in 211,252 objects. More than 70 per cent of those buildings were constructed before 1979. From the undertaken statistics (Antonín J, 2014), the most frequent multi-family residential building in the Czech Republic is a 3-story house built in the period from 1946 to 1960. Another very frequent type is multi-family prefab-panel house (various systems) built approx. between 60's and late 80's.

Ventilation in these buildings was designed as natural with air change ensured by windows opening; in the meantime air infiltration occurred through leakages. Bathrooms and kitchens were usually equipped with mechanical exhaust fans connected to common ducts exiting the building above the roof. In most cases windows opening and thus ventilation was not sufficient, mainly in cold periods, because of thermal discomfort while opened windows. Additional problems arose if the original wooden frame windows have been replaced with new, mostly PVC frame, are air-tight ones – air change rate via leakages was reduced and the insufficient ventilation supports a mould growth and condensation.

4.4.5 Portugal

In Portugal most of the buildings are naturally ventilated. Only very old buildings were built without shafts for ventilation in kitchens and bathrooms. The fireplace chimney also worked for ventilation, when not in operation.

In Portuguese buildings supply air was designed to intake air from air leakages, mostly through the windows. Until 1960 buildings had natural air intake through air leakages and exhaust through ventilation shafts located in kitchen and bathrooms. In buildings built during the 1970s, 1980s and 1990s, the most common was the installation of extractors in kitchens and ventilators in bathrooms and WC (that didn´t had windows). They were only turned on when cooking or bathing, to extract moisture produced due to cooking and bathing. In more recent buildings this option is also the most common, and there are some buildings in which the kitchen extractor and the bathroom/WC ventilators operate continuously. Systems with air insufflation are not usual.

Natural ventilation, with auto-controlled air inlets (and extractor in kitchens and ventilators in bathrooms which only operate when cooking or bathing to extract moisture) is also usual in some recently built buildings. The ventilation systems of recent dwellings are designed according to NP 1037-1 (2002). However, by the time the Portuguese pilot building was constructed, the minimum required airflow ventilation rate was 1 air change per hour (D.L. 40/90).

4.4.6 Netherlands

In The Netherlands in 2015 the number of *dwellings* was 7.588.000, divided in 4.908.100 single family dwellings and 2.679.900 apartments, while the number of *households* was 7.665.198.

1.458.66 are built < 1945: 100% natural ventilation

2.476.400 are built between 1945 and 1975: 100% natural ventilation

2.158.270 are built between 1965 and 1995: multifamily: 35% natural, 65% ME;

single family: 50% natural, 50% ME

1.494.730 are built > 1995: 90% mechanical exhaust, 10% MVHR

In total 45.8% is rented; 54.2% is owned.

The reason for applying mechanical exhaust is that it was mandatory for apartment buildings in the Dutch Building Code as from 1974. Before 1974 mechanical ventilation was (hardly) used.

Due to the Energy Performance Regulation new buildings have almost 100% MVHR.

Latest developments are decentralized heat-recovery ventilation systems and combinations with hot air supply for room heating.

Most single family houses and the oldest apartment blocks have natural ventilation. In the apartment blocks this functions through “chimneys” from kitchen and bathrooms with stack effect supported by wind pressure. In newer or renovated apartment blocks the ventilation capacity of these systems have been improved by exhaust air ventilation systems.

In renovated apartment blocks and single family dwellings, with focus on energy saving, (‘NOM’ renovation = ‘zero on the meter’ renovation) balanced mechanical ventilation systems with heat recovery is used. The heat recovery efficiency of these systems are in the range of 75-90%.

4.5 Air exchange change rates

This section is to provide information on normative air exchange rates in multi- apartment buildings for countries involved in the project stated by the actual regulations. This information in needed in order to calculate energy consumption for ventilation needs and to determine the necessary duct sizing, which is very important for integrated solution as the ducts are placed inside insulation.

Table 2 Necessary residential ventilation airflow rates according to local regulations

		Geo-cluster and countries that national energy calculation methods were used					
		GC 1	GC 2		GC 3	GC 5	GC 6
Room	unit	Denmark	Estonia	Latvia	Czech Republic	Portugal ***	Netherland
Toilet	m^3/h	36	36	25	25 (50)^X	30 ($V \le 8\ m^3$) 45 ($8 < V \le 11\ m^3$) 60 ($11 < V \le 15\ m^3$)	36
Bathroom with toilet	m^3/h	54	54	50	50 (90)^X	45 ($V \le 11\ m^3$) 60 ($11 < V \le 15\ m^3$) 90 ($15 < V \le 22\ m^3$)	54
Staircases	$m^3/(h \cdot m^2)$	1.08	1.25	1	(2)	(1)	1
Bedroom	$m^3/(h \cdot m^2)$	1.08	12 (8)*	3	15 (25)^{XX} or 0.3 (0.5)^{XXX}	30 ($V \le 30\ m^3$) 60 ($30 < V \le 60\ m^3$) 90 ($60 < V \le 90\ m^3$) 120 ($90 < V \le 120\ m^3$) 150 ($120 < V \le 150\ m^3$) 180 ($150 < V \le 180\ m^3$) 210 ($180 < V \le 210\ m^3$) 240 ($210 < V \le 240\ m^3$)	1,6
Kitchen	m^3/h	72	30 (22)**	60-90	100 (150)^X	60 ($V \le 15\ m^3$) 90 ($15 < V \le 22\ m^3$) 120 ($22 < V \le 30\ m^3$)	70
Hall	h^{-1}	0.5	-	0.5 - 1	0.5–1	(1)	1
Technical room, storage room	h^{-1}	0.5	0.5	0.5 - 1	0.5–1	-	1
Total supply air	$m^3/(h \cdot m^2)$	1.08	1.5	-	The sum of the supply air of all bedrooms and living rooms	The sum of the supply air of all bedrooms and living rooms	1,6

** l/s (l/s in <11m² bedroom);*
*** for 1 room apartment;*
**** air flow to be extracted from kitchens, bathrooms and toilets and air flow to be supplied to bedrooms (V – volume of the room; all air flows expressed in m^3/h) (according to NP 1037-1 (2002))*
^{X} spasmodic ventilation; minimal value (recommended value)
^{XX} [m^3/h per person]; minimal value (recommended value)
^{XXX} [h^{-1}] minimal value (recommended value)
(1) Air flow rates for staircases and halls are not defined in PT regulations;
(2) 0.1–0.3 h^{-1}

To determine the design ventilation rate a calculation of both supply and exhaust must be performed. Afterwards the largest value must be applied as a design value. In Estonia Multi-apartment Building and Denmark exhaust airflow can be lower if required supply airflow is guaranteed.

To compare the actual necessary ventilation air volumes from country to country a case building has been chosen. The building type is a multi-apartment and the ceiling height should be assumed to be 2.5 m. There are two types of apartments. Most of them are with one bedroom but one in each staircase has two bedroom flats. Therefore the ventilation volume must be calculated for each of these situations.

The supply should be organized in the bedrooms and living rooms while the exhaust in WC, bathrooms and kitchens. The entrance areas are determined to be ventilated with the transfer air of exhaust air. The ventilation air must be rounded up to the nearest 5 m^3/h. Afterwards ventilation air volume for whole building section must be estimated. It involves multiplying the calculated ventilation air volume of one apartment with the number of apartments located in one buildings section (staircase) and with the number of stories, in this case five. This will give the design ventilation volume for one AHU as it would be possible to divide building into sections regarding staircases.

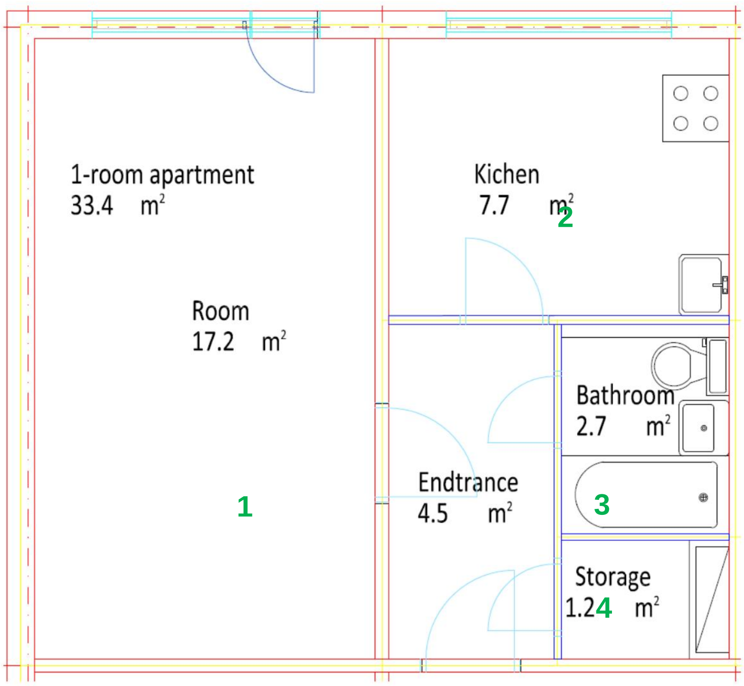


Figure 9 Plan of 1-room apartment of case building

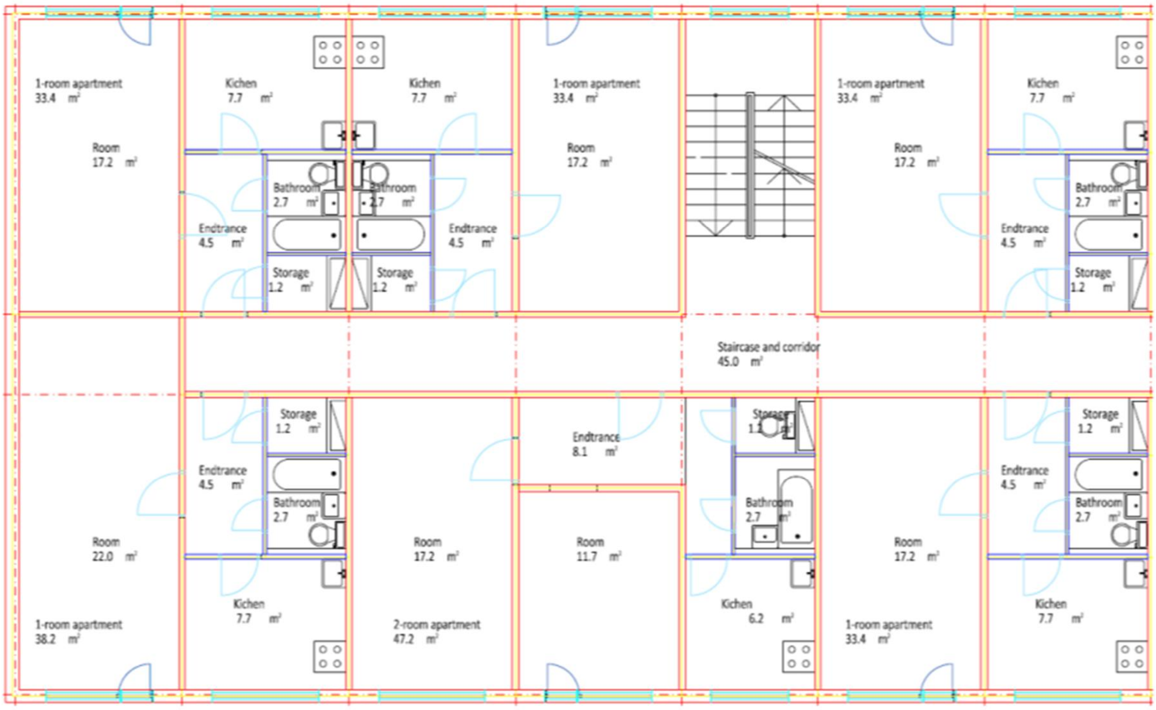


Figure 10 Plan of one staircase section of case study building

Table 3 Calculated ventilation air volumes for Latvian case study building

Room nr.	Room type	Supply air m^3/h	Exhaust air m^3/h
1	Bedroom	55 (90 for 2-room apartment)	-
2	Kitchen	-	90
3	Bathroom	-	50
4	Storage	-	-
Total for an apartment (m^3/h)		55 (90)	140
Total for whole building (m^3/h)		$6 \cdot 5 \cdot 140 = 4200$	

Table 4 Calculated ventilation air volumes for Estonian case study building

Room nr.	Room type	Supply air m^3/h	Exhaust air m^3/h
1	Bedroom	86*	-
2	Kitchen	-	22 (30 for 2-room apartment)
3	Bathroom+WC	-	54
4	Storage	-	10
Total for an apartment (m^3/h)		86*	86
Total for whole building (m^3/h)		$(5 \cdot 86 + 119) \cdot 5 = 2745$	

**Minimum supply air calculated based on bedrooms supply air requirements is 43 m^3/h (12 l/s); minimum supply air calculated based on total is change rate requirements is 50 m^3/h (14 l/s=0.42*33.7). The final supply air flow is larger because of larger exhaust airflow.*

Table 5 Calculated ventilation air volumes for Denmark case study building

Room nr.	Room type	Supply air m^3/h	Exhaust air m^3/h
1	Bedroom	20	
2	Kitchen	-	72 - VAV
3	Bathroom	-	54 - VAV
4	Storage	-	-
Total for an apartment (m^3/h)		40 (50)*	40 (50)*
Total for whole building (m^3/h)		(5 · 40 + 50) · 5 = 1250	

**Minimum supply air calculated based on minimal necessary air exchange rate requirements which are 0.3 l/s/m² (40 m³/h for 33.4 m² apartment, and 50 m³/h for 47.2 m² apartment).*

Table 6 Calculated ventilation air volumes for Czech Republic case study building

Room nr.	Room type	Supply air m^3/h	Exhaust air m^3/h
1	Bedroom	75	0
2	Kitchen	51	72
3	Bathroom	0	54
4	Storage	0	
Total for an apartment (m3/h)		126	126
Total for whole building (m3/h)		6 · 5 · 126 = 3780	

Table 7 Calculated ventilation air volumes for Portugal case study building

Room nr.	Room type	Supply air m^3/h	Exhaust air m^3/h
1	Bedroom	60 (90 for 2-room apartment)	-
2	Kitchen	-	90
3	Bathroom	-	45
4	Storage	-	-
Total for an apartment (m^3/h)		60 (90)	135
Total for whole building (m^3/h)		6 · 5 · 135 = 4050	

Table 8 Calculated ventilation air volumes for Netherland case study building row house 3 rooms, 125 m^2

Room nr.	Room type	Supply air m^3/h	Exhaust air m^3/h
1	Bedroom	36	36
2	Kitchen	70	70
3	Bathroom	54	54
4	Storage	1	1
Total for a row house (m^3/h)		200	200
Total for whole building (m^3/h)			

As the above results show the necessary ventilation air volumes strongly vary from country to country. The highest demand for ventilation according to local regulations is in case of Latvia – 4200

m^3/h for whole building, while the lowest one is for Denmark – 1250 m^3/h. However it must be noted that the results could differ in other cases depending on the planning of apartments due to different relations between room areas. The highest value is taken into further calculations as a design value.

4.6 Duct design

After determining the necessary ventilation volume, it is possible to calculate the duct sizes. To determine the optimal duct size and shape it is assumed that the air velocity in the ducts that are placed in the modular elements should be in range of 3 to 6 m/s. Higher values could lead to noise problems, while lowering it means that the duct sizes need to be larger and therefore the insulation thickness is reduced.

The optimal shape for ventilation air ducts is round due to the aerodynamic properties. In table below it is calculated what the duct sizes should be to provide the necessary air volume for the apartments with limited velocity of 3; 4 and 6 m/s. In case of natural exhaust the air velocity should be less than 1 m/s. The standard size increments (100mm; 125 mm; 160 mm, 200 mm, 250 mm, 315 mm, 400 mm, ...) of ducts are used. It is also possible to make the supply duct in rectangular shape to decrease the thickness. At the same time the relation between sides of rectangular shaped duct should not exceed 4:1.

Two different approaches of supply air duct design are evaluated. The first approach is when each apartment has a separate duct, which is coming from the main branch near the AHU. The second approach is with one main raiser that gradually decreases in size starting from top to bottom floor.

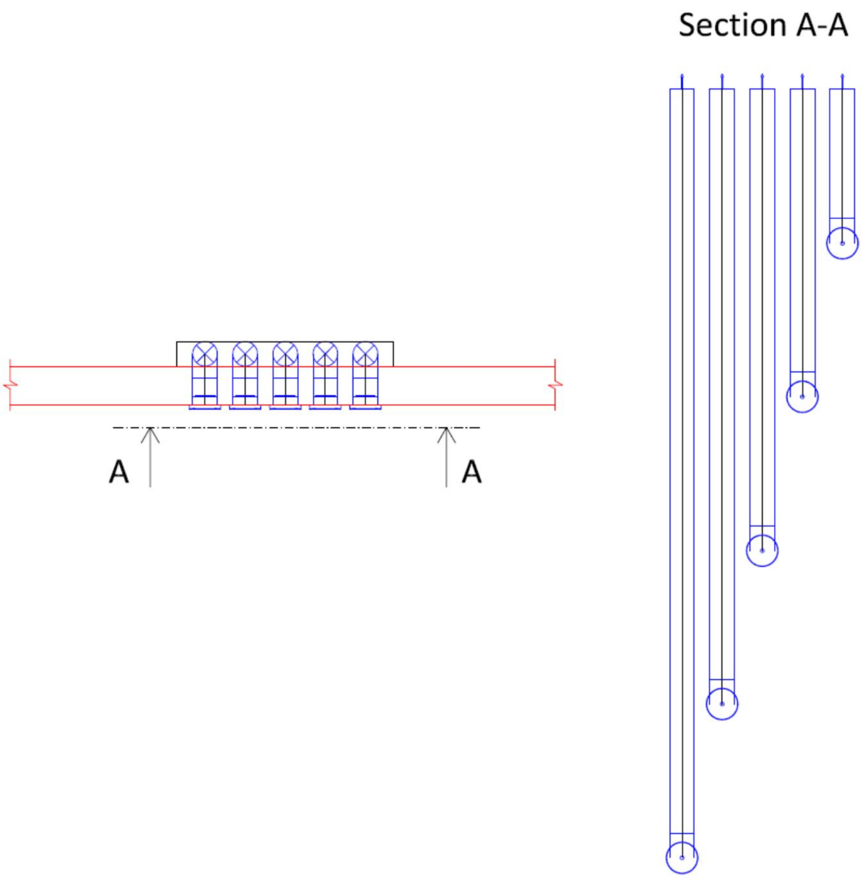


Figure 11 Case of separate ventilation duct risers to each apartment

In case when a separate duct is lead to each of the apartments the size of each duct can be smaller, which is important as the thickness of insulation where it is possible to place the ducts is limited. However, in this case more ducts are necessary and they take up more horizontal space besides the facade if compared to single risers situation. The necessary riser duct diameter in case of each country is given in the table below.

Table 9 Necessary diameters of ducts in case of separate ducts (raiser) to each apartment

In the Netherlands all rooms are separately supplied and deducted

Velocity in ducts	Round duct size, mm					
	Latvia (140 m^3/h)	Estonia (119 m^3/h)	Denmark (50 m^3/h)	Czech Republic (126 m^3/h)	Portugal (135 m^3/h)	Netherlands (200 m^3/h)
< 3m/s	160	125	100	125	160	80
< 4m/s	125	125	100	100	125	80
< 6m/s	100	100	100	100	100	80

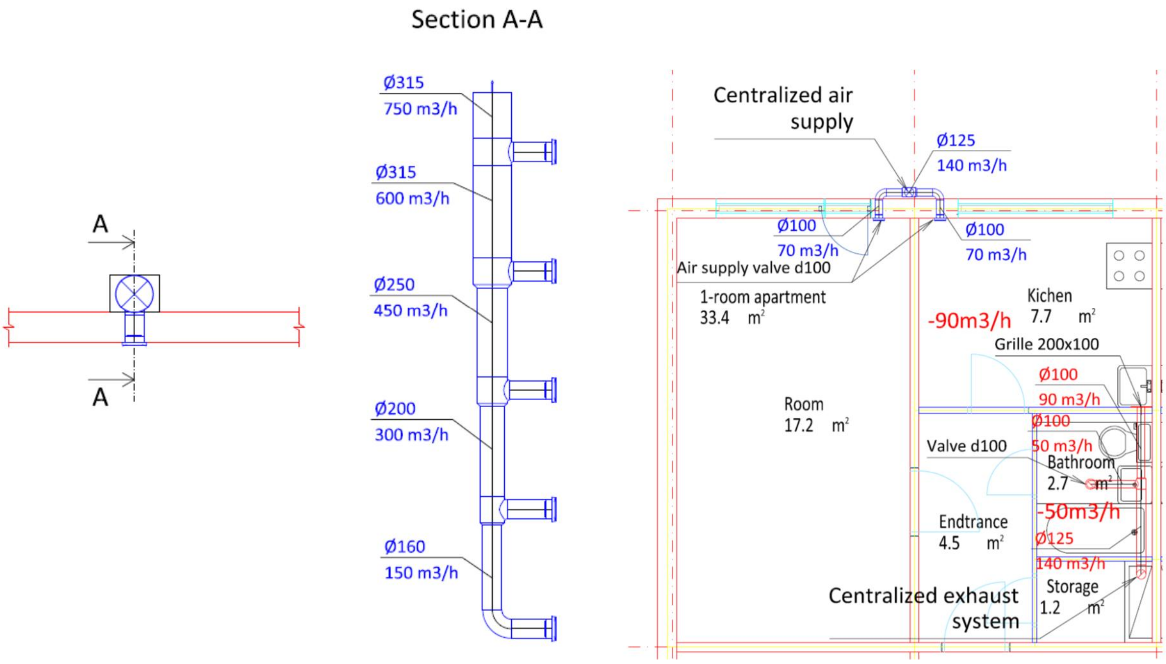


Figure 12 Case of one main ventilation duct riser for apartment section

Table 10 The necessary diameter of largest air duct in case of one main riser

Not applicable for Netherlands pilots (row houses)

Velocity in ducts	Round duct size, mm					
	Latvia (700 m^3/h)	Estonia (595 m^3/h)	Denmark (250 m^3/h)	Czech Republic (630 m^3/h)	Portugal (675 m^3/h)	Netherlands (200 m^3/h)
< 3m/s	315	315	200	315	315	n/a
< 4m/s	250	250	160	250	250	n/a
< 6m/s	250	200	125	200	200	n/a

4.7 Design examples of ventilation systems

The following chapter gives design examples for possible ventilation systems as described in chapter 4.1. The shown air volumes are for case of Latvia as it had the highest necessary ventilation volumes according to regulations. For each ventilation type, a rough specification is provided to show the necessary elements and average prices of them. The specification does not include fittings, mounting elements or work price. To compensate this the final cost of the system is assumed to be higher by 10 to 30%. These values are later used to compare the overall installation and running costs between different solutions.

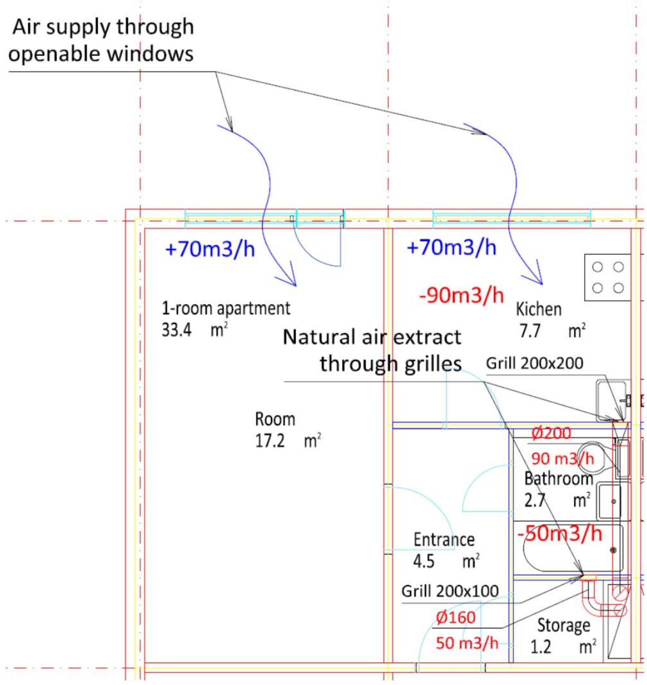


Figure 13 Ventilation system through openable windows and natural exhaust

Table 11 Specification of ventilation system through openable windows and natural exhaust

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
Extract grille	200x100 mm	Pcs.	1	17.00
Extract grille	200x200 mm	Pcs.	1	20.00
Duct	Ø200 mm	m	2	1.90
Duct	Ø160 mm	m	3	1.50
Total cost with 30 % added				60.00

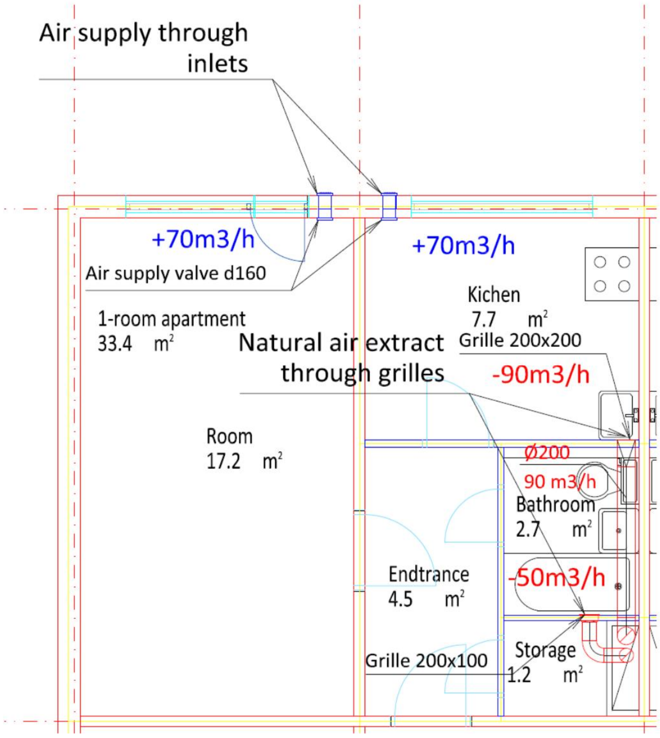


Figure 14 Ventilation system through air inlets and natural exhaust

Table 12 Specification of ventilation system through air inlets and natural exhaust

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
Supply vents	Ø160 mm	Pcs.	2	120.00
Extract grille	200x100 mm	Pcs.	1	17.00
Extract grille	200x200 mm	Pcs.	1	20.00
Duct	Ø200 mm	m	2	1.90
Duct	Ø160 mm	m	3	1.50
Total cost with 30 % added				370.00

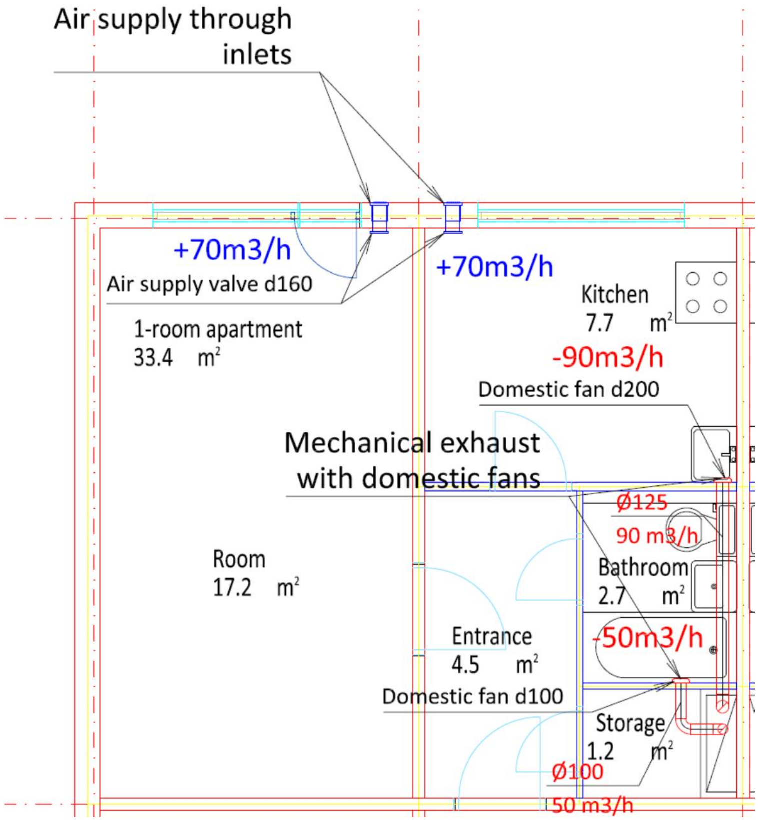


Figure 15 Hybrid type ventilation system with supply through air inlets and mechanical exhaust

Table 13 Specification of hybrid type ventilation system with supply through air inlets and mechanical exhaust

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
Supply vents	Ø160 mm	Pcs.	2	120.00
Domestic type extract fan	Ø100 mm	Pcs.	1	70.00
Domestic type extract fan	Ø200 mm	Pcs.	1	90.00
Duct	Ø125 mm	m	2	1.20
Duct	Ø100 mm	m	3	0.90
Total cost with 30 % added				525.00

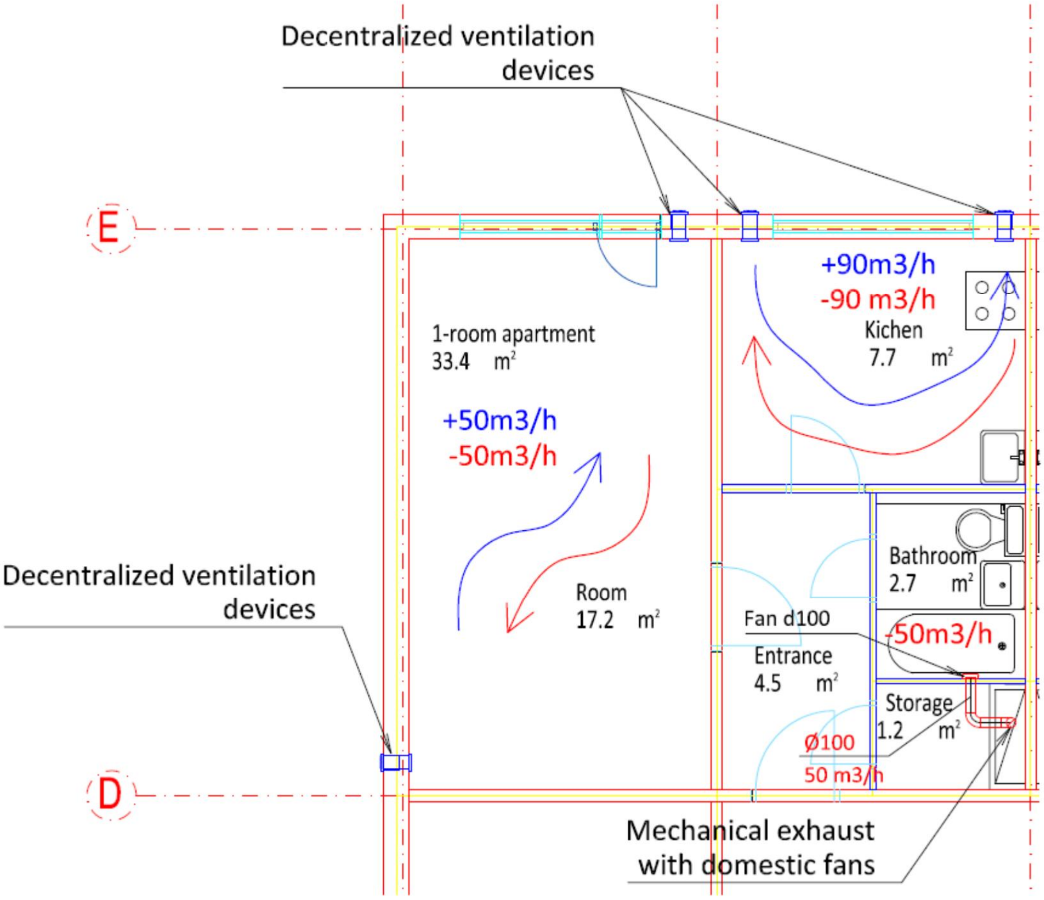


Figure 16 Decentralized ventilation system with room based mechanical supply and exhaust with room based heat recovery

Table 14 Specification of decentralized ventilation system with room based mechanical supply and exhaust with room based heat recovery

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
Paired decentralized ventilation devices (50 and 90 m^3/h)	-	Pcs.	2	1000.00
Domestic type extract fan	Ø100 mm	Pcs.	1	70.00
Duct	Ø100 mm	m	2	0.90
Total cost with 10 % added				2280.00

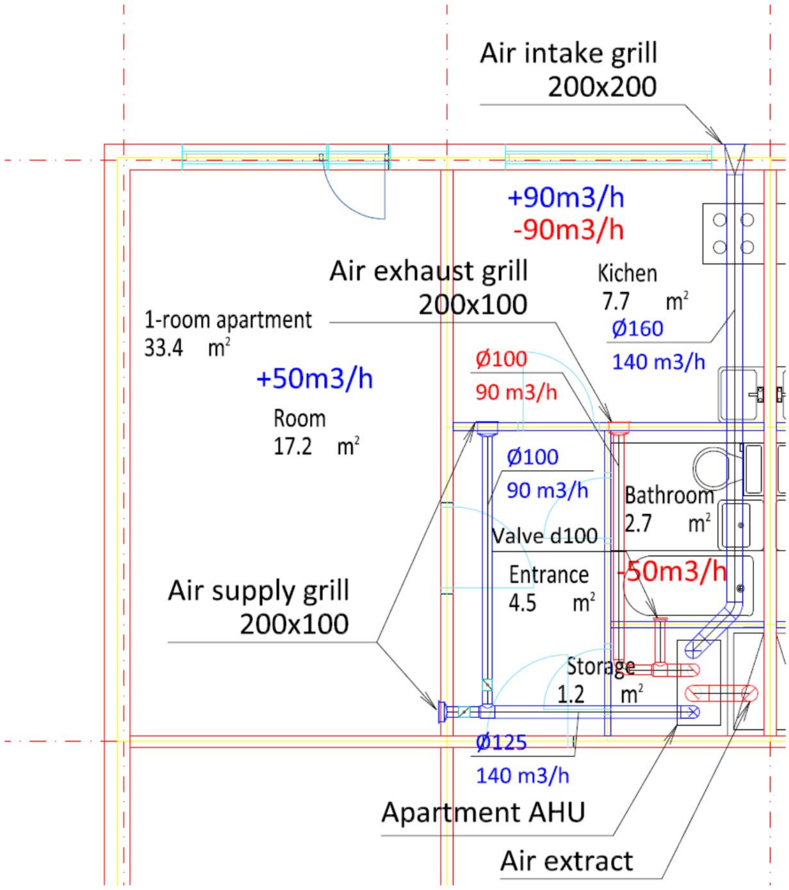


Figure 17 Decentralized ventilation system with apartment based mechanical supply and exhaust with apartment based heat recovery

Table 15 Specification of decentralized ventilation system with apartment based mechanical supply and exhaust with apartment based heat recovery

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
AHU (140 m^3/h)	-	Pcs.	1	1800.00
Air intake grill	200x200 mm	Pcs.	1	40.00
Extract air roof hood	Ø160 mm	Pcs.	1	200.00
Air supply grill	200x100 mm	Pcs.	2	17.00
Air exhaust grill	200x100 mm	Pcs.	1	17.00
Air exhaust valve	Ø100	Pcs.	1	5.00
Duct	Ø160 mm	m	10	1.50
Duct	Ø125 mm	m	4	1.20
Duct	Ø100 mm	m	7	0.90
Silencers	Ø100 mm/ L=1000mm	Pcs.	4	75.00
Total cost with 20 % added				2900.00

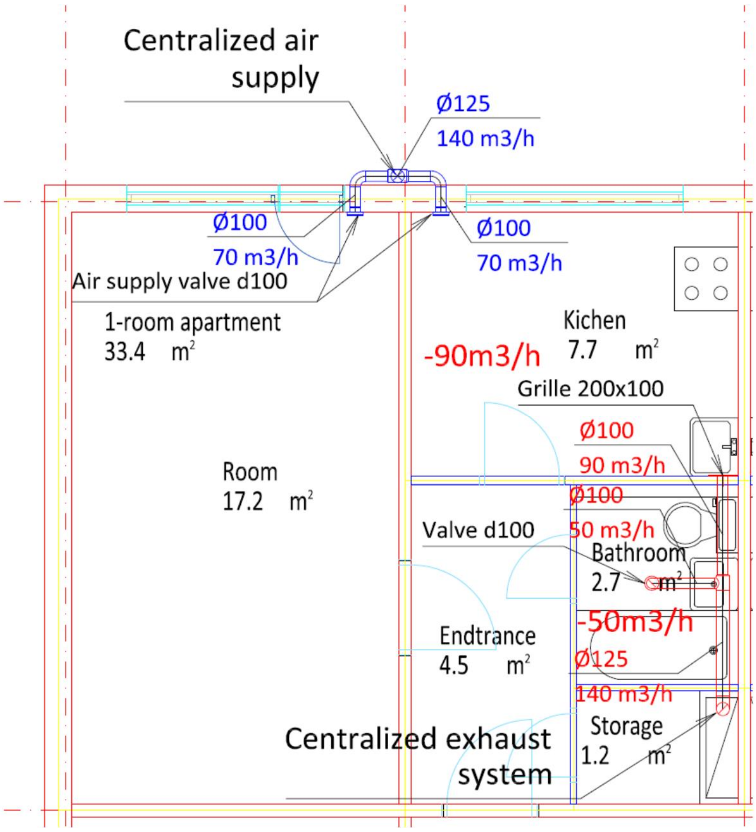


Figure 18 Centralized ventilation system with building based mechanical supply and exhaust with heat recovery

Table 16 Specification of Centralized ventilation system with building based mechanical supply and exhaust with heat recovery

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
For whole building				
Centralized AHU (4200 m^3/h)	-	Pcs.	1	9500.00
Air intake grill	Ø560 mm	Pcs.	1	100.00
Extract air roof hood	Ø560 mm	Pcs.	1	700.00
Silencers	Ø560 mm/ L=1000mm	Pcs.	4	250.00
Duct	Ø560 mm	m	20	17.30
For apartment				
Air supply valve	Ø100 mm	Pcs.	2	5.00
Air exhaust grill	200x100 mm	Pcs.	1	17.00
Air exhaust valve	Ø100 mm	Pcs.	1	5.00
Duct	Ø160 mm	m	3	1.50
Duct	Ø125 mm	m	4	1.20
Total cost with 30 % added*				560.00

**The total cost includes the cost of all units located in the apartment and 1/30 of whole price for whole building units, as there are thirty apartments that would be served by the AHU.*

4.8 Cost analysis of ventilation systems

A major importance in choosing the appropriate ventilation system is the cost analysis. To compare cost efficiency of different ventilation systems the following factors must be taken into account:

- installation costs,
- maintenance costs,
- heating costs to heat up the ventilation air,
- electricity consumption for powering the ventilation system.

The cost comparison is done for the previously described case study buildings one staircase (6 apartments and 5 stories).

Table 17 Comparison of installation and running costs for Latvian case study

Type of ventilation system	Installation costs[1] (EUR)	Maintenance costs[2] (EUR)	Heating costs[3] (EUR)	Powering costs[4] (EUR)	Total Yearly costs (EUR)
Natural by opening windows and natural exhaust	1800	-	8390	-	8386
Natural by having inlet valves and natural exhaust	11 100	300 (10 per apartment)	8390	-	8686
Hybrid by having inlet devices in walls and mechanical exhaust	15 750	450 (15 per apartment)	8390	640	9478
Decentralized mechanical supply and exhaust with heat recovery (room based heat recovery)	68 400	750 (25 per apartment)	1680 (heat recovery efficiency 0,80)	1285	3712
Decentralized mechanical supply and exhaust with heat recovery (apartment based heat recovery)	87 000	1050 (35 per apartment)	1260 (heat recovery efficiency 0,85)	960 (SFP 1.0)	3268
Centralized mechanical supply and exhaust with heat recovery	16 760	250	1680 (heat recovery efficiency 0,80)	1150 (SFP 1.2)	3080

[1] Cost of installing all necessary equipment;

[2] Yearly maintenance cost for all necessary equipment for whole staircase section;

[3] Cost of heating supply air for one heating season assuming the average heating season outside temperature according to local regulations, indoor temperature +22,0°C, length of heating season according to local regulations, assuming the heating occurs by district heating system with following costs: for Latvia: 55.55 EUR/MWh; for Estonia: 55.55 EUR/MWh; for Portugal: 55.55 EUR/MWh; for Denmark: 55.55 EUR/MWh; for Netherlands: 55.55 EUR/MWh; for Czech Republic: 55.55 EUR/MWh;

[4)] Yearly cost of all energy necessary to power the ventilation devices for whole staircase apartment assuming that they are powered by electricity with the cost of 0.169 EUR/kWh for Latvia; 0.169 EUR/kWh for Estonia; 0.169 EUR/kWh for Netherlands; 0.169 EUR/kWh for Czech Republic. 0.169 EUR/kWh for Denmark, 0,2279 EUR/kWh for Portugal.

Table 18 Comparison of installation and running costs for Estonian case study for indoor climate category II (0.42 l/(sm^2)

Type of ventilation system	Installation costs (EUR)	Maintenance costs (EUR)	Heating costs (EUR)	Powering costs (EUR)	Total Yearly costs (EUR)
Natural by opening windows and natural exhaust	-	-	20 220	-	20 220
Natural by having inlet valves and natural exhaust	20 000	-	20 220	-	20 220
Hybrid by having inlet devices in walls and mechanical exhaust	40 000	-	13 500	2100 (SPF1.0)	15 600
Hybrid by having inlet devices in walls (behind radiators) and mechanical exhaust with heat pump heat recovery	160 000	250	10 100	10 200 (SFP 1.2 + electricity demand of the heat pump)	20 550
Decentralized mechanical supply and exhaust with heat recovery (room based heat recovery)	176 000	750 (25 per apartment)	8000 (heat recovery efficiency 0,40)	2900 (per apartment; SFP1,4)	11 650
Decentralized mechanical supply and exhaust with heat recovery (apartment based heat recovery)	240 000	1 500 (50 per apartment)	3600 (heat recovery efficiency 0,75)	3300 (SFP 1.6 Per apartment)	8 400
Centralized mechanical supply and exhaust with heat recovery	216 000	250	3600 (heat recovery efficiency 0,75)	4100 (SFP2.0)	4260

4.9 Comparison of ventilation strategies

4.9.1 Comparison of advantages and disadvantages

To summarize the chapter a brief overview of each ventilation systems advantages and disadvantages is given in the table below.

Table 19 Comparison of different ventilation strategy advantages and disadvantages

Type of ventilation system	Advantages	Disadvantages	Comments
Windows opening and natural exhaust	+ Low investments and maintenance + Does not involve any technologies (solid) + Easily controllable + Does not affect architecture	- Incoming air does not heat up therefore causing draft - Incoming air does not go through filters therefore letting insects and dust - Low control options - Requires human interaction - Very low working efficiency during warm period of year - Let's through extra noise from outside - No possibilities for heat recovery - Affected by outside weather (wind, temperature)	Not allowed in some countries by building reg's
Natural ventilation with inlet valves	+ Relatively low investments and maintenance + Requires only some equipment + Easily controllable + Incoming air goes through filters therefore not letting insects and dust inside + Moderate control options	- Incoming air does not heat up therefore causing draft (can be solved by placing inlet valves behind radiators) - Requires some human interaction - Very low working efficiency during warm period of year - Let's through extra noise from outside - No possibilities for heat recovery - Affects building façade by requiring openings	Solution not always possible when the ambition is nZE renovation
Mechanical exhaust ventilation with natural supply through inlet valves	+ Relatively low investments and maintenance + Requires only some equipment + Easily controllable + Incoming air goes through filters therefore not letting insects and dust inside + The exhaust fans can be equipped with light switch or moisture sensor	- Incoming air does not heat up therefore causing draft (can be solved by placing inlet valves behind radiators) - Let's through extra noise from outside - Low possibilities for heat recovery - Affects building façade by requiring openings	

		+ Stable working throughout the year		
	Room based	+ Requires only some equipment + High control options + Incoming air goes through filters therefore not letting insects and dust inside + The devices can be equipped with moisture sensor + Stable working throughout the year + With heat recovery therefore reducing heating costs and supplying warm air	- Very high investment costs - Let’s through extra noise from outside and is a source of noise (relatively quiet) - Affects building façade by requiring openings - Low air volumes - Requires multiple devices for each apartment	
Mechanical supply-exhaust ventilation	Apartment based	+ All-in-one equipment includes all necessary parts + Complete control options + Incoming air goes through filters therefore not letting insects and dust inside + The devices can be equipped with moisture, CO_2, VOC or occupancy sensors + Stable working throughout the year + With heat recovery therefore reducing heating costs and supplying warm air	- Very high investment costs - Can be a source of noise if designed incorrectly - Requires place for ducts in shafts and rooms	
	Building based	+ All-in-one equipment includes all necessary parts + Average investment costs + High control options + Incoming air goes through filters therefore not letting insects and dust inside + The device can be equipped with moisture, CO_2 occupancy sensors + Stable working throughout the year + With heat recovery therefore reducing heating costs and supplying warm air	- Occupants are not in control of the centralized device - Can be a source of noise if designed incorrectly - Requires place for ducts in shafts, building envelope and rooms	

4.9.2 Selection of ventilation systems and strategies for deep renovation in relation to reliability

Ventilation reliability can be defined in a number of ways. From a scientific point of view, reliability is expressed as a probability that something is working in an acceptable way (or better). There is also a time-dependence involved. Most mechanical components are torn over time and finally, components break down or perform less and less well until the performance is unacceptable.

Ventilation reliability means - in general - the probability that the chosen ventilation system performs in an acceptable way for a certain building in a certain climate between scheduled maintenance measures. Following aspects concerning reliability can be discriminated:

- Reliability as indicated by air flow rate stability
- Reliability as indicated by performance over time

In order to understand the meaning of ventilation reliability it is important to realise the difference between the reliability behaviour of a "perfect" system and a system under influence of ageing. It is not necessarily so that the "perfect" system creates a reliability of 100 %. The principal influence of situational factors on reliability are shown in table below for different ventilation strategies.

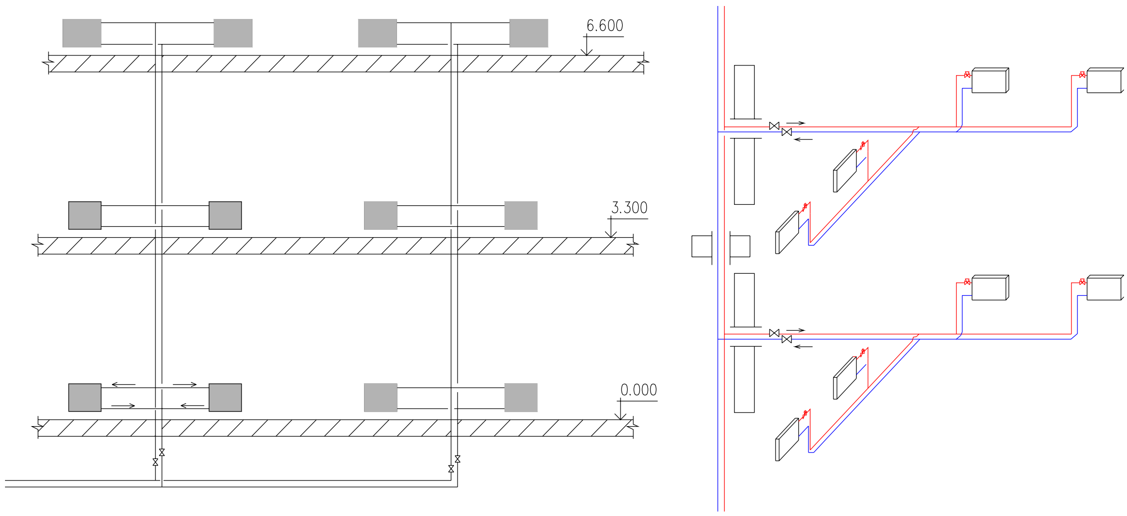
Table 20 Situational factors influencing ventilation reliability

Factor	Degree of influence				
	Natural ventilation		Mechanical ventilation		Hybrid ventilation
	Window airing	Passive stacks	Mechanical exhaust	Mechanical supply/exhaust	
Climatic conditions	Strong	Strong	Moderate, especially regarding distribution of ventilation between rooms	Strong, if the envelope is untight	Moderate
Air tightness of building envelope	Strong	Strong	Small	Strong, if the envelope is untight	Strong
Window airing user patterns	Extremely strong	Strong	Strong, especially regarding distribution of ventilation between rooms	Strong	Strong
Outdoor air supply devices	Strong	Extremely strong	Strong, especially regarding distribution of ventilation between rooms	n/a	Strong
Central fan flow rate	n/a	n/a	Extremely strong	Extremely strong	Moderate
Local fans in kitchen and bathroom	Strong, for kitchen and bathroom	Strong, for kitchen and bathroom	Strong, for kitchen and bathroom	Strong, for kitchen and bathroom	Strong

5 Heating systems

During the retrofitting process, the main influence can be felt regarding the heating system as the improved insulation drastically reduces the need of energy for heating. Therefore, it is a wise decision to also renovate the heating systems and to make them in sync with the new building needs. This not only means changing the heating elements to new and smaller ones, but also the balancing of the system as well as modernizing the heart of system – the heating unit. If the existing system is very old than it can mean that all the pipelines must be changed and the system can be made in better way. Regarding pipes, it is much easier to implement changes as they are notably smaller compared to ventilation ducts. Therefore, they can be placed in the modular retrofitting element without any problems.

Major part of old heating systems doesn't have possibilities for regulation valve installation on heating elements. Regulation valves on single pipe systems may not be installed without additional bypasses that allow continuous water circulation in systems. In some cases old heating systems have 3-way valves, which give a possibility for manual water flow regulation in each heating element without blocking water circulation in heating systems. During building refurbishment, double pipe systems mainly are used. Two major solutions are presented in Figure 19.



a) with lower supply b) loop system

Figure 19 Double pipe system

The loops system can be implemented also during renovation of existing buildings. But the practical implementation of such heating system is limited by extensive construction works in apartments, reduction of space due to new pipes usually are placed along the walls and bigger initial investments.

Table 21 Design parameters for heating calculations according to local regulations

		GC 1	GC 2		GC 3	GC 5	GC 6
		Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
Design parameters	Indoor air temperature	+20 °C	+21 °C	+20 °C	+20 °C	+ 18 ºC	+20 °C
	Design outdoor air temperature for heating	-12 °C	-21 °C	-20,7 °C	-15 °C*	+ 11,3 ºC	-5 °C

		GC 1	GC 2		GC 3	GC 5	GC 6
		Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
	Length of heating period in days	-	-	203	247*	186	180
	Average temperature of heating period	4 °C	-	+0,0 °C	+ 3,7 °C*	+ 9,9 ºC	4 °C

* for locality of pilot building – Milevsko (The Czech Rep. is divided into several regions of different design outdoor conditions).

There are two main options for heating pump integration:

- ✓ Inside the apartments;
- ✓ Integrated into prefabricated panels;

5.1.1 Latvia

The majority of old non-renovated buildings in Latvia have one-pipe heating system with the upper distribution (see Figure 20). This means that the hot supply heating water is pumped to the highest level of building and afterward it flows down due to gravitational forces as well as due to difference in density which is caused by decrease in temperature. Such system often causes problems of uneven heating as higher floors receive more heat than needed while lower ones are often left in cold. Such systems usually are not balanced as the only means of balancing was through changes in pipe diameter.

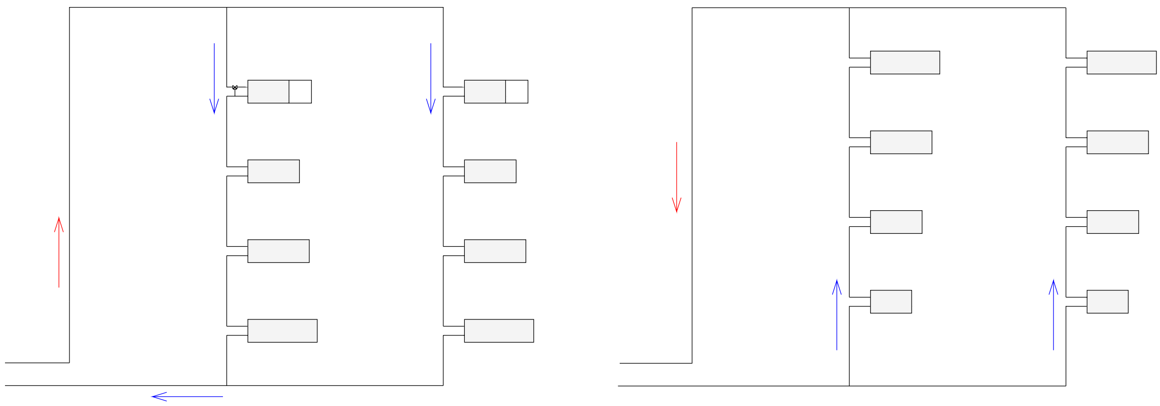


Figure 20 The principal schemes of single pipe systems used before 1990ies

However the number of buildings with such type of system is decreasing as almost all renovated and all newly built buildings are designed and built with two-pipe heating system with proper balancing possibilities or adding special by-pass valves that help balancing the one-pipe system.

As for the heat source the buildings most often use connection to centralized heating system if there is one in close proximity. Each house is equipped with individual heating substation which includes heat exchanger therefore providing detached connection between the major external heat supply system and internal heating system.

5.1.2 Portugal

The majority of the existing Portuguese buildings do not have a central heating system. The proportion of households with fixed heating systems and central heating systems is relatively small in the country. However, that fraction has progressively increased in buildings that are more recent. The commonly used heating system is based on individual/portable heaters on each dwelling. The same is observed regarding the DHW system (individual water heater). Therefore, the largest majority of Portuguese buildings do not have a pipeline for this purpose.

6 Passive cooling integrated solutions

Space cooling can be implemented using passive strategies, which can eliminate or significantly reduce the need for mechanical systems. Some passive strategies take advantage of cold sources that allow cooling the building. Examples of the most common cold sources are the ground, whose temperatures, during summer, are lower than outdoor temperatures, and exterior air, which in particular periods of the day (night and early morning) presents lower temperature than the building's indoor temperature. These temperature differences occur due to the wide daily temperature ranges in the summer period, especially in the South of Europe (Gonçalves & Graça, 2004).

Other cooling strategies include radiative cooling, that takes advantage of the radiative temperature difference between the building environment and the sky temperature, and cooling due to water evaporation. Furthermore, the adoption of solutions that lead to the prevention and mitigation of heat gains (e.g. shadings, insulation) and strategies that can lead to heat dissipation processes, is fundamental to reduce the cooling needs and improve thermal comfort. Figure 21 presents a diagram of all the passive cooling solutions that can be integrated in buildings.

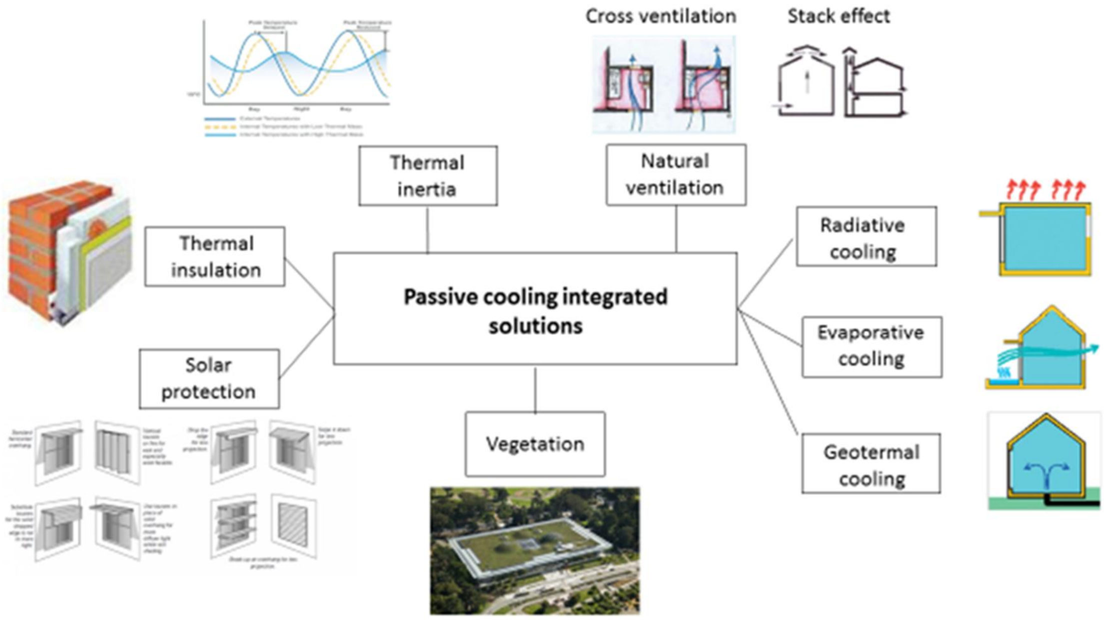


Figure 21 Passive cooling integrated solutions for buildings

Although many passive strategies for passive cooling are available, only solar exposure protection and natural ventilation are further discussed.

6.1 Solar exposure protection

Preventing solar radiation from reaching the building and its interior is one of the fundamental strategies for avoidance of overheating conditions in its interior. Although solar protection of the envelope is beneficial, most crucial is shading of the openings. This can be achieved by creating obstacles to the sun path (shading devices) or manipulating the solar-optical properties of glazed surfaces (high reflectivity, thermochromics, electrochromic, holographic glasses).

Shading devices can significantly reduce the building's peak heat gains and cooling requirements. Due to transmission, reflection and absorption characteristics of glazed surfaces, exterior shadings are normally preferred over interior shading. Interior shading devices are less thermally efficient than exterior ones because they allow sunlight to penetrate into the space, where it can cause some heat gain. The effectiveness of an internal shading device depends on its ability to reflect incoming solar radiation back through the fenestration before it is absorbed and converted into heat within the building. Thus, light-colored, reflective shades are more effective than dark ones at keeping out unwanted solar heat. The major advantage of interior shading devices is that they are typically easier to operate and maintain that most operable exterior elements. Draperies, venetian blinds, vertical blinds and roll up shades are common additions to residential windows

External devices commonly make use of strategies such as overhangs, shutters, trellises, louvers and awnings. The most common form of exterior shade is an exterior fixed horizontal overhang. In West and East façades, the overhang is not very effective because the sun height is low during sunrise and sunset. These façades often have more need of vertical fins (louvers) in order to avoid low-angled sun. For south-facing windows is fundamental to provide shading to prevent solar radiation of penetrating in summer, though allowing it during winter. Figure 22 shows some examples of different strategies for external fixed devices.

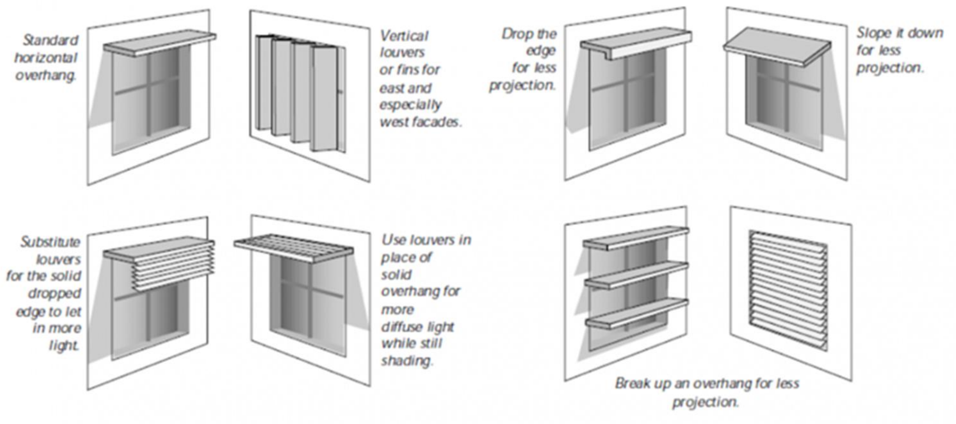


Figure 22 Examples of different exterior shading strategies (DTTN, Upatras & CUT, 2016).

Calculation for a 24m^2 room with a southern-oriented window had shown the significant effect of external shading at latitude 56 °. Window area is 5,2m^2. Figure 23 presents energy consumption for room cooling with different shading strategies.

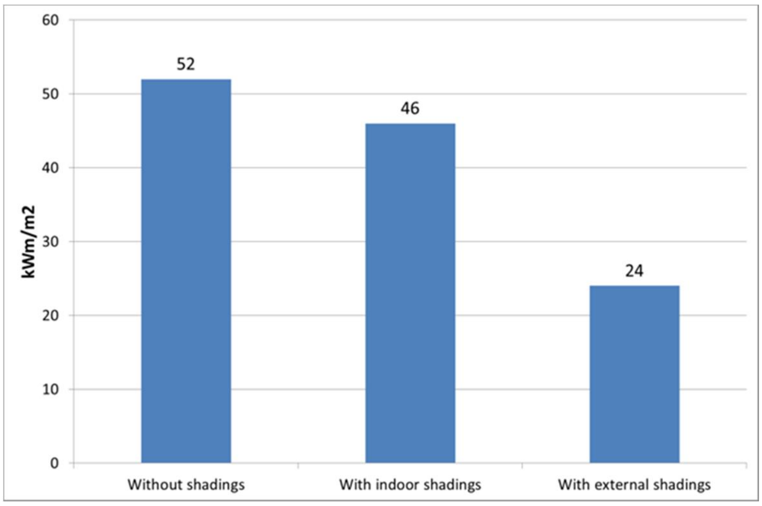


Figure 23 Room energy consumption for cooling with south oriented window [Borodinecs 2015]

Trellises and overhangs are popular and inexpensive options. They are fixed structures and should be sized to reduce the amount of sun reaching the glazing in the cooling season, while allowing as much sunlight as possible to strike the glazing in the heating season (Figure 24).

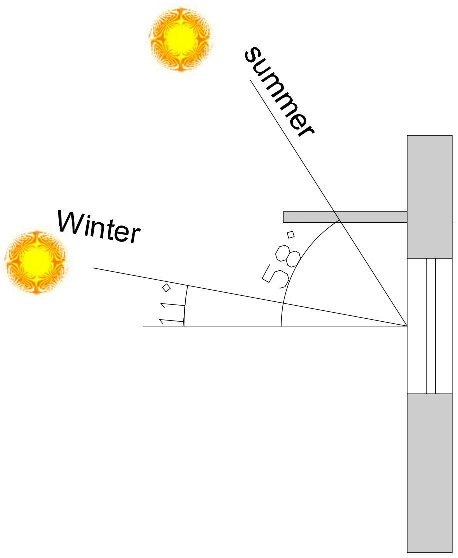


Figure 24 An overhang shades in summer but allows heat in during winter (Latitude 55N Riga)

Roll shades can be solid or translucent, allowing some slight into the living spaces. The fabrics used should be resistant to ultraviolet degradation and must be weather-resistant.

Awnings may be fixed or movable. The fixed awnings should be designed as overhangs in order to allow for solar gain during the heating season (Figure 24), whereas movable awnings should be removed and stored during the heating months. The latter provide shade only when is needed, adjusting to the angle of the sun, thus providing more flexibility.

Louvers can be horizontal or vertical and can be installed in the interior and exterior. In either location, movable, adjustable louvers can reduce solar gain and glare and also provide insulating and/or reflecting qualities. Vertical louvers are particularly effective for southeast and southwest exposures. Both louvers and awnings can be manually or electrically operated (Steven Winter Associates, 1997). Advanced systems can have automated windows or louvers actuated by thermostats. Figure 25 shows the GSW headquarters in Berlin, which comprises a double-glazed aluminium curtain wall solar shading devices.

Figure 25 GSW Headquarters passive building (left) and façade detail (right) (Source: http://www.sauerbruchhutton.de/images/GSW_headquarters_en.pdf).

Another solution to avoid solar radiation through glazed surfaces is to manipulate the solar-optical properties of glazed surfaces. Chromogenic windows have the capacity to regulate their properties, especially its solar transmittance in response to changing temperature: as the temperature increases, the solar transmittance decreases to block the undesirable solar radiation. There are two different types of chromogenic windows: i) thermochromic (TC), which uses adhesive coating to adjust tinting passively with window surface temperature; and ii) electrochromic (EC), which uses operable switches or automated building control systems to actively tint the window via electric current. Figure 26 shows the performance of thermochromic windows in different periods of the day.

Figure 26 Suntuitive® Glass windows installed at an educational facility in Keller, Texas, USA. Photo courtesy of Pleotint, LLC.

Solar protection of the envelope is also important, especially for the roof, that has an increased solar exposure. Roof protection can be achieved through strategies such as thermal insulation, green roofs and cool roofs. Solar protection of the envelope can also be achieved through the presence of vegetation in the building surroundings.

6.2 Natural ventilation

Natural ventilation is the process through which it is possible to take advantage of the temperature difference between indoor and outdoor, during specific periods of the day. This effect is especially significant in mild climates where the temperature range between day and night can reach 20°C. It is a very effective strategy for evacuation of the building interior heat gains whenever the outdoor temperature is below the indoor temperature. It contributes to reduce the indoor temperature, remove the sensible heat stored in thermal mass and increase comfort, by increasing heat losses by convection and evaporation in the occupants. This process occurs through pressure differences (between windows, doors, etc.) created by temperature differences or by wind action on the building.

The ventilation strategies are essential to mitigate heat gains through the building envelope that occur during the day. These heat gains depend on the thermal mass of the building and its capacity of storing heat in the structure. A strong thermal inertia reduces the peak values of cooling and mismatches the exterior and interior temperatures, thus resulting in steadier interior conditions and narrower temperature range. Therefore, night cooling through natural ventilation can easily evacuate the heat gains in the interior of the building.

There are three main types of ventilation: single-sided ventilation, cross ventilation and stack ventilation, which are further presented.

Single-sided ventilation occurs when the openings are located on only one façade of a ventilated space, as shown in Figure 27 When compared with other types, single-sided ventilation mainly provides lower ventilation rate as well as less penetration of airflow. In order to strengthen the airflow rate and its penetration length, openings in different heights with greater vertical size should be designed (Chenari et al., 2016). Having two windows in the same wall also improves ventilation rates. Furthermore, architectural elements, such as ventilation fins, help to induce and improve ventilation.

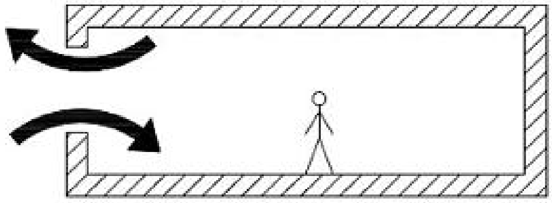


Figure 27 Single-sided ventilation (DTTN, Upatras & CUT, 2016).

Although this strategy is common, it presents some disadvantages. It often results in poor ventilation due to the small net driving forces. Furthermore, the depth of penetration of air is restricted. In general, whenever possible single-sided ventilation should be avoided.

Cross ventilation occurs in spaces that normally have openings on opposite façades. In this case, the outdoor air enters the space from the windward façade and leaves from the leeward side (Figure 28). Cross ventilation is generally the most effective form of natural ventilation.

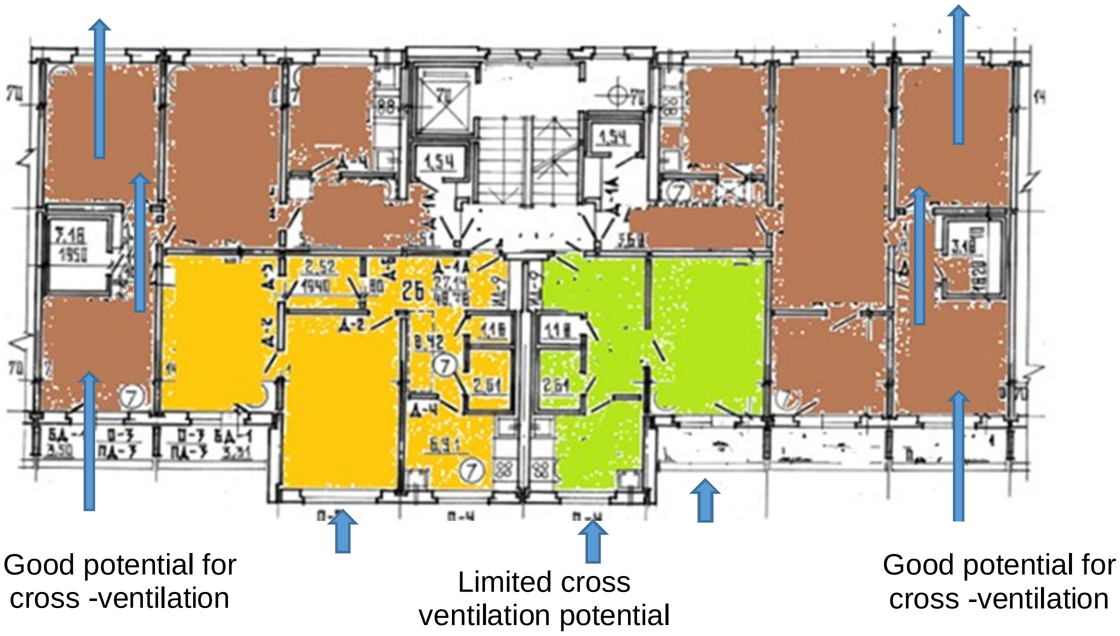


Figure 28 Cross ventilation potential in multi apartment building

As it can be seen, one-bedroom apartments usually have limited possibilities for cross ventilation. The operation of exhaust fan is recommended for apartment facing one façade. One of possible solution is use of rotary chimney cowl.

The effect of cross-ventilation can be reinforced by building proper orientation towards the direction of prevailing winds. However, it is not possible to change existing building orientation.

The position of ventilation openings is significant to optimize the path air follows through the building. The openings should not be placed exactly across from each other in a particular space. Although it provides effective ventilation, it also causes some parts of the room to be poorly cooled, while placing openings across from, but not directly opposite, each other causes the room's air to mix and thus better distributes cooling and fresh air.

Placing inlets low in the room and outlets high in the room can cool spaces more effectively, because they leverage the natural convection of air. This last effect is particularly important for stack ventilation. Positioning of openings should also take into account the direction of prevailing winds and place inlets upwind and outlets downwind.

Figure 29 and Figure 30 show how the design of openings influences natural ventilation.

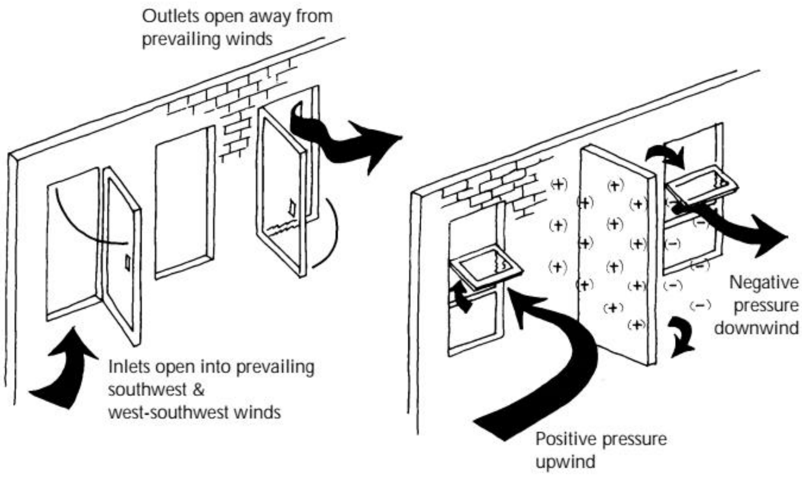


Figure 29 Influence of the wind direction and pressure on natural ventilation and positioning of openings (Source: Cole et al., 1999).

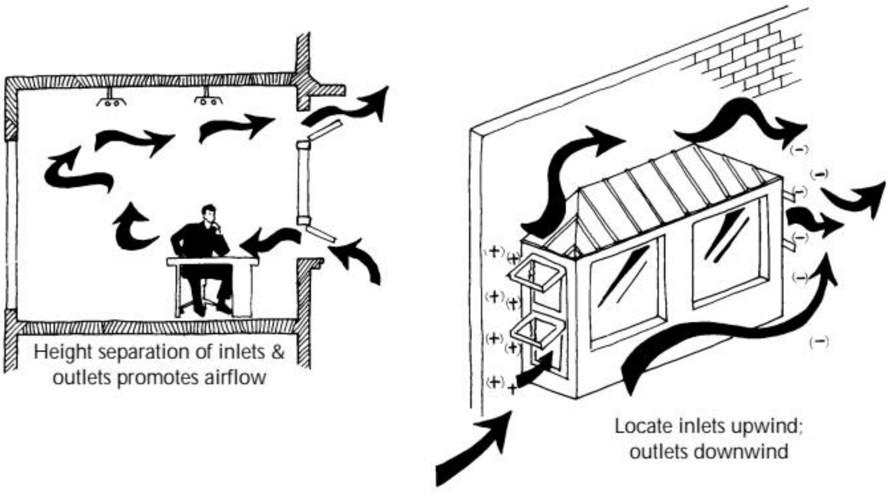


Figure 30 Influence of openings height and location in the building envelope on natural ventilation (Source: Cole et al., 1999)

Stack ventilation results from air buoyancy, which is a force that results from the difference in air density, which depends on temperature or humidity differences. It takes place when the airflow enters the ventilated space through openings located in different façades and goes out through an opening located in a higher level such as a chimney (Figure 31).

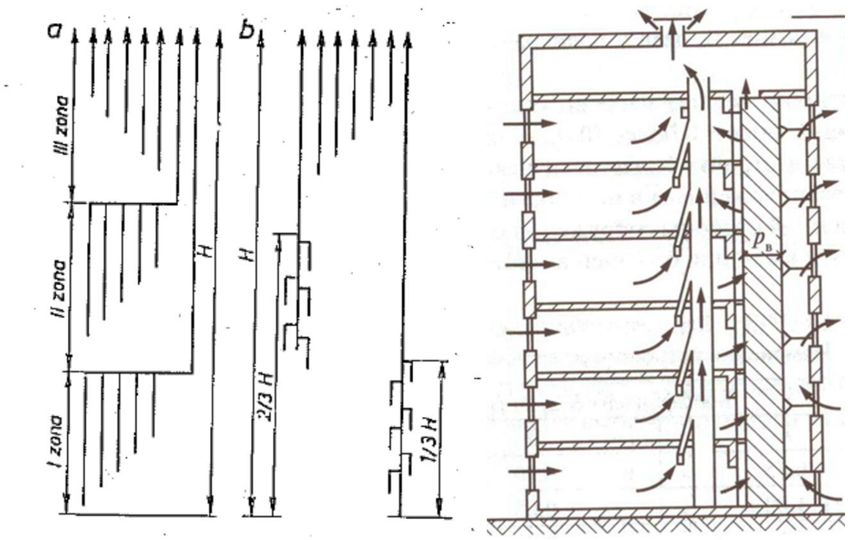


Figure 31 Examples of the use of stack effect in multi apartment buildings

Solar radiation can be used to enhance stack ventilation in tall open spaces. Solar chimneys (Figure 32), which have considerable effects on decreasing heat gains, and enhancing natural cooling and ventilation, work with stack effects. Solar heat gains warm a column of air, which then rises, pulling new outside air through the building. A solar chimney allows extracting the warmer air from occupied spaces, and it should end at a superior height than the one from the roof of the building.

Principal scheme
Source: Gonçalves, & Graça, 2004

Practical application in cold climate

Figure 32 Solar chimney

There are also other solutions for natural ventilation and air treatment, such as using wind towers. A wind tower is a system that introduces air in a building. It takes the wind at certain height above the roof, where it is most intense, and then the air is carried by a duct, which can be introduced by the lower part of the premises. This system is more common in dry hot climates and is able to chill indoor spaces in the middle of the day in a desert to cold temperatures.

Towers, chimneys, atria, skylights or clerestories can be useful to carry air up and out. For these strategies to work, air must be able to flow between levels. Multi-story buildings should have vertical atria or shafts connecting the airflows of different floors.

Strategies for natural ventilation include operable windows, ventilation louvers, and rooftop vents. Installing weatherproof vents contributes to passive ventilation of attic spaces in hot climates. In addition to simply preventing overheating, ventilated attics can use natural ventilation principles (e.g. stack effect) to help cool a building. There are several styles of passive roof vents: open stack, turbine, gable, and ridge vents (Figure 33).

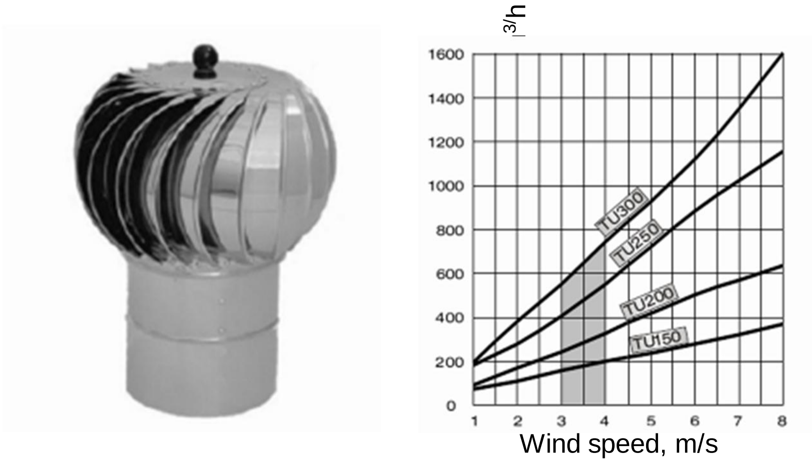


Figure 33 Open stack, turbine and gable vents (Source: Anna http://www.a-v-s.lt/vejo_turbinos_turbovent_1.html).

The use of vegetation can also contribute to reduce the cooling needs of a building. When used in the building surroundings it helps to regulate the temperature and humidity of the exterior air that surrounds the building, whereas when integrated in the building itself (greenery systems), it serves as thermal insulation.

Two examples of buildings whose design included passive techniques are show in the next figures. Figure 34 shows the wind cowls that contribute to natural ventilation through stack effect.

Figure 34 BedZED housing development (The environment centre, 2016).

7 Installation of RES

After implementing all the necessary basic elements of prefabricated multifunctional building envelope elements there is still need for some additional energy for heating and hot water preparation to reach ZEB level. Therefore the need for renewable energy source installations. The most common renewable energy sources used are solar panels for production of heating and hot water preparation, solar PV panel for electricity production and heat pumps. For more information regarding the calculated areas of produced renewable energy on site for various renovation scenarios see material D2.1 “Initial performance criteria and requirements for innovative and multifunctional building envelope elements”.

In cases when building does not fully reach for ZEB status there must be combination between renewable and other energy sources. The non-renewable sources can differ from case to case and involve connection to common district heating system or local boilers either running on gas, woodchips or pellets. Below is an example of principled scheme with solar heating energy with addition of gas boiler. Nowadays all major gas boiler manufactures provide standardized integration of solar thermal collectors into gas-fired hot water systems.

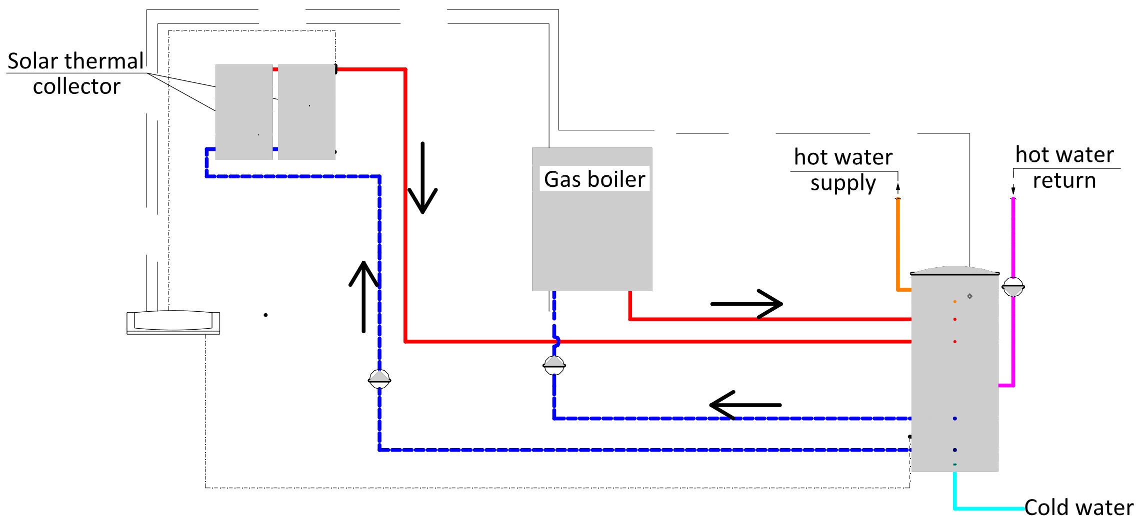


Figure 35 Principled scheme of hot water and heat preparation with solar collectors and additional heating source

In cases when building is designed to be zero energy then no no-renewable energy sources are allowed. This means that all the energy needs must be covered by renewable sources. Sometimes it can be challenging due to different limitations like space to put solar collectors, architectural reasons or the local weather that does not allow to cover all the needs for energy during winter time. In these cases it could be need to combine the solar energy with some additional energy, for example ground heat pump. The principled scheme of such case can be seen below:

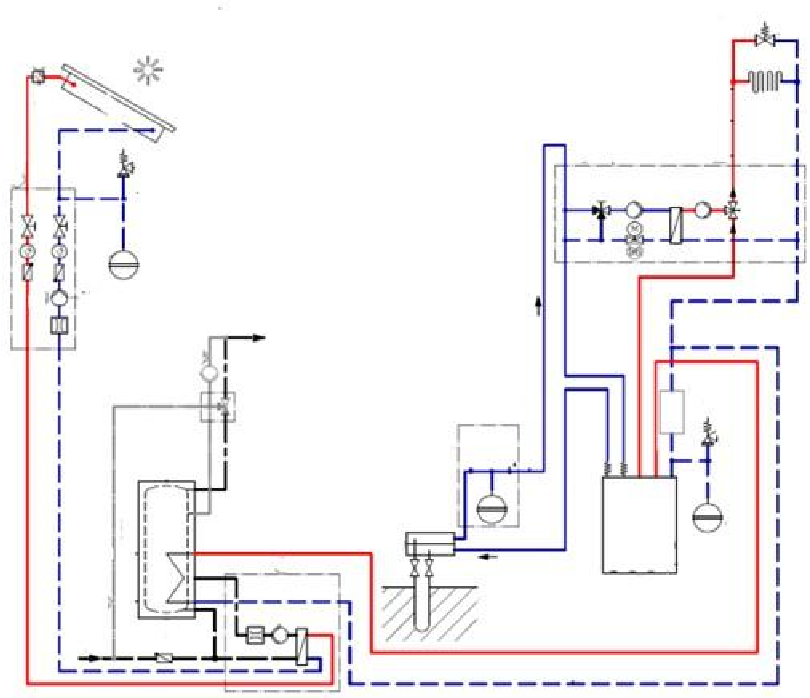


Figure 36 Principled scheme of hot water and heat preparation with solar collectors and heat pump (developed based on standardized Viesmann solutions)

In case of district, heating systems there are several opportunities to integrate renewable energy into existing heating system. One of the main challenge is to match temperature curves of district heating systems and renewable energy sources. Also the need to heat up the hot water above 60 degrees can be challenging but is necessary to prevent growth of legionella bacteria's. This can be solved by using some additional electricity ten or through disinfection.

All before mentioned solutions represents "parallel" connection. In this case, water storage tank has two separate connections. These solutions are suitable and can be easy implemented in buildings with individual heat sources. In district heating systems, series arrangements of different heat sources can be applied. However, different temperature profiles of district heating system and renewable units should be taken into account. Figure 16 presents temperature profile of Riga district heating company.

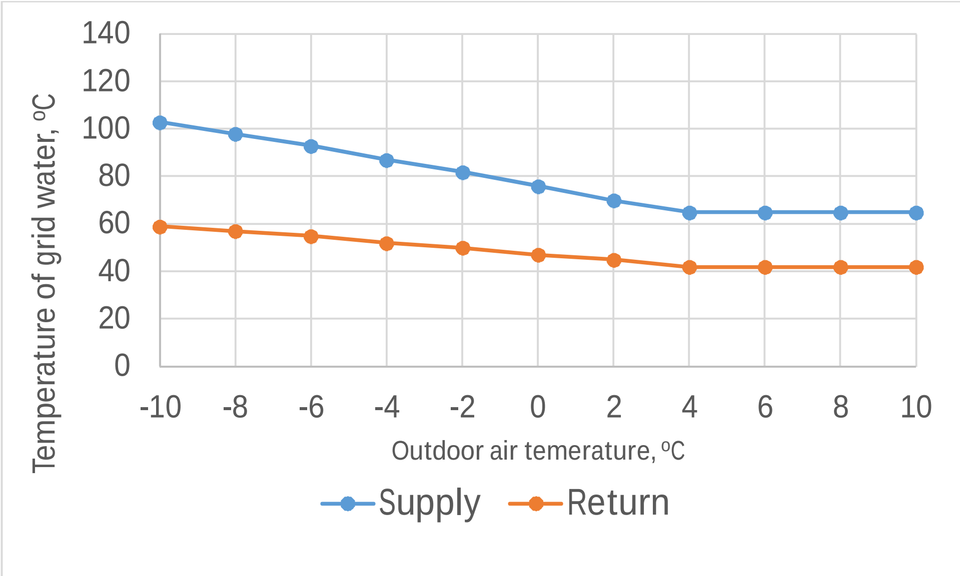


Figure 37 Supply and return water temperature in Riga district heating system

As in can be seen, the minimal supply temperature is 65ºC, while the heat pumps maximal supply temperature is 55 ºC. Improper connection of heat pump can increase temperature of return loop. Thank causes unbalance of supply/return temperature curve of district heating system.

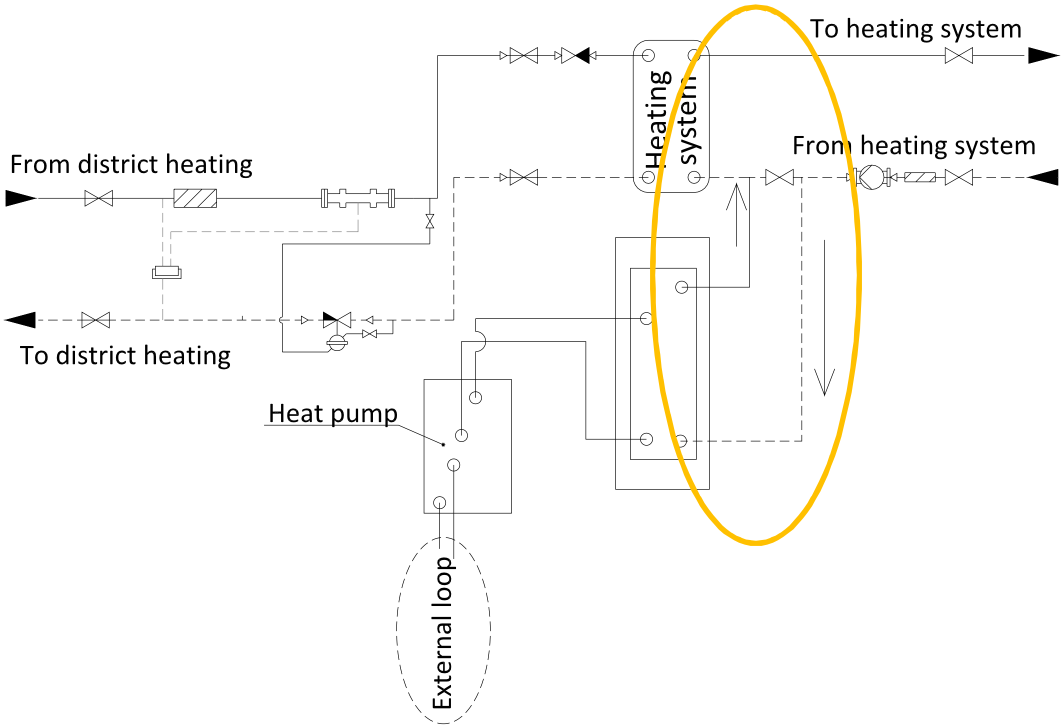


Figure 38 Heat pump series connection to heating system return pipe in combination with district heating system

Such design scheme allows increasing efficiency of heat pump while reducing temperature difference in supply and return pipes.

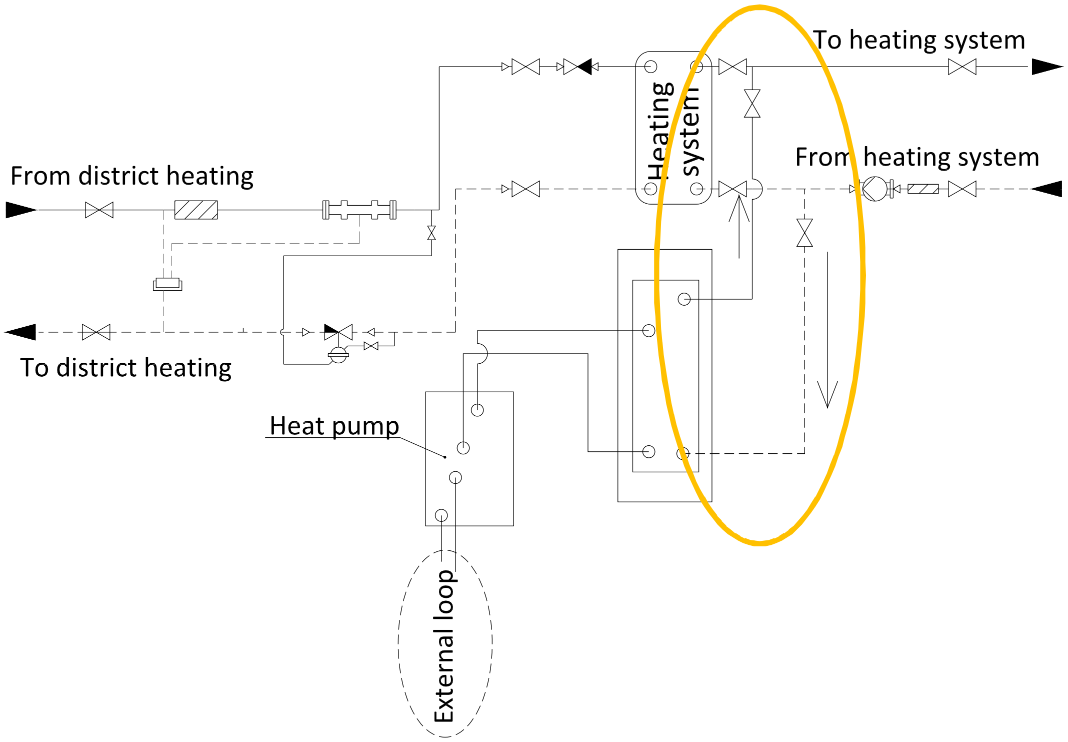


Figure 39 Parallel connection of heat pump to district heating system

In both before mentioned cases special automation system should be introduced for temperature control of supply and return pipes.

Several companies offers typical solar unit for district heating systems.

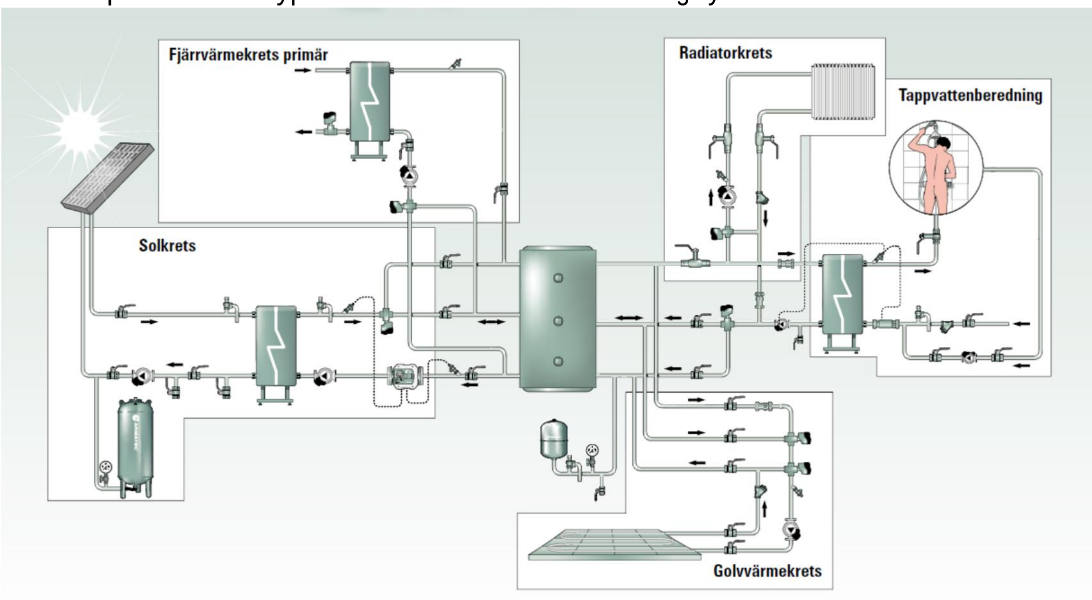


Figure 40 Standardized solar unit for district heating

(from: http://armatec.com/upload/broschyrer/Solcentral.pdf)

8 Integrated solutions

8.1 Duct integration into prefabricated panels

One of the major challenges and benefits, at the same time, while performing modular renovation, is connected with ventilation. As the building after renovation needs mechanical ventilation system it is important to find the best solution of duct placement. As described in chapter 4 only centralized mechanical ventilation system can ensure rational use of exhaust heat and provides lowest energy consumption results. Therefore, ventilation ducts must be placed somewhere.

Possible solution for this would be to put the ducts inside the modular panel, as they are prefabricated and therefore can ensure accurate installation whit minimal time consumption. However, by placing the ducts inside the insulation part of external envelope the U-value is reduced, this means that the ducts should not be too large or the insulation layer must be sufficient. At the same time knowing that the ventilation ducts are outside the building envelope the allowed air velocity in them could be increase compared to situation when they are placed inside the rooms. Also the air flowing through the ducts is preheated at the AHU and therefore the theoretical heat loses through building envelope are non-existent as there is no temperature gradient between inside and outside.

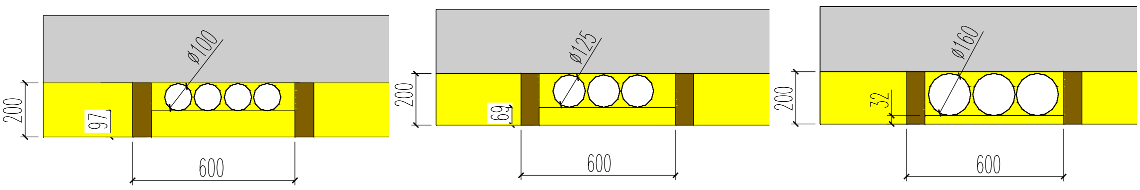


Figure 41 Integration of ducts into prefabricated panel (approx. U-value is 0.18 W/(m2K))

As it can be seen, in case of separate ventilation duct risers to each apartment, ducts can be easily integrated into prefabricated panel with thickness of 200mm. Such heat insulation thickness insures approximate U-value 0,18W/(m^2·K).

Tallinn University of Technology has developed first demonstration units (demo) of integrated ventilation ducts solutions.

Figure 42 First demonstration units (demo) of integrated ventilation ducts solutions

Demonstration videos is available here:

https://www.dropbox.com/s/0wp5t69tec6bwie/00069.wmv?dl=0

https://www.dropbox.com/s/xl5ebish2eth1qo/00071.wmv?dl=0

https://www.dropbox.com/s/h9lnjlh7v06ide9/00076.wmv?dl=0

There are two main option for heating pipe integration into existing building construction:

- ✓ Inside the apartments;
- ✓ Integrated into prefabricated panels;

Figure 43 Heaitng pipe integration infto skirting-cover (http://www.talon.co.uk/products/skirting-cover.html)

MORE-CONNECT report T2.6 Smart connectors provides description of optional pipe integration solution.

8.2 Heating system

In case of district heating system, there are already solution available on the market. For the multi apartment building connected to district heating systems, standardized solutions of heat substations are available on the market (Figure 45).

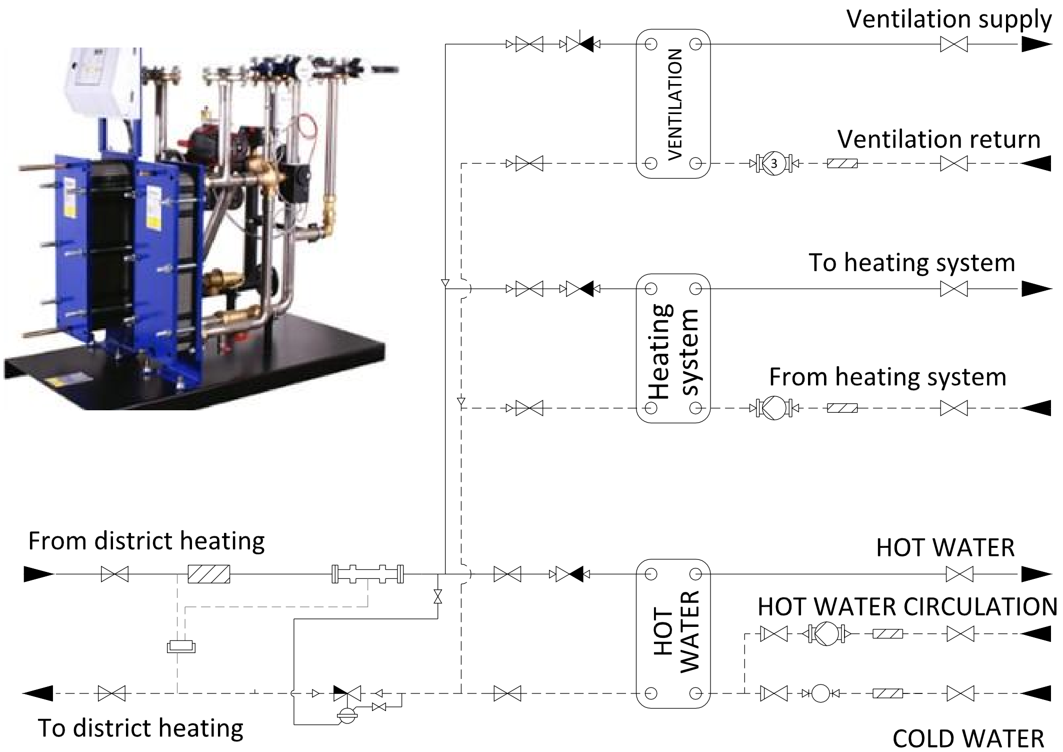


Figure 44 Typical principled scheme of heat substation

Typical solution of heat substations may include all necessary connection for renewable energy, ventilation and hot water. It should be mentioned that in practice implementation of such integration solutions in existing buildings have several limitations:

- ✓ Lack of space in technical room;
- ✓ Limited access possibilities (width and height) to technical room;

Schematic design of modular solutions is shown in Figure 45.

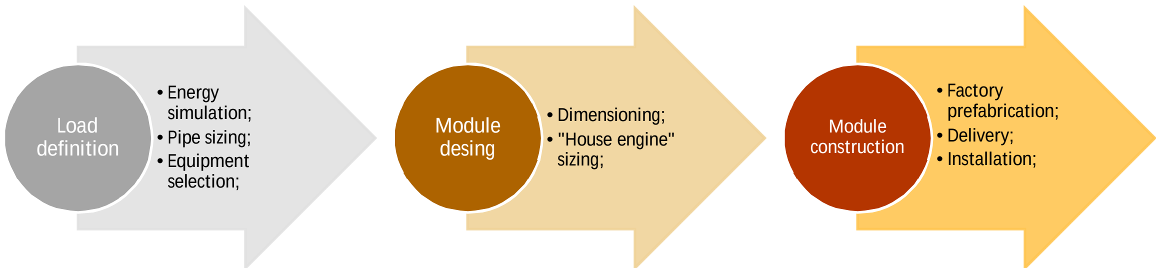


Figure 45 „House engine" development process

The possible solution for modular "house" engine is shown in figure 46

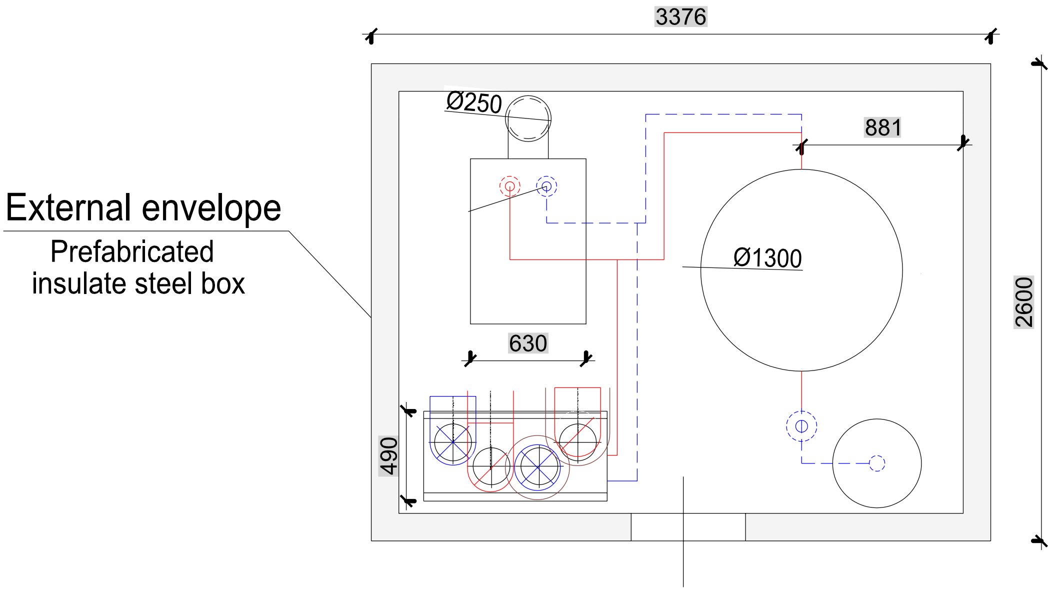


Figure 46 Principled plan design of modular house engine

The integration of ventilation unit may require some minor system modernization during assembling of modular HVAC engine. The constant supply and exhaust air flow through the heat exchanger can cause an overheating during the summer season. The windows opening by inhabitants can lead to ventilation system unbalance by improper supply and exhaust air balance. Dust infiltration through opened windows can cause often supply and exhaust filter replacement.
Some of already available solutions offer bypass line (ex.Zehnder ComfoAir) to provide a free cooling. However majority of available heat recovery units should be modified before the installation. Prefabricated approach allows precise and most suitable modification of air handling units. Our proposed solution (Figure 47) propose installation of extra exhaust fan on the bypass line.

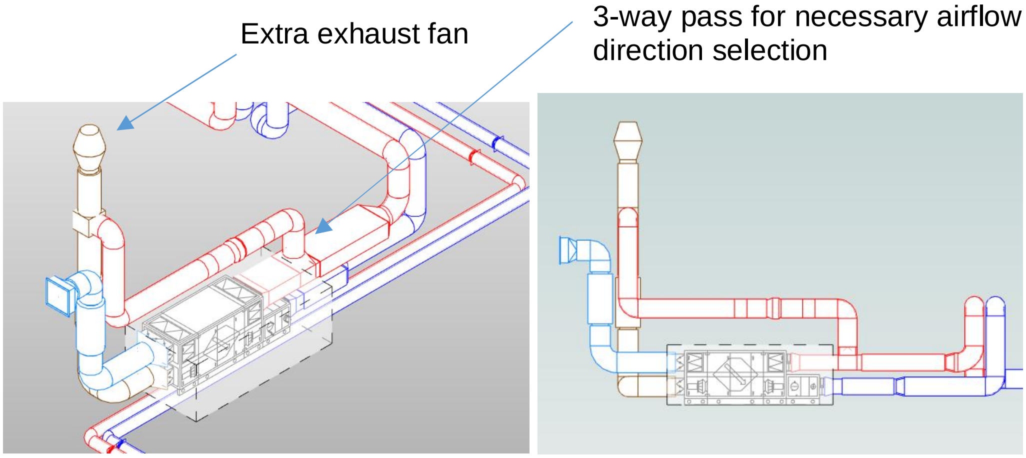


Figure 47 Bypass solution for AHU

Such solution allows to minimize electrical energy consumption by fan.

9 Conclusion

This report provides technical recommendations for development of modular solutions for prefab platforms for building services, so called ‘engines’ for real buildings. Existing multi apartment buildings in Latvia, Estonia and Czech Republic usually are connected to district heating systems. This connection to district heating in typical case already includes such modular solution as heat-substation. Existing heat substation and storage tank offers technical possibility for integrates connection of solar energy.

Detached and semidetached houses, such as in the Dutch demonstration case, have a great technical option for application of modular solution. Proposed solution should be adapted to existing buildings, taking into account available land plot, building floor planning, available energy sources, etc.

A comprehensive ventilation strategy analysis is made and necessary ventilation volumes for case building are calculated for each of the participating countries. The data showed that the necessary ventilation volumes are very diverse and range 1250 m^3/h in case of Denmark to 4200 m^3/h for Latvia. According to these calculations a comparison of ventilation life cycle costs is prepared taking into account the installation costs, running costs, costs for heating and electrical energy. Therefore, it is possible to see which of the ventilation principles is most cost efficient for each country.

Prototypes of prefabricated integrated ventilation ducts has been developed and presented in several demonstration cases such as in Latvia, Estonia and Czech Republic. General criteria and design principles of modular solutions were evaluated. Analysis of normative requirements for each project country showed notable differences in design values.

Development of unified modular solutions is limited by national legislations, building location, house owner needs, existing engineering networks, etc.

Comparing the installation cost of different ventilation systems for case study building it can be conclude that the cheapest solutions, of course, are the ones that ensure the least amount of automation and control and with this also the worst indoor climate. For example, the natural ventilation just by having exhaust grills in the walls and shafts to roof would cost around 2000 EUR per apartment. If inlet valves are added for more ventilation volume and higher comfort level than they would cost around 10 to 20 thousand EUR per apartment, depending on the country. By further improving ventilation system by adding mechanical ventilators for exhaust, the prices would rise to 15-40 thousand EUR. The next step is to introduce mechanical supply-exhaust ventilation with heat recovery, which decreases the necessary heating power for ventilation air. If decentralized room type ventilation is used than the estimated instillation price would vary between 70 and 160 thousand EUR depending on the chosen elements. However, the yearly energy cost would be reduced by about 6000 EUR per apartment per year. If an apartment based ventilation system is designed with an AHU for each flat than it would cost around 90 to 240 thousand EUR. The most economically feasible choice would be to use building based ventilation system with one or more centralized, larger AHUs. In this case the cost would be reduced by spreading it evenly through all the flats and also the maintenance would be lower due to need to only take care of one or two units compared to 30 if each apartment has separate AHU. Despite all this, it must be strongly noted that to make the final decision when choosing ventilation type not only economical factor must be accounted for. The most important task of the ventilation system is to provide good indoor climate even if it means larger investments during construction phase.

In cases when it is possible, it is strongly advisable to use passive cooling strategies. Some of the most common cold sources include the ground, whose temperatures, during summer, are lower than outdoor temperatures, and exterior air, which in particular periods of the day presents lower temperature than the building’s indoor temperature. These temperature differences occur due to the wide daily temperature ranges. The most widely applied passive cooling methods are the shading and natural ventilation. There are various shading possibilities, but the best ones are with the external shading elements and taking into account the location and orientation of the building. This determines whether the shading should be vertical or horizontal or the overhang length to gain the maximal effect. However in many cases the external shading is not applied due to its expensiveness, therefore at least the natural ventilation can be used. It can serve during summer time when the heat recovery in AHU is bypassed and therefore save some energy as well as increasing the indoor comfort level. The natural ventilation is based on general physical principles like buoyancy and stack effect. To help utilize theme careful planning must be done or additional elements like atriums, openable windows, solar chimneys and turbine type roof vents.

The possible principles of “house engine” are described and the main possibilities of them described. It is believed that they can be the future of engineering systems and serve as the heart of the house. Especially in cases of renovation when all the systems need to be made compact while connected to existing networks. They must include all the basic equipment such as heat exchanger for heating systems connection, hot water heat exchanger, local energy source, expansion tanks and all the necessary valves, air handling unit with heat recovery section and in some cases even cooling source.

Potential integration of renewable energy sources into renovation process is a major issue to approach the nZEB status. A change of mind-set must be made to do this but with the changes in legislation as well as economic benefits it can be done. For example, already all of major gas boiler manufactures provide standardized integration of solar thermal collectors into gas-fired hot water systems as well as many provide the possibility to add ground heat pumps into the system. Although there could be some technical challenges like the need to match temperature curves of district heating systems and renewable energy sources they can be solved by careful design process and use of automation.

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