Sets of deep renovation solutions of buildings HVAC systems

Deliverable Report D1.3

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P2ENDURE
Plug-and-Play product and process innovation for Energy-efficient building deep renovation

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 7723391.

Sets of deep renovation solutions of buildings HVAC systems

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Colophon

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Publishable executive summary

P2Endure promotes evidence-based innovative solutions for deep renovation based on prefabricated plug and play (PnP) systems. The primary objective of this Deliverable 1.3 is to evaluate innovative as much as possible PnP heating, ventilation and air-conditioning (HVAC) components and systems that can be used for deep retrofits. Therefore, new approach is developed where all components are to be integrated into one platform in order to reduce installation size and costs.

The task started with defining main objectives and requirements of modular HVAC installations. Secondly, a technology inventory and a critical review was done of the several EU-funded projects that deal with the development of the novel modular and PnP prefab HVAC components and systems. This helped to identify state-of-the-art advanced technologies in the field of HVAC energy generation applications. Afterwards, technical requirements of the P2Endure ''HVAC engine'' were defined. Following this programme of requirements, HVAC engine can be designed and implemented for different demonstration buildings (in respect to individual building requirements) inside the P2Endure project.

List of acronyms and abbreviations

ATES: Aquifer Thermal Energy Storage

BIPV: Building-integrated photovoltaics

BTES: Bore Hole Energy Storage

DHW: Domestic Hot Water

EU: European Union

HP: heat pump

HVAC: Heating Ventilation Air Conditioning

ICT: Information and Communication Technology

IEQ: Indoor Environment Quality

ME: Mechanical Exhaust ventilation

MEP: Mechanical, Electricity and Plumbing

MVHR: mechanical ventilation with heat recovery

nZE: nearly Zero Energy

PnP: Plug and Play

PV: Photovoltaics

RES: Renewable Energy Source

P2ENDURE
PLUG & PLAY BUILDING RENOVATION

Contents

1. Introduction

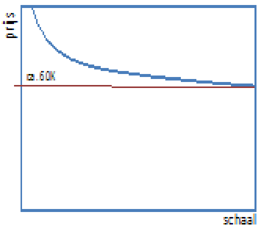
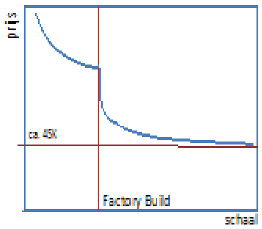
1.1 Current situation on building services in deep renovation

Until now product and process innovations, necessary for large scale deep and nearly zero energy (nZE) renovation, mainly focus on building components. These innovations focus particularly on prefabrication of components for the building envelope (for example prefab multifunctional facades, roofs with Building-integrated photovoltaics (BIPV) etc.). Several products and concepts have been developed now and a number is available on the market already (see P2Endure report D6.5 State-of-the-art report on innovations for deep renovation). One of the main objectives for these innovations is to come to a substantial price reduction, by mass production and prefabrication. Yet, after some years of experience with prefab renovation (for example, the Dutch national renovation program Energiesprong, the H2020 MORE-CONNECT project) one of the conclusions is that at this moment prefabrication still cannot totally 'substitute' traditional retrofitting and that there are still some steps to go to come to an acceptable price level (€ 45.000 – € 50.000 for a nZE renovation). At this moment the average cost break down for deep renovation is:

- Prefab envelope: 1/3
- Building services and PV: 1/3 (platforms with traditional building services, not yet smart miniaturized prefab engines)
- Finishing, interior, small works, failure costs: 1/3 (while the aim is < 5% hours spent on site)

One of the reasons of the relatively large part of building services in this cost breakdown is 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, domestic hot water (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. 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. As an example in following overview the current state (generation 1) and proposed state (generation 2) of developments are given, based on the experience of Energiesprong (and addressing the Dutch renovation market). Generation 2 will be aiming at price reduction due to profound use of new technology, industrialisation, implementation of robotics and high possibilities of modification. Also there will be the focus on the creation of 'building streams' instead of building projects. The next generation anticipates an upscale up to 8 fold.

Table 1: Overview current state and proposed state of development in deep renovation.

Features	Generation 1	Generation 2
Scale of industrialisation	800 to 1500 year	7.000 to 10.000 /year
Partnering	Purchase model	Risk sharing partnership
Supply-Network-Penetration	First Tier	Form raw material
Time to Market	1 year	3 year
First Factory	2016	2018
Marktable Proposition	2016	2019
Factory-technology	CAD-CAM-3D	Robotics
Modification possibilities	Limited	High
Installation	Integrated existing tech.	New technology
Facade / Roof	Existing technology	New and existing tech.
Assemblage time on-site	3 to 10 days	< 1 day
Core qualities OEM	Coordination / Proces / assemblage on-site	System Integration Systems Engineering
Cooperation Supply Chain	nihil	Trusted partnership
Focus	Projects	Building Flow
Quality level	sufficient - margin of error	Good - flawless
Satisfaction	Okay	Happy
Performance guarantee	Laboured	Standard
Value supply	NOM / EPV	Customer Experience
Cost curve (standard specs of standard terraced house)		

1.2 Main objectives of the D1.3 and the HVAC engine

In general, Mechanical, Electrical and Plumbing (MEP) covers a broader range of building services which present systems making our buildings functional and safe. These building services and installations are an important part of a building project and need to be addressed carefully during building retrofit as they can make our buildings more comfortable and efficient if designed correctly. One part of MEP presents heating, ventilation, air conditioning (HVAC) systems.

The main purpose of HVAC systems is to provide good, healthy and comfortable indoor environment for the occupants. The findings of an extensive review on buildings energy consumption information [1] show that HVAC consumption in developed countries accounts for half the energy use in buildings. When considering building's deep retrofits decision on improving consuming HVAC system can significantly contribute to overall building's energy saving while still maintaining or even improving indoor air quality (IAQ). When improving building's performance, good indoor environment should be reached with the lowest possible energy usage. Consequently, technological improvements in the area of HVAC installations are necessary in order to achieve European Union's (EU) energy reduction targets. EU is trying to enhance innovative design of new HVAC equipment and solutions also by funding different research and innovation projects through instruments such as H2020, FP7, IEE [2]. Energy consumption can be mostly reduced by the choice of energy generation (heat pump, heat exchanger, boiler, chiller), type of energy source and distribution system. The technology development is not only trying to meet energy reduction targets but also to satisfy new needs (cooling, hot water) and sustainable requirements (higher efficiency, renewable generation). Furthermore, with the growing demand for nearly zero retrofits also seasonal energy storage is under development.

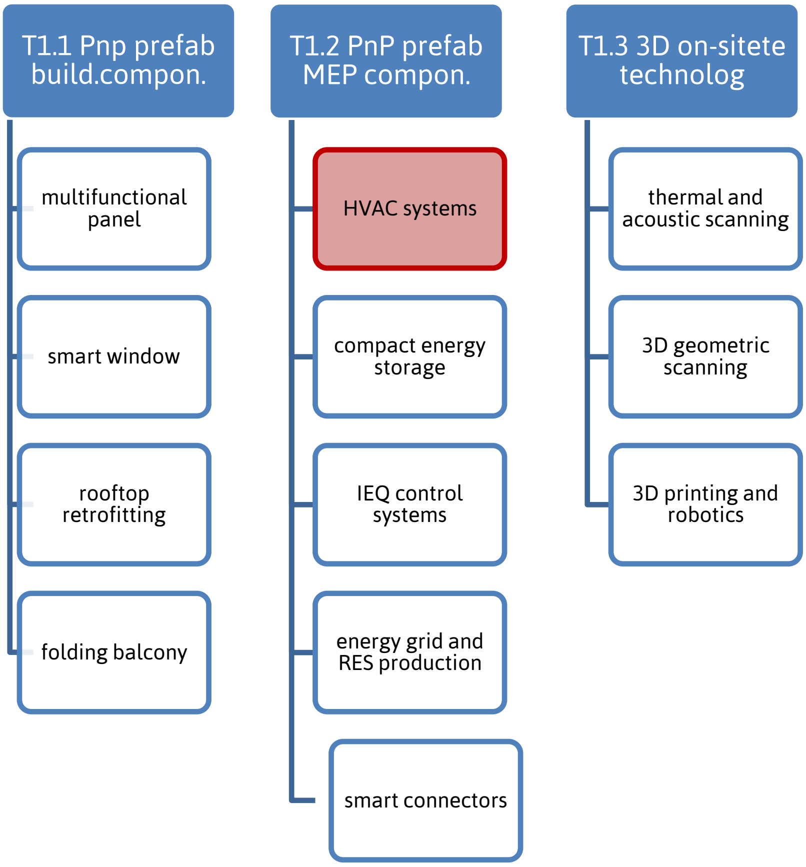


Figure 1: Allocation of the D1.3 inside a work package 1.

The P2Endure tasks T1.1, T1.2 and T1.3 are focusing on the analysis and selection of the advanced technologies allowing energy efficient advanced deep retrofits. The main focus is the selection, consolidation, optimisation and integration of innovative PnP prefab components (T1.1 and T1.2) that are necessary to achieve the targeted quality and performance in terms of energy-, cost- and time-saving as well as improved IEQ and reduced disturbance during on-site processes.

This deliverable 1.3 introduces a modular compact HVAC unit concept where all needed HVAC conversion and generation components are combined in one platform. Not only that allows reduction of the needed space and installation costs due to its compact nature, but it also allows 'one-stop shop concept' where a client receives complete HVAC system from one supplier (who provides best quality components from different manufactures) and therefore simplifies purchasing and logistics process for the client. It makes new business and operating models where based on modular interchangeable installation HVAC engine there is a shift from labour work needed to optimized technology intelligence. The HVAC engine or certain components can be replaced when needed where people can choose engines and components of different (or better) quality and functionalities according to their needs or financial possibilities. In this report most favourable technologies allowing efficient heating, cooling, ventilation, domestic hot water are presented with the necessary components. The energy retrofit concepts are preferably using renewable resources, using demand controlled technologies for heating and ventilation and low temperature emission devices.

Within this deliverable D1.3 the goal is to define a single-source guideline (set of requirements) upon which it can be decided which are the necessary modular produced mechanical HVAC components for energy generation and can be part of HVAC compact engine. The requirements for key components were defined to satisfy the retrofit needs for residential and non-residential buildings used in P2Endure. This report presents the technical potential and design guidelines of the 'engine concept' containing state of the art HVAC components. However, it does not include specifications for any subsystems such as heat/cold generation, energy distribution part or control systems. Where relevant, interaction or interdependency between different components of a HVAC-engine system is being described.

1.3 Main objectives (performance requirements) for the HVAC components

Based on the lessons learnt from previous projects and programs (like Interreg IV MODLAR, H2020 MORE-CONNECT, Energiesprong the Netherlands), the main idea for the ''HVAC Engine'' is to combine the components in a compact frame, preinstalled in compact units with a possibility to mount it as a box unit to façade, standalone unit on the roof or as a compact unit in the attic (keeping building aesthetics and appearance intact). Furthermore, HVAC components from different local manufacturers could be considered if feasible with the modular engine concept and that satisfy the building needs.
HVAC design and choice for components relate to specific building characteristics (building type, orientation, area, envelope, usage etc.), national building regulations and mandatory requirements for indoor air quality. Therefore, the detailed design of the key components will depend on particular building case, local characteristics and national codes.
Most building legislation prescribes HVAC system with the purpose of:

- Efficient air-conditioning for thermal and humidity comfort
    - Heating
    - Cooling
    - Dehumidification
    - Humidification

- Efficient ventilation:
  - Introduction of required outside air
  - Filtration of recirculated air
  - Exhaust of undesirable air (toilet, kitchen, lab exhaust)
  - Air movement in space

1.4 Modularity and industrialization of HVAC components

HVAC systems installed in the existing buildings are often difficult to retrofit since the components of installations as part of a system are spread through the whole building in different spaces and in some cases have indoor and outdoor components in floors and ceiling. The modular compact HVAC engine is introduced as a multifunctional platform combining all necessary HVAC components which, in comparison with traditional ''spread'' retrofit, requires less space, improves quality assurance, reduces renovation time and costs, allows optimization of installed capacities (ensures better quality) and can be easily exchanged and replaced. This is possible due to the flexible modular design during industrialized production process where two concepts are most relevant: industrialization and modularity.

- Industrialization: A high quality of the components and systems can be ensured with the industrialized manufacturing due to automated well controlled process. With the industrialized process, variety of available component options can be available to fit particular building requirements.
- Modularity: Modular flexible design allows that the HVAC components present individually developed elements which can be integrated and fitted into the HVAC engine box. This modules (HVAC components) are prefabricated, easily transported when necessary and then fitted together with smart connectors (developed in MORE-CONNECT project) allowing coupling of pipes and different HVAC parts. Due to modular design, lower installation costs are considered with easier maintenance and serviceability when necessary.

1.5 Design guide for a P2Endure modular HVAC Engine

The flow-chart in Figure 2 presents a three-stage approach to design a P2Endure modular HVAC engine that is proposed to be adopted when considering an installation of HVAC Engine for the P2Endure demonstration cases.

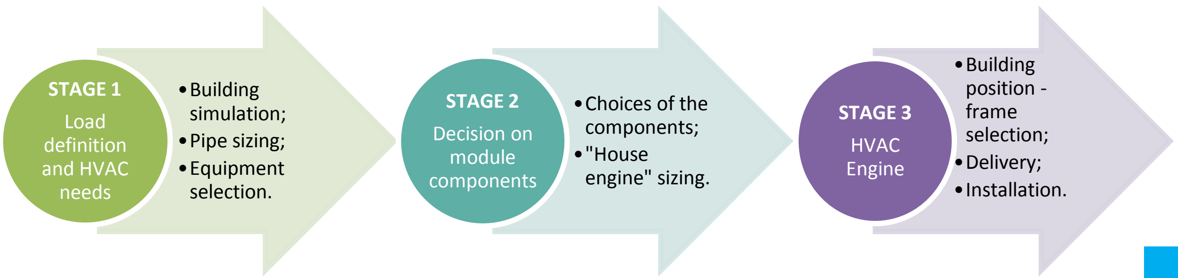


Figure 2: A 3-step guide to design a modular HVAC engine.

Stage 1: Load definition and HVAC needs

In order to make correct sizing of a modular HVAC engine, the needed capacity of all elements should be correctly calculated. The main HVAC system parameters such as maximal airflow of ventilation unit, maximal capacity of heating/cooling equipment and duct and pipe diameters affect overall size of modular HVAC unit. To investigate the potential application of different modular offered possibilities, detailed analysis should be performed regarding different HVAC principles, indoor requirements as well as actual possibilities to integrate the solutions in existing buildings. A further requirement is the balance between the overall modular HVAC concept and its flexibility with the variety of different prefabricated component possibilities and the conditions on-site (building requirements, national codes). It should be noted that not any feasible solution for a building is transferable to all other buildings. More detailed calculations and practical consideration are needed not only to compare different engineering principles but also regarding different needs and legislation rules.

Stage 2: Decision on module components

Once HVAC requirements for a specific building are defined and based on the available state-of-the art components, most feasible components are chosen and applied on the common installation platform. Each of these components has a specific function within the HVAC system. In order to satisfy the set of requirements, the components (type, size) are chosen to satisfy the set of requirements from Stage 1. As part of the HVAC engine each of these components present a component of the whole engine.
Figure 3 shows Engine diagram and decision tree for specific units and Figure 4 – Figure 5 show HVAC units for commercial buildings.

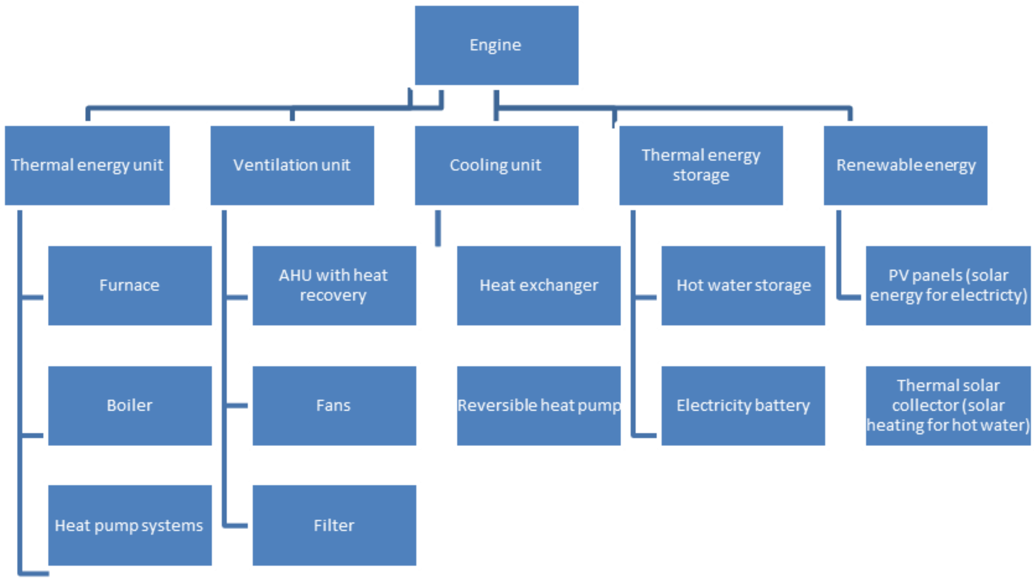


Figure 3: Engine diagram and decision for specific units depends on the building requirements, units related to heating, ventilation, cooling and renewable energy production and storage.

Figure 4: Example of a stand-alone AHU unit for commercial buildings.

Figure 5: Example of a heat pump and a buffer tank for utility buildings.

Stage 3: HVAC Engine

Once elaborated which modules to install (type and size), appropriate size and appearance of the installation platform needs to be chosen. The platform presents a unit in which all the components are fitted in. Depending on the position of the engine, different base frame concepts of the installation platform can be chosen. The frames can be adapted according to the available installation possibilities: from very flat upright frames for limited narrow areas, different architectural design frames for outdoor façade application to self-standing durable frame for rooftop installation (if there are limited installation possibilities on the outer façade). If the engine unit is to be placed on the outside wall or as a rooftop unit, it needs to be protected against weather to withstand certain pressures and be durable for the projected life span of a HVAC unit. An installation frame does not only serve as a structural support for the HVAC components but also it can be designed to satisfy current building aesthetics (to blend in with the existing surrounding). Furthermore, the frame should be highly insulated in order to reduce the noise of the operating components.

Figure 6: Different base-frame possibilities of the HVAC engine. Dimensions and orientation depends on the engine placement in the building, e.g.: between narrow areas, outdoor façade position, self-standing rooftop placement. Furthermore, different materials for the outdoor walls of the engine can be chosen based on desired architectural aesthetics.

1.6 EU-funded focusing on a development of innovative HVAC components and systems

The table 2 shows a list of projects that tried to develop new advanced HVAC technologies and systems allowing deep retrofits.

Table 2: EU-funded projects developing integral and advanced HVAC solutions and concepts that could be used for deep retrofits.

Funding scheme	Name of the project (official website)	Main objectives
H2020	THERMOSS (2016-2020) http://thermoss.eu/	THERMOSS proposes an industry-focused, innovation-intensive approach to ease and foster the introduction of cutting-edge heating and cooling technologies for building energy retrofitting at European level, targeting residential buildings and buildings connected to District Heating and Cooling (DHC) networks.
H2020	MORE-CONNECT (2014-2018) www.more-connect.eu/	Within MORE-CONNECT project a modular 'engine' is developed combining all necessary installations and building services in one prefab unit with easy plug and play connections for installing.
H2020	REnnovates (2015-2018) www.rennovates.eu	REnnovates project aims to develop an energy module where all installations necessary for heating/cooling, ventilation, domestic hot water, monitoring and the inverter for the solar panels are integrally combined.
H2020	E2VENT (2015- 2018) www.e2vent.eu	E2VENT system will develop an external thermal refurbishment solution with the Smart Modular Heat Recovery Unit allowing to recover energy from the extracted air while performing the air renewal using double flux heat exchanger in the air cavity.
FP7 - NPM	NANO-HVAC (2012-2015) www.nanohvac.eu	The NANO-HVAC project concept aims at developing an innovative approach for ducts insulation while introducing new cleaning and maintenance technologies, all enabled by cost-effective application of nanotechnology.
FP7	RetroKit www.retrokitproject.eu	RetroKit project develops and demonstrates multifunctional, modular, low cost and easy to install prefabricated modules in order to significantly increase the EU retrofitting rate and contribute to EU energy reduction commitments.
Interreg IV	MODLAR project	MODLAR delivers a one stop shop solution where the house-owner can select, visualize and retrofit his house into a Nearly Zero Energy House according to his own preferences, for a fixed-price and guaranteed energy performance. A financial package is offered to finance the renovation. Basic idea is that the renovation is paid by the energy saving of the house within 15 years. Furthermore, the residents can remain in their house during renovation period which is limited to 8-working days. The house will be roof- and windowless for only 1 day.

Several EU projects also developed prefabricated building modules (wall panels) where pipes and distribution channels through the house are part of the designed components (integrated shafts) making deep building retrofits to be as much as possible prefabricated [3, 4].

2. Boundary conditions for necessary developments of engines

2.1 Modularity

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: 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, for example a heat pump and storage in a small prefab cellar and a part integrated in the façade (ducts or decentral MVHR units).

In all cases, it is preferable that the engines are accessible from outside for maintenance or replacement of modules.

b. Modularity in medium of heat transfer: water, air, all-electric, hybrid

- Air: An advantage of air as medium is that it can be combined with ventilation and that (with a heat pump as source) can be also used for cooling. Especially in zero energy and passive house renovation concepts the necessary air volumes for ventilation are (in many cases) large enough for heating. This can be combined with modular prefab façade elements with embedded ducts.
- Water: An advantage of water as medium is that it is very versatile and can be combined with different kind of emission systems such as radiators, convectors, floor and wall heating. Also a combination with decentral (local) MVHR units is an interesting option for renovation.

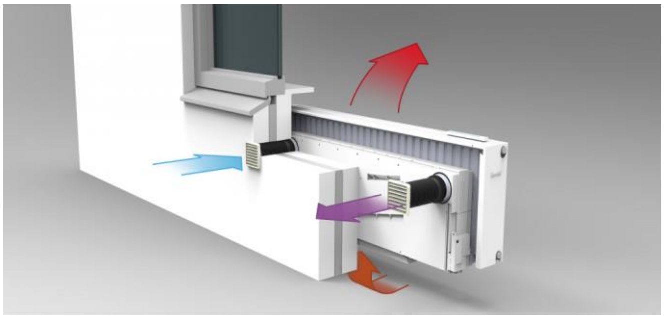


Figure 7: Example of decentral MVHR unit combined with a radiator, CO_2 controlled where no ducts are necessary.

- All-electric: All-electric emission systems can be interesting in combination with (sufficient) PV, in combination with a high grade of thermal insulation, minimizing ventilation losses 9air tight building and MVHR) and (eventually) internal thermal compartmentation (an example is the Gyproc Activewarmth concept in combination with PV).

c. Modularity in phased composition of the engine in time

Modularity of the composition and sizing of engines, phased in time, is one of the most important features of modular engines. The functionalities of this modularity are:

- To start with (cheaper) basic options that can be upgraded if more budget is available, for example 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 way of modularity offers so called no-regret options, both to individual owners as for housing companies.

2.2 Miniaturization

There is already a first generation of prefab engines (for example developed in The Netherlands by BAM, Volker Wessels, Van de Kreeke/BJW). However, these 'engines' are composed by adding 'traditional' components, in most of the cases, including the original casings. This way of combining components make the engines too big (3500 – 5000 dm^3) and too heavy (500 – 600 kg). Because the available space in existing dwellings is always limited it is necessary to miniaturize and re-design the components. Also some functions could be combined (fans, pumps). Miniaturization should limit both sizes as weight to at least 65%.

Figure 8: Examples of first generation engines developed in Energiesprong (BAM), modular HVAC unit (left), modular HVAC unit with heat pump and ventilation heat exchanger (middle), and gas boiler installation (right). No miniaturization yet.

Figure 9: Examples of first generation engines developed in Energiesprong (Volker Wessels), engine in portal next to front door.

Figure 10: Schematic picture of a prefab renovated single family dwelling with engine next to front door.

Furthermore, Dutch manufacturer Energy Zero (http://factoryzero.nl/) already has market available products with the similar HVAC Engine concept. Their iCEM is a compact fully integrated energy module that provides the home with a conditioned indoor climate (ventilation and heating) and hot tap water. The installation includes (externally placed) the delivery of PV panels fitted with your compatible inverter. The performance of the module and the PV system are monitored in real time.

Figure 11: Energy Zero installations module applications in real-life environment (http://factoryzero.nl/).

Figure 12: Examples of hydraulic push fit connectors and air duct socket connectors.

2.3 Connectivity

One of the main foreseen advantages of modular prefab installation platforms is the fast installing time on site. This has major benefits in terms of cost reduction (limitation of labour costs on site), limitation of disturbance of occupants and better quality and quality control (in factory instead of on site).

The quantitative objectives for these improvements are:

- Limitation of labour costs: < 5% of labour time on installing HVAC systems spent on site.
- Limitation of disturbance: Installing of a complete prefab unit with smart connectors in only 2 hours

- Better quality and quality control: Construction failure cost reduced to < 5% (traditional 15 – 20%)

So called plug & play connectors can further limit the mounting time on site. Several smart connectors have been developed (for example In H2020 MORE-CONNECT) and/or are available on the market (hydraulic, air, electricity, ICT etc.).

The combination of prefab 'engines' and smart connectors should limit the total mounting time on site to a maximum of 2 hours.

2.4 Competitiveness

One of the main goals and drivers for the development is cost reduction. However, competitiveness in the market is not only a matter of costs but also on other issues as better technology, better quality, user friendliness in relation to the tradition replacement of building services. In terms of absolute costs it is expected that, due to the higher quality of the components (and use of technologies such as heat pumps) the costs of these engines are about 20 – 30% higher than the separate components but the yields are in substantial lower labour costs, so it is a shift from labour to technology and intelligence. This also implies new related business models, based on modular and exchangeable modules (and submodules). The business model is not based on 'selling and installing building services and - components' but on offering 'energy (or rather (thermal) comfort) as a service'. This services model also implies that in general no maintenance work to the engines is necessary inside dwellings/apartments as these are accessible from outside.

The expectation is that in total, including the described services, a cost reduction is achievable of 35%. After scale enlargement a further reduction of 50 to 60% is possible. (For example, in the Netherlands building services for nZE renovation cost now € 25.000 to € 30.000, including material (heat pump, MVHR, DHW, PV) and installing. The first generation of engines can bring this back to € 16.000 to € 19.500 (Energiesprong, MORE-CONNECT).

Presented solutions (market inventory) in this Chapter 2 still present first generation of prefabricate modular HVAC compact engines and needs further technical improvements and design optimization (e.g. as seen nn Figure 11 the ventilation ducts are due to the space optimization bended). Therefore this chapter builds upon what market has to offer now and makes an attempt in the technical development of the HVAC engine that could overcome certain barriers shown and exposed in Chapter 2.

3. Set of requirements for HVAC components and systems for deep renovation

3.1 Installation platform unit

Installation platform unit is designed in order to fit all the components and also to allow sufficient space to access the units easily (maintenance/change). The philosophy of these platforms is based on several possibilities of component configurations and also placements inside the building. If the engine unit is to be placed on the outside wall or as a roof unit, it needs to be protected against weather influence. If the engine is considered as a room unit inside the building or between the buildings, the noise reduction needs to be satisfied accordingly (efficient noise insulation).

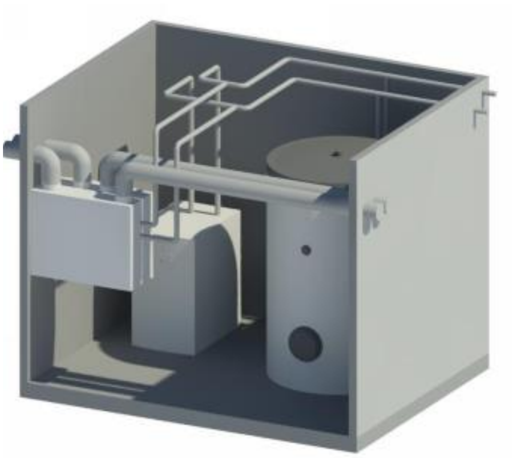


Figure 13: Example of a residential HVAC engine unit [left, D2.3 MORE-CONNECT] and for utility building [right, http://www.systecon.com/pages/products/]

The idea is that the whole engine is fabricated in the factory and delivered on the site in one piece (exceptions are large AHU units or cooling towers). As for the transportation of the engine from the factory to the construction site, the idea is that the engine unit can be delivered on the site with a high capacity fork lift trucks.

Figure 14: Example of delivery of HVAC components on the site comparable to delivery of HVAC engine delivery.

3.2 Required technical components

In general, the following technical features are needed for the engine:

- Local energy source (gas boiler, heat pump, connection to external energy sources – also district heating or cooling);
- Heat exchanger for heating loop;
- Hot water heat exchanger;
- Expansion tank;
- Air handling unit including ventilation heat recovery;
- In certain cases and countries also cooling source (chiller or heat exchanger).

Construction of the units is also completed to allow advanced control system through which every component operation is monitored.

3.2.1 Ventilation supply:

For ventilation, the system is most often based on:

- Natural supply and mechanical exhaust based on CO_2 scheme
- Local balanced ventilation with a heat recovery
- Balanced ventilation with heat recovery and air-heating.

As seen when doing state-of-the-art research, it seems that the future lies within a balanced ventilation with heat recovery. As important P2Endure Engine generation component AHU unit with fan, drive and a heat exchanger is considered as these have the substantial influence on energy efficiency of the ventilation system. Therefore for P2Endure Engine development, the focus will be in offering efficient AHU units with a heat recovery where the heat is extracted from the exhaust air and used to preheat the fresh supply air. It is possible to use preheating, pre-cooling, humidifying and/or an air filter. The heating element or coil is used to heat up air to a desired level. A cooling element or coil is used to cool the air or to remove excessive moisture. Common approach to mechanical cooling include: cooling water or glycol, direct expansion refrigerator, heat pump and direct and indirect evaporative cooling. Different types of heat exchangers can be considered:

- Fixed plate: (cross flow and counter flow) heat exchanger
- Heat recovery wheel
- Heat pipe (not common nowadays)
- Twin coil

Silencers are used for the noise damping generated by the ventilation units and spreading via air ducts of the ventilation system.

3.2.2 Heating (and cooling) with heat pump systems:

For the development of P2Endure Engine heat pumps are considered as these are one of the most efficient heating and cooling systems (if done by aquifer thermal energy storage (ATES) or bore hole storage (BTES)) on the market today. Because most of the heat is moved instead of generated, a heat pump has a high efficiency. Depending on the climatic location and demand, outside air or ATES is used as an added heat and/or cool source. In winter, a heat pump is used to bring the low temperature from the source to a higher temperature for space heating. During the summer, if an ATES is used, the source is sufficiently cold to be used for space cooling directly, when the outside air can be used as a source the heat pump operates as a cooling machine. At periods of low demand a buffer tank is used to store the excess of heat or cold generated by the heat pump, this prevents short cycling of the heat pump while allowing for a continuous supply to the distribution circuit. For peak heating demands, often a gas-fired boiler is added, either to limit the size of the heat pump, or compensate for periods where the source (outside air) is unable to provide sufficient heat. In the near future, more gasless buildings will need to be constructed/retrofitted. A heat pump system is suitable for low temperature heating and high temperature cooling systems, meaning that terminals units should be designed in accordance. A typical supply temperature for low temperature heating is 30-35°C, for cooling this is 10-12°C.

The main components of the heat pump systems are:

- Heat pump (compressor, evaporator, expansion valve and condenser)
- ATES (Well, source pump, heat exchanger)
- BTES
- Gas-fired boiler
- Distribution circuit
- Buffer tank

3.3 Smart connectors

An important feature and advantage for the P2Endure HVAC engine is a very fast installation time on building/during the renovation. This not only has an advantage with respect to costs (and also saves the installation time) but also limits the residence disturbance and the final quality (less chance of errors). For a quick installation, a number of smart links is needed (hydraulic, air, electrical, ICT) in order for the engine to work as a PnP system. The current ongoing H2020 MORE-CONNECT project developed a several possibilities of smart connectors to be used for prefabricated renovation and supposedly the installation time of the engine can be reduced up to 2 hours [MORE-CONNECT, D2.4 Smart Connectors, 30-11-2016]. It is recommended to use these smart connectors when considering a practical application of the HVAC engine for the specific actual applications. For more information on smart connectors development it is recommended to visit the MORE-CONNECT website: http://www.more-connect.eu/.

3.4 Control systems

Nowadays, advanced control systems or building automation systems are operating the HVAC system. The main objective of these control systems is to monitor and control the desired thermal comfort and indoor air quality. The goal is to embed sensors in components like heat pump or ventilation units during the factory assembly of the HVAC engine and then the information coming from a large number of sensors is incorporated in the building control system. During the construction and commissioning, a large number of control settings will determine the operation of HVAC system. In the following chapters, the control system implementation as part of the HVAC engine development is not considered as this is out of the scope of task 1.3.

4. Combination of functions and components in engines for single family dwellings

4.1 Inventory of components and functions

In order to make a first step in reducing the sizes and the weight of prefab installation platforms the first step is to combine functions and/or components and optimizing the positioning of components and products in the platforms. Following first steps can be taken to minimize the volume and weight of an engine without redesign of components:

- Inefficient shapes of products could be made more compact
- Storage tanks are often cylindrical, other shapes (box shaped) could optimize the use of space
- Connections could be tuned concerning place (shortest duct length) and type of connectors
- Reconsidering which components really should be placed in the prefab platform and which not
- Omitting all casings

A further minimization of volume and weight can be achieved by:-

- Combining functions.
- Re-design for a further miniaturization of components.

First of all an engine in which the several building services for a nZE dwelling are combined is composed by following modules, as presented in the following scheme:

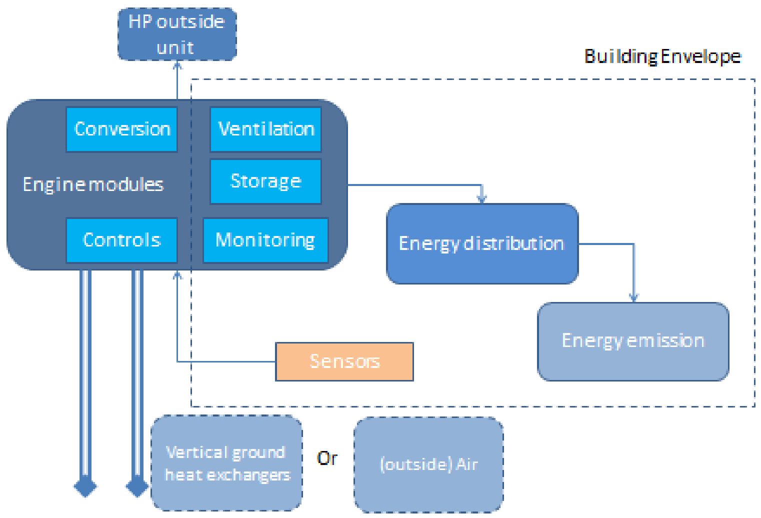


Figure 15: Schematic overview of modules needed in an engine.

As an example how functions and components can be combined three situations have been schematized:

- Hydronic heating with central mechanical ventilation and heat recovery (MVHR)
- Hydronic heating with decentral ventilation
  - With supply grills in façade and mechanical exhaust (ME)With decentral mechanical ventilation and heat recovery (in each habitable room) and mechanical

exhaust in service rooms (decentral MVHR can be combined with a radiator or convector)

- Warm air heating with central mechanical ventilation with heat recovery (MVHR)

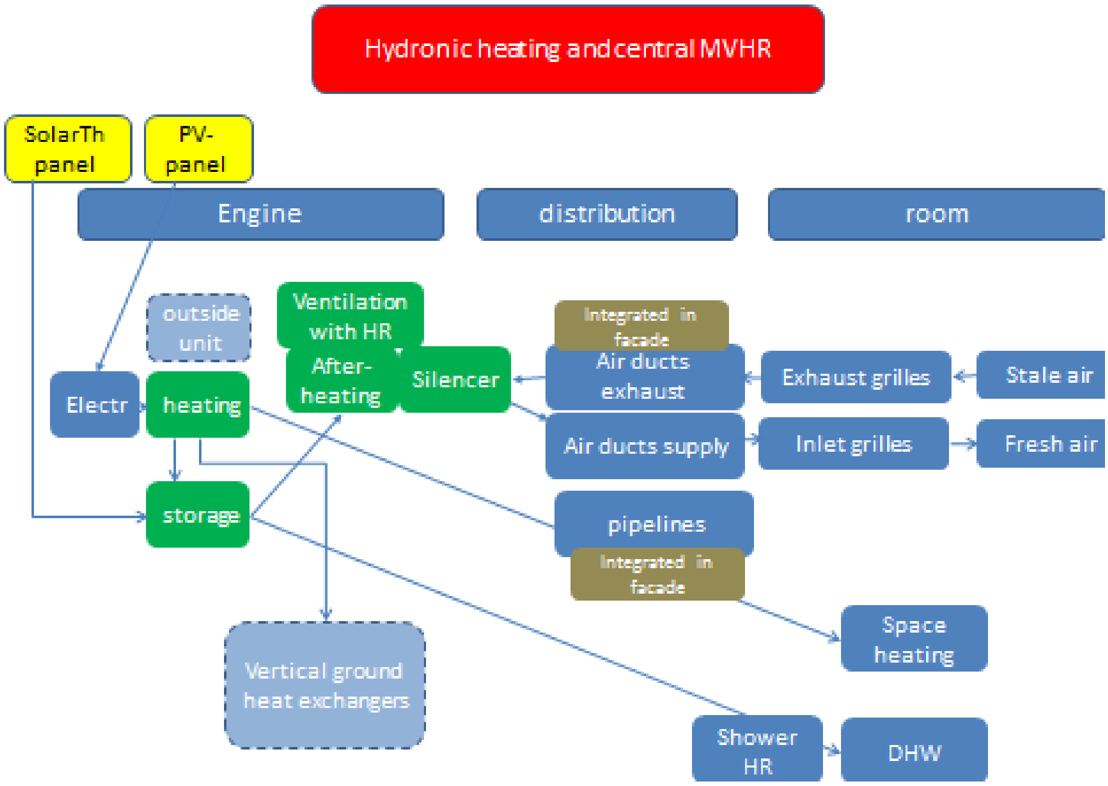


Figure 16: Scheme hydronic heating with central mechanical ventilation and heat recovery (MVHR).

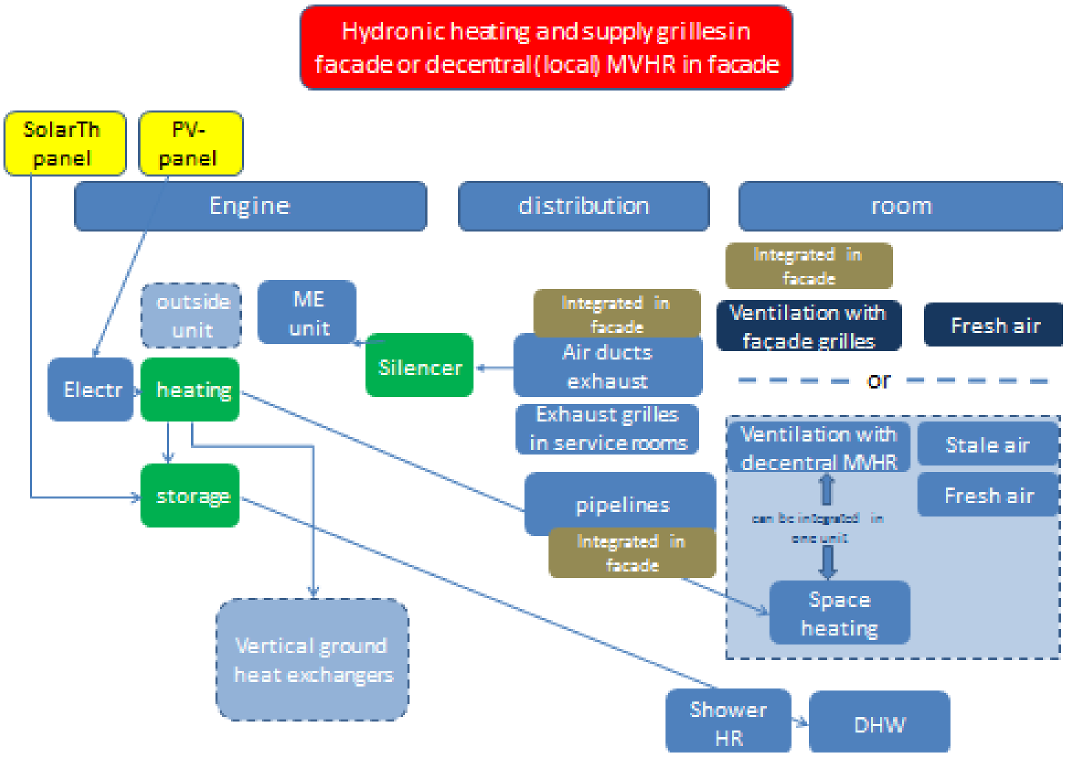


Figure 17: Scheme hydronic heating with decentral ventilation.

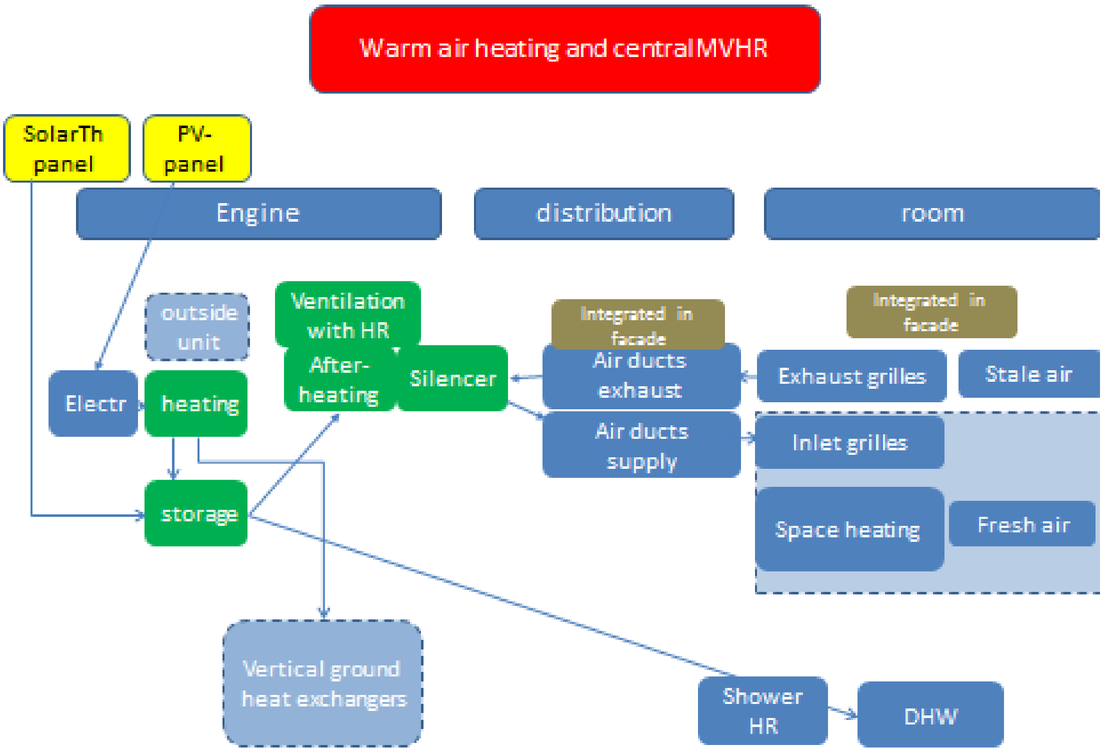


Figure 18: Scheme warm air heating with central mechanical ventilation with heat recovery (MVHR).

4.2 Optimizing the volume of engines

The first two steps can be taken without any re-design of components. In order to get an impression how the sizes of an engine can be further reduced an inventory of components is made. Table 3 gives a description of the necessary components and sizes for single family dwellings:

Table 3: Overview of separate components in an engine

Component	Description	Sizes
	Compressor heat pump + heat exchangers	600 x 600 x 900 mm = 0,324 m3
	Outside unit:	800 x 600 x 300 mm = 0,144 m3, (excl. Space for ventilation air)
	DHW tank, with thermal insulation	560 x 1360 mm2 (= 560 x 560 x 1360 mm3) = 0,426 m3
	Expansion tank	0,020 m3

	Balanced ventilation unit with heat recovery	Large unit: 765 x 677 x 564 = 0,292 m3 Small unit: 600 x 560 x 302 = 0,11 m3
	Balanced ventilation unit with heat recovery, flat box model	1185 x 644 x 310 mm = 0,237 m3
	Silencer (supply and exhaust)	1000 x 140 x 140 = 0,02 m3 x 2 = 0,04 m3
	Air heater	678 x 787 x 526 = 0,28 m3

Taking into account the components and sizes from Table 3 following volumes can be achieved with an optimal integration of components.

Table 4: Overview of components and volumes

Type ventilation system	**balanced ventilation + warm air heating**		**local balanced ventilation and m exhaust**	
Type heat generation	**with HP on outside air**	**with HP on ground source exchanger**	**with HP on outside air**	**with HP o source e:**
HP compressor and heat exchangers	0,32	0,32	0,32	0,
External unit HP	0,14	x	0,14	x
storage tank DHW	0,43	0,43	0,43	0,
MVHR unit	0,29	0,29	x	x
Warm air heating unit	0,28	0,28	x	x
mechanical exhaust unit	x	x	x	0,
silencers	0,16	0,16	0,16	0,
exopansion tank	0,04	0,04	0,04	0,
Total minimum volume engine in m3	**1,67**	**1,52**	**1,05**	**1,**
Target volume in m3 (65% of 1,5x1,5x1,5 m3)	2,19	2,19	2,19	2,
still available	0,53	0,67	1,14	1,

The so called target volume is the volume that should be achieved in order to make the engine 35% smaller as the current state of art (ca. 3,375 m3). However, it is also possible to split an engine in two separate units. As the engines are designed for (n)ZE renovation dwellings they will always have a heat pump for heating, DHW and, if applicable, cooling. As source for the heat pump there are two possibilities:

- water: in general with vertical ground heat exchangers
- air: outside air (sometimes in combination with exhaust air or preheated air)

In case of outdoor air as a source it is important to select the right type of hat pump. 'Traditional' heat pumps with outdoor air as a source have a (tool) low COP with low outdoor temperatures and therefor too little heating capacity. New developments like flash-injection technology (of the cold medium in the compressor) give a rather constant COP value at lower temperatures (e.g. Mitsubishi Zubudan). A major advantage of air/air or air/water heat pumps is a significant cost reduction as no drillings are necessary.

Table 4 shows that it is possible to optimize the volume below the target volume, without any further re-design of the components. The space in the engine that is still available can be utilized for other functionalities like:

- connections between components
- smaller electronics for control
- smart meters for heat and electricity
- PV converters
- extra sound proofing.

5. Integration of the HVAC engine concept for P2Endure demonstration cases

First decision criteria should be based on the building type. For P2Endure project it is distinguished whether the building is to be used for residential (Breda, Korsløkke, Palmanova, Enschede, Tilburg) or non-residential purposes (Gdynia, Warsaw, Genova). Furthermore, when dealing with historical buildings (Genova) more cautious decisions on the HVAC retrofit need to be taken due to cultural heritage constraints. As explained in Introduction, the HVAC engine covers the generation components and when necessary thermal storage unit. This chapter is therefore organized into two subchapters in respect to building type: residential and non-residential. First package 5.1 presents prescriptive requirements for HVAC system in residential buildings. Package 5.2 presents HVAC package for utility buildings.

5.1 HVAC engine for residential buildings

5.1.1 HVAC Engine for P2Endure demonstration cases

For residential buildings the most common installations are:

- a boiler for hot water,
- a ventilation unit,
- a solar inverter,
- an air-conditioning unit,
- and a heating unit (heat pump or heating coil).

To demonstrate practical application of the HVAC engine for a single residential unit, the P2Endure demonstration case Breda is considered. According to the HVAC Engine application for this demonstration case, only a ventilation unit, a boiler, a heat pump and a solar inverter are required components for the engine. Based on the calculations of the needed capacity of the chosen HVAC components, installations where chosen to fit the requirements (see Table 5).

Table 5: The needed capacity of the chosen HVAC components for the Breda demonstration case

Ventilation unit	63 dm3/s maximum Nominal capacity 42 dm3/s
Boiler	200 L, 3 kWe (emergency heater)
Heat pump	5 kWth

All these installations have certain dimensions and need space around the installation for maintenance and in case of needed replacement. In Figure 19 it is shown how these installations fit together including the outdoor heat pump unit.

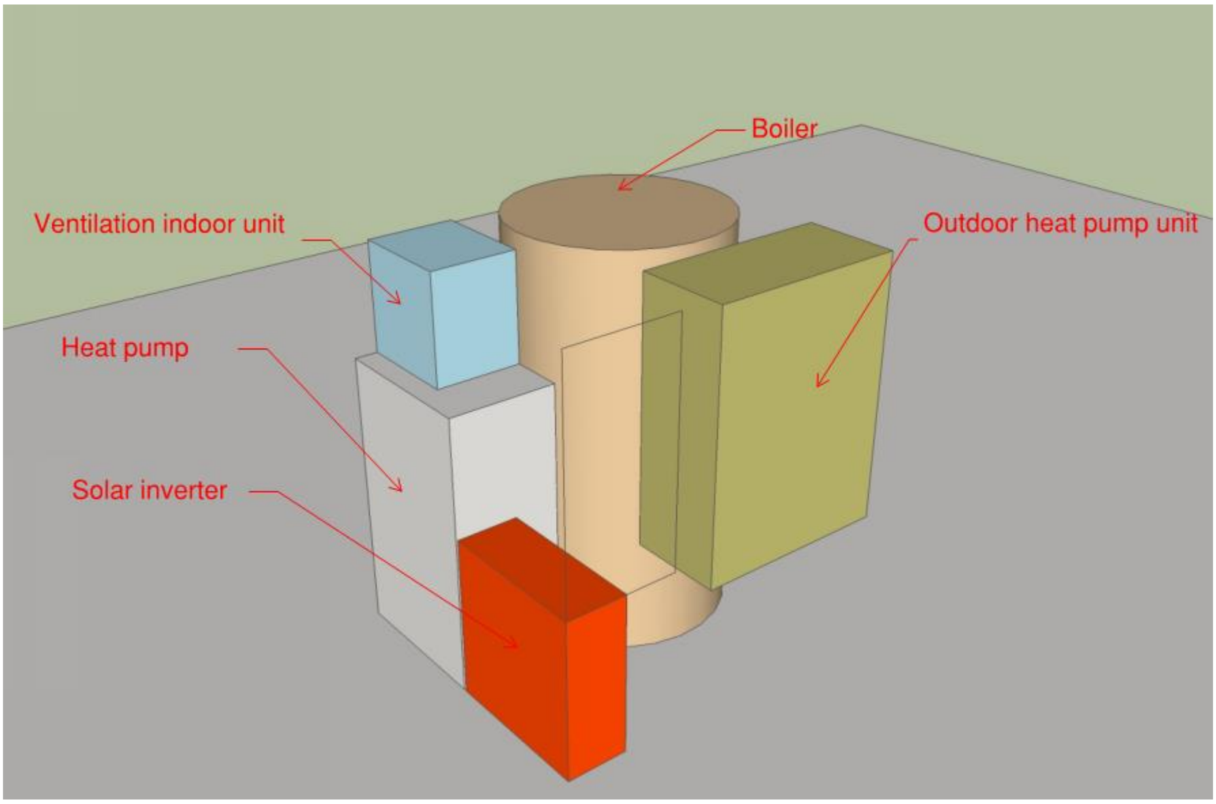


Figure 19: Graphical visualization of all the HVAC components for the Breda residential demonstration case in one 1m3 space.

All the components can be mounted in the factory on the adequate installation platform unit (steel or wooden frame). The insulation layer should be placed around the outdoor heat pump unit as visualized in Figure 20. As explained in Chapter 3.1 and shown in Figure 14, the idea is that the whole engine is transported from the factory to the construction site with a high capacity fork lift trucks. Therefore, the engine needs to be designed in a way that it is possible to lift the engine on and off transportation vehicles and lift it to the installation place (on the outer facade, roof or inside the dwelling). For this reason a lifting bracket is part of the engine frame.

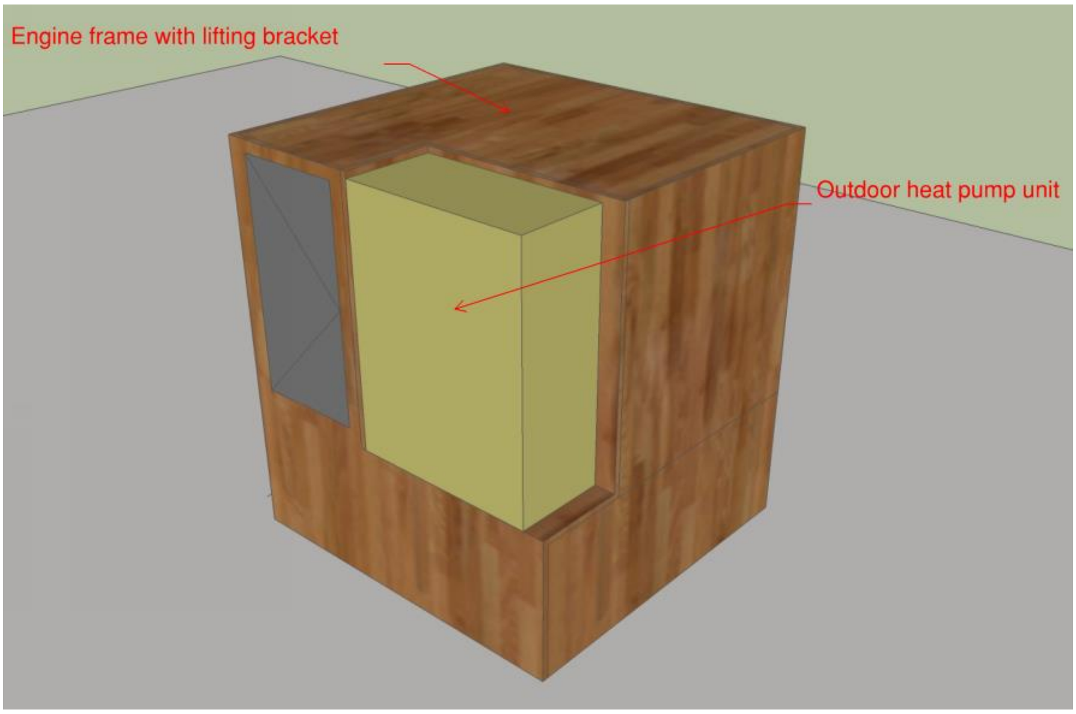


Figure 20: Graphical visualization of the HVAC Engine for the Breda demonstration case.

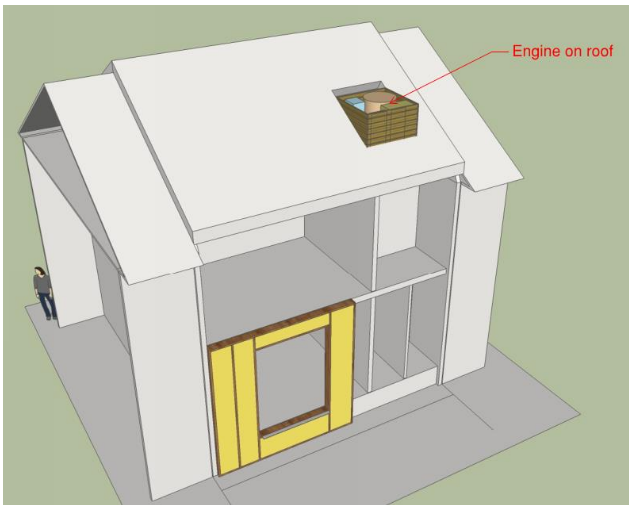


Figure 21: HVAC Engine Sketch-Up model located on the roof (left) and in real life environment (right).

Further integration of the components is done to optimize the size of the engine where all the components for air conditioning, space heating, hot water usage are combined in one integral installation (similar to car engine concept). Chapter 6.2 describes the integrated concept and guidelines for a further technical development in this area. The paragraph before presents the technical application of the concept for a real life environment - P2Endure Breda demonstration case.

According to the building needs, the needed component capacity was calculated. The Figure 22 shows the front and the side section view of the integrated HVAC engine design concept developed for the P2Endure Breda demonstration case. The text below presents a textual description of the technical design idea and the conditioned air and hot water generation flow. The components that exist on the market (boiler, heat exchanger etc.) and satisfy the needed component capacity were chosen and are presented in Figure 22. As for the heat pump, it was disassembled into its main components (as seen on Figure 22) in order to satisfy the requirements for the HVAC engine (modular and optimized installations). The product from Danfoss manufacturer was chosen to satisfy the needed sizing of the heat exchanger and the compressor (http://products.danfoss.nl/all-products/#/). For the heat/cool batteries of the air ducts the product from a Dutch manufacturer (http://www.inatherm.nl/368/4857/PGK_400x200.html) was used as Breda case is located in the Netherlands (reduced distance of transportation). The air duct system and the water tank were dimensioned according to the elaborated calculations. The innovative idea presented in Figure 22 lies within placing an air duct inside another air duct. However, using the exhaust air instead of the outside air is already an existing system (the heat pump boiler). To check if the principle of the heat pump boiler differs from another heat pump, following website was used: http://www.warmtepompinstallateur.nl/warmtepompboiler.html. Other components like valves and pumps are relatively small components and their sizing is not critical. These components can be bought from different market producers.

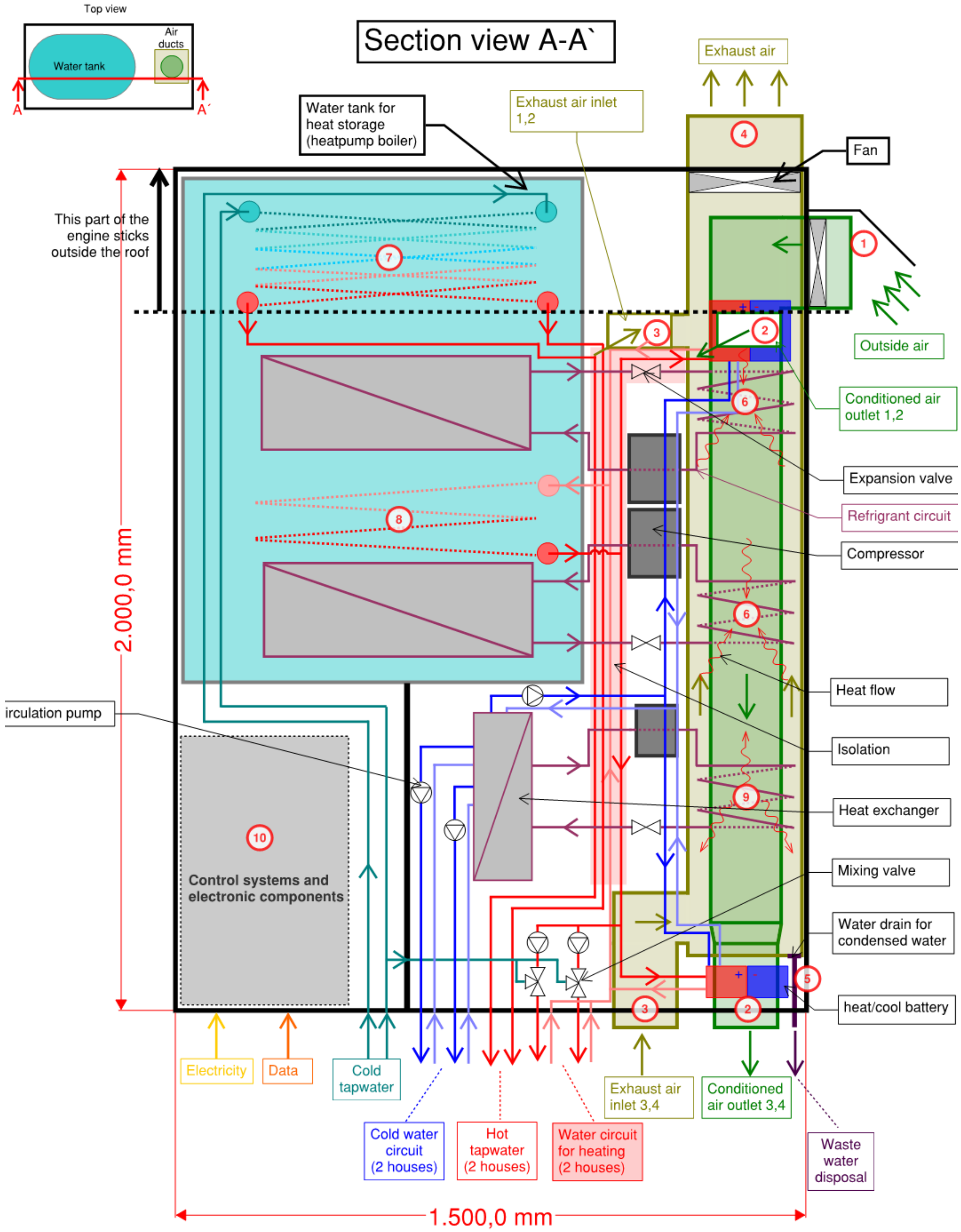


Figure 22: The front and the side section view of the developed integrated HVAC engine design concept developed for the P2Endure Breda demonstration case.

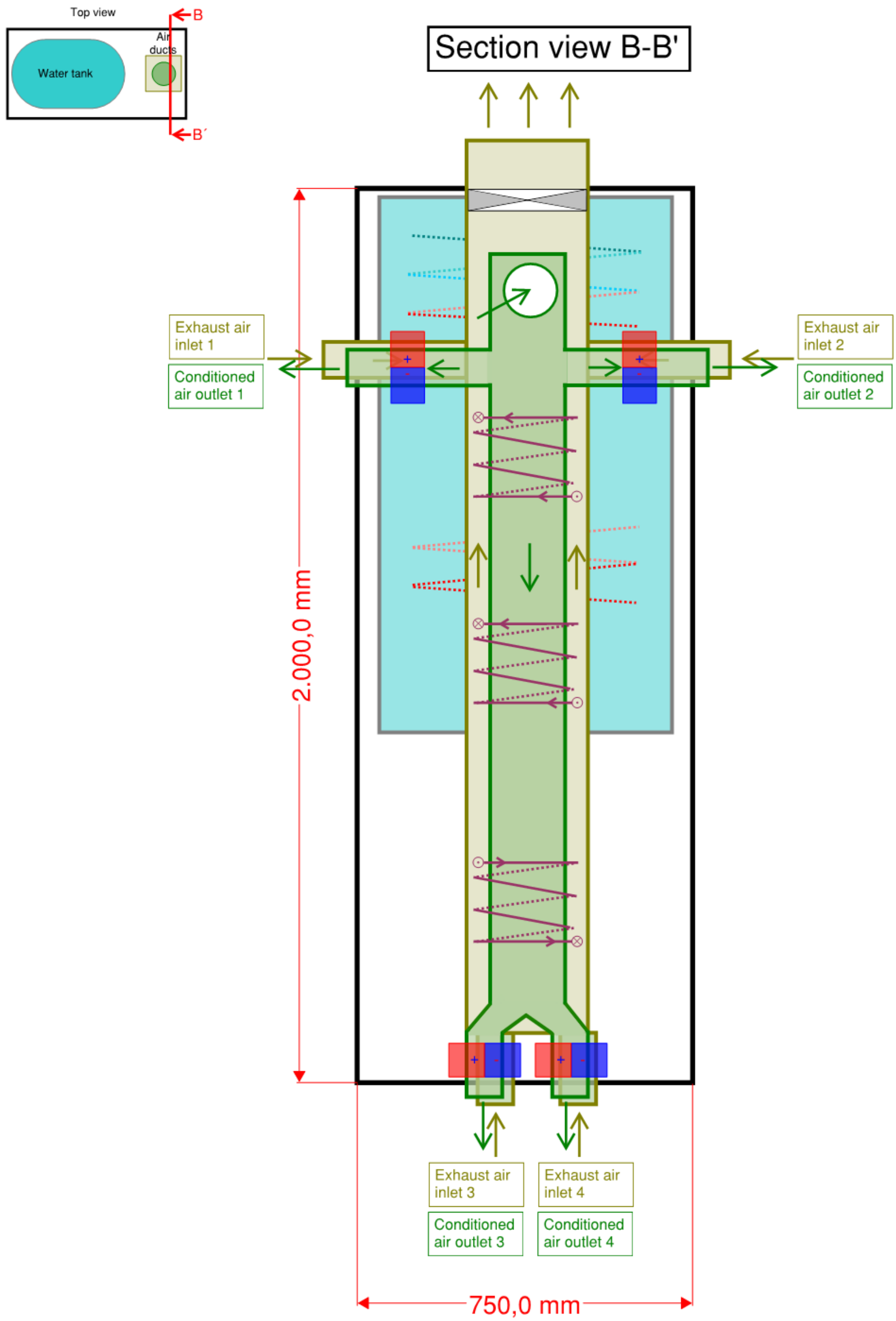


Figure 23: Side section of the HVAC engine for the Breda demonstration case.

This engine, with an internal volume of 2,25m^3 is designed for a location inside a wall of two adjacent households while the upper part of the engine sticks outside the roof. Its dimensions are 2 x 1.5 x 0.75 m^3 and it is capable to provide both households with conditioned air, DHW and water for central heating/cooling. This engine is also equipped with a water tank designed to store redundant heat for a possible later use.

Conditioned air

At Figure 22, (1) outside air is sucked into the inner air duct. The outside air will be warmed or cooled at the demand temperature by cool/heat battery and is blown into both households as seen at (2). The air from both houses will be returned at (3) as exhaust air and will leave the engine at (4) via the outer air duct. There are two reasons why the air ducts are inside each other: Firstly, it reduces the space required for the installations inside the HVAC engine. Secondly, it causes heat exchange to take place between the air in the inner air duct and the exhaust air in the outer air duct. Due to this heat recovery less energy is required to warm up the air which results in an increase of the overall efficiency of the HVAC engine. Depending on the ambient and inside air temperatures condense could be formed at the outside of the inner air duct. To prevent air duct rusting another material could be used like plastic. However, to allow heat transfer to take place the material need to have a high thermal conductivity. To remove the condensed water from the air ducts a water drain is placed at the bottom of the outer air duct at (5). From here the water is led to the sewerage.

DHW and water for central heating/cooling

The exhaust air can be used to heat up the refrigerant at (6). The refrigerant is a special liquid that will evaporate at low temperatures. The compressor will heat up the evaporated refrigerant in such a way that it is capable to heat up the water tank. The compressed evaporated refrigerant is led to a heat exchanger inside the water tank and from there to an expansion valve to turn the evaporated refrigerant back into a liquid. This is the principle of a water/air heat pump. The engine contains two heat pump circuits to increase the rate in which the water in the water tank heats up. The water tank is an oval shaped flat tank that contains about 600L of water. It is oval shaped to reduce the amount of heat loss. Cold tap water from the water company flows from the top of the water tank down through a spiralized pipe placed in the tank at (7). The water temperature is highest at the top of the tank so that is why this part of the tank is used to generate hot tap water. The tap water leaving the water tank has a temperature around 60 ^{o}C and will leave the HVAC engine at the bottom of the engine.

Water for central heating is heated in the same way at (8) but it doesn't require as much energy as water for DHW. So the generation of central heating water will take place beneath the generation of DHW (about halfway the water tank). A large amount of the heated water (between 35-55^{o}C) is used for central heating of both households but a fraction is used to heat the air via the heat/cool batteries.

This engine is also capable to generate cold water at (9) to cool floors for example. Cold water is generated with the same heat pump principle as the heating of the water tank. Instead of

heating the refrigerant, heat needs to be transferred from the refrigerant to the exhaust air. To accomplish this, the circuit needs to go the other way around. So after the refrigerant compresses heat, the refrigerant will flow inside the air ducts to transfer the heat to the air. After it flows through an expansion valve to transfer into a liquid state of the refrigerant again. When the refrigerant is a liquid it is cold enough to cool the water in the cold water circuit to about 12°C in the heat exchanger. After heat exchange has taken place the refrigerant shall evaporate again.
At (10) designated area for a control system is foreseen. A control system that allows automatic control of the desired temperature for water heating and air conditioning works as follows. A sensor (thermostat) is placed in the living room and bedrooms to measure the actual temperature in those rooms. These temperatures will be registered and send as electrical signals to the HVAC engine as logged data. Inside the HVAC engine several modules are placed. These modules have the task to read the data and give the mixing valves orders to open or close the third valve. For example when it is recorded higher temperature in the room as desired (set point), the module will give the mixing valve the task to open the third valve so cold tap water can mix with the central heating water to cool the water down. This principle is the same for the heat/cool batteries inside the engine.

This concept engine is intended to provide needed services for two adjacent households (see Figure 24).

Figure 24: Example of the HVAC engine placement for the Breda demonstration case.

Figure 25 shows alternatives to the HVAC engine location presented on Figure 24. Breda demonstration case is only presented as an example for possible installation of the HVAC engine for the residential buildings. However, in real-life appication several possibilities of engine allocation are possible and the decision depends on the agreement with the building owner, budget, available space and desired building aesthetics. According to these constraints, the engine can be placed on the roof, outer façade, inside the house (attic, technical space) or between two houses in a narrow space. According to these different possibilites of position of HVAC Engine, different base frame solutions can be used as presented in Chapter 1.5 – Stage 3 of the design.

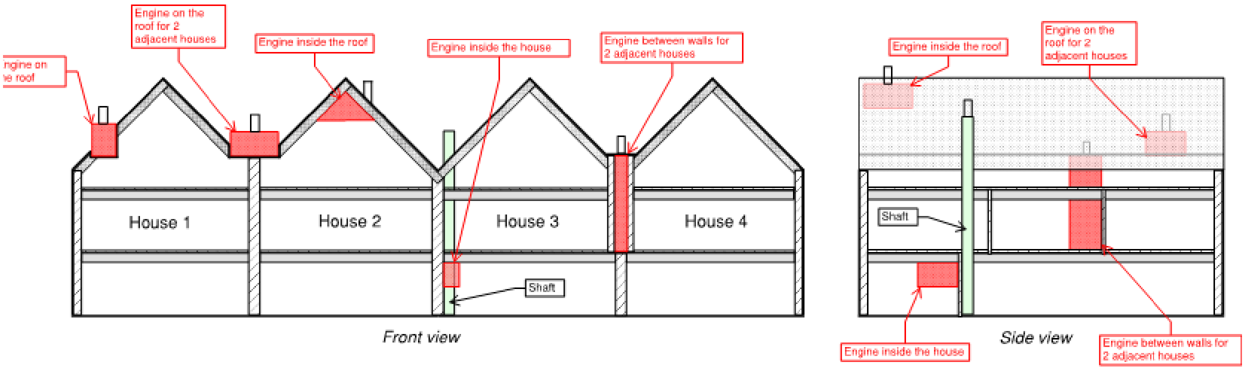


Figure 25: Different location possibilities for the HVAC engine placement.

5.2 HVAC engine for non-residential buildings

5.2.1 HVAC Engine type

For the utility buildings the capacity of installations is bigger, therefore the installations are consequently larger. Engines for these types of buildings are already on the market as air handling units (AHU), see Figure 26 and Figure 27. As it can be seen from Figure 26, the concept for the development of HVAC engine for residential buildings is similar as the component design of AHU parts in the singular base frame. The AHU frame is designed in a way that allows access for maintenance and replacement of separate units (e.g. air filters) when necessary.

Figure 26: Modules of the AHU units mounted in one steel framework.

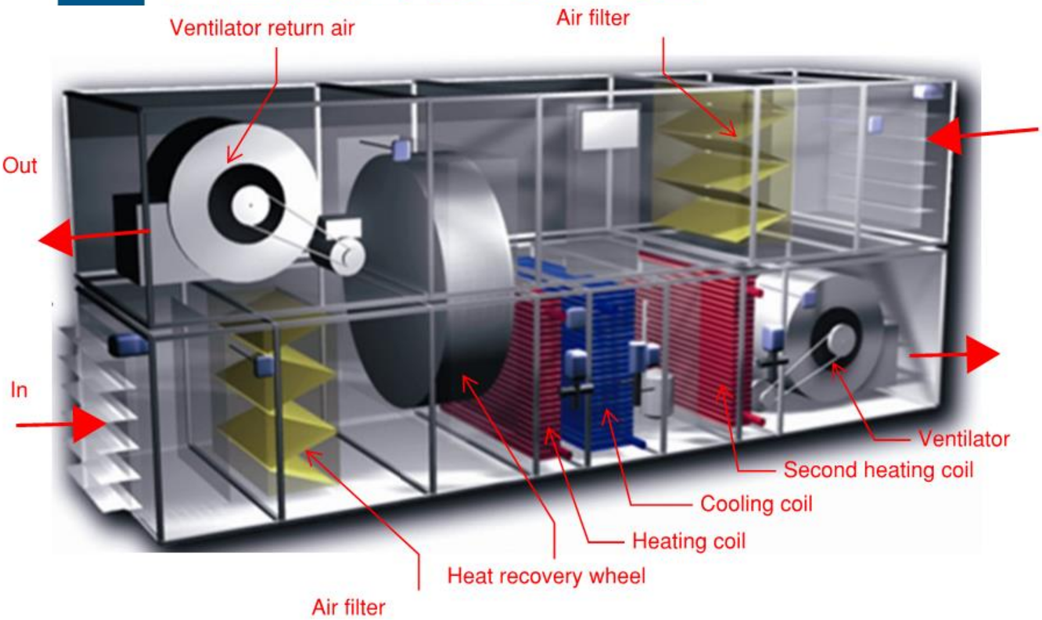


Figure 27: Example of a stand-alone AHU unit for commercial buildings.

The installations in utility buildings are placed in different locations in a building (e.g. garage, basement, technical rooms, roof). To make the air handling unit and all other installations PnP, they need to be placed together in a convenient easy accessible place in the building. To demonstrate the application of HVAC components (heat pump and AHU), the calculations of the needed capacity is done for the Warsaw demonstration case. The rooftop retrofit design of P2Endure consortium partner PAN+ is considered where this modular rooftop module will be heated, cooled and ventilated by the P2Endure Engine having required capacities. After the calculations, the air handling unit and heat pump where chosen to fit the requirement as presented in Table 6.

Table 6: The needed capacity of the chosen HVAC components for the Warsaw demonstration case.

Heat pump	31 kWth
Air handling unit	5060 m^3 with a heat recovery

Because of the dimensions of the installations, it was desirable to have the engine positioned into two separate technical rooms as seen Figure 28. Both the air handling unit and the air-air heat pump have an air inlet and outlet. It is best to place these in the corners of the building to prevent the mixing of the outlet air with the fresh air. Furthermore, both 'engines' need space to allow easy access and maintenance around the installations. These spaces are marked in the schematic overview as well in Figure 28.

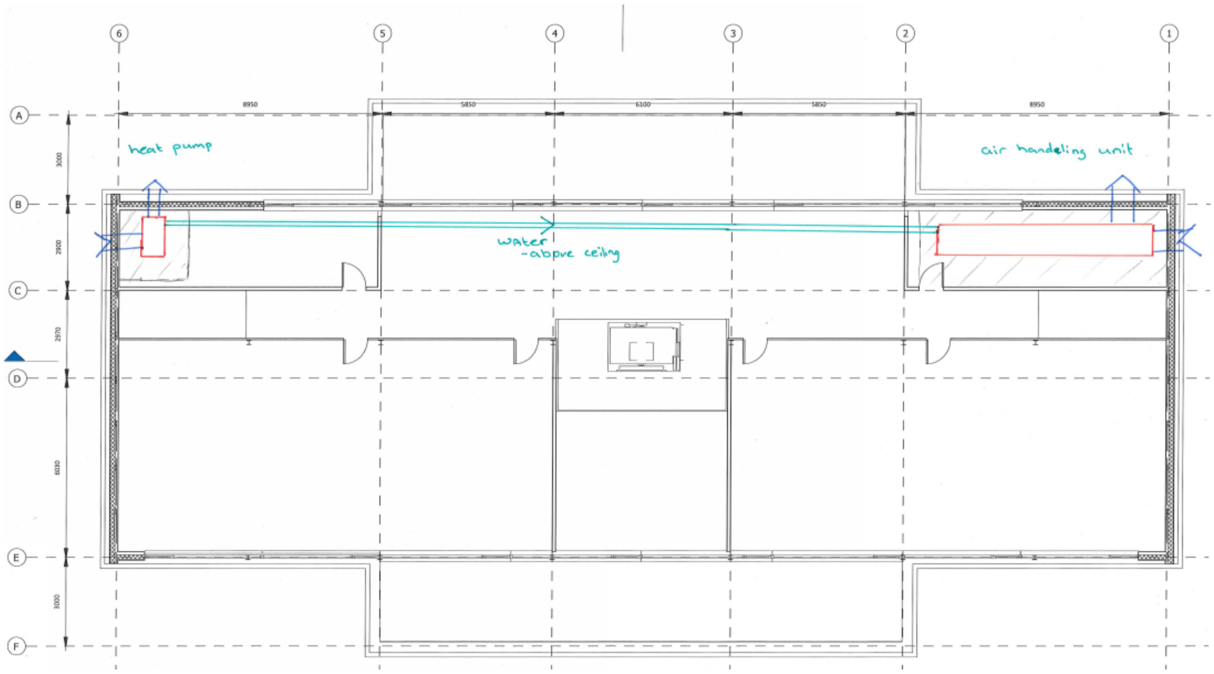


Figure 28: Position of the heat pump and air handling unit for the utility building.

In addition it needs to be kept in mind that the 'engines' need to be easily transported and positioned on the site. The air handling unit and heat pump with some piping attached can be placed on a steel frame (skid) so that it can be lifted into the building with a hydraulic platform or otherwise. In addition, the façade needs to be detachable at the places of the technical rooms. Besides, there cannot be any elevations in the floor around the engine(s) (façade side) otherwise the engines cannot be lifted by a hydraulic platform.

6. Holistic renovation approach

A modular high performing HVAC system cannot be effective if it is coupled with poorly designed building envelope or other building components therefore, a holistic view is needed. A set of reliable, energy efficient and affordable retrofit solutions will be made available, which execution is facilitated by industrialized, modular and flexible HVAC, façade and Information and communication Technology (ICT) systems developed. Furthermore, as explained in chapter 1, if a complete building retrofit is considered, prefabricated building modules (wall panels) can have integrated pipes and distribution channels (integrated shafts) furthermore simplifying the retrofit process.

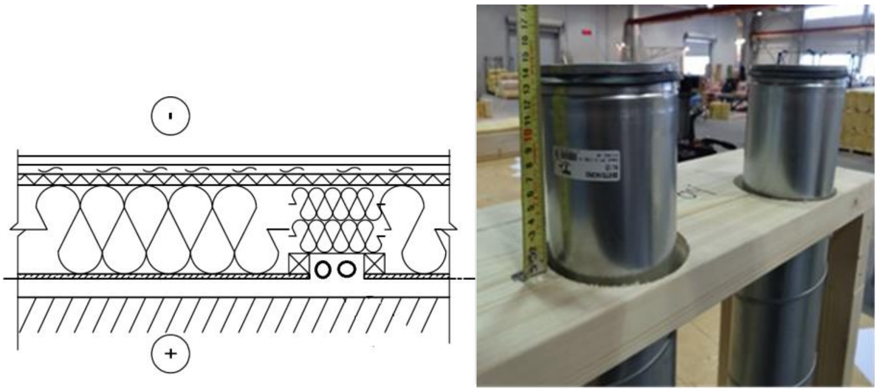


Figure 29: Example of the integrated shaft for HVAC pipes, ducts and distribution channels inside a prefabricated building module (wall panel).

6.1 Different practical applications of modular HVAC Engine beyond P2Endure scope

6.1.1 Application for student housing

The Figure 30 shows how possible locations of an engine for a multi-story student dormitory. As seen from the figure, due to the modularity the HVAC engine can be designed to satisfy the needs of the building complex in a most optimized way (decreasing the installations size and costs). A single heat pump located on the roof can supply enough heat for the 8 apartments. In addition, every student apartment has a boiler in order to satisfy the needs for the hot water.

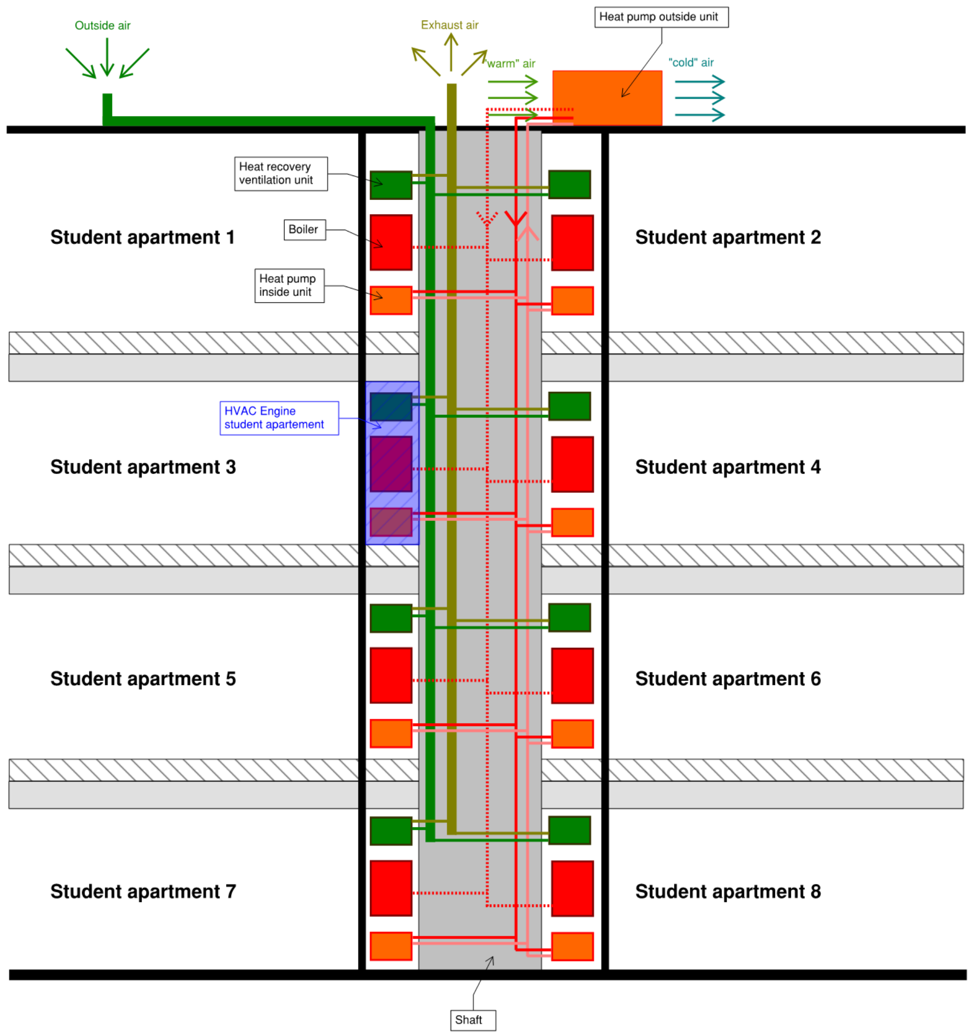


Figure 30: The HVAC engine concept developed for the student housing.

6.1.2 Application for row houses

The idea of a modular integrated HVAC engine can be adopted also for row houses (multifamily buildings) where the engine can be installed according to the available space and demand requirements.

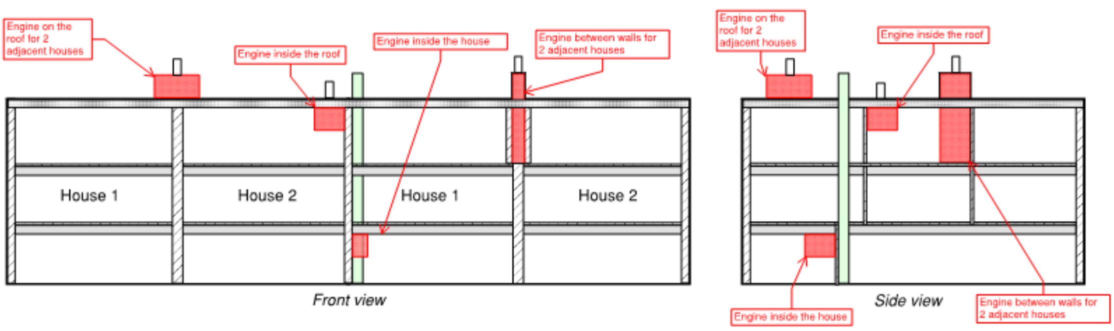


Figure 31: Possible locations of P2Endure Engine for the semi-detached houses.

The Figure 32 presents a possible installation of the HVAC engine for the semi-detached house where a single HVAC engine can be able to satisfy two adjacent households.

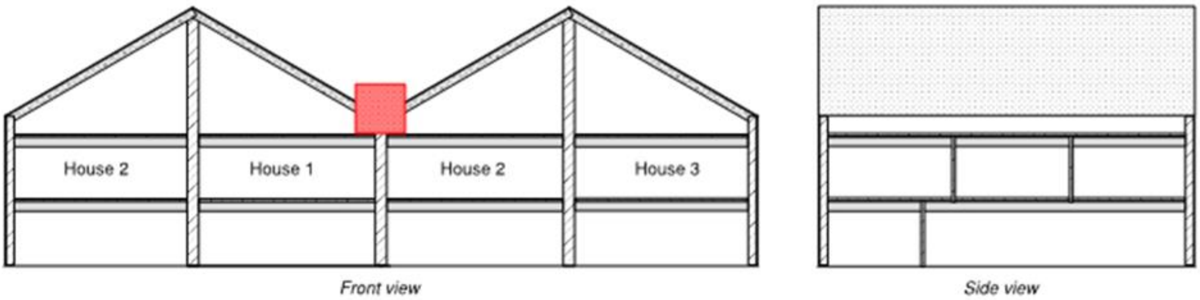


Figure 32: Single P2Endure Engine unit used to satisfy HVAC needs for the 2 neighbouring houses (adjacent walls).

6.2 Further recommendations for the development and optimization of the HVAC Engine – From modular to integrated HVAC Engine

The described HVAC engine concept presents a modular engine where all separate parts are bought from different manufacturers and placed on a compact installation platform and frame. Further research study can be done to develop an engine where all components are further disassembled and only individual parts are integrated within one unit. This integrated approach can be compared to a car engine structure where instead incorporating the individual HVAC components (AHU, ventilation unit), these components are further disassembled into the singular differently sized parts. Afterwards the complete HVAC engine is built to perform the intended integrated function of heating, cooling and ventilation. Further, all elements of the installations will be integrated into one installation without buying HVAC components (ventilation unit, AHU etc.) from different manufacturers. This can allow further miniaturization of the whole HVAC unit reducing size and costs of the HVAC integrated engine compared to HVAC modular engine. Such an integrated HVAC engine concept can be compared to the car engine parts composition.

Traditional installations Engine 1.0 (BAM) Engine 1.2 (LG and BJW) Engine 2.0

Figure 33: Development of traditional building services into engines (1.0,1.2, 2.0).

6.3 Parametric modelling as a design tool for the modification of HVAC Engine components

The P2Endure e-Marketplace provides the user with the possibility to supply energetic, thermal and financial inventory and development information by integrating a parametric modeller. This modeller takes the as is BIM, which is provided by the user, as a basic value. By adding the products, which are provided by suppliers in the P2Endure e-Marketplace, a calculation between the old and new values can take place. In order for the parametric calculation to be made, the products of the P2Endure e-Marketplace must be described as precisely as possible by the respective provider. To describe the product parameters, the TU Berlin has developed a UML diagram describing the minimum requirements for information on the respective elements. Table 2 shows the parameters necessary for calculation in an HVAC system.

Table 7: Parameters for an HVAC system

HVAC	Cooling room element	Heating room element	Ventilation room element
Parameters	Element name Provided cooling level	Element name Provided heating level	Element name Provided ventilation level

Users will be able to personalize their renovation projects through the products they find on the P2Endure e-Marketplace. Using the example of HVAC systems, it is possible to combine the individual (heating, cooling, ventilation) elements in order to fulfil the demands and requirements of the renovation project. This means that the user is not tied to an "out of the box" solution. He will have the possibility to put together a system according to his requirements.

A detailed description of the parametric modeller is given under work package D2.2.

7. A review of EU projects developing novel HVAC components and systems for deep renovation

This chapter gives an overview on the projects that deal with the development of the similar concept of combining all the HVAC components in one compact unit or present novel advanced developments in the field of HVAC systems. With a help of EU funded project, different HVAC experts and designers are trying to develop breakthrough smart optimized HVAC packages that allow for easier and more efficient improvement of the existing HVAC installations. The developed prefabricated modules often include certain HVAC components (ventilation with heat recovery, DHW with solar panels etc.).

7.1 MORE-CONNECT HVAC Engines (H2020)

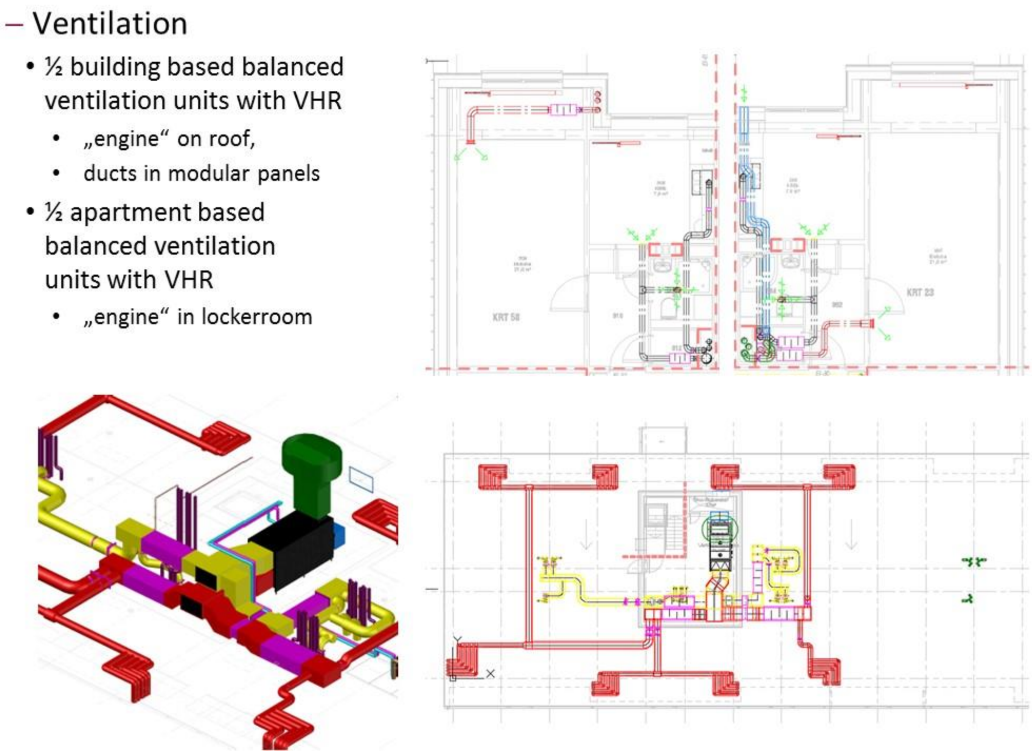
MORE-CONNECT aims to develop a packaged HVAC solutions minimizing the required space for the installations. In order to minimize installation costs and time as well as to ensure installation quality and simple modernization during lifetime, the multifunctional modular HVAC unit “house engine” is introduced. Figure 30 presents a modular HVAC installation unit implemented in the Netherlands. In order to prevent freezing of the developed HVAC unit in cold climates, further development is needed. 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 exposed by MORE-CONNECT team 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.

MORE-CONNECT project also aims to develop roof modules with integrated renewable energy sources (RES) and combined heat units. The first prototypes are already developed and applied in Heerlen, the Netherlands. Hence the full testing on demonstration sites is planned for 2017 and 2018. The Dutch dwellings (prototype) from the 60’s are fully retrofitted with modular prefabricated integrated roof. The facades include integrated combined heating units (convectors) with decentral demand and CO_2 controlled mechanical ventilation units with heat recovery. The roof elements have 40.0 m^2 PV panels for 6.4 kWp. A fully prefabricated installation box (engine) contains an air-to-air heat pump, boiler, mechanical exhaust fan and PV converters. This box is placed in the roof and can be accessed and replaced from the outside. In case of maintenance or replacement no access or activities in the dwellings are necessary, thus minimizing the disturbance for occupants [4].

Figure 34: Prefabricated installation platform placed in an integrated PV roof.

Prototype presented in Figure 34 includes a fully prefabricated installation box (engine) mounted on the roof of the dwelling containing an air-to-air heat pump, boiler, mechanical exhaust fan and PV converters. This box is placed on the roof and can be accessed and replaced from the outside. In case of maintenance or replacement no access or activities in the dwellings are necessary, thus minimizing the disturbance of the occupants [4].

Figure 35 shows the designs of a prefab 'engine' for ventilation and for domestic hot water systems for a multifamily building, designed by Technical University of Tallinn (Estonian demonstration building for MORE-CONNECT).



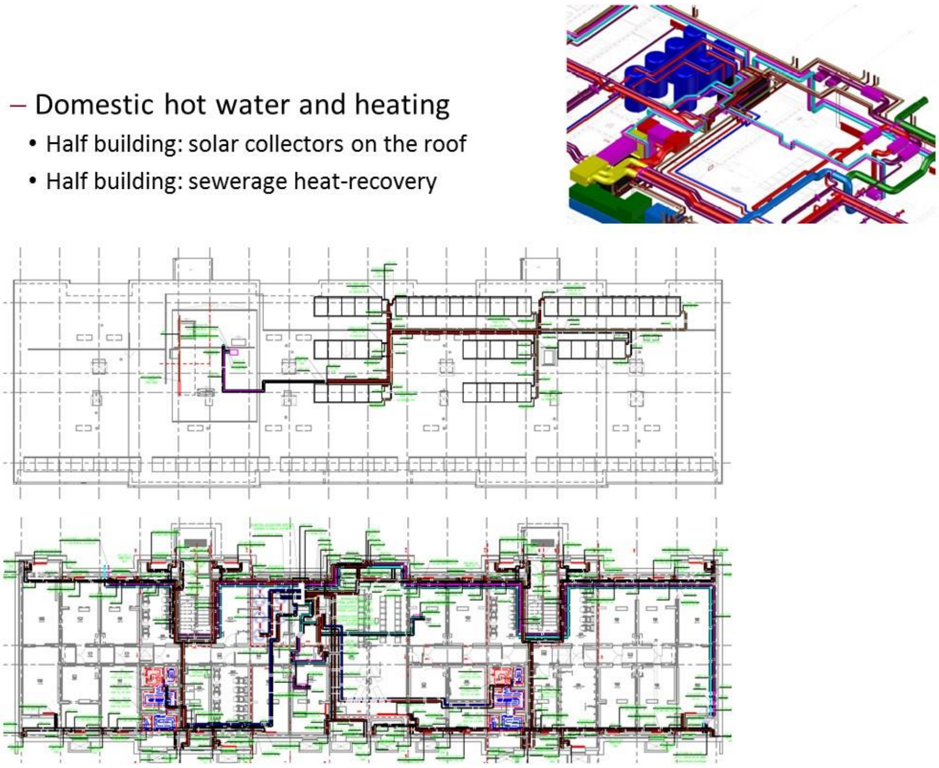


Figure 35: Prefabricated installation platforms for ventilation and DHW, Estonian demonstration building, MORE-CONNECT

Project website: http://www.more-connect.eu/ (product in a research and development phase).

7.2 NANO-HVAC solution (FP7)

Poorly insulated HVAC ducts can lose through conduction up to 50 % of the energy used to heat and cool the indoor environment. The main goal of the NANO-HVAC project is a new innovative development of ducts insulation.

Safe, high insulating HVAC-ducts enabling minimization of heat/cool losses: cost-effective, safe and extremely thin insulating duct layers that can be applied both to circular ducts (wet-spray solutions) and to square ducts (pre-cast panel). Insulation is obtained using spray able aero clay-based insulating foams that can be automatically applied during manufacturing of ducts, avoiding manual operation needed for conventional materials. Such technologies, coupled with advanced maintenance systems can guarantee a 50 % saving in energy losses compared with conventional ducts. The whole system aimed to be developed with a requirement of service life of the building of 25 years.

The full scale demonstrator was developed and installed on an existing commercial demo building in Spain. The installation was used to measure and evaluate the performance of the system to be installed in HVAC system, regarding the low energy consumption in combination with the high antimicrobial capability [5].

Figure 36: Preparation of the demonstration site in Spain [5].

Project's website: http://www.nanohvac.eu/Default.aspx (finished in 2015)

7.3 E2vent system (H2020)

The technical objectives of the E2vent ventilated facade system are to:

Develop an adaptable smart modular heat recovery unit (SMHRU) adjustable to work into the ventilated façade cavity, and able to recover heat from ventilation air, preheating the ventilation air in winter and precooling it in summer.

Study the energy recovery potential of the SMHRU, as well as its use for free-cooling and thermal storage strategies.

Develop a latent thermal heat energy storage system (LTHES) based on phase change materials fitting in the cavity and complementary to the SMHRU.

Allow effective photovoltaic technology adaptation for the ventilated façade system, ensuring adaptability of PV modules in the external cladding, analysing sun-tracking technologies and integration of PV inverters in the cavity of the ventilated façade, to improve the modularity of the system [6].

Project's website: http://www.e2vent.eu/ (2015-2018).

7.4 REnnovates Energy module (H2020)

Energy module contains appliances and measurement and control infrastructure required to provide energy services for tenants. Essentially it is a skid where all installations necessary for heating/cooling, ventilation, domestic hot water, monitoring and inverter for the solar panels are integrally combined so it is to be prefabricated (test-run off site), easy to transport, easy to install and easy to maintain. The energy module is to be prefabricated (test-run off site), easy to transport, easy to install and easy to maintain. The skid is slightly insulated and waterproof. The following components are integrated in the energy module [7]:

- Air-water based heat pump with buffer vessel for space heating and domestic hot water use. Because of the climate conditions in the Netherlands cooling is not applicable. The existing radiators in the house are used as a heat emission system.

- Balanced ventilation system with heat-recovery for ventilation. Air supply in living-room, sleeping rooms and kitchen, air exhaust in toilet, bathroom and kitchen.
- Inverter to convert DC (unidirectional flow produced by PV-panels) to AC (alternating flow, form in which electric power is delivered to residences)
- To monitor the energy performance of the house a monitoring system is integrated in the energy module. Energy use for space-heating, hot-water and ventilation is measured as well as the actual performance of the PV-panels.

Project website: http://rennovates.eu/ (2015-2018)

8. Conclusions

The deliverable 1.3 presents a new technological development in the field of HVAC. Here are all HVAC components integrated in one unit called *P2Endure Engine*. State-of-the-art inventory of the compact HVAC systems available on the market was elaborated. As for large commercial buildings most of the HVAC components available on the market are designed optimally (efficient sizing), therefore more interesting is utilization of the developed HVAC engine concept for the residential area. It has been shown that following a simple 3-step design guide (see Chapter 1.5) different configurations of P2Endure Engine applications can be elaborated for residential as non-residential buildings. Technical requirements and several design possibilities have been shown for different deep retrofit situations. To summarize how the

a. To which extent does the optimization of the innovative products meet the P2Endure goal (in terms of energy saving, cost saving, time saving)?

With a careful design the HVAC Engine installation can help reducing renovation time, installation costs and space. In this report, it has been discussed that with such modular and industrialized HVAC Engine development approach lower installation costs and reduced renovation time can be achieved than compared to traditional retrofits. This also proves why such an innovative PnP technical solution is a smart solution to adopt for deep retrofits compared to traditional techniques (satisfying the objectives of P2Endure project).

- Energy saving: Application of engines with heat pumps combined with deep renovations will reach more than 60% energy savings on heating and hot water.
- Cost saving: Production in factories will reduce the waiting time on site substantial compared to just mounting an engine on site. Total cost reduction for HVAC is assumed to be 20%.
- Manufacturing of engines as mass production will be efficient: Mounting engines on site will require less than 1 day. Now HVAC-systems are assembled on site during several months, component by component.

b. What are the inter-relations with the other WPs in P2Endure?

The approach of the engine gives input for the parametric modeller. The size of the engine is dependent on the size of the building and the typical use of the building. By introducing the P2Endure parametric modeller (reference to the D2.2) the HVAC components sizing is done and appropriate HVAC components can be chosen accordingly (directly incorporated as part of the BIM model). Such design process allows quick and optimized design of the HVAC engine satisfying specific building requirements and its needs.
The performance of the HVAC engine is continuously monitored and commissioning can be done remotely with ICT-solutions part of the engine (Figure 22: integrated control box as part of the engine).

c. *What are the remaining challenges? Are there plans to tackle these challenges within or beyond P2Endure?*

The first generation of these engines has been developed and applied in a number of deep renovation demonstration projects (in The Netherlands and Estonia) but there are still a number of steps to take in optimization and to come to mass production and further price reduction. Second generation (Table 1) will be aiming at price reduction due to profound use of new technology, industrialisation, and implementation of robotics and high possibilities of modification. With the second generation, industrial production processes can lead to a mass production of the HVAC engine products. As shown in some of the previous projects (MORE-CONNECT, Energiesprong) such industrialized HVAC engine solutions (with the second generation realized) can lead to a cheaper, faster and more sustainable renovation. Further challenges, beyond P2Endure, lie in technical improvements of the components to satisfy all the needed requirements for the installations (e.g.: reach sufficient air flow despite reducing the duct and pipes diameter/length or bending the pipes). The main stakeholder for this should be the manufacturers of heat pumps, heat storage techniques and ventilation equipment together with installers.

d. *What is the expected exploitation?*

In the demonstration case of Tilburg (roof top module) a separate engine for heating (heat pump) and for ventilation (AHU) will be applied. Therefore the architectural design and the installations design (ducting, piping) will be prepared for easy PnP-mounting of these engines.

It is believed that with such an integrated renovation concept new business models can be developed where energy is seen as a service. By developing PnP connections, fast installation on the site is achieved where holistic renovation approach should be adopted with prefabricated building components having included shafts for the distribution pipes and ducts. HVAC-engines are adjustable to the specific needs of dwellings or more particularly of households. Due to the modular structure flexibility, building owners and users can add/remove/replace HVAC Engine based on their new needs, technical improvements and budget availability. In case of malfunction it is easier to replace the engine and do repairs in the factory than repair on site. It makes the business model with lease-engines possible where energy is delivered as a service.

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