NLD Wansdronk 2021-01-08, Green Deal - Emporium

Wansdronk Architektuur BV
WG Plein 286, 1054 SE Amsterdam, Netherlands
ir. Renee Wansdronk, architect
rw@wansdronk.com, www.wansdronk.com
+31(0)85.8784298 line, +31(0)6.19716671 cell

Challenges: Dominance of heat and cooling demand, and of new construction, in 2050

Emissions

The ten largest pollutants (countries) emitted together more than 70% of the global greenhouse gases, and the 100 least polluting countries less than 3%. Energy is by far the largest pollutant. A 50% chance global warming not exceeding 2 ˚C requires cumulative CO2 emissions to be limited to 3,010 Gton CO2. A 1,960 Gton CO2 'carbon budget' was emitted in 1870-2013, so from 2014 the 'carbon budget' is 1,050 Gton CO2 to have a 50% chance not to exceed 2 ˚C.

Buildings account for around 40% of total energy consumption and 36% of CO2 emissions in Europe. The European Union (EU) aims at drastic reductions in domestic greenhouse gas (GHG) emissions of 80% by 2050 compared to 1990 levels, and the building stock should achieve even higher reductions of at least 88-91%. Carbon used in the building construction and materials will get more impact, especially for new buildings built to high standards for operating the building.

Buildings

Heating in building energy demand is global 50%, and in Europe 70%, and nearly 75% including cooling. The energy transition, requiring security of supply, is a heat crisis, with a need to reduce gas imports, and to switch from fossil fuels to renewable heating and cooling technologies. Alternative gas sources are not necessary, because a differentiation of energy sources is needed, and the electrification of heating buildings is not a desirable solution.

In 2050, globally, the number of households is expected to rise nearly 70%, from 1.9 billion in 2010 to 3.2 billion in 2050, and the total floor area (residential and services) is expected to increase 70%, from 206 billion m2 in 2010 to 356 billion m2 in 2050. When 78 billion m2 demolition 2010-2050 is included, only 128 of the 206 billion m2 (Pre-2010 stock) will be part of the 356 billion m2 in 2050, and 228 billion m2 (Post-2010 stock) will be new build.

More than one quarter of the European 2050s building stock is still to be built. The energy consumption and related GHG emissions of those new buildings need to be close to zero in order to reach the EU’s highly ambitious targets. For meeting the EU long term climate targets, the buildings CO2 emissions related to the energy demand is recommended to be below 3 kg CO2/m2yr.

Storage

The global installed Distributed Energy Storage System (DESS) power capacity is expected to grow 7,066 times larger in 10 years (2014-2024). The power capacity unit hints that this mainly concerns electrical and, to a lesser extent, heat storage. Community energy storage seems to lag behind the residential and commercial energy storage markets.

Aims: Low exergy, solar energy, zero emission buildings with seasonal heat storage

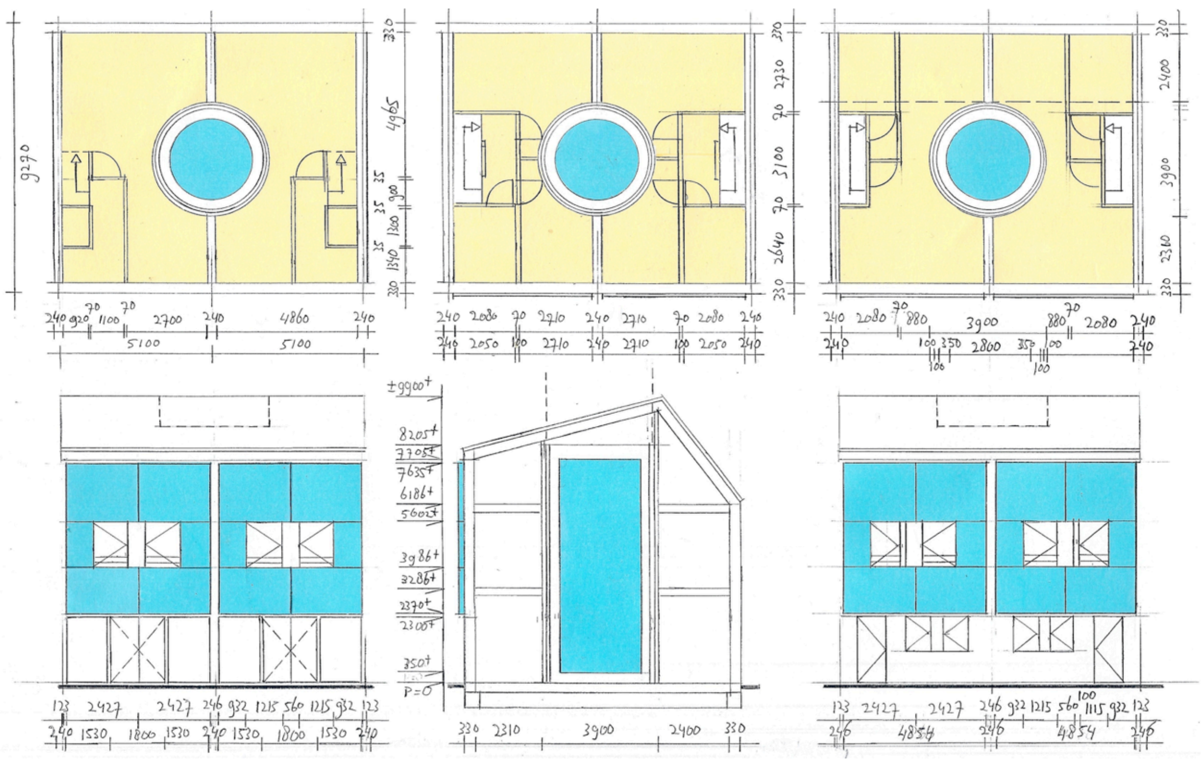
Emporium

Emporium is a solar energy, low exergy and zero emission building concept with an integrated seasonal storage system without energy losses, supplying indoor heating and hot tap water, for residential and utility buildings, in all climate zones.

Buildings, compared to products, face +30% transport costs as part of the construction costs, which characterizes the local organized construction process, instead of fabricating at great distance. Emporium is currently in the implementation phase, and locations and projects are searched for, to learn to deliver with local partners.

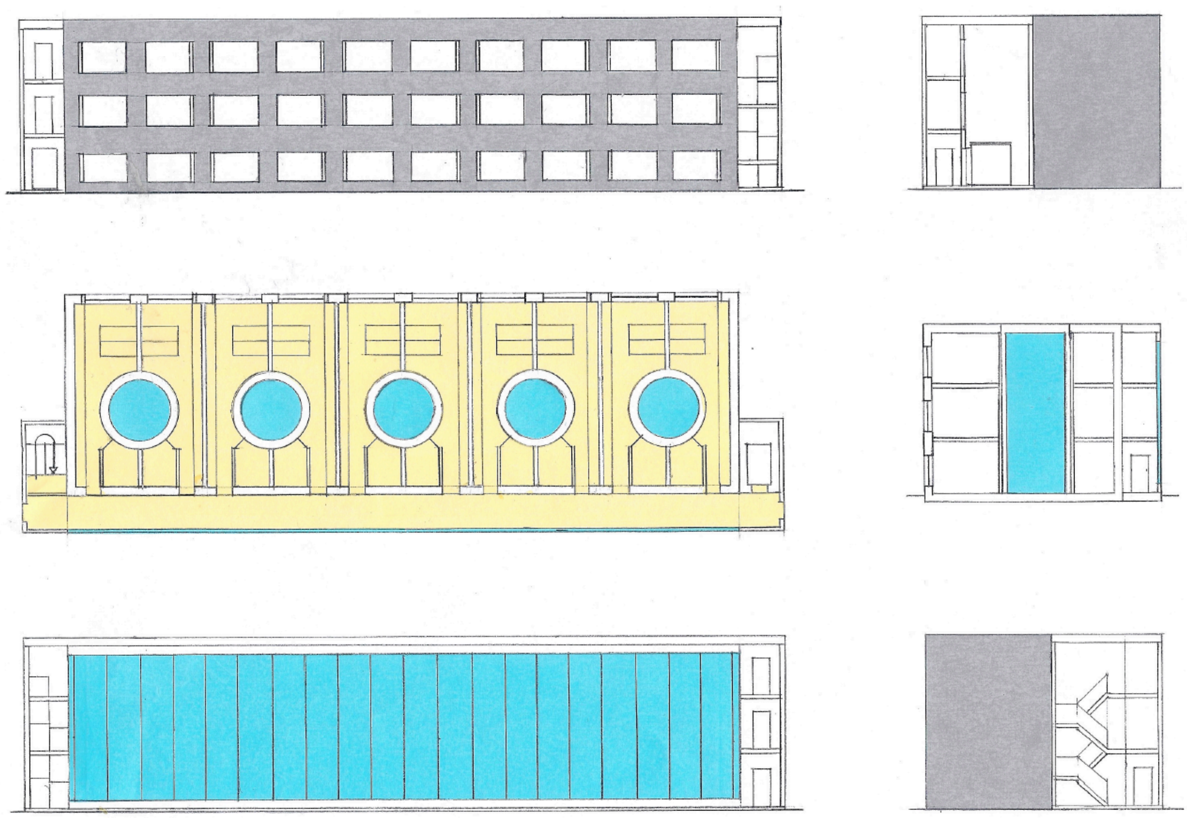
The Emporium design below shows two semi-detached houses, with the building integrated solar heat storage (blue), and vacuum tube solar collector facade, which is oriented to the south (blue).

semi-detached house integrated solar heat storage (top view)



vacuum tube solar thermal collector facade (front view)

The Emporium design below shows a 3 floors high 30 rooms hotel, with the building integrated solar heat storage (blue), and a vacuum tube solar collector facade, which is oriented to the south (blue).



Objectives: Learn to deliver solar facade and water column buildings with local partners

Building integration

Low-exergy system

The Emporium concept is characterized as a solar heating system with the smallest exergy loss (low-exergy). Exergy (applicability or quality of energy) stands for the temperatures which are used in the Emporium system, and which are as close as possible to the demand temperatures (20 ˚C indoor and 45 ˚C shower). The heat storage water temperature is above these two demand temperatures and below 100 ˚C, and 50 to 90 ˚C over the year. These temperatures are produced with a vacuum tube semi-transparent solar heat collector, integrated in the southern facade of the building. The seasonal heat storage volume is integrated with the building volume to achieve that all heat storage losses (more than 50% through 50 cm glass or stone wool insulation) flow into the building and are used as indoor heating.

No energy losses

The Emporium concept is characterized as a seasonal heat storage without any energy loss. An adjustable ventilation cavity around the storage serves as a heat loss control, and as a leakage protection. A 50 m3 storage tank (9.00 m height, 2.65 m diameter, 86 m2 wall surface) with an annual 50 to 90 ˚C temperature curve and 8.4 GJ heat load, gives, at an annual average storage temperature of 70 ˚C with a temperature difference of 50 ˚C with the 20 ˚C indoor space, and a U-value of 0.080 W/m2K, an average heat loss of 4.00 W/m2, that gives an annual heat loss of 3,013 kWh or 10.8 GJ for 86 m2 wall surface during 8760 hours. In an optimal embodiment, this heat loss benefits to the building.

100% heat supply

A 50 to 60 m2 vacuum tube solar facade collector is required, for an annual supply of indoor heating, and hot tap water, for two houses. The heat content of an at least 50 m3 heat storage is 8.4 GJ. The 10.8 GJ heat loss and this 8.4 GJ heat content added together comes to 19.2 GJ. This is sufficient as seasonal storage for two houses with a total heat demand of 50 GJ/year, of which 12.5 per dwelling for indoor heating and 12.5 GJ/year for hot water. This 50 GJ/year corresponds to approximately 1430 m3 of natural gas of 35 MJ/m3.

100 times cheaper

The 50 m3 storage vessel, with a capacity of 8.4 GJ by its 50-90 ˚C temperature curve, 10.8 GJ by its heat losses, and 19.2 GJ or 5,333 kWh per year in total, costs approximately € 6,800 for the steel vessel, € 7,800 for the insulation material, and € 14,600 in total, which is equal to 2.74 €/kWh. A today electric home battery costs approximately 300 €/kWh, which means that the Emporium low-exergy storage technology is 100 times cheaper, compared to electric and high-exergy storage technologies.

Temperature stratification

A storage vessel is a vertical water cylinder, in which temperature stratification arises, improving the system performance. The solar collector efficiency increases by connecting the solar collector inlet tube at the coldest water layer at the bottom of the storage vessel. The warm (shower) water availability extends by connecting the warm water heat exchanger at the hottest water layer at the top of the storage vessel.

The temperature stratification in the water column can also be used as internal overcooking protection, in case that the solar collector heat supply is too high, or the indoor and tap water heat demand is too low. In such a situation, the hottest water layer at the top of the storage can be cooled, by circulating and mixing this hottest water with the coldest water layer at the bottom of the storage.

Thermosyphon circulation

The heat circulation has a minimum of moving parts, such as pumps, is robust and silent, and requires little maintenance. Heat Cold Storage (HCS) for example, requires both water pumps for pumping up soil heat and heat pumps for converting the soil water to the demand temperature, requires a permit based on the groundwater law, and the storage of exergetic high-quality energy such as gas or electricity, and has pump runout risks and soil heat source uncertainties.

The solar collector, turned to the position of the winter sun, in an almost vertical position, leads to the smallest heat storage volume. Compared to a roof position, the façade position of the solar heat collector has the advantage that the collector surface increases proportionally with the widening or raising of the building, in case of increase in the building volume and therefore energy consumption.

The façade collector and the storage vessel form a water loop that can act as a thermosyphon because of the water temperature and water weight differences, assuming there is no risk of freezing in winter, or loss of start-up in the morning. In the case of multiple storage vessels, these can be coupled by means of a thermosyphon, for heat exchange between houses, and to save the oversizing of a storage vessel for an only temporary increased individual heat demand.

Urban integration

Network costs savings

Construction and maintenance of energy networks, such as district heating systems, becomes especially costly for areas with a low building density, and for buildings far away from the network. In case that per building the energy network investments are higher, compared to solar collector and seasonal storage investments, it can be more profitable to choose for a stand-alone heating solution.

Renovation costs savings

Sustainable renovation can be expensive, especially in the case of high emissions reduction targets. Drastic construction interventions are required to make existing buildings zero-emission. Compared to renovation only, achieving these reduction targets at neighborhood or district level can be more economical, through replacing the existing homes with worst quality, by new zero emission homes with seasonal storage.

Small-scale urban planning

Prefabricated constructions with small scale, building integrated, energy storage can be added to, or fitted in, an urban district without any nuisance, due to a very short construction period and compact construction transport. Unlike, for example, aquifers, where multiple buildings must be connected at the same time, the Emporium storage can be installed separately per each building.

Temporary urban planning

Above ground and collapsible energy storages give more flexibility to the urban planning. In case that, for a better planning of the permanent development, the land allocation is limited to five or ten years for example, the energy storage can, as a temporary solution, be assembled and disassembled, and moved to a next location.

Rocky or water-bearing soil

Underground unlike above-ground energy storages require additional investments in digging or drilling in rocky soil. Underground unlike above-ground energy storages in a wet or water-bearing soil, require additional water-retaining constructions to keep the heat-insulating material around the storage vessel dry. This boat-in-boat solution doubles the construction and investment of the storage vessel.

Environmentally protected soil

Above-ground energy storages avoid perforations in protective and water sealing soil layers, like clay layers. Under ground energy storages, and drilling pipes for heat pumps, perforate these water sealing soil layers, with the risk that soil water or seawater below, mixes with the soil environment or soil water above.

Impact: Low exergy, seasonal storage systems, locally delivered for off-grid communities

Low exergy system

Building heating demand, both indoor heating and hot tap water, is a low exergy demand of 20 °C and 45 °C only, which is provided by an energy system that keeps the system temperatures as close as possible to the demand temperatures, in order to minimize its exergy losses.

Seasonal heat storage

Seasonal heat storage is characterized by only one charging and discharging cycle per year, with its consequently sizable heat loss compared to the charged and discharged energy, which is used as indoor heating, by integrating the seasonal heat storage in the building volume.

Local solar generation

Local solar heat production and storage on the building site avoids heat transport, requiring high exergy electricity finally supplied for a low exergy demand, and heat network losses, especially at a lower heat demand or at a lower distribution density.

Local construction process

Buildings are one of the heaviest products on the market, and the low value to weight ratio, and 30% transportation costs as part of the construction costs, characterizes a close-to-the-site construction process and consequently to learn to deliver with local partners.

Off-grid communities

The design, construction, and operation of the building integrated renewable energy generation and seasonal storage system by local workforce, supports an off-grid community and a sustainable local economic development by small-scale executable implementations.

References: European storage system related research projects and deliverables

FP7 MESSIB (2009-2013)

Multi-source Energy Storage Systems Integrated in Buildings (MESSIB)

Source: CORDIS

The overall objective of MESSIB is the development, evaluation and demonstration of an affordable multi-source energy storage system (MESS) integrated in building, based on new materials, technologies and control systems, for significant reduction of its energy consumption and active management of the building energy demand. This new concept will reduce and manage smartly the electrical energy required from the grid favouring the wider use of renewable energy sources . It will reduce raw material use for thermal performance and improve the indoor environment, the quality and security of energy supply at building and district level, including Cultural Heritage buildings. Furthermore, a significant reduction of the energy unit cost for end-users will be achieved. MESS is composed by two thermal and two electrical storage systems, integrated with the building installations and a control system to manage the building energy demand. The MESSIB basic principles are: 1.Rational use of thermal energy for primary energy savings and for increasing the indoor comfort. 2.Improvement of electrical energy storage in combination with RES to shift the demand with the production and to optimise the use of low cost “off peak” power from the grid. 3.Integration of the technologies in the building. Each of the technologies developed in the project will be integrated with conventional installations optimizing their functionality. 4.An active control system will manage the profile of use of each storage system and their interactions. This will contribute to the intelligent management of building energy demand and to ensure its security, quality and reliability.

Soft copy

ESP Acciona 2013-01-01, MESSIB Brochure

GRC University NTUA, Founti 2009-05-01, MESSIB D1.1 Identification of products and technologies energy related, relevant stakeholders and building classification according their different uses and typologies

FP7 EINSTEIN (2012-2015)

Effective INtegration of Seasonal Thermal Energy Storage Systems IN existing buildings (EINSTEIN)

Source: CORDIS

Energy use in buildings accounts for approximately 40% of EU energy consumption. Energy efficiency in new buildings is important, but existing building stock is the main target. Existing buildings, however, are characterised by particular requirements and constraints that are not present in new buildings and that requires new developments and adaptation of existing technologies.

In order to fulfil the most recent EU directives, solutions for a drastic reduction in primary energy consumption are required. Space heating and domestic hot water (DHW) represent the largest part of energy use in buildings nowadays, thus solar thermal energy seems to be one of the most promising heat source.

The overall objective of EINSTEIN project is the development, evaluation and demonstration of a low energy heating system based on Seasonal Thermal Energy Storage (STES) concept in combination with heat pumps for space heating and DHW requirements for existing buildings to drastically reduce energy consumption (primary energy savings up to 70% compared to conventional existing thermal systems).

This goal will be achieved by:

- Technological developments for STES systems adaptation for existing buildings and integration with the built environment

- Development of a novel, high-efficiency, cost-effective and compact heat pump suitable for existing buildings and optimized for higher temperature heat sources such as STES systems

- Development of new business and cost models which consider the entire life cycle of a building and incorporate the benefits of reduced operating costs; a decision support tool will help the planners to find the best technology to install in each particular case

- Development of integrated building concept. As cost-effectiveness is one of the main aspects to be considered in building retrofitting, a methodology and a software tool for most cost-effective global energy intervention framework definition for building retrofitting will be developed

Soft copy

DEU SOLITES, Mangold 2016-01-31, EINSTEIN Guideline for Seasonal Thermal Energy Storage Systems in the Built Environment, Deliverable 3.8

ITA Appolonia, Reccardo 2015-07-31, EINSTEIN Seasonal Thermal Energy Storage Assessment, Turin Congress

NLD TNO Bouw en Ondergrond, Spijker 2012-11-22, EINSTEIN Technology assessment of HVAC and DHW systems in existing buildings, Deliverable 1.2

H2020 CHESS-SETUP (2016-2020)

Combined HEat Supply System by using Solar Energy and heaT pUmPs (CHESS-SETUP)

Source: CORDIS

The project objective is to design, implement and promote a reliable, efficient and profitable system able to supply heating and hot water in buildings mainly from renewable sources. The proposed system is based in the optimal combination of solar thermal (ST) energy production, seasonal heat storage and high efficient heat pump use. Heat pumps will be improved technically in order to obtain the best performace in the special conditions of the CHESS-SETUP system.

The used solar panels will be hybrid photovoltaic and solar thermal (PV-ST) panels, which is a promising solution for also producing the electricity consumed by the heat and water pumps of the heating system and part of the electricity consumed in the building. Hybrid solar panels are a key element to achieving energy self-sufficiency in buildings, especially in dense urban areas where the roof availability is one of the most limiting factors.

Also will be considered the integration of other energy sources as biomass or heat waste, to make the system suitable for any climate conditions. The project will also explore the possibility to integrate the system with other electricity or cooling technologies (solar cooling, cogeneration).

The system operation will be optimized according to some external factors, as electricity price or user requirements by using a smart control and management systems developed specifically for the project.

This proposal will be materialized in three pilot experiences: a small-scale prototype in Lavola's headquarters (Spain), 50 new dwellings located in Corby (England) and a new sport centre located in Sant Cugat (Spain).

Soft copy

ESP Veolia, Grau 2017-05-31, CHESS-SETUP D2.2 Report on Construction Techniques

ESP Veolia, Lloveras 2016-11-29, CHESS-SETUP D2.1 Report on storage materials and systems

H2020 Emporium (2021-2025)

The FP7 MESSIB project (GA No. 211624), about Multi-source Energy Storage Systems Integrated in Buildings, investigated four different technologies for electric and thermal storage: a flywheel, a redox-flow battery, a ground heat exchanger (GHEX), and phase change material (PCM). The two thermal storage technologies which were analysed and tested concern a GHEX in a 80 to 100 m deep borehole using phase change slurry (PCS) as an alternative circulation medium, and new PCM material and component developments such as micro-encapsulation of salt hydrates, and PCM boards integrated in interior walls and ceilings.

The H2020 EINSTEIN project (GA No. 284932), about Effective INtegration of Seasonal Thermal Energy Storage Systems IN existing buildings, implemented an outdoor underground 800 m3 steel tank, a 180 m3 9 to 10 m high water vessel at the back side of a building, and flat plate solar collectors and heat pumps as heat sources.

The CHESS-SETUP project (GA No. 680556), about a Combined HEat Supply System by using Solar Energy and heaT pUmPs, implemented an earth energy bank with 600 1.5 m deep boreholes, a 120 m3 horizontal heat storage cylinder in a basement, and PV and PVT roof panels and heat pumps as heat sources.

The ground heat exchanger (GHEX) development in the MESSIB project has very different characteristics compared to Emporium, which is integrating seasonal solar heat storage with the building volume, and is not using phase change slurry (PCS) as an alternative circulation medium. **The H2020 TESSe2b project (GA No. 680556)**, about Thermal Energy Storage Systems for Energy Efficient Buildings, seems more related to the MESSIB ground heat exchanger, developing a high efficiency PCM tank, enhanced PCM borehole heat exchanger, nano-composite enhanced paraffin PCM, a protective thin film coating against corrosivity of salt hydrates, and a compact modular tank including a high performance heat exchanger.

The phase change material (PCM) outcomes in the MESSIB project, about micro-encapsulation of salt hydrates, and PCM boards integrated in interior walls and ceilings, also have very different characteristics compared to the Emporium seasonal heat storage. PCM applications need for example at least several hundred upload and unload cycles to equal the energy consumption and related CO2 emission to produce the PCM itself, which is a characteristic cycles number for daily storage in interior boards, but especially critical for long(er) term heat storage tanks, such a seasonal heat storage tanks with one upload and one unload per year only.

The thermal energy storage system (TESS) development of the steel tanks - outdoor, in the basement, and underground - and of the earth energy bank of the EINSTEIN and CHESS-SETUP projects, and the PV and PVT roof panels and heat pumps as heat sources, have very different characteristics compared to the Emporium project. Emporium is a low exergy system without energy storage losses, by using vacuum tube solar heat collectors and vertical seasonal heat storage cylinders, integrated in the building volume.

The Thermo Chemical Material (TCM) Technology Readiness Level (TRL) is much lower compared to alternatives such as PCM systems for example, and is not part of the MESSIB, EINSTEIN, CHESS-SETUP, and Emporium projects. **The H2020 CREATE project (GA No. 680450)** about Compact REtrofit Advanced Thermal Energy storage, seems more related to TCM, and aims to develop and demonstrate a heat battery for the existing building stock to reach at least a reduction of 15% of the net energy consumption with a potential Return-On-Investment (ROI) shorter than 10 years. Novel high-density materials will be used in order to limit the use of available space to a maximum of 2.5 m3 TCM, with an energy density of more than 1.5 GJ/m3 (420 kWh/m3).

Tasks: Implementation milestones, and deliverables in cooperation with local partners

1. Preparation

Emporium simulation model

To calculate the solar collector and seasonal storage dimensions, simulations models are available, using software programs which are based on an iterative calculation method, and, depending on its quality, with a day by day or week by week calculation frequency for example, using the last day or week heat storage temperature outcome to calculate the next day or week heat storage temperature outcome.

An Emporium simulation model, using the Transient Systems Simulation (TRNSYS) Program, is developed in which different solar collector typologies, and different solar collector positions, from horizontal to vertical position, are compared. Reducing the seasonal storage volume to its minimum, for the Dutch Test Reference Year (TRY) annual outdoor climate characteristics, requires a vertical (60-70˚ angle) collector position to harvest as much as possible solar energy in winter, and a vacuum tube insulation to achieve the required highest possible temperatures in winter.

TRNSYS is very detailed simulation software with reality modules, such as a Test Reference Year (TRY), solar collector measurements, and resident behavior modules. The TRNSYS investigations and reports have been successively executed by Dutch consultants and national research center engineers, co-financed by the Netherlands Enterprise Agency (RvO), and have been distributed confidentially so far. A demo building can be calculated for the local climate conditions with this Emporium TRNSYS simulation model.

The main Emporium simulation data characteristic, is the outcome of the solar heat storage annual temperature curve between 50 °C (March) and 90 °C (September) in case that 45 °C hot water is required, and between 30-40 °C and 90 °C for example in case that only indoor heating is required.

Input data

. Test Reference Year (TRY) with the local annual outdoor climate characteristics

. vacuum tube solar collector performance (measured by a protocol such as Solar Keymark)

. solar heat storage vessel insulation (50 cm glass/stone wool, or 30 cm PUR)

. Rc envelope (m2K/W): basement, facades, roof, entrance doors, windows, window frames

. ventilation flows (m3/h): preferred hybrid ventilation requires controllable facade openings

. ventilation rate by infiltration (air leakage envelope): for example 0.1

. facade or window shading devices, in case that these apply

. internal heat gains, such as people, lighting, and (laboratory) equipment

. indoor heating temperature set points: 17 °C or 19 °C for example

. hot water demand (liter/day) and hot water demand temperature (°C): 43 °C for example

. heat recovery hot water (shower) demand, and in that case its efficiency (%): 25% for example

Output data

. annual temperature curve: between 50 °C (March) and 90 °C (September)

. vacuum tube solar collector surface (m2): mainly vertical due to winter sun position

. solar heat storage vessel volume (m3): integrated in building to use heat losses

2. Engineering

Water column and solar facade

The Emporium research project concerns a demo building, including the water column and the solar facade. By integrating the storage vessel in the building volume, the annual heat losses can be used as building heating. In case of a 50-90 °C temperature curve, a 50 m3 storage vessel heat capacity is 8.4 GJ, while the annual heat losses through 50 cm glass wool or 30 cm PUR are 10.8 GJ. The 10.8 GJ heat losses, used as building heating, are part of a 50 GJ annual heat consumption for indoor heating and hot water in the two Emporium semi-detached houses, with 12.5 GJ for indoor heating or for hot water per house per year.

Heat storage

The seasonal solar heat storage is a steel vessel with a thermal insulation layer, and is enclosed by an air cavity for safety in case of leakage, and for natural ventilation in case of overheating in the summer period.

Heat storage heat exchangers

The heat storage tank requires an independent water volume to avoid legionella risks. Due to the 50 to 90 ˚C temperature curve, the risk that legionella survives is very low. Nevertheless local legislations and standards will require strictly separated water circulations for hot water consumption by a single tube or sandwich tube heat exchanger. The indoor heating circulation, and the vacuum tube solar collector circulation, could require heat exchangers as well.

Heat storage water expansion

Heat storage in water tanks requires an expansion volume. The water storage volume expands in a 50 to 90 ˚C temperature curve 2.35% from 1012.07 to 1035.90 dm3/kgton, and in a 70 to 90 ˚C temperature curve 1.29% from 1022.71 to 1035.90 dm3/kgton.

A membrane top, or membrane ceiling, can be used for expansion by sinking downwards and rising upwards, whereby the membrane gets free from the above subsurface. In case that the weight of the membrane top or ceiling causes too much pressure in the water, floating bodies such as air-filled balls in the water, or air-filled tubes in the membrane, can support the membrane. The water expansion can be provided by an EPDM air bag in the upper part of the storage, which sucks up outdoor air in case that the storage water cools down. An expansion vessel can be filled with nitrogen to avoid corrosion in case of leakage. An alternative is a tube from the storage bottom to outside of the storage top to evacuate expansion water. A nitrogen blanket above the water surface in the storage can serve as an expansion space.

Solar collector

The solar collector, with vacuum tubes and on the southern facade, is looking to the winter sun position, to minimize the seasonal storage volume. Vacuum tubes have standard lengths of approximately 2.0 m, that can be incorporated into the design, by adjusting the grid size of the building, or the facade, or by adapting fitting pieces in the solar collector water circulation. The vacuum tubes are horizontally positioned and integrated in a glass facade.

Solar collector indoor heating

The 20-25 °C indoor heating circulation is connected to the 50-90 °C heat storage. In case that the solar collector is connected to this circulation as well, the 20-25 °C indoor heating is directly heated by the solar collector, without using the higher temperatures of the 50-90 °C heat storage. Saving heat storage temperatures, and exergy losses, may also contribute to a heat storage volume reduction.

Facade ventilation

The natural ventilation is controlled by open slots in the facade, which can be closed in case that the indoor space is not used. An indoor fan is in standby to support the natural ventilation. Louvers in the open slots, besides the windows for example, break the wind, and exted the route for heating the incoming air.

3. Construction

4. Monitoring

Water column temperature stratification

The heat storage temperature stratification is not included in the Emporium simulation model. Temperature sensors on different height positions of the heat storage water column are required to measure the temperature differences between the bottom and the top of the vessel. The temperature stratification measurements can be used in the Emporium simulation model to calculate the heat storage volume reduction.

Technology, comfort and behavior monitoring and tests

The technical measurements concern, for example, all volume flows for heat production and heat consumption, the temperature stratification in the seasonal storage water column, that will offer advantages for the (shower) temperature availability at the top of the storage vessel and the solar collector efficiency with a lower temperature inlet at the bottom of the storage vessel, the indoor climate comfort in connection with whether or not to use the ventilation cavity around the water column in the summer, and the behavior of residents in a building in which, although all energy has been paid in advance, however also no more energy is available than has been paid in advance.