NEWTREND

NEW INTEGRATED METHODOLOGY AND TOOLS FOR RETROFIT DESIGN TOWARDS A NEXT GENERATION OF ENERGY EFFICIENT AND SUSTAINABLE BUILDINGS AND DISTRICTS

GA NO. 680474

DELIVERABLE D4.1:

BUILDING AND DISTRICT RETROFIT TECHNOLOGIES REVIEW AND CHARACTERISATION

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DELIVERABLE D4.1: SHORT DESCRIPTION

This deliverable is about the definition and description or different retrofit technologies. This technologies and measures are at building and district level. Through the different characteristics and feasibility of the systems the interaction between the retrofit technologies is so selected, that only realisable retrofit concepts arise. The mentioned technologies and methods of this report are summarized in a data file which is the base for a library of measures and technologies. This technology library will then implement in the simulation and design tool that will be the result of the NewTrend project.

Keywords: retrofit; technologies; building level; district level; building typologies; active; passive

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ABBREVIATIONS AND ACRONYMS

ACRONYM	DEFINITION
AACAES	Compressed air stored underground incorporating heat storage
AC	Air conditioning
AHU	Air handling unit
AMOLED	Active-matrix organic light emitting diode
ASHRAE-55	Thermal Environmental Conditions for Human Occupancy by the **A**merican **S**ociety of **H**eating, **R**efrigerating, and **A**ir-Conditioning **E**ngineers
a-Si	Amorphous Silicon
BCO	British Council for Offices
BS	British Standard
BIPV	Building-Integrated Photovoltaics
BMS	Building Management System
CAES	Compressed Air Energy Storage
CAV	Constant air volume
CCGT	Combined Cycle Gas Turbine
CdTe	Cadmium telluride
CHAdeMO	CHArge de Move
CHP	Combined Heat and Power
CHPC	Combined Heat and Power and Cold generation
CIS/CIGS	Copper indium gallium selenide
CISBE	Chartered Institution of Building Services Engineers
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Coefficient of performance
CPC	Compound Parabolic Concentrator
Csa	Temperate, dry summer, hot summer
CV	Constant volume
CV-VT	Constant volume, variable temperature
DC	Direct current
Dfb	Cold (Continental), without dry season, warm summer
Dfc	Cold (Continental), without dry season, cold summer
DHW	Domestic hot water
DIM	District Information Model
EPS	Expanded polystyrene foam
EV	Electro Vehicle
FASUDIR	**F**riendly and **A**ffordable **S**ustainable **U**rban **D**istricts **R**etrofitting (EU project)
FCU	Fan coil unit
GA	Grant Agreement
GWP	Global Warming Potential
H_2	Hydrogen
H_2O	Water
HAWT	Horizontal axis wind turbine
HP	Heat pump
HRV	Heat recovery ventilation
HVAC	Heating, Ventilation and Air Conditioning

ACRONYM	DEFINITION
IA	Innovation Action
IDA	Indoor Air
IEC	International Efficiency Classification
LCD	Liquid crystal display
LED	Light emitting diode
LiBr	Lithium Bromide
LPG	Liquefied petroleum gas
NaNiCl	Sodium nickel chloride
NaS	Sodium sulphide
NewTREND	**New** integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts
NO_x	Nitrogen
O_2	Oxygen
OLED	Organic light emitting diode
PCM	Phase Change Material
PDA	Photo Diode Array
PMOLED	Passive-matrix organic light emitting diode
PV	Photovoltaic
QAM	Quality Assurance Manual
RES	Renewable Energy Systems
SAE CSS	Society of Automotive Engineers- Combined Charging System
SDH	Solar District Heating
SMES	Supraconducting Magnetic Energy Storage
SNG	Synthetic natural gas
SRF	Specified Recovered Fuel
SUPERBUILDINGS	**Su**stainability and **Per**formance Assessment and Benchmarking of **Buildings** (EU project)
SWOT	**S**trengths **W**eaknesses, **O**pportunities and **T**hreats
TCS	Thermal Chemical Storage
TES	Thermal Energy Storage
UMBRELLA	Business Model Innovation for High Performance Buildings Supported by Whole Life Optimisation
VAV	Variable air volume
VAWT	Vertical axis wind turbine
VFD	Variable Frequency Drive
VOC	Volatile Organic Compounds
VRF	Variable Refrigerant Flow
VRV	Variable refrigerant volume
VV-CT	Variable volume, constant temperature
VVT	Variable volume temperature
VV-VT	Volume variable temperature
WC	Water Closet
WP	Work Package
XPS	Extruded polystyrene foam

UNIT INDEX

UNIT	DEFINITION
%	Percent
EUR	Euro
°C	Centigrade
a	Year
Amp	Ampere
dB	Decibel
h	Hour
J	Joule
K	Kelvin
kg	Kilogram
l	Litre
lm	Lumen
m	Meter
m^3	Cubicmeter
ppm	Parts per million
R_W	Sound reduction index
V	Volt
Var	Reactive Power
W	Watt
Wh	Watt-hour

EXECUTIVE SUMMARY

This report summarises the work completed for Task 4.1 'Renewables, design options and energy schemes for buildings and districts'. It forms part of Work package 4 'Simulation & Design Hub' which aims to develop all the required simulation framework needed to assess and evaluate different retrofit options during the design phase from the point of view of energy performances, comfort and economic impact. The work was focused on collecting all the information related to available retrofit technologies at building and district level (starting from already existing technology repositories created with other research projects), in order to enable the development of a comprehensive library of retrofit technologies to be used also to showcase successful applications and impacts of each technology.

Initially, previous outputs from other EU funded projects were reviewed, and retrofit technologies were divided into active and passive and split at building and neighbourhood/district levels. Research was also carried out to understand which technologies would be appropriate in the various climatic and weather conditions across the demo sites in the project. The information required to be obtained through research on each technology was defined and a set field of criteria was agreed. The final part involved a strength and weakness analysis for each technology.

In total, 133 technologies were investigated, and were broken down further into 289 separate classifications depending on size and applications for use. An overview on the investigated active and passive retrofit technologies is shown in the table below, and it should be noted that whilst this only shows the main categories of the technologies, more detailed distinctions are demonstrated later in this report. Further details are also available in the technology description sheets (see examples in Annex 1), which will be passed to Task 4.2 to build together the technology library and task 4.4 the Simulation and Design Hub.

	Passive technologies	Active technologies
Building scale	○ Thermal insulation ○ Doors ○ Windows ○ Shading ○ Natural ventilation	○ Fuel types ○ Alternate fuels ○ Conventional heating systems ○ Combined heat and power (CHP) ○ Heat pump ○ Solar thermal collector heat distribution systems ○ Cold generation ○ Heat exchanger ○ Storage ○ Forced ventilation ○ Photovoltaic ○ Micro wind turbine ○ Small hydro power ○ Electrical battery storage ○ Electric and motors ○ Lighting ○ Light control ○ User specific control ○ General control
Neighbourhood scale	o No technologies were described in detail because the energy simulation of these is considered out of scope of this project.	○ Local heating grids ○ Local cooling networks for neighbourhood retrofitting ○ Storage ○ Electricity ○ Control

1. INTRODUCTION

This deliverable D4.1 is the conclusion of the NewTREND Task 4.1 “Building and district retrofit technologies review and characterisation”. The content was elaborated by the task leader JER and the project partners MUAS, REGENERA, GC, STAM and IES.

The main goal of Task 4.1 is to collect all relevant information about available retrofit technologies on district and building level. Both passive and active technologies were considered and characterised in terms of technical parameters, suitability for different building typologies and climatic conditions, ease of application, specific installation procedures and criteria for applicability.

A list of fields has also been defined in order to facilitate the use of this information by the Simulation and design hub (T4.4).

As a base to define suitable technologies the data collection of three pilot projects in Europe are available. Those projects are discerning among other things in location, construction, user behaviour and the heat supply system. To satisfy the needs of all participants of the district or housing complex the choice of the right retrofit technologies is very important. Besides the data bank with qualitative and specific information for the brought up technologies this deliverable respond on each technology category. Those will be split in two categories- passive and active strategies for building and district level. An evaluation of the technologies by different factors is very important to generate retrofit variants that can be rated by diverse criteria. The structure of the report is as follows. First the structure of the Task4.1 is explained in Figure 1. The work will be done in four steps. While the work on this task, there are links to other tasks within the NewTREND project.

Step 1 provides the base for the investigation of the retrofit technologies. The defined data requirements of Task 2.1 are very important to get an overview about the starting points for the retrofit, potentials and the selection of the fitting technology. Therefore, the template for the data collection of T2.1 was used and adapted for the technology library for Task 4.1. The second step is about the investigation and definition of the database of retrofit technologies from already completed projects. They are on building level as well as on neighbourhood level. Important for the discussion and choice is the Structure of the task with the interaction to other tasks within the project:

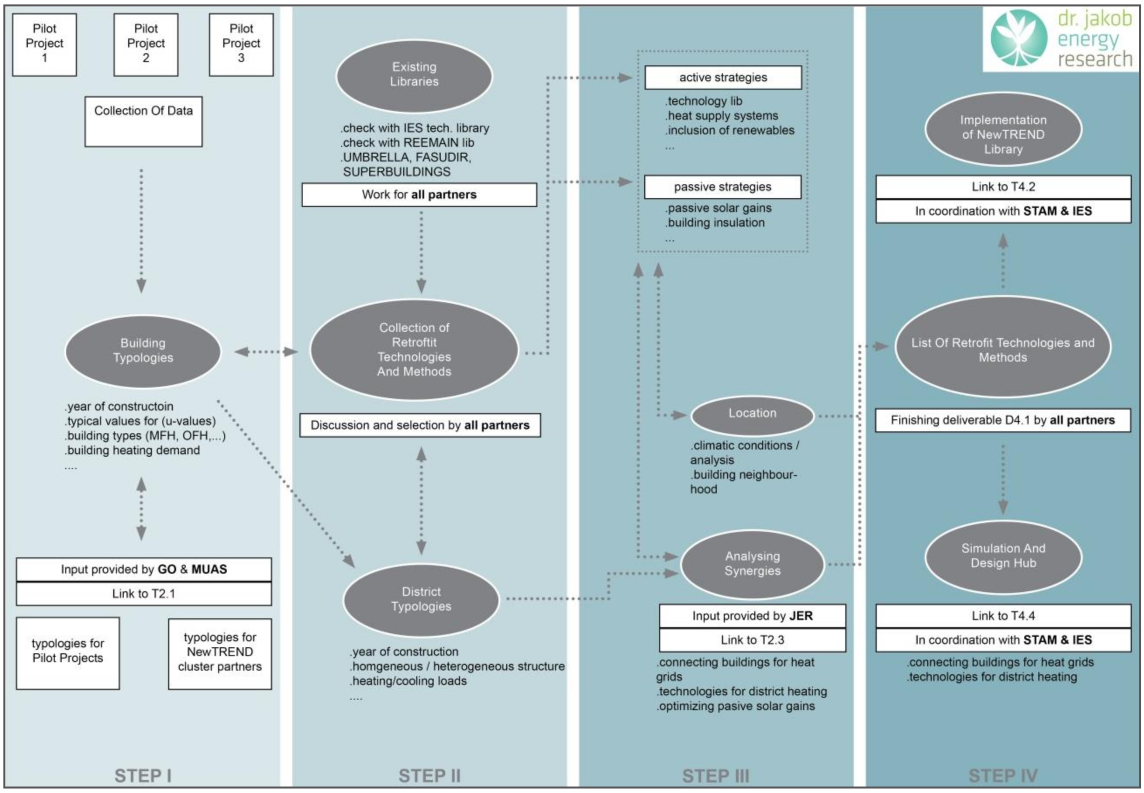


FIGURE 1: DRAFT OF THE STRUCTURE OF TASK 4.1 (CREDIT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

In step 3 out of the collected retrofit interventions a selection is made with suitable technologies for the NewTREND scale. After that a subdivision into passive and active technologies is done. At the same time the input from other task, especially Task 2.3, is added. In parallel to this the final technology library is completed with the specific data for each technology so they can be used in the further Tasks of WP4 and implemented in the NewTREND tool.

For the success of this implementation an untimely agreement and communication with the partners of the subsequent tasks is necessary (step 4).

For the analysis of the data collection and the structuring of the technology library, selection of fitting technologies and considerable parameters for the scope of NewTREND, already existing projects were investigated. Besides projects where other partners were involved, like UMBRELLA or SUPERBUILDINGS the main output came from FASUDIR. The scope of this EU-funded project was a bit rougher than the scope of NewTREND, so a few technologies and structures could be adjusted and adopted for NewTREND.

2. Boundary conditions of the retrofit technology description

In the following chapter different boundary conditions are explained, which influence the selection of retrofit technologies.

Chapter 2.1 is about a detailed description of climate zones by Koeppen-Geiger. By the different conditions in each climate zone the development defiance of a coherent retrofit concept can be very complex and a lot of parameters have to be considered, like the ambient temperature, humidity, solar irradiance, traditional construction methods reduce of the energy demand, comfort requirements of the user and further aspects. All of them act together and affect the selection of the fitting retrofit technologies more or less, depending on the weighting of the mentioned parameters.

After an explanation of the climate zoning by Koeppen-Geiger a detailed weather analysis of all three demo site cities is following (Chapter 2.2). Subsequent a comparison of the demo sites pertaining to

- Ambient temperature
- Psychrometric conditions
- Global and direct horizontal radiation
  - Wind speed

continues. The perceptions are summarized in Chapter 2.2.5. Chapter 2.3 is about the project scale of NewTREND. It describes the building and neighbourhood typologies, which the investigated and described retrofit technologies are suitable for. An introduction to the active and passive retrofit technologies can be found in Chapter 2.4, which generates a bridge to the main part of the deliverable – the technology descriptions – starting at Chapter 3.

2.1. Climate Zones by Koeppen-Geiger

To get a general overview of the climate conditions of a specific location it can be helpful to classify the location using the Koeppen-Geiger-Classification. It is the most frequently used classification map. The classification of the climate results from three different climate factors - main climate, precipitation and temperature. Therefore, the classification via the Koeppen-Geiger-Map allows a general statement about temperatures, precipitation and the main climate of the investigated location. As well as seasonal climatic differences which might influence the use of renewable energy potentials.

Temperature and humidity conditions

Besides general climatic conditions, as it can be analysed via Koeppen-Geiger-Classification, also a more detailed examination of temperature and humidity can be quite reasonable. Therefore, the course of the dry ambient temperature and the wet bulb temperature of one year will be analysed. Both parameters may influence significantly the climatic and comfort conditions as well as the use of renewable energy potentials and technologies at a site. The wet bulb temperature describes the lowest achievable temperature by evaporating water into the air. However, the relative air humidity is dependent on air temperature and can also be indicated by the dew point temperature. A relative humidity percentage of 100% is called saturated air. Below the dew point temperature air condenses.

Demo site countries

The three pilot projects are in different climate zones in Europe. The projects are in the project participating countries Finland, Hungary and Spain. In the following Koeppen-Geiger map the countries are framed in black with a red dot with the location of the demo site city. So every country has a specific climate were the retrofit measures have to deal with and adjusted to the existing building types. Especially Spain is an interesting country, because of its amount of climate zones, which are given by the topography and the sea.

Given by the climate conditions is the use of renewable energy sources, for example use of solar energy, wind or water energy or the use of ground probes. Additional to these active technologies in Chapter 0 and 7 more active technologies are described that contributes to the reach of the goals of the user.

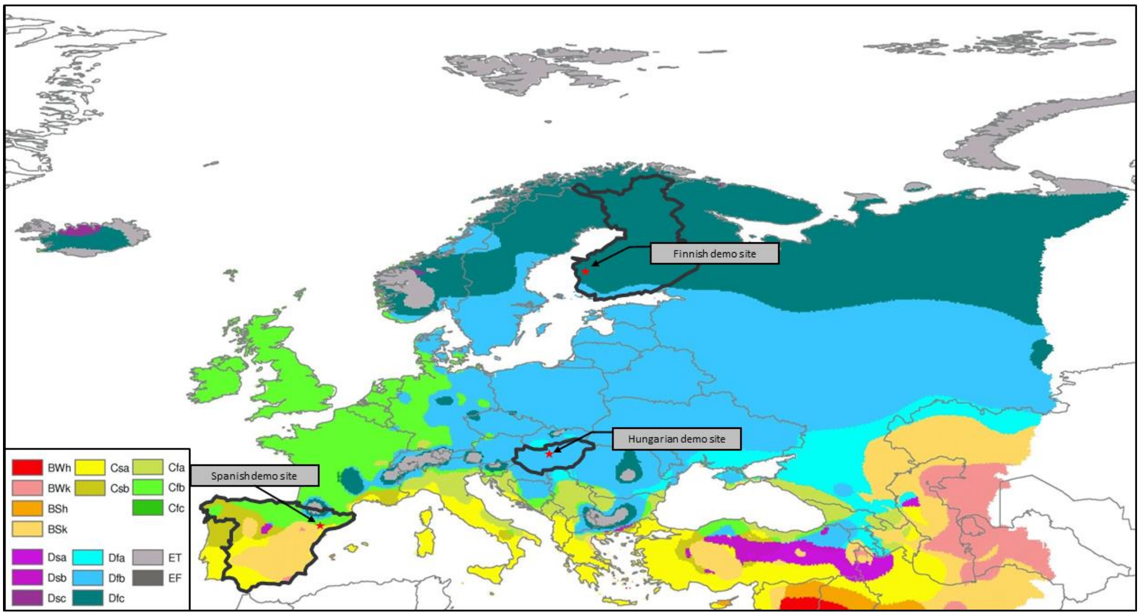


FIGURE 2: KOEPPEN-GEIGER MAP OF EUROPE ADPATED FROM PEEL ET AL (2007) (SOURCE: UNIMELB.EDU.AU)

2.2. Weather analysis

A detailed weather analysis for all pilot project locations was carried out. The benefit of the analysis is to understand the information about the climatic conditions and the potential of the implementation of renewable energy systems. For builder-owners or investors it is then easier to understand the reasons for the choice of measures and the strength and weaknesses of their building or district location.

Finnish demo site

Seinäjoki is located about 300 km north of Helsinki in the western part of Finland. Its climate is characterized as continental subarctic or boreal (taiga) climate. The Koeppen-Geiger classification is ***Dfc***. Solar radiation and weather data with hourly resolution was available from the Meteonorm 7 database for Kauhava (latitude 63°10'N and longitude 23°03’E), Kauhava is located about 35 km north of Seinäjoki. Therefore, the weather data for Kauhava has been used for this study. The annual average temperature is 4.5°C. Total minimum temperatures in winter are often dropping below -20.0°C. However peak temperatures in summer are exceeding frequently the 20.0°C mark. This temperature spread can be named typically for continental climates. Finland in common is highly influenced by its massive difference in sun shine hours between summer and winter period. Longest day of the year has about 20:00 hours of daylight, shortest day not even 5:00 h. Wind conditions can rather described with moderate breezes, main wind direction is south.

HUNGARIAN DEMO SITE

Budapest is located in the central-northern part of Hungary. Its climate is characterized as a warm summer continental or hemiboreal climate. The Koeppen-Geiger classification is ***Dfb***. Solar radiation and weather data with hourly resolution was available from the Meteonorm 7 database for Budapest (latitude 47°30'N and longitude 19°03'E). Therefore, the weather data for Budapest has been used for this study. The annual average temperature is 11.6°C. Total minimum temperatures in winter are even dropping in to negative double-digits. Peak temperature range in summer reaches about 33°C. This high temperature spread is typically for continental climates. Precipitation values are very constant throughout the whole year; annual average rainfall is 564 mm. Budapest itself is influenced by typical urban microclimatic effects as the heat island effect. Wind conditions can be described as light/gentle air breezes, main wind direction is varying between south and west.

SPANISH DEMO SITE

Sant Cugat del Vallès is located in the north/east of Spain, close to the city of Barcelona in its north. Its climate is characterized as dry-summer or Mediterranean climate. The Koeppen-Geiger classification is ***Csa***. Solar radiation and weather data with hourly resolution was available from the Meteonorm 7 database for Barcelona (latitude 41°24'N and longitude 2°10'E). Due to its availability the weather data for Barcelona has been used for this study. The annual average temperature is 15.7°C. Total minimum temperatures are rarely dropping below the freezing point. Peak temperatures in summer are even exceeding 30.0°C. Typically hot and dry summers are dominating this climate, the nearby coastal area is causing reduction of absolute peak temperatures in summer time. Wind conditions can be described as moderate breezes; main wind direction is south with few exceptions from north-east.

COMPARISON OF DEMO SITES

A comparison of the monthly dry bulb ambient temperatures of the three demo sites is shown in Figure 3. Conditioned by the location in the north, the temperatures from Seinäjoki differ highly from the values of the other countries, especially in winter. The temperatures in San Cugat de Vallès are the highest, because of the southern location and the proximity to the sea. In Budapest the temperatures are in between of Seinäjoki und San Cugat de Vallès. By means of this figure the need of construction and technologies to reach a high user comfort can be read. For example, on the Finnish demo site is the need of thermal insulation and duration of heating higher than on the Spanish.

TABLE 1: COMPARISON OF WEATHER DATA FORM ALL THREE DEMO SITE CITIES

	Unit	Kauhva (Seinäjoki)	Budapest	Barcelona (San Cugat del Vallès)
Temperature:				
• average • max. • min.	°C °C °C	4.5 28.6 -25.8	11.6 33.6 -11.7	15.7 30.4 -2.8
• Heating days[1] • Cooling days[2]	d d	315 18	218 107	186 145
Relative humidity:				
• average • min.	% %	80 28	67 22	74 17
Radiation:				
• Global horizontal irradiation (GHI) average • GHI max. • Share of DNI • GHI hours over 300 W/m²	W/m² W/m² % h	195 830 52 1,542	313 1008 51 1,703	267 961 53 1,856
Wind:				
• Speed average in 10m / 50m height • Hours of potential wind speeds (10m / 50m) • Main direction(s)	m/s h 	3.1 / 4.5 3,771 / 5,414 South	2.4 / 3.6 2,593 / 4,034 South / West	3.4 / 4.9 4,924 / 6,470 South

[1] With heating set temperature: Tamb. ≤ 15 °C

[2] With cooling set temperature: Tamb. ≥ 18 °C

2.2.1. AMBIENT TEMPERATURE

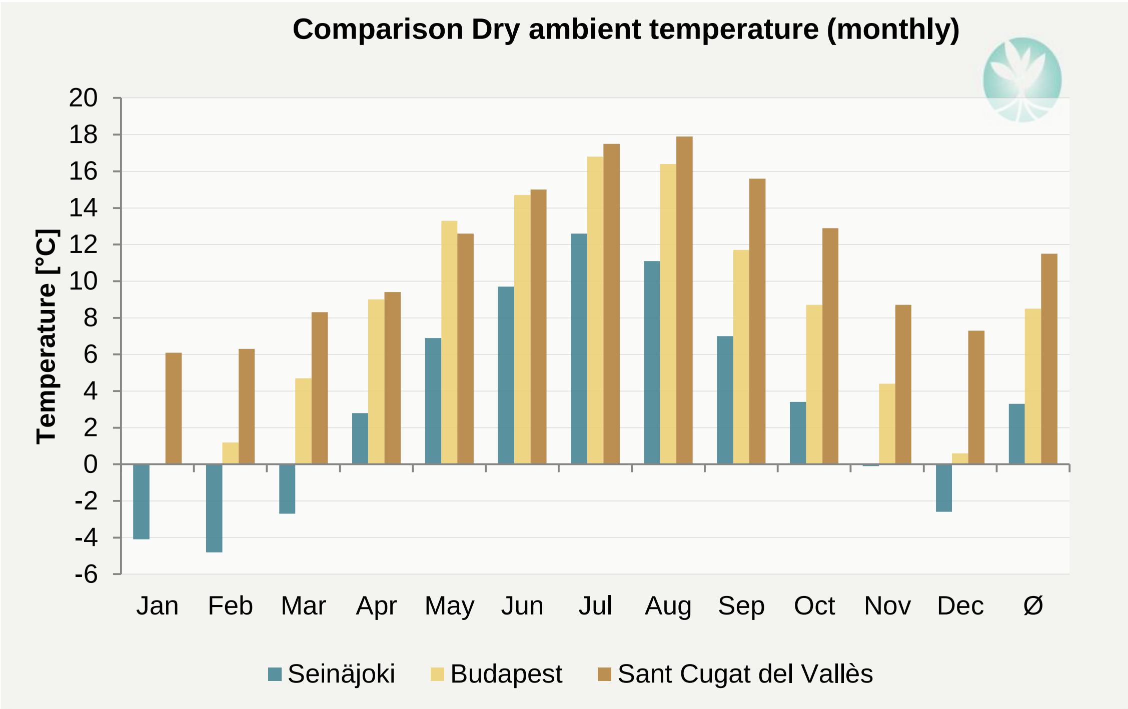


FIGURE 3: MONTHLY AVERGAE DRY BULB TEMPERATURE IN THE DEMO SITE CITIES (CREDIT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG; DATA SOURCE: METEONORM)

Figure 3 shows a comparison of the monthly dry bulb ambient temperatures of the three demo site cities. It is obvious that Seinäjoki in Finland has the lowest temperatures, while Sant Cugat des Vallès is on average 6°C warmer. Budapest is in between both cities. On the basis of this diagram the requirements on buildings can be detected. For instance, the low temperatures in Seinäjoki quote a higher thermal insulation standard and a longer heating period than in San Cugat or Budapest. This aspect has among others an impact on the choice of the heating system.

In context with a psychometric chart more requirements can be read from the weather data. In Figure 4 the necessary interventions for room conditioning in a schematic psychometric chart are shown. The parallelogram in the centre marks the comfort area in winter and summer according to ASHRAE-55. On the x-axis the dry bulb temperature is shown. The curves stand for the air humidity in percent, with saturation from 100% on the top curve. The descriptions around the comfort area specify the interventions that have to be done to reach thermal comfort.

Figure 4 shows the surroundings of the 8.760 hourly values of ambient temperature and absolute humidity. By means of that besides the requirement on buildings and retrofit interventions the influence of the location, for instance in San Cugat with its near to the sea and the high air humidity can be seen. Further the comparison confirms the findings from Figure 3 in relation to the amount of duration of the heating period and more conditioning measures, like the cooling and dehumidification demand in the Spanish and Hungarian demo site to reach comfort by ASHRAE-55.

2.2.2. PSYCHROMETRIC CHART

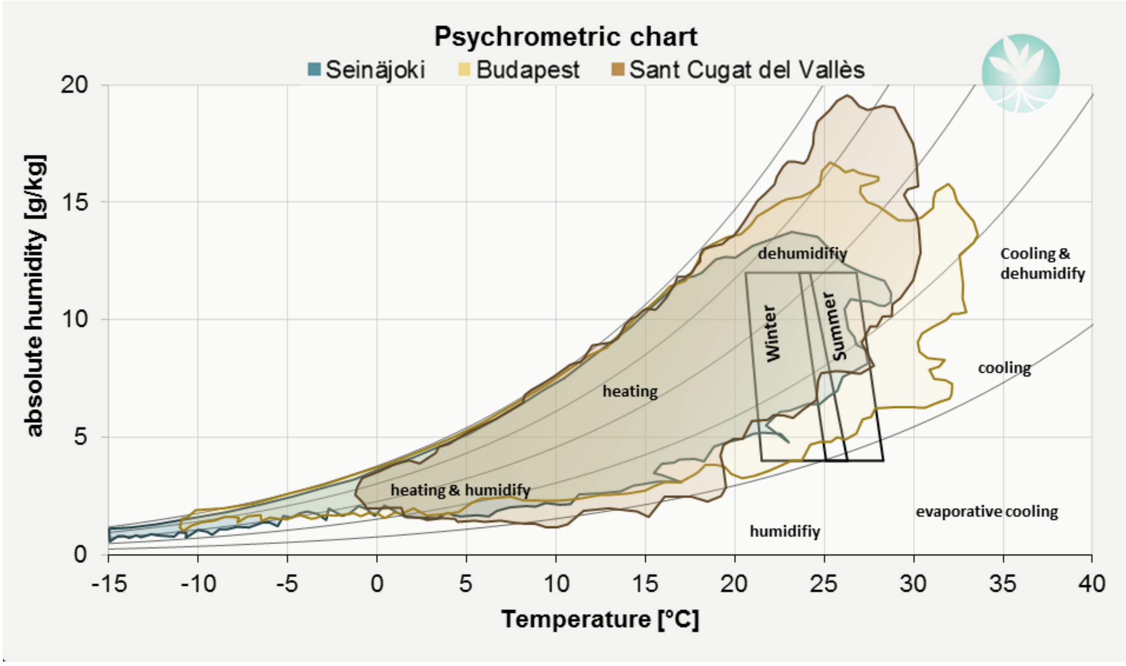


FIGURE 4: COMPARISON OF THE HOURLY VALUES OF AMBIENT TEMPERATURE AND ABSOLUTE HUMIDITY MEASURES FOR ROOM CONDITIONING IN RELATION TO THE PSYCHOMETRIC DIAGRAMM (CREDIT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG; DATA SOURCE: METEONORM)

2.2.3. Global and direct horizontal radiation

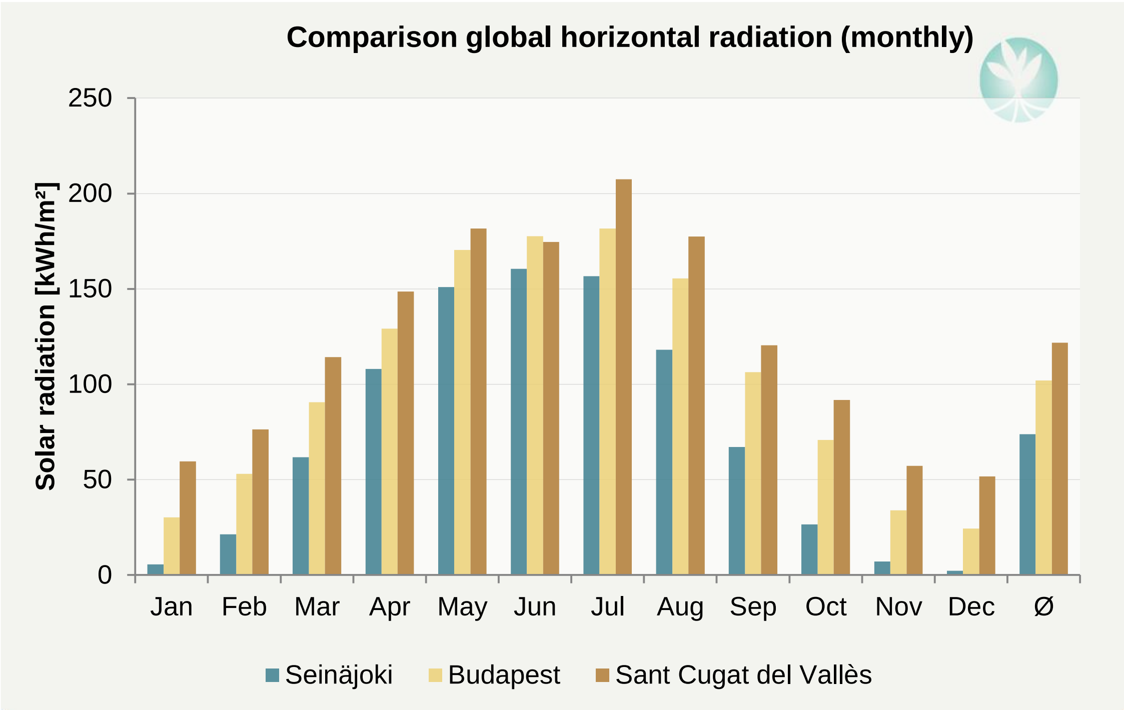


FIGURE 5: COMPARISON OF THE GLOBAL HORIZONTAL RADIATION (CREDIT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG; DATA SOURCE: METEONORM)

Figure 5 and Figure 6 represent the monthly global horizontal and direct horizontal radiation of the demo sites, which is among others important for the design and the implementation of solar thermal collectors (Chapter 5.4).

Due its location in the north Seinäjoki has especially during winter very low radiation values, which is owed to the angle of incidence and the intensity of solar radiation. Out of it the potential for solar driven systems is not as high as in the other demo sites and the demand of artificial lighting in the time with low daylighting respectively high. Solar heat has its potential for domestic hot water and supply for the heating system during the transitions periods. Further the consequence is the lack of passive solar gains during winter that could be used by an increase of window areas, atria or winter gardens and decrease the heat demand.

The radiation in Budapest is higher than in Seinäjoki and during the whole year available. Especially in the transitions periods it can be used for domestic hot water and heat supply, but also for photovoltaic systems. On neighbourhood scale these systems can also be used to supply the local heat or power net. The high amount of radiation in summer has to consider by the design of the window areas and the shading systems to prevent overheating of the building zones.

The highest amount of solar radiation of all three demo sites has San Cugat. An important point in the planning of buildings and retrofit concepts in relation to the solar radiation is the shading, window area and to prevent overheating of the buildings. The potential for solar renewable energy systems is hence high. Similar to the conditions of Budapest systems like photovoltaic, and solar heat system can be installed for DHW, heat supply and power generation. The heat also can be used for solar cooling, given due the number of cooling days. A side from the potential on building scale, solar heat und PV systems can also be used on neighbourhood or district scale.

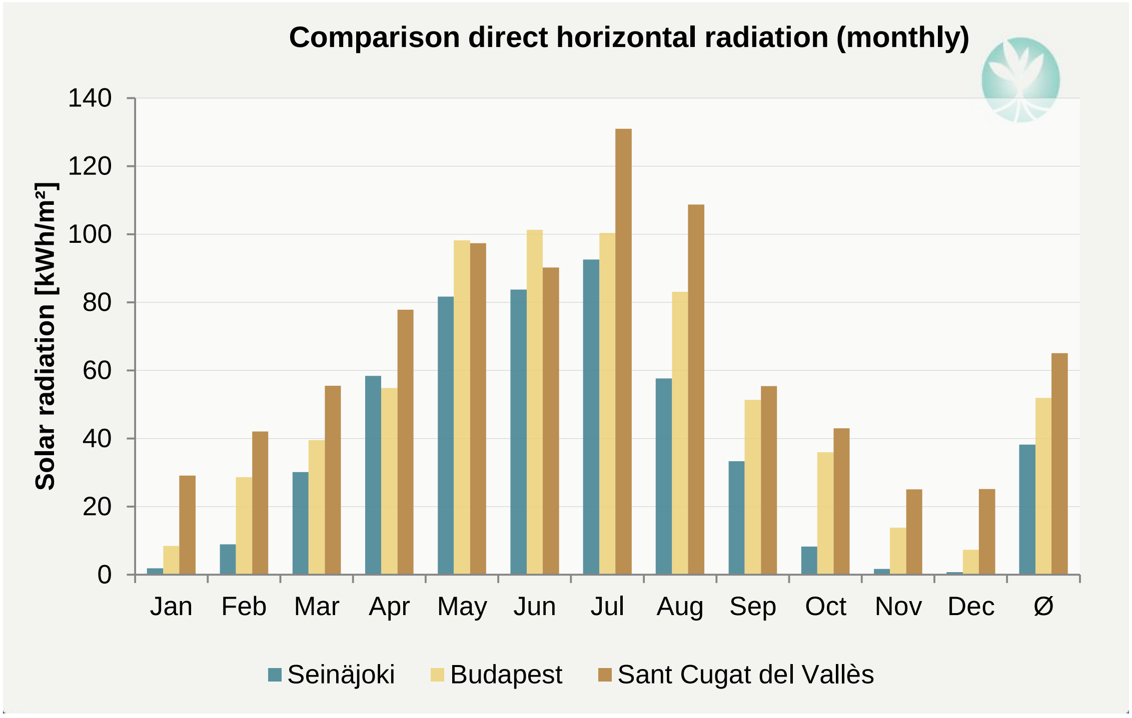


FIGURE 6: COMPARISON OF THE GLOBAL DIRECT RADIATION (CREDIT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG; DATA SOURCE: METEONORM)

2.2.4. WIND SPEED

For the potential of wind turbines (Chapters 5.13 and 7.4.2) as energy generation system the duration of wind speed per year is important. For technologies on building scale wind turbines in about 10 m height (Figure 7) are feasible, while wind turbines on district scale mostly installed in about 50 m height (Figure 8).

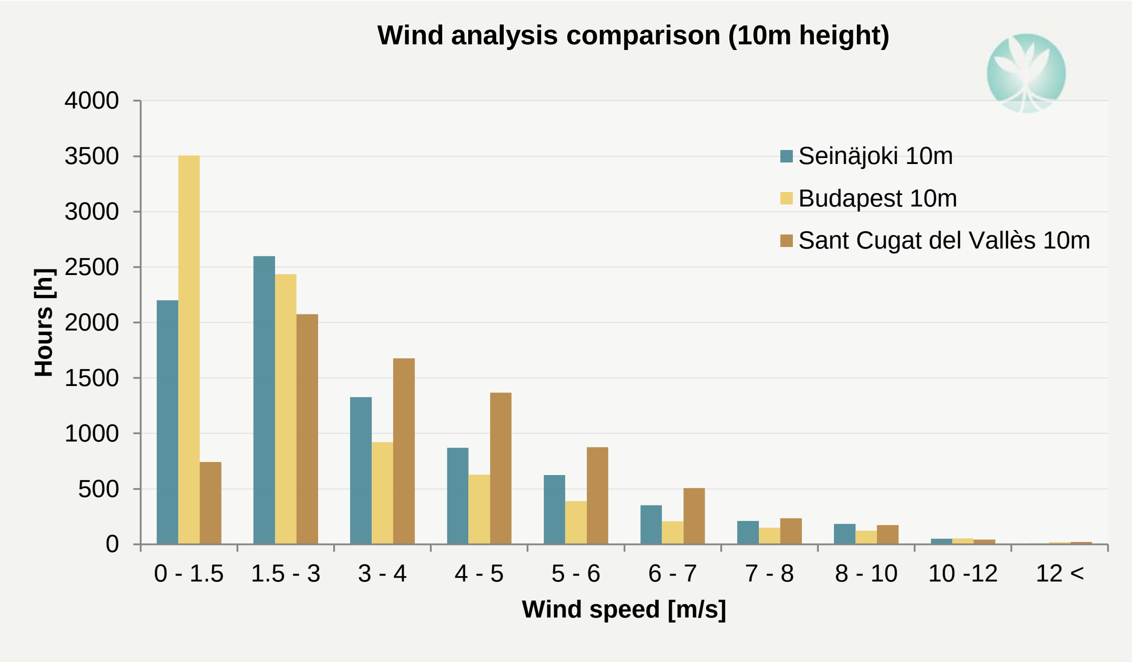


FIGURE 7: COMPARISON OF THE WIND SPEED DURATION IN 10 M HEIGHT (CREDIT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG; DATA SOURCE: METEONORM)

The location of the cities Seinäjoki and Budapest are recognisable on the duration of wind speed per year. In both cities the most frequent wind speed is between 0-0.15 m/s (Budapest) and 1.5-3.0 m/s (Seinäjoki). One reason for this low speed is the location of the cities in the inland and the boundary landscape. In contrast to these both cities Sant Cugat des Vallès has more hours with higher wind speeds hence its location to the seaside.

This effect is clearer if the wind speed hours in 50 m height are investigated (Figure 8). The wind speed in Budapest is the most time of the year between 0 and 3 m/s, the same as for Seinäjoki, except the wind speeds between 3- 4 m/s respectively 4- 5 m/s. With the most wind speed hours between 5- 6 m/s in 50 m height Sant Cugat des Vallès has the biggest potential for large wind turbines for neighbourhoods or districts.

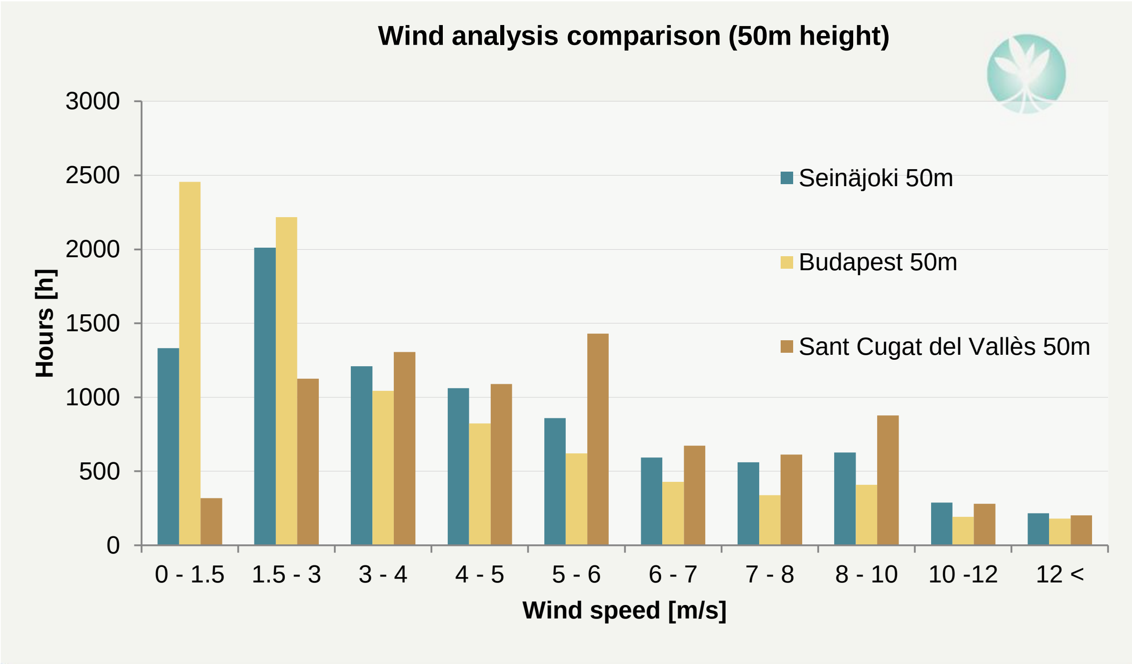


FIGURE 8: COMPARISON OF THE WIND SPEED DURATION IN 50 M HEIGHT (CREDIT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG; DATA SOURCE: METEONORM)

2.2.5. Summary and conclusion

The previous findings for each demo site out of the weather data, reveals how different climatic conditions influence the requirements for the building structure and retrofit technologies. Thereby it's also important to consider further boundary conditions of the retrofit object. Referring to the scope of NewTREND, building or neighbourhood scale, but also the type of building and its user profile has an enormous influence on the right choice of technologies. Those technologies will be considered in the Chapters 2.4 and 6.

In the next chapter the scale of the NewTREND project is described more detailed.

2.3. Description of the project scale

To ensure that NewTREND can function with maximum efficiency it is essential to define system boundaries within which, NewTREND is intended to function and to be used. NewTREND is designed to for to retrofit the existing European building stock, at a neighbourhood scale. In this report the NewTREND system boundaries at the buildings and neighbourhood level are provided.

2.3.1. Building level

The described retrofit technologies in this report are suitable for most common building typologies. The main categories of residential, commercial, governmental and public buildings are catered for in the mentioned technologies. As sub categories these types can described in more detail in apartment houses, shopping malls, hospitals, factories or schools, e.g.). The technologies also can be used for special buildings such as airports, military buildings or religious houses, e.g., in another way.

2.3.2. Neighbourhood level

In the previous Task 2.1 (New approach for an advanced data collection process) a definition for what a neighbourhood is within the scope of NewTREND project is given. A neighbourhood is an urban phenomenon and an urban design unit that used to describe urban structure that are larger than a city block but smaller than a city district. In NewTREND a neighbourhood is defined as the urban unit that include buildings, street objects and power stations which fall within a maximum radius of 500 from the main analysed building centre. In NewTREND it is expected that the number of buildings that to be analysed at a neighbourhood level not to exceed 10 buildings. Thus the described neighbourhood retorting technologies in this report reflect the system boundaries of a neighbourhood within NewTREND.

2.4. Definition of retrofit passive and active technologies

Retrofit measures that are carried out at building scale can be categorized under either passive or active retrofitting technologies. Passive technologies refer to a wide array of interventions and design measures that contribute to the building performance mainly without consuming energy to do so. This include measures that aim to reduce the required energy for heating, cooling, lighting and ventilation as well as other measures that contribute to the improvement of wellbeing of building users.

Active technologies on the other side, describe the set of energy consuming, producing and storing interventions that improve the building performance. This is achieved usually by either increasing the efficiency of the building services systems or by installing more efficient energy production/storage technologies.

3. Data Collection for the Technology Library

In order to obtain relevant, consistent and accurate data, Task 2.1 outputs were reviewed and enhanced to produce a defined list of fields required for each technology. These can be seen in the figure below:

FIGURE 9: FIELDS FOR THE STRUCTURE OF THE TECHNOLOGY LIBRARY (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

The list of fields above was used to form an Excel file. As this file is too large to include in this report, it is available upon request, and will also be used to facilitate the collected data in Task 4.4, which works on the Simulation and Design Hub (SDH).

Technologies were then divided between partners to research, with the information obtained to be entered into both the excel file and also technology description templates (see Figure 10).

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

Technology description - building scale / neighbourhood scale

NewTREND

Name of the technology / material:

This row contains the name of the technology for a clear identification

Category referring to technology library:

This row is referring to the structure of the technology library and defines the classification of the technology

Images:

of the technology / material	of use / built-in
Here will be a image / scheme / photo of the technology function or the material itself	Here will be a image / scheme / photo of the technology function or the material in the build in or use

Short description:

WHAT

The short description contains information about:
- the function and benefit of the technology
- capacity and specific value range of the retrofit technology

Advantages, disadvantages:

WHY

Pros of the technology in general and retrofit use	Contras of the technology in general and retrofit use

Specific applications / where to use it:

WHERE

Description of the specific application and the intended use

Under which conditions can it be used:

WHEN

Description of boundary conditions and example scenarios when the implementation is feasible

Typical technical characteristics

Specific characteristics of the technology (For instance: volume [m³]; capacity [kW], specific heat capacity [kJ/(kg•K)], e.g.)

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

Typical costs of the technology (without VAT and costs for build in or necessary technicians)

Influence on inhabitants / building owners / building management:

Influence on the inhabitants (have they to move out, no water for a certain time, e.g.); building owners (lack of rental income, e.g.); building management (implementation of an BMS system, e.g.)

Impact on the environment:

Impact on the environment by the implementation of the technology (possive aspects referring to the CO2 emissions, use of harmful operation media, e.g.)

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

Frequency of maintenance in years and the necessary of qualified technicians to maintain the technology

Expected lifetime:

Expected lifetime of the technology in total years

Aesthetical issues:

Mention of aesthetical issues of the technology and the influence on facades, characteristic of the building, e.g.

Ease of application:

Ease of application in the rating from easy (1) to high (5) effort, referring to the technology library

Restriction criteria of applicability:

Restriction criteria such as governmental regulations, building regulations or technology specific standards, e.g.

Potential of combination with other technologies:

Description of possible combinations with other retrofit technologies within the mentioned technologies in NewTREND

Hint for suboptimal practies:

Mention of problems that can occur by false use of the technology (Input from Task 2.4)

Compatibility with historical buildings: ☑ Compatibile

Can the technology be used with historical buildings / neighbourhoods ? (Yes / No)

FIGURE 10: TECHNOLOGY DESCRIPTION SHEET OF NEWTREND (CREDIT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

In total, 133 technologies were investigated, and were broken down further into 289 separate classifications depending on size and applications for use. Besides conventional technologies and described measurements, furthermore innovative technologies are affiliated to raise this report to the state of the art.

An overview on the investigated active and passive retrofit technologies is shown in Table 3. This only shows the main categories of the technologies. More detailed distinctions, like different types of fuel, chillers, heating systems, insulation variants or electrical systems are in the same consistent structure as in the chapters in this report.

Because of the enormous number of description sheets only 10 sheets can be found in Annex 1 as an example.

TABLE 2: OVERVIEW ON NUMBER OF DESCRIBED TECHNOLOGIES

	Passive technologies	Active technologies
Building scale	23	84
Neighbourhood scale	2	20

TABLE 3: OVERVIEW ABOUT THE INVESTIGATED TECHNOLOGIES ON BUILDING AND NEIGHBOURHOOD SCALE (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

	Passive technologies	Active technologies
Building scale	○ Thermal insulation ○ Doors ○ Windows ○ Shading ○ Natural ventilation	○ Fuel types ○ Alternate fuels ○ Conventional heating systems ○ Combined heat and power (CHP) ○ Heat pump ○ Solar thermal collector heat distribution systems ○ Cold generation ○ Heat exchanger ○ Storage ○ Forced ventilation ○ Photovoltaic ○ Micro wind turbine ○ Small hydro power ○ Electrical battery storage ○ Electric and motors ○ Lighting ○ Light control ○ User specific control ○ General control
Neighbourhood scale	○ No technologies were described in detail because the energy simulation of these is considered out of scope of this project.	○ Local heating grids for neighbourhood retrofitting ○ Local cooling networks for neighbourhood retrofitting ○ Storage ○ Electricity ○ Control

4. PASSIVE retrofit technologies on building scale

Within the NewTREND framework, the passive retrofit technologies are divided into interventions that address the building envelope and interventions that address the building services.

4.1. BUILDING ENVELOPE AND ZONES

The below described building envelope retrofitting interventions address interventions that can be made at the building external walls, internal walls, basement walls, roof, windows and doors. The described buildings services passive interventions address the piping, the hot water tank and the ventilation ducts.

4.2. THERMAL INSULATION

Thermal insulation is used to decreases the heat transfer between the building interior and the exterior environment. Thus reducing the amount of energy required to keep the building interior temperature within the comfort zone. The heat loss through the building envelope is responsible for over 70% of total heat losses in existing building [1]. Therefore, improving the building thermal insulation can be seen as the most effective energy conservation measure. Thermally insulated building tends to offer their users a higher comfort and overall better building performance. In the market a large number of different materials used for thermal insulation are available, each having their pros and cons. These materials differ from one another basing on their thermal conductivity, Endurance, fire behaviour, and their eco friendliness, which relate to the production technology and the origin of the materials. It is always preferred when possible to use natural insulating materials such as wood fibre, mineral wool, sheep wool, hemp bred, etc.

4.2.1. EXTERNAL WALL INSULATION

The thermal insulation of exterior walls is the most effective and cost efficient method of isolating the exterior envelope of the building. Nowadays, this is usually carried out using a thermal insulation composite system. Thermal insulation composite systems are preferred due to their effectiveness, relative low cost and easy to install nature. Thermal insulation composite system can be made out of mineral wool or rigid foam panels (EPS). In this system the insulation boards are glued directly onto a suitably prepared facade. The EPS panels are then coated with a special reinforcement fabric to protect the insulation from impact damage. In addition, the building structure is protected by the facade insulation from damage due to temperature fluctuations, moisture, and mould or algae growth, thus ensuring a healthy living environment and longer durability.

FIGURE 11: INSTALLATION OF THERMAL INSULATION COMPOSITE SYSTEMS (SOURCE: DEUTSCHE ROCKWOOL)

4.2.2. Cavity wall insulation

Cavity wall insulation is done by blowing or pouring the insulation material in the cavity between the wall shells. Thus, reducing the heat losses without impacting the interior spaces or the outer facade.

In new buildings, cavities are usually filled with insulating panels or boards. However, for existing buildings that has no insulated cavities the insulating material are blown or poured between the wall shells depending on the selected insulation. However, a sufficient cavity of at least five centimetres must be available to improve the thermal insulation of the facade. Having a Ten centimetres cavity that is filled with high-quality insulating material can result into achieving good insulation performance.

FIGURE 12: CAVITY WALL INSULATION (SOURCE: DEUTSCHE ROCKWOOL)

4.2.3. Roof insulation

Roof insulation is made depending on the nature of the building's roof. In wooden structures and gabled roofs this is done either between the rafters or over the rafters or in combination of both systems.

Over-rafter insulation is installed as its name indicate above the rafters, thus thermal bridges can be completely avoided compared to between-rafter insulation. Depending on the type of insulation it may be necessary to install roof boards on the rafters before adding the insulation panels. Alternatively, there are rigid insulation boards which can be directly attached to the rafters. Usually materials like rigid boards made of polyurethane, extruded polystyrene, wood fibres or glass and rock wool in combination with roof boards are used. The insulating material is installed from the outside of the roof. Therefore, the top floor rooms stay inhabitable during construction works. To prevent structural damage, the insertion of a steam brake on the underside of the insulation is necessary. The insulation itself has to be protected by a sub-roof that ensures that it is water- and wind proof. The installation of over-rafter installation is always accompanied by the renewal of the roof covering.

Between rafters insulation is made by installing rigid insulation boards, rolls or foam between the rafters. However, the depth of the rafters will determine how much insulating material can be fitted between them. A combination of both Over-rafter insulation and between-rafter insulation is often used to achieve a higher insulating effect. For flat roofs it is preferably to insulate them from above. A layer of rigid insulation board can be added either on top of the roof's weatherproof layer, or directly on top of the timber roof surface with a new weatherproof layer on top of the insulation. In the first system, known as inverted warm roof, the insulation protects the weather membrane from heat and cold which can shorten its life and that of the roof deck. It can even protect against wear and tear if there is access to the roof. The top-most layer is generally made of gravel or a similar material. The second option, known as warm roof, can be done when the roof covering needs replacing. Moreover, the maintenance of the weatherproof layer (replacement or sealing of infiltrations) will be done without removing the insulation.

It is possible to insulate a flat roof from underneath (cold roof), but this can lead to condensation problems if not done correctly. Typically, a gap will have to be left for ventilation.

FIGURE 13: BETWEEN RAFTER INSULATION (SOURCE: DEUTSCHE ROCKWOOL)

4.2.4. LOFT INSULATION

Loft insulation is one of easiest and most effective thermal insulation measures. Insulating the loft is usually done by applying the insulating material directly on the loft floor using rigid board or mineral wool rolls. It acts like a blanket, helping prevent heat escaping through the roof. This will keep the building warmer in the winter and cooler in the summer, reducing the energy consumption for heating or cooling purposes. This technique is easy to apply, straightforward and usually takes less than a day to install. Lofts are usually cheaper and easier to insulate than roofs. But if the loft is being used as a living space, it would be necessary to insulate the roof.

4.2.5. Internal wall insulation

Internal wall insulation works by adding a thermal layer of material to the inner face of the existing wall. Internal wall insulation, rather than external, is usually carried out when it is necessary to maintain the external appearance of the building (e.g. in a heritage context). There are various ways to insulate a solid walled building from within like the use of rigid insulation panels, dry lining or using flexible thermal lining. In dry lining battens are fixed to the walls, insulation is fitted between them and then covered with plasterboard. This is a good option if the wall has a lot of heavy fittings or if the original wall is rough and uneven. Flexible thermal lining is used in the form of blanket rolls and is fixed to the wall, mechanically or chemically. It does not provide the same level of insulation as the use of panels and boards, but it is a good option for rooms that have limited space. Generally, this internal wall insulation has a poorer performance in comparison to external wall insulation.

The insulation of the of exposed floors such as basement ceilings is one of the most profitable and easy to do retrofitting measures, partly because homeowners can carry on the insulation themselves. The insulation of exposed floors and basement ceiling can lead to up to 10% reduction in the heat energy losses. The insulation of exposed floors is done by attached insulation boards to the ceiling and around the parameter walls to avoid the creation of thermal bridges. However, the ceiling for this must be as even as possible and the installation is carried out without gaps between the ceiling the insulation material for optimum results. Sheets of polyurethane or Rook wool can be used. The height of the ceiling as well as the fire safety requirements determines the final choice of the insulation material.

FIGURE 14: BASEMENT CEILING INSULATION WITH ROCKWOOL (SOURCE: DEUTSCHE ROCKWOOL)

4.2.6. Perimeter insulation

The insulation of the basement walls from the outside is called perimeter insulation or base insulation. Since the basement walls are mostly hidden in the ground, the perimeter insulation is particularly complex and therefore expensive. Perimeter insulation is recommended when the cellars are used and heated for domestic purposes. Firstly, a bitumen coatings or mineral sealing waterproofing layer is installed. Thereafter, the insulation panels are glued to the basement wall. It is necessary to ensure that this is done void free to prevent the occurrence of thermal bridges. Equally important is the proper connection to the basement windows and the insulation of the outer walls of the upper floors of the house.

The perimeter insulation is exposed to numerous stresses such as weather conditions, humidity and earth pressure. Therefore, only certain insulating materials can be used as they need to be waterproof and resistant to pressure. These are, for example, insulating materials made of XPS (extruded polystyrene foam) foam glass and EPS (Expanded polystyrene foam). Therefore, the perimeter insulation is specialist task.

FIGURE 15: XPS PERIMETER INSULATION (CREDT BY: ©UNIVERSITY OF APPLIED SCIENCES MUNICH)

TABLE 4: STRENGTHS AND WEAKNESSES ANALYSIS FOR THERMAL INSULATION

Strengths	Weaknesses
○ Reduce heat losses effectively ○ A wide verity of technologies and material available with many systems ○ Short amortisation ○ Enhance the comfort level of the building ○ Some technologies can be done in a short time by the owner himself	○ Best results achieved when a holistic retrofitting of the building is made ○ Incorrect execution might lead to thermal bridges

4.2.7. FLOOR INSULATION

The insulation of the of exposed floors such as basement ceilings is one of the most profitable and easy to do retrofitting measures, partly because homeowners can carry on the insulation themselves. The insulation of exposed floors and basement ceiling can lead to up a considerable reduction in the heat energy losses. The insulation of exposed floors is done by attaching insulation boards to the ceiling, extending this insulation to cover the parameter walls is advised in order to avoid the creation of thermal bridges. To achieve best results, it is desired that the ceiling or exposed floor that is to be insulated is as even as possible and the installation is carried out without gaps between the ceiling and the insulation material. Sheets of polyurethane or Rook wool are commonly used as an insulation material. However, the available height of the ceiling as well as the fire safety requirements determines the final choice of the insulation material.

4.2.8. Piping insulation

Insulation of heating/ hot water and cold-water pipes prevent costly heat loss and save up to 5% on the energy bills. Insulating the hot water pipes is one of the easiest and inexpensive retrofitting interventions that can be implemented and in many cases can be carried out in less than a day time. Insulating cold water pipes will prevent them from dripping condensation, which can lead to further damages other than heat losses. Furthermore, insulating exposed water pipes can prevent them from freezing in cold winter times. There are two main types of water pipe insulation: pipe wrap and tubular sleeves.

Pipe wrap is the most common type of insulation. It comes in a number of different materials such as regular fiberglass and plastic, foil backed natural cotton, and rubber pipe insulation tape. Pipe wrap insulation is more suitable for insulating small amount of pipes for short distances. When more pipes need to be covered tubular sleeve is more suitable. The tubular sleeves can be made of either foam or rubber insulation and both are usually available as a self-sealing option.

In addition to the economic related benefits. Insulating the pipes have acoustic comfort related benefits as the sounds from pipes expanding and contracting with changes in temperature will be decreased, due to slower heat loss.

FIGURE 16: INSULATION OF HEATING PIPES (CREDT BY: ©UNIVERSITY OF APPLIED SCIENCES MUNICH)

4.2.9. Tank insulation

Insulation of heaters, hot and chilled water tanks reduces costly heat losses by 25%–45% and save up to 10% in water heating costs. [2] Insulating the heaters hot and chilled water tanks is one of the easiest and inexpensive retrofitting interventions and in many cases can be carried out in less than a day time. However, it’s advised for this to be carried out by qualified plumbing and heating contractor.

4.2.10. Insulation of ventilation ducts

The insulation of ventilation ducts fulfils three main tasks: reduce heat losses, prevent moisture from condensing on the duct outer surface and reduce noise and vibration of ventilation system. The thickness and nature of the insulation of the duct varies according to the purpose and the location of the ventilation duct. Vapour diffusion-tight insulation "flexible rubber" or mineral fibre insulation with a tear-resistant vapour tight taped jacket can be used.

FIGURE 17: INSULATED VENTLAITION DUCTS (CREDT BY: ©UNIVERSITY OF APPLIED SCIENCES MUNICH)

TABLE 5: STRENGTHS AND WEAKNESSES ANALYSIS FOR INSULATION OF BUILDING SERVICE COMPONENTS

Strengths	Weaknesses
○ Reduce heat losses ○ Easy to implement with minimal impact on the inhabitants ○ Short amortisation time	○ none

4.3. Doors

Exterior Doors and even interior doors between heated and unheated rooms leave much heat escape. Replacing the old doors with thermally insulated ones can help reduce heat losses. The thermal properties and exact amount of heat saving that can be achieved through replacing the old doors depend on the selected material of the door frame and the door leaf as well as their thickness and structure. To realize the full potential of thermal insulation of the door, sealing the gaps under and around doors is required. Furthermore, thermally as well as sound proof doors can be combined to achieve higher acoustic comfort. Depending on the door type and specification the door can reach a sound reduction index (Rw) of 27 to 42 decibel (dB) [3].

4.4. Windows

A great amount of energy can escape of (or in hot climates penetrates through) the building through windows. A thermally insulated window system can help reduce the amount of heat losses, air infiltration draught, thus improving the thermal, acoustic and visual comfort of the building. A modern window would have a thermally insulated frame and consists of a two- or three-pane laminated glass filled with inert gas and a so-called low-e coating. Low-emissive coat reduces the amount of passing ultraviolet and infrared light through glass without compromising the visible light. In this the outwardly directed side of the inner pane with a long-wave heat radiation reflecting layer is coated. Thereby, the heat loss is limited by heat radiation to the outside.

4.5. Secondary glazing

Secondary glazing is the installation of an independent window system on the room side without altering the existing window. Secondary glazing is used cut down the heat loss and provides some acoustic insulation to the existing window opening. Secondary glazing can reduce heat loss as well as reducing the air draughts. Usually it is preferred to leave the outer windows without draught-proofing so that there is a degree of ventilation to the air space between the outer windows and the secondary glazing. This helps prevent the build-up of condensation. Secondary glazing can be built as movable or fixed units. Opening of both the external windows and secondary glazing is required for ventilation. This solution is usually preferred in historic buildings.

FIGURE 18: SECONDARY GLAZING IN A HISTORICAL BUILDING (CREDT BY: ©UNIVERSITY OF APPLIED SCIENCES MUNICH)

TABLE 6: STRENGTHS AND WEAKNESSES ANALYSIS FOR DOORS AND WINDOWS IN BUILDINGS

Strengths	Weaknesses
○ Reduce heat losses and summer heat gains effectively ○ Enhance thermal, visuals and acoustic comfort level of the building ○ Can be combined with whole faced renovation	○ Not always applicable for heritage protect building ○ The building might require the addition of mechanical ventilation ○ Incorrect execution might lead to thermal bridges

4.6. SHADING

4.6.1. OVERHANGS

Overhangs allow the entrance of lower winter sun whereas summer sun is blocked. Therefore, the use of this shading device, especially in south-facing windows, limits heat gains and glare while allowing for effective daylighting, i.e. it is possible to improve the amount of light without undesirable heat gains caused in summer by direct sunlight. The latitude of the location, the height of the opening and its geometry will have influence in the overhang size.

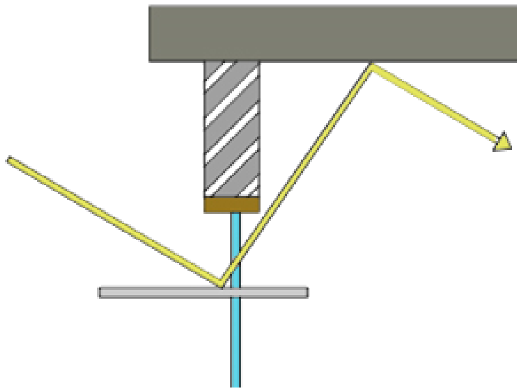


FIGURE 19: SKETCH OF AN OVERHANG LIGHT SHELVES USED TO REFLECT THE DAYLIGHT DEEP INTO THE SPACE (CREDIT BY: ©UNIVERSITY OF APPLIED SCIENCES MUNICH)

Overhangs can be formed by the very roof of the building. Its orientation can be fixed or can be adjustable by the user. Moreover, overhangs can be used to improve the amount of daylight within the building, this technology is known as daylight shelves. By means of reflective surfaces placed in their upper side, direct sunlight is reflected in winter into the room's ceiling, whereas in summer sun is directly blocked.

4.6.2. SHADING BRISE SOLEIL

A set of louvres (Brise soleils) is formed by horizontal parallel slats. The slates are angled to allow for daylight and air, but to prevent the access of rain and direct sun. The angle of the slats can be fixed or adjusted as per the current weather conditions and the exact position of the sun in the sky either manually by means of a metal lever, pulleys, or through motorized operators that is connected to the BMS. Louvers can be made of aluminium, metal, wood, or glass.

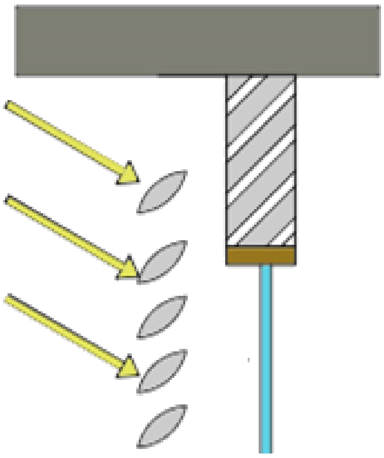


FIGURE 20: LOUVERS SKETCH (CREDIT BY: ©UNIVERSITY OF APPLIED SCIENCES MUNICH)

4.6.3. Shading side fins

Side fins (also called fin, sun blades or vertical louvres) are usually used on east or west facing windows to prevent direct sunlight from penetrating the room. Fins can be used to reflect the blocked sun as diffused light into the room. Fins can be fixed elements of the facade, or moveable. When a movable system is used the amount of blocked sun can be adjusted, thus allowing for light to be admitted in winter, while blocking this undesired sun during the hot summer months. The orientation of the side fins can be adjusted by means of BMS.

4.6.4. Shutters

Shutters are moveable devices that cover openings in a building such as windows and terrace doors. They are very versatile and used in many different climates. Shutters can perform a number of functions such as reducing heat losses in winter time at night and allowing daylight into the room in day time. In summer they can reduce direct light entering a room thus reducing heat gains during the day. In warmer climates, at night, they are usually kept open at night to allow for night-time passive cooling of the building. Shutters may have fixed or moveable louvres integrated into them to allow light and air flow. Shutters can be used to protect against weather, to provide privacy and security, and to enhance the aesthetics of a building.

FIGURE 21: WINDOW ROLLER SHUTTERS (CREDIT BY: ©UNIVERSITY OF APPLIED SCIENCES MUNICH)

4.6.5. Shading blinds

A window blind is an interior window covering that comes in many different kinds with a variety of control systems. A typical window blind is made up of several horizontal or vertical slats of which are held together by cords that run through the blind slats. Window blinds can be adjusted by rotating them from an open position to a closed position with other types of window blinds that use a single piece of material instead of slats. Blinds are mainly used to reduce glare and to allow for more privacy.

TABLE 7: STRENGTHS AND WEAKNESSES ANALYSIS FOR SHADING TECHNOLOGIES

Strengths	Weaknesses
○ Reduce summer heat gains effectively ○ Reduce glare effectively ○ Enhance thermal and visuals comfort level of the building ○ Some systems can be individually adjusted ○ Can be combined with whole faced renovation ○ Can be combined with PV systems	○ Not always applicable for heritage protect building ○ Change the building appearance ○ Incorrect execution might lead to thermal bridges ○ Some systems might get damage when exposed to high wind speeds

4.7. Natural Ventilation

4.7.1. Airtightness

As buildings become more contemporary in their design, sustainable strategies, such as natural ventilation, are becoming increasingly important to a structure's core principles. Not only does such an approach allow for a building to use 60 per cent less energy, it also drastically improves the air quality for the occupants within. Natural ventilation takes advantage of both wind and buoyancy in order to drive fresh air through a building. This removes the need for the use of intensive fans - which can often be expensive in terms of energy use and installation. Using the 'stack effect' this ventilation method makes use of the fact that warm air rises above cold air. Naturally ventilated buildings can utilise this so that an atrium allows warm air from an occupied space to rise and escape through vents situated at the top of the building [4].

An airtight building envelope is an important cornerstone in achieving the high energy performance. The airtight building envelope ensures that no disruptive drafts occur, and reduce the heat losses as well as risk of mould formation. The airtightness of a building envelope is determined using a blower door test. Here, a fan is mounted in the front door opening and the air flow rate at positive and negative pressure at a pressure difference of 50 Pascal "n50 value". This "n50 value" represents a quality proof of the tightness of the building envelope.

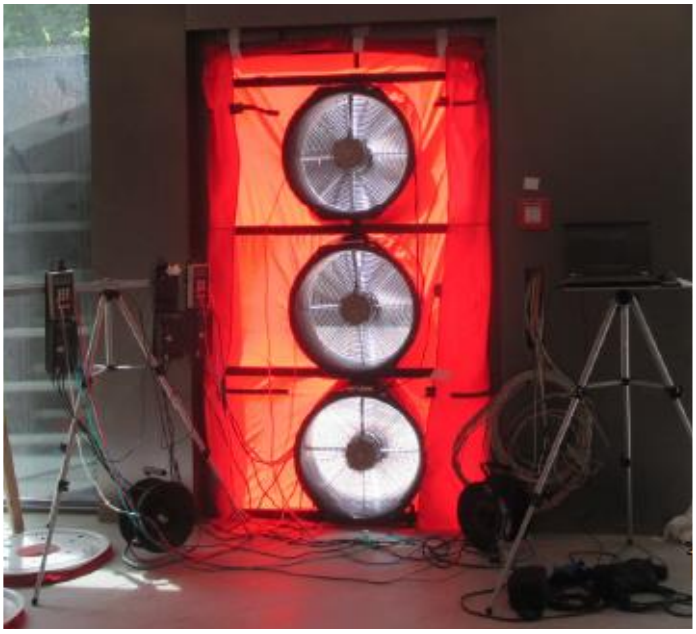


FIGURE 22: BLOWER DOOR TEST (CREDT BY: ©UNIVERSITY OF APPLIED SCIENCES MUNICH)

A n50 value of 3.0 (1 / h) is recommended for naturally ventilated buildings. For buildings with mechanical ventilation, a n50 value of an of 1.5 (1 / h) is advised. In passive energy houses usually an n50 value of 0,6 (1 / h) is required [5].

Installing a permeable wind seal on the building envelope and an airtight seal on the doors and windows of the building as well as between conditioned and unconditioned rooms help improve the building airtightness greatly and reduce the heat losses.

4.7.2. Fresh air rate

The general purpose of ventilation in buildings is to provide healthy air for breathing by both diluting the pollutants originating in the building and removing the pollutants from it; ventilation rate is one of the three basic elements in building ventilation and it defines the amount of outdoor air that is provided into the space.

Next tables, prepared by David Clark in his paper summarises the drivers behind the minimum fresh (outside) air requirements in office buildings [6],

TABLE 8: SUMMARY OF FRESH AIR REQUIREMENTS IN OFFICE BUILDINGS

Issue	Fresh Air Requirement
Odours	Occupant's perception of indoor air quality is strongly influenced by odour. This can be controlled by introducing fresh air and/or treating recirculated air. Toilet exhausts are an example of removing odours at source without recirculation.
CO_2	CO_2 concentrations are often used as a surrogate indicator for odours inside buildings, with a limit of between 1,000 to 1,500 ppm typically adopted [3], (compared to 450 ppm currently found in outside air).

[3] Adapted from guidelines from CIBSE and ASHRAE.

Issue	Fresh Air Requirement
	This typically requires between 7.5 to 10 l/s/person of outside air to achieve. Prolonged CO_2 levels above 1,500 ppm may cause occupants to feel drowsy, get headaches, or function at lower activity levels.
Indoor pollutants	These include volatile organic compounds (VOC) and formaldehyde (off gassing from carpets, paint and furniture), ozone (from photocopiers), carbon monoxide, radon, sulphur dioxide, and a host of other substances. The best approach is to avoid introducing pollutants in the first place by selecting low off gassing materials and to exhaust sources of pollution locally (e.g. direct exhaust of photocopy rooms).
Cigarette smoke	Smoking indoors was a major source of indoor pollutant and has been banned in many countries. A ventilation rate of at least 30-45 l/s/person is typically required if smoking is permitted.
Oxygen to breathe	To meet the human body's demand for oxygen when seated typically requires less than 0.2 l/s/person of fresh air. This is clearly not a driver for minimum ventilation rates in buildings.

The minimum fresh air requirement of 8 to 10 l/s per person typically adopted in mechanically ventilated spaces is supported by a variety of sources, while fresh air requirements for naturally ventilated spaces are treated differently. British Standard BS EN 13779 provides four classifications of indoor air quality as shown in next Table.

TABLE 9: SUMMARY OF FRESH AIR REQUIREMENTS IN OFFICE BUILDINGS

Classification	Indoor air quality standard	Fresh air ventilation range (l/s/p)	Fresh air default value (l/s/p)	Approximate indoor CO_2 concentration (ppm) *
IDA1	High	>15	20	700 to 750
IDA2	Medium	10–15	1 2.5	850 to 900
IDA3	Moderate	6–10	8	1,150 to 1,200
IDA4	Low	<6	5	1,550 to 1,600

* taken from Table 4.2, CIBSE Guide A, including CO_2 concentration rise plus external CO_2.

Next Table provides a summary of various regulations, standards and guidelines related to minimum fresh (outdoor) air rates.

TABLE 10: OVERVIEW OF FRESH (OUTDOOR) AIR RATES REGULATIONS OF DIFFERENT GUIDELINES

Source	l/s per person	Comments
Part F, UK Building Regulations 2010	10	Total outdoor air supply rate with no smoking and no significant pollution sources. Extract rates are also given: • Printers / Photocopier rooms – 20 l/s per machine • WC/Urinal – 6 l/s each • Shower – 15 l/s each

Source	l/s per person	Comments
CIBSE Guide A, Table 1.5	10	Applies to executive, general and open plan offices. Assumes no smoking.
CIBSE Guide A, section 8.4.1.2	8	As a general rule, the fresh air supply rate should not fall below between 5 and 8 l/s per occupant but this will depend on various other factors including floor area per occupant, processes carried out, equipment used and whether the work is strenuous. For office workers, 8 l/s fresh air is roughly equivalent to an elevation of 600 ppm of carbon dioxide (CO_2) which, when added to the normal outdoor CO_2 of 400 ppm, gives an internal CO_2 concentration of 1,000 ppm; 5 l/s would be equivalent to 1,350 ppm internally. The higher ventilation rate of 8 l/s per person is recommended. **Note:** Schools have prescribed ventilation rates of 3 l/s per person for background ventilation and 8 l/s per person when required.
BCO Guide to Specification 2009	12-16	Suggests an allowance of 1.2 to1.6 l/s per m^2, which based on a standard occupancy of 1 person per $10m^2$ equates to 12 to16 l/s/person. For occupancy of 1 per 6 m^2 this equates to 7 to 10 l/s/person.
ASHRAE Handbook: Fundamentals 2009, chapter 16.10	10	Engineering experience and field studies indicate that an outdoor air supply of about 10 l/s per person is very likely to provide acceptable perceived indoor air quality in office spaces, whereas lower rates may lead to increased sick building syndrome symptoms.
ASHRAE Technical FAQ ID 34 www.ashrae.org	7,5	At the activity levels found in typical office buildings, steady-state CO_2 concentrations of about 700 ppm above outdoor air levels indicate an outdoor air ventilation rate of about 7.5 l/s/person. Laboratory and field studies have shown that this rate of ventilation will dilute odours from human bio-effluents to levels that will satisfy a substantial majority (about 80%) of un-adapted persons (visitors) in a space.'

5. Active retrofit technologies on building scale

Besides the passive technologies, which describe interventions without any devices or functionality that improve the building active technologies are also important to consider within a retrofit. Active technologies need operation energy and can interact with the inhabitants by control panels. The active technologies are from small scale, for instance air conditioning units, up to complex systems like CHP units or combinations out of it. In this Chapter the selected active technologies for building scale within NewTREND described in detail. Furthermore, the operation materials, like fossil or alternative fuels or periphery systems are described.

5.1. Fuel types

5.1.1. Heating oil

Heating oil is a fraction obtained from petroleum distillation, with chemical composition of 86 % C, 11-13 % H, with remaining is consisted of O, N and S. Heating oil is used for heating and domestic hot water systems, it has lower viscosity and therefore pre-heater is not needed. Heating oil is made from crude oil and therefore is a fossil fuel with high impact on environment. To lower environmental impact in some places heating oil is mixed with biodiesel. Calorific value of heating oil is approx. 42,7 MJ/kg [7; 8; 9].

5.1.2. Natural gas

Natural gas is a naturally occurring hydrocarbon gas mixture consisting primarily of methane. It is acquired from natural gas fields or together with oil from oil fields. Natural gas is non-poisonous, without color, taste and smell, lighter than air and it burns with blue flame. Even though it is odorless, for safety reasons it is odorized with intensive smell. It is probably the “cleanest” fossil fuel, as it emits less CO_2, negligible amounts of sulfur, mercury and particulates and lower levels of NOx. Calorific value of natural gas is 43 MJ/m^3 [10; 11; 12].

5.1.3. LPG

LPG or liquefied petroleum gas is a fossil fuel gas made by processing natural gas or as by-product from crude oil production. It is liquefied for easier storage and transportation, because its volume decreases approx. 300 times. It is heavier than air, so in case of leak it can be found at floor level. LPG burns as a yellow flame. Compared to natural gas it has much higher calorific value (94 MJ/m^3 compared to 43 MJ/m^3), which means that LPG cannot simply be substituted for natural gas. To use same equipment as with natural gas, LPG should be mixed with air which produces so called synthetic natural gas (SNG) [14].

5.1.4. Coal

Coal is solid fossil fuel, which is used as energy source for the production of electricity and heat and is also used for industrial purposes. Coal is made as a part of biological and geological process when dead plant matter is converted into peat, which turns into lignite, then coal and in the end anthracite. Process from dead plant matter to coal takes roughly 150 – 220 million years, which is why this energy source is considered non-renewable. By-products of burning coal have serious health and environmental effects. Health effects include lung cancer, “black lung” disease and many other health issues. While environmental issues include acid rain, contamination of water systems, release of carbon dioxide (coal is the largest contributor of CO_2 increase in the atmosphere). Calorific value of coal varies from 20 MJ/kg to 33 MJ/kg [15; 16].

5.1.5. PEAT

Peat is solid fuel, which is used as energy source for the production of electricity and heat and is also used for industrial purposes. Several organizations consider it as a slow-renewable fuel, because of its slow accumulation, which is roughly a millimeter per year. It is usually found in swamp areas. Peat is made as a part of biological and geological process when dead plant matter is converted into peat, which turns into lignite, then coal and in the end anthracite.

Peat usage has many environmental and ecological issues such as: damaging habitats with distinctive fauna and flora by peat gathering or high effect on global warming (106 g CO_2/MJ, which is higher than coal). Calorific value of peat varies from 13 MJ/kg to 21 MJ/kg [17; 18].

5.1.6. ANTHRACITE

FIGURE 23: ANTHRACITE (SOURCE: JAKEC - OWN WORK, CC SA 4.0, COMMONS.WIKIMEDIA.ORG)

Anthracite is solid fossil fuel; it has highest carbon content, less impurities and highest calorific value of all types of coal (except graphite, which is not used for energy production). Anthracite is made as a part of biological and geological process when dead plant matter is converted into peat, which turns into lignite, then coal and in the end anthracite. Process from dead plant matter to anthracite takes roughly 250 – 300 million years, which is why this energy source is considered non-renewable.

Compared to other types of coal, anthracite produces less pollution and it has also very high calorific value. Drawbacks are: its price and difficult ignition. Calorific value of anthracite is roughly 33 MJ/kg [19; 20].

TABLE 11: STRENGTHS AND WEAKNESSES ANALYSIS FOR FOSSIL FUEL TYPES

Strengths	Weaknesses
- Mature distribution and supply industry - Well known and simple technologies - Investment costs are usually low - If local supply of some type of fossil fuel is available, price can be very low - Some of fossil fuels can be mixed or replaced completely with biofuel (natural gas with biogas or coal with biomass)	- High environmental impact - Decrease of local air quality, which brings health issues - Some of listed fossil fuels can be explosive and systems using them require regular inspection - Dependency on prices determined by global market - Long term fuel price trends are almost impossible to predict - Fuels supply can be dependent on geopolitics

5.2. Alternate fuels

5.2.1. Biomass

Biomass is a general term for material derived from growing plants or from animal manure. Bio energy already provides the majority of renewable energy worldwide and is considered to have the potential to provide a large fraction of world energy demand over the next century. At the same time, if biomass systems are managed properly, bio energy will contribute to meet the requirement of reducing carbon emissions. Biomass is considered carbon neutral technology as burning it emits same amount of carbon dioxide as is absorbed while plants are growing. For domestic heating purposes biomass comes most often in forms such as wood pellets, wood chips or logs. Wood pellets and chips are more practical as their storage and feeding system can be automatic, while logs require more manual labour. Not only that is eco-friendlier than fossil fuels, but it is often cost-friendlier, especially in rural areas where local sources of biomass exist.

Even though it is carbon neutral technology, it still emits other air pollutants such as: carbon monoxide (CO), nitrogen oxides (NO_X), volatile organic compounds (VOCs), etc. Depending on the local supply of fuel, biomass fuels can be more cost effective than fossil fuels. In the carbon emission calculation, the emission from transporting the biomass to the building should also be considered [21; 22].

Wood pellets

FIGURE 24: WOOD PELLETS (SOURCE: PUBLIC DOMAIN IMAGE)

Wood pellets are usually cylindrical compressed wood fuel products made of by-products of mechanical wood processing industry. They belong to group of biomass fuels. Wood pellets are practical as their storage and feeding system can be automatic, while for example wood logs require more manual labour. The net calorific value of pellets ranges between 16.9 and 18 MJ/kg [23].

WOOD CHIPS

FIGURE 25: WOOD CHIPS (SOURCE: PUBLIC DOMAIN IMAGE)

Wood chips are a medium-sized solid material made by cutting, or chopping larger pieces of wood. They belong to group of biomass fuels. Wood chips are more practical than wood logs as their storage and feeding system can be automatic, but less practical compared to pellets because of smaller density. Furthermore, wood in form of chips has higher ash content and higher moisture than in pellet form, which lowers calorific value of fuel. The net calorific value of pellets is around 12.5 MJ/kg [24; 25].

5.2.2. BIOGAS

Biogas is gas which is formed by anaerobic micro-organisms. These micro-organisms feed off carbohydrates and fats and produce methane and carbon dioxides as metabolic waste products. Biogas is considered to be a renewable fuel as it originates from organic material that has been created from atmospheric carbon by plants grown within recent growing seasons, which places it in biomass as well. The net calorific value of biogas from anaerobic digestion is around 23 MJ/m^3 [26; 27].

5.2.3. ORGANIC WASTE

Organic waste can be used as a fuel for production of electricity and for district heating. There are several methods of turning waste into energy, such as: incineration, depolymerisation, gasification, pyrolysis, plasma arc gasification and anaerobic digestion. Depending on the literature waste to energy could be categorized as a renewable technology. These procedures have lower environmental impact compared to burning of fossil fuels. Organic waste can also be mechanically and biologically processed into a form of SRF (specified recovered fuel), which has to satisfy environmental and technical quality criteria from European SRF standard.

Calorific values of organic wastes can differ significantly, but as an example calorific value range for SRF is 17 – 37 MJ/kg and for dry household waste is 18.5 – 23.4 MJ/kg [26; 28; 29].

TABLE 12: STRENGTHS AND WEAKNESSES ANALYSIS FOR ALTERNATIVE FUEL TYPES

Strengths	Weaknesses
○ Renewable energy source ○ Relatively low investment price ○ Relatively low fuel costs ○ Possible subsidiaries for using biomass as a fuel ○ Supports local economy (example: instead of buying imported fuel, money goes to local forest industry)	○ Availability and price is location dependent ○ Emission of volatile organic compounds ○ Requires a lot of labour for operation and maintenance ○ Supply of biomass is often local and limited and high increase in demand can produce problems and raise fuel prices

5.3. Conventional heating systems

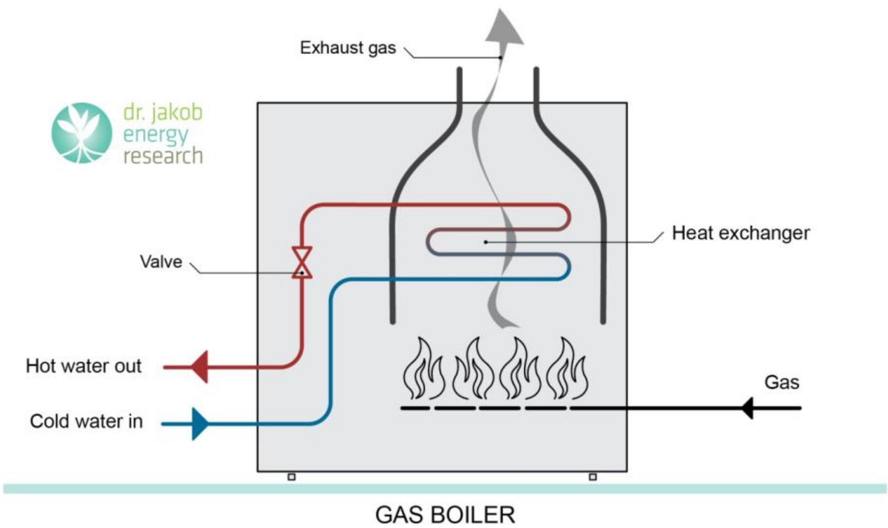


FIGURE 26: FUNTIONAL SCHEME OF A GAS BOILER (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

5.3.1. Standard boiler

Standard boiler is a boiler with low efficiency and high pollutant emission. This boiler type is not installed anymore. Standard boilers can be divided by the type of fuel used on: gas, oil or solid fuel (wood, pellets, coal, etc.). Water in boiler is kept on constant temperature while temperature of distribution water should not fall under 60°C. This limitation is because of avoiding possible condensation of flue gases, which would lead to corrosion. Therefore, flue gases exit the boiler at high temperatures (160-240°C), this means that a lot of thermal energy exits through the chimney unused. Resulting boiler efficiency is low, usually at 60 – 80 % [30].

5.3.2. Modern boiler

Modern boiler is a boiler where water temperature can vary depending on a heating need of the building. This kind of boiler is made of materials which are resistant to low temperature corrosion, which allows water temperatures as low as 40°C at return side. Condensation of flue gases can occur but it is avoided. As a result, modern boilers have: smaller heat losses on flue gas side, smaller convection and radiation losses through boiler casing (lower working temperatures), higher efficiency and lower pollutant emissions than standard boilers [30].

5.3.3. Condensing boiler

Condensing boiler is boiler where water temperature can vary depending on heating need of a building and with additional efficiency increase by condensing flue gases. Condensing the flue gases uses latent heat stored in them. This kind of boiler is made of materials which are resistant to low temperature corrosion. Compared to modern low temperature boilers, condensing boilers have higher efficiency: 10 % higher for natural gas boilers and 5 % higher for fuel oil boilers. Overall condensing boiler efficiency can reach up to 98 %, claimed by manufacturers. Recommended use is in low temperature heating systems.

As a result, condensing boilers have: smaller heat losses on flue gas side, smaller convection and radiation losses through boiler casing (lower working temperatures), higher efficiency and lower pollutant emissions than standard or modern boilers. Condensing boilers require special type of exhaust chimney, which in case of building retrofit creates additional costs [30; 31].

TABLE 13: STRENGTHS AND WEAKNESSES ANALYSIS OF GAS BOILERS

Strengths	Weaknesses
○ Low investment costs ○ Reliable production of heating energy (depends on fuel reliability) ○ Operation is not influenced by external parameters, such as weather (if boiler is sized correctly) ○ Depending on a boiler type, it can have high efficiency ○ Boiler can be fired with biogas, which would make it renewable source	○ Uses fossil fuel ○ Recommended to be used as a centralized heating source, to increase efficiency and decrease environmental impact ○ Required regular maintenance (safety reasons) ○ Increase in gas prices or reduced gas availability can threaten performance of gas boilers

5.3.4. Decentralized system (electric / gas boiler)

Decentralized system for domestic hot water (DHW) applications is characterized by being very close to the point of use. They are most commonly electric boilers, but can be also gas powered. They are best suited to discreet low volume applications such as wash hand basins or single shower cubicles. Because of short distribution pipes, heat loss is minimal. For larger applications it is recommended to use centralized systems, as in those cases they tend to be more energy efficient [32].

5.4. Combined heat and power (CHP)

Combined heat and power (CHP) is an integrated way to use the heat, which comes as a by-product of electricity generation from fossil/biomass fuels, as a useful energy for heating buildings and domestic hot water. This way one facility produces electric and heating energy simultaneously and can save fuel energy of 30-40 % compared with separate power and heat production. CHP technology is scalable from one house level, through neighbourhood level to city level with large CHP plants. First two are called micro and mini CHP with output power ranging from 10 kW_e to 1 MW_e respectively, usually powered with internal combustion engine running on natural gas or LPG. Diesel powered CHPs are larger and vary from 1 to 100 MW. Gas turbine CHP are consisted of three sections mounted on one shaft: the compressor, the combustion chamber (or combustor), and the turbine. Compressor brings the air flowing through it to the high pressure, when it is mixed with fuel and ignited to create high-temperature flow. This flow then enters turbine, where it expands to the exhaust pressure, producing a shaft work output in the process. Part of produced work goes to driving the compressor, while rest powers generator which produces electricity. Exhaust gases go to waste heat boiler to heat the water.

Biomass based CHP plants are most often made from energy stored as a solid biomass or as a renewable waste. Five basic categories of biomass material used for energy are:

- Virgin wood from forestry or wood processing.
- Energy crops: high yield crops grown specifically for energy applications.
- Agricultural residues: residues from agriculture harvesting or processing.
- Food waste, from food and drink manufacture, preparation and processing and post-consumer waste.
- Industrial waste and co-products from manufacturing and industrial processes.

Another source of sustainable energy can be biogas and waste (which depending on the literature is not the same as biomass). Based on EU directives, burnable wastes must be applied to energy use when it is reasonable. Gases from landfill places and waste water treatment are also mostly collected for energy use. Furthermore, industrial waste heat can be used as source of energy for CHP plant. The CHP plant can utilize wastes from industrial process, such as burnable gases, liquids like black liquor and/or solid material, such as wood wastes and bark. The CHP can generate electricity for the site’s own use and steam for the process. Traditional investors in CHP are coming from industries such as: food processing, pulp and paper, chemical, metal and oil [26].

For an economic operation of CHP units, the operation hours for residential buildings should be between 6.000-6.500 h/year, while for office 5.000-5.500 h/year (office with absorption chiller 7.000-8760 h/year). For the design of a CHP plant the annual heat duration curve is a helpful diagram. Load peaks of heating will be covered by boilers. Furthermore, heat storages for an optimisation of the operating hours can be added.

Micro CHP units (1-3 kW_{el}) are very efficient and silent. Thus the slight capacity, they are feasible for single and double- houses. The heat source for this type of engine is it the ambient, which is good controllable and easy for maintenance. The space demand of this small engine is very low, why it is simple for retrofit.

Larger CHP units up to 200 kW_{el} or even up to 400 kW_{el} are for larger buildings with a higher heat demand. For instance, buildings up to 8 or more than 8 dwelling units. These CHP units need a noise protected plant room due the high noise emissions. Another point to consider is the space demand and the structure of the plant room, because of the weight of the CHP unit. Furthermore, the chimney for the exhaust fumes needs to integrated aesthetical, especially at historical buildings.

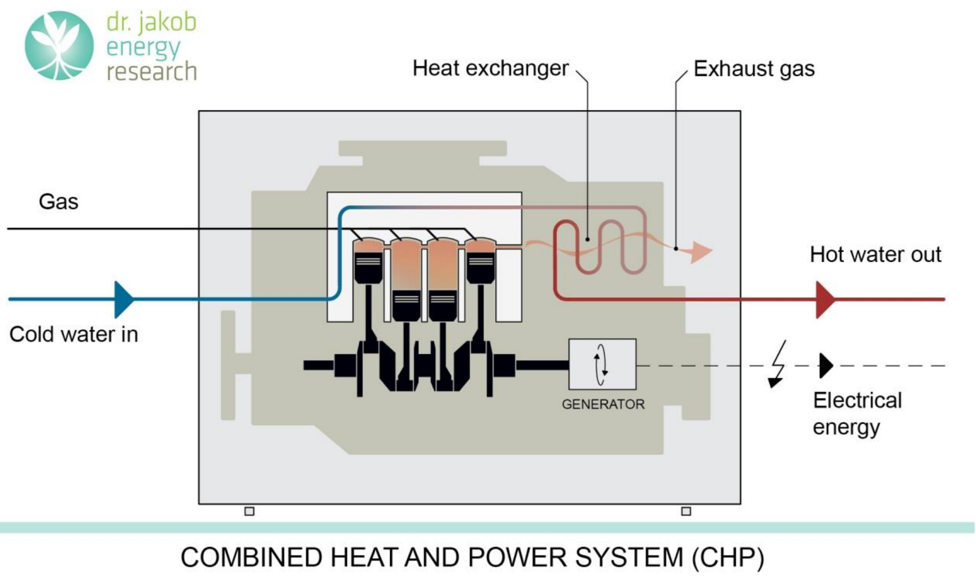


FIGURE 27: FUNCTIONAL SCHEME OF A COMBINED HEAT AND POWER SYSTEM (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

TABLE 14: STRENGTHS AND WEAKNESSES ANALYSIS OF CHP SYSTEMS

Strengths	Weaknesses
○ Generation of heating and electrical energy simultaneously (higher efficiency compared to separate production) ○ Possibility to sell produced electricity (if feed-in tariffs exist) ○ Very good for remote locations ○ Can be very cost-effective, especially if feed-in tariffs exist ○ Depending on the fuel used (biomass) it can be considered as renewable energy source ○ In the case of power shortage CHP can be used as a back-up generator	○ Space requirement for the system components ○ High investment costs ○ Costly maintenance ○ Impact on local air quality ○ CHP has strong dependency on fuel & electricity prices

5.5. Heat pump

Heat pump (HP) is a device which applies external work (through compressor) to extract the heat from a cold reservoir (source) and delivers it to the hot reservoir (sink). Most of the energy for heating/cooling comes from the external environment (outside air, ground, groundwater) while fraction of energy comes from electricity (usually) to power the reverse heat transfer process done by compressor. Heat transferred with heat pump can be several times higher than the electrical power consumed, which is usually the energy which costs. Coefficient which describes ratio of heating or cooling provided to work required is called coefficient of performance (COP) and it depends on temperatures of heat source/sink and efficiency of the heat pump. For example, electrical heating has a COP of approx. 1, which means 1 kWh of electricity needs to be used to produce 1 kWh of heating energy. Heat pump with COP of 4, can with 1 kWh of electrical energy produce 4 kWh of heat.

COP is higher when temperature difference between heat source and sink is lower, therefore buildings with low temperature heating will be more energy efficient. This is important to consider in building retrofits, because older buildings usually have high temperature heating. Replacing it with low temperature heating system is recommended if the heat pump system will be used.

Depending on the source of electrical energy, heat pump can be considered renewable energy, or in the case if electricity is coming from fossil fuels HP is considered partly renewable [33; 34].

5.5.1. Air heat pump

Air source heat pump (HP) is a heat pump, which uses air as a heat source (for heating) or as a heat sink (for cooling). Air contains some energy, depending on its temperature and humidity. Air source heat pump is usually able to provide COP of 1,5 to 5. It can be problematic during cold winters, when its COP and capacity decrease (while heat demand increases). Often because of that this type of HPs requires secondary heat source. A freezing temperatures air source HP requires defrost cycle which consumes energy and stops the heat generation during it. Because of the fan on the external unit it produces more noise than other HP types.

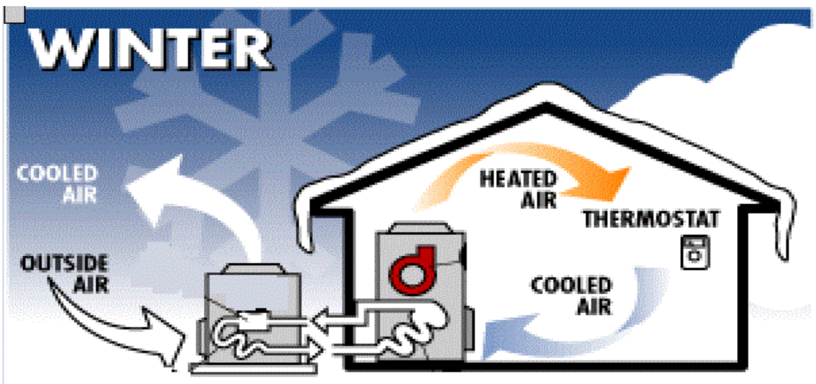


FIGURE 28: AIR-AIR HEAT PUMP IN HEATING MODE [SOURCE: WWW.HEATPUMP-REVIEWS.COM/IMAGES/AIR-TO-AIR-HEAT-PUMP-HEATING.GIF]

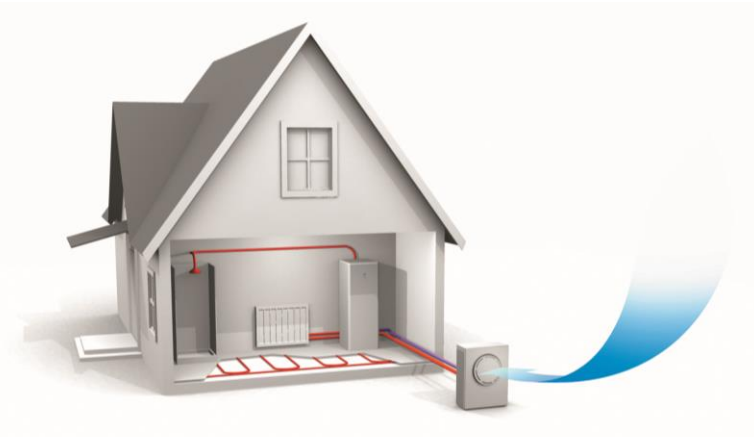


FIGURE 29: AIR HEAT PUMP EXAMPLE (SOURCE: THERMIA HEAT PUMPS)

Depending on the heat distribution medium there are two types of air heat pumps: air to water (Figure 29) and air to air (Figure 28). First one distributes heat through water system, while second one distributes the heat through air heat exchanger to the interior. Usually systems with water distribution system have somewhat lower efficiency because of additional medium conversion from water to air (which happens on radiator surface or on the floor in the case of floor heating) [35; 36].

TABLE 15: STRENGTHS AND WEAKNESSES ANALYSIS OF AIR SOURCE HEAT PUMPS

Strengths	Weaknesses
○ Very good COP in moderate weather conditions ○ Lowest investment cost compared to other types of HPs ○ Moderate energy consumption ○ Possible usage for heating and cooling ○ Combination with photovoltaic modules can decrease the energy demand from grid	○ Use high-grade operation power with high primary energy factor ○ Low COP in very low temperatures (back-up heater recommended) ○ Periodic cleaning of outdoor unit (dirt, ice decreases performance) ○ Outdoor unit can be noisy in operation, requires space and can be aesthetically displeasing ○ Existing building envelope and heating distribution system should be retrofitted (to ensure high performance) ○ High global warming potential of the used refrigerants

5.5.2. Geothermal heat pumps

Geothermal heat pump is a heat pump, which uses earth as a heat source (for heating) or as a heat sink (for cooling). It takes advantage of relatively stable temperatures of ground throughout the year; where ground is usually warmer than outside air in heating season while colder than air during cooling season. Geothermal heat pump is usually able to provide COP between 3 and 6.

There are two types of installation: vertical and horizontal. Vertical installation (Figure 30) means that heat exchanger (pipes) is placed vertically and reaches depths of several hundreds of meters. In horizontal installation (Figure 31), pipes are placed underground on a horizontal plane through the yard. Horizontal installation requires large part of yard to be reserved for pipes, which means that land should not be covered. Even growing flora could be problematic above horizontally placed pipes because of heat being extracted or inserted into ground. In the case when there is little or no available land around the building, vertically placed pipes should be used, which on the other hand are more expensive to install.

Once the installation of geothermal heat pump is completed it can last for a long time (50+ years), while only maintenance is required for the heat pump, which is usually placed in the house. Designing the geothermal heat pump system and installation should be done by experts as it is not a simple task; this is one of the reasons for the high initial cost of these systems [37; 38, 39].

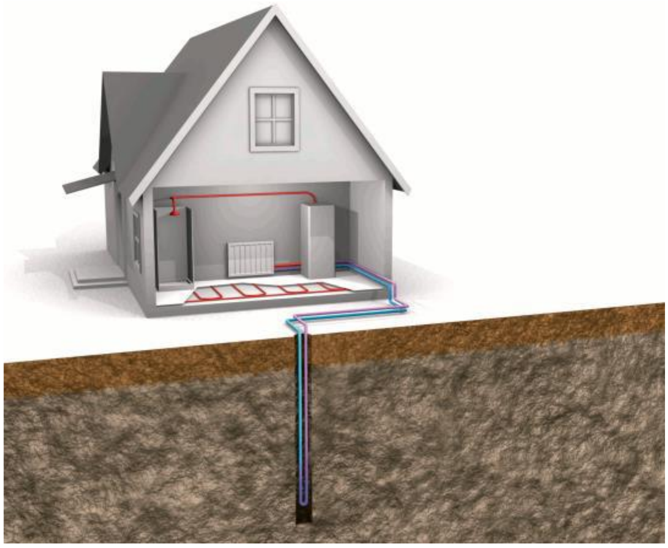


FIGURE 30: GEOTHERMAL HP WITH VERTICAL INSTALLATION (SOURCE: WWW.THERMIA.FI/VARMEPUMP/THERMIA_HUS_BERGVARME_CMYK.GIF)

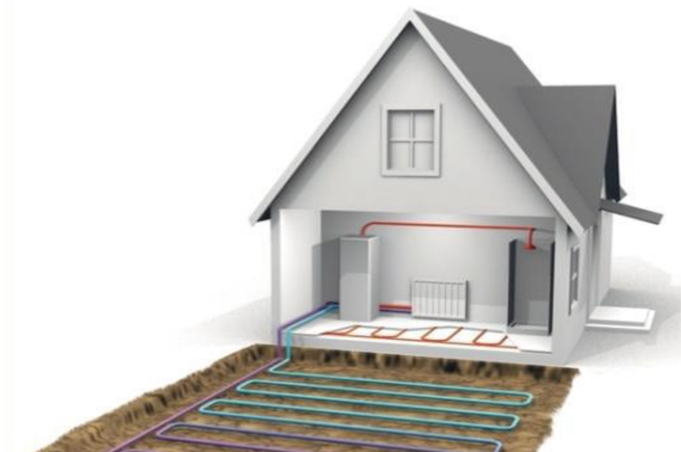


FIGURE 31: GEOTHERMAL HP WITH HORIZONTAL INSTALLATION (SOURCE: THERMIA HEAT PUMPS)

TABLE 16: STRENGTHS AND WEAKNESSES ANALYSIS FOR GROUND SOURCE HEAT PUMPS

Strengths	Weaknesses
○ Very good COP ○ Low space requirements ○ Stabile ground temperature throughout the year (efficient heating even in coldest winter) ○ Ground heat exchanger life time is 50+ years ○ Can be used in heating and in cooling mode ○ Heat pump can be categorized as renewable technology if electricity from renewable sources is used	○ Use high-grade operation power with high primary energy factor ○ Expensive installation of ground heat exchanger ○ In some countries permit may be required for installation of ground heat exch. ○ Horizontal gr. heat exch. has effect on flora growth above it ○ Possible soil freezing, which can reduce COP and heave structures near GHP (good design & control can prevent this) ○ Existing building envelope and heating distribution system should be retrofitted (to ensure high performance) ○ High global warming potential of most common refrigerants ○ COP can be decreased if more GHPs are installed nearby

5.5.3. Groundwater heat pumps

Groundwater heat pump (HP) is a heat pump, which uses groundwater as a heat source (for heating) or as a heat sink (for cooling). Water is usually pumped from one well and brought to HPs heat exchanger where heat is extracted from/inserted into water, which is returned to second well. Second (return) well needs to be located far enough downstream from extraction well. Groundwater heat pump is able to provide high COP throughout the year, depending on the temperatures of groundwater source used. Usually the water is pumped to the heat pump (open loop), but depending on the water quality this can be problematic (corrosion, impurity, etc.), in those cases closed pond loop can be used. From administrative point of view, open loop groundwater HP should have special permits and even somewhere the amount of water pumped is charged [37; 38; 39].

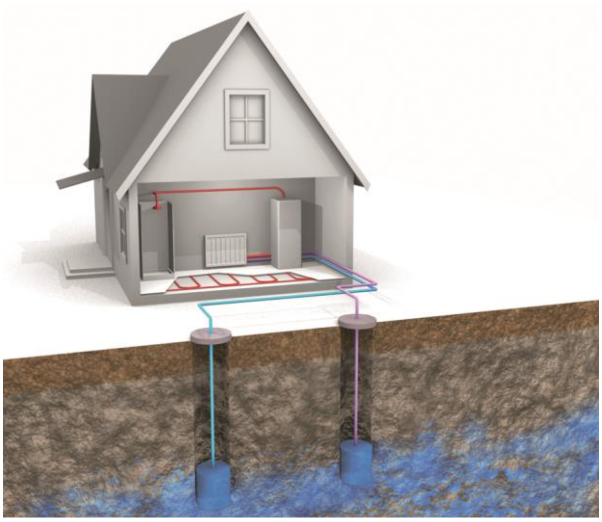


FIGURE 32: GROUNDWATER HEAT PUMP EXAMPLE (SOURCE: WWW.THERMIA.COM/HEATPUMP/WATER-SOURCE-HEAT-PUMPS-VERTICAL_ID3741.JPG)

TABLE 17: STRENGTHS AND WEAKNESSES ANALYSIS FOR GROUNDWATER SOURCE HEAT PUMPS

Strengths	Weaknesses
○ Very good COP (water has good heat transfer properties and water temperature is stabile) ○ Stabile groundwater temperatures throughout the year give good performance even in coldest winters ○ Can be more economic than ground source HPs, especially for large systems ○ Can be used in heating and in cooling mode ○ Heat pump can be categorized as renewable technology if electricity from renewable sources is used	○ Use high-grade operation power with high primary energy factor ○ Location needs to have available groundwater nearby ○ Recommended to install intermediate heat exchanger (to avoid freezing and corrosion of HP), which will decrease efficiency ○ In some countries permit may be required for installation of groundwater heat exch. ○ Possible fouling of a system, because of limescale, or biofouling with bacterial growth (water filtration) ○ Existing building envelope and heating distribution system should be retrofitted (to ensure high performance) ○ High global warming potential of most common refrigerants ○ COP can be decreased if more GHPs are installed nearby

5.5.4. WASTE HEAT PUMP

Waste heat (exhaust air) heat pump recovers the waste heat in the exhaust air. Temperature of the waste heat is increased in heat pump so that the recovered heat can be used for heating air and water in the building. To install this heat pump in the building there needs to be enough potential from waste heat in the building exhaust system. This is most effective in zero energy and passive buildings, where usually internal space volume is large in relation to the heating power requirement. This type of HP has nearly consistent power output, as room temperature doesn't vary much throughout the year (this also depends what is on the other side of HP, true in case of heating DHW) [40; 41].

TABLE 18: STRENGTHS AND WEAKNESSES ANALYSIS FOR HEAT PUMPS TYPES

Strengths	Weaknesses
○ Can be combined with different heat sources ○ Easy retroactive installation within retrofit, depending on the type of heat pump (waste heat, air heat pump) ○ High COP ○ Wide capacity range ○ Lo Can be combined with other renewable energy sources (for instance PV for energy generation for compressor) ○ Financial incentives, depending on the country w amortisation time ○	○ High investment costs ○ Maintenance costs ○ Electricity as operation energy needed (eventually high primary energy factor, depending on the generation) ○ Boundary conditions need to be suitable (temperature level of waste heat, air temperature, soil conditions, etc.) ○ Restrictions on the permission of geothermal use needs to be requested

5.6. Solar thermal collector

For the conversion of solar radiation into heat solar thermal collectors can be used. Therefore, the radiation is collected via an absorber and transferred to a fluid. For the heat transport to the consumer or the storage system, usually water or water-glycol is used. The collector fluid reaches temperatures between 40-110°C, according to the used collector type. This low temperature level is for the use in the building service, where mainly two collector types are used.

Further the generated heat from the collectors can be used for processes that drive other building service systems. One example is solar cooling, which is especially in hot regions with a high cooling demand and solar irradiation efficient.

The collectors can be installed on flat and sloped roofs as well as on facades. Especially for larger systems multiple collectors can be connected in one field, which also has efficient and aesthetical issues. In the following two collector types for retrofit interventions on building and neighbourhood scale are described in more detail.

5.6.1. Flat plate collector

Flat plate collectors reach temperatures between 40-80°C. The most common use is for domestic hot water (DHW) or radiant floor heating. There are also advanced types of this collector with an additional foil between the glass envelope and the absorber or double glazing to reduce the heat losses and to generate higher temperature levels, up to 100- 120°C.

The construction of a flat plate collector is general like the following:

The housing of the collector is made of a frame, normally made of aluminium. Bedded in this frame construction is the absorber. The absorber is a thin metallic (copper) stripe construction that is connected with a piping for the fluid. The piping can be installed in meander-type or harp-type. For the improvement of the absorption effect they are covered with black paint or selective coating. To reduce the heat losses, thermal insulation encases the absorber. A translucent cover (usually glass) protects this construction against weather conditions and also reduces the heat losses. The losses are from transferred heat via conduction and emitted long-wave radiation from the absorber to the glass and hence on the outside of the glass. To minimise these losses by convection an additional layer of glass or foil, which reduces the emission of the long-wave radiation, but has a high absorption rate for the short-wave radiation. This foil can be inserted between the glazing and the absorber [42].

Typical optical efficiency values for flat plate collectors are between 0.65- 0.85, while the thermal losses are between 3-7 W/(m²·K) [42].

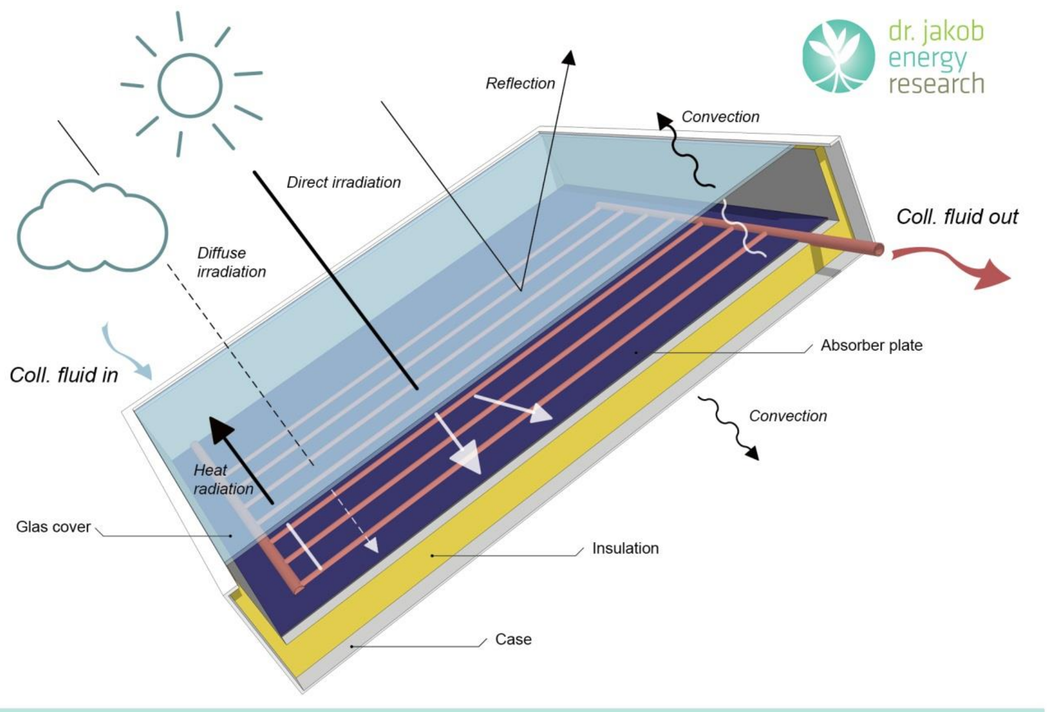


FIGURE 33: SECTION OF A FLAT PLATE COLLECTOR (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

5.6.2. EVACUATED TUBE COLLECTORS

Another collector type is the evacuated tube collector. The temperature range of this thermal collector is between 50-110°C. In comparison with flat plate collectors evacuated tube collectors have a higher efficiency in transitions periods and therefore better to supply the heat demand long-lasting during a year. The difference between flat plate and evacuated tube collectors is basically the construction. Evacuated tube collectors have single glass tubes with vacuum inside to reduce the heat losses by convection to a minimum where no further insulation is need. To reduce the radiation losses, there is a low emission coating that absorbs the short-wave radiation and releases less long-wave radiation.

The absorbed radiation hit a metal sheet absorber. Each glass tube is connected with a pipe, the collection tube, where the fluid is circulating. The heat exchange between the absorbers and the fluid occurs by direct contact among absorber sheet and fluid.

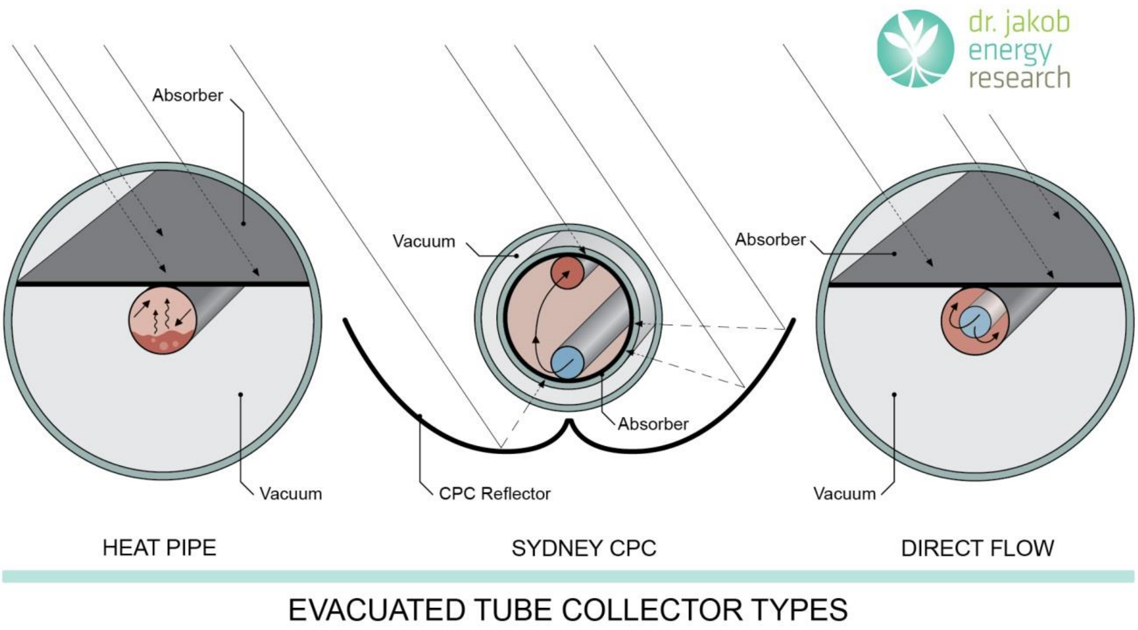


FIGURE 34: EVACUATED TUBE COLLECTOR TYPES (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

Evacuated tube collectors can be categorised in three main construction types (Figure 34).

- **Heat pipe:** The heat pipe technology describes a heat pipe within an evacuated glass tube in which the heat transfer fluid circulates as liquid and vapour, respectively. The solar radiation is collected by an absorber on top of the pipe. The heat of the evaporated liquid is transferred at the heat pipe to a separate fluid cycle that transfers the heat to the thermal storage.

- **Sydney CPC**: The Sydney CPC technology describes a piping loop within an evacuated glass tube. On the inside of the tube a special absorption coating is plotted. On the outside of the tube an additional compound parabolic concentrator is installed to increase the efficiency of the collector. The liquid circulates in direct flow through the pipes before it gets collected in the main liquid circuits (inlet and outlet flow).

- **Direct flow:** In the direct flow collector the heat transfer fluid flows in a coaxial pipe. In the inner pipe the cold liquid flows to the bottom of the pipe and absorbs the heat on the way back to the top of the collector.

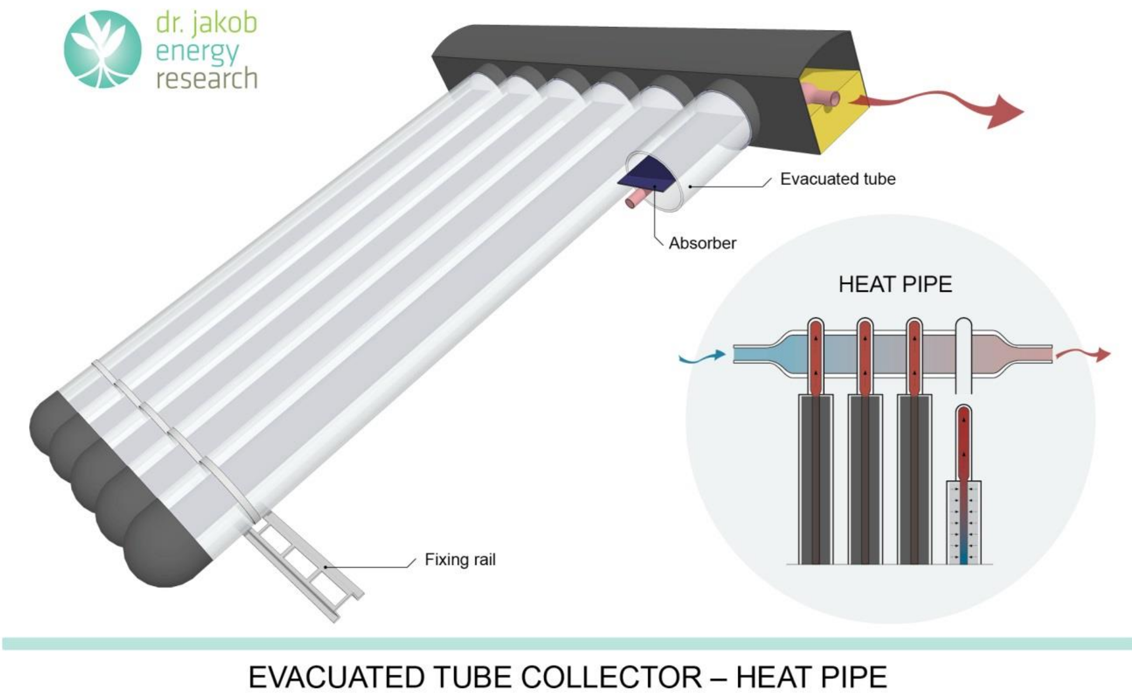


FIGURE 35: WORKING PRINCIPLE OF EVACUATED TUBE COLLECTOR WITH HEAT PIPES (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

The collectors are the main part of a solar heating system. The heated up fluid (water or water-glycol) can be either directly used or feed into a storage. If water-glycol is used the heat has to be transferred indirectly via a heat exchanger with the fluid in the storage (water). This system is called closed circuit with two separated fluids that need pumps for each circuit. Very important to consider is that if storage is included, this one is well designed (Chapter 5.10). Due the variability of solar irradiation conditioned by season and the project location a back-up system is necessary. Therefore, solar thermal collectors can be included easily in existing heating systems and decrease the energy demand of the existing heating system.

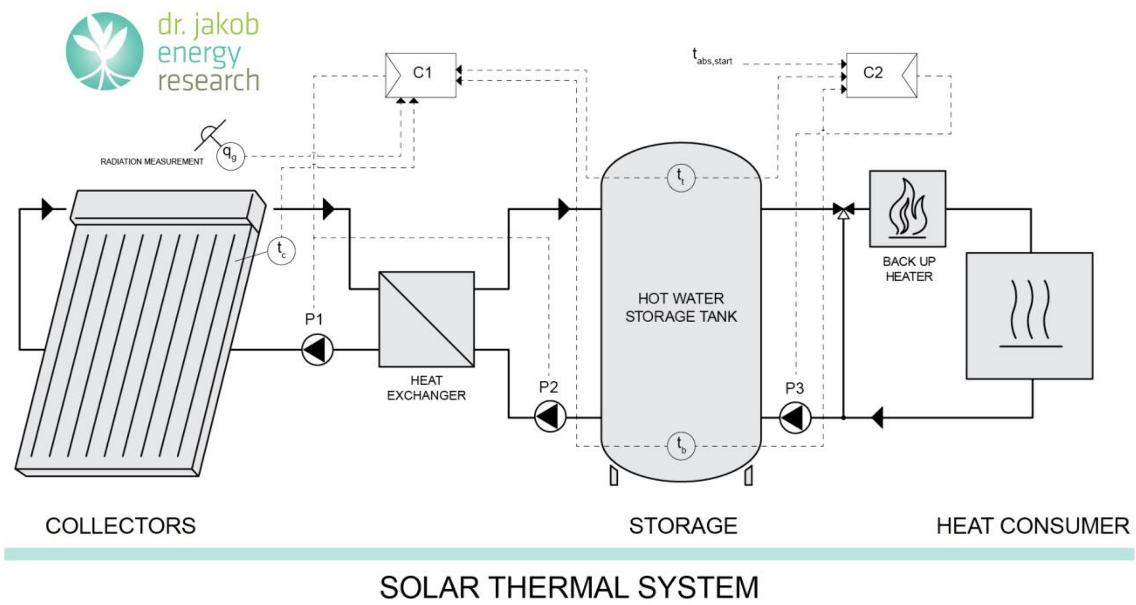


FIGURE 36: SCHEME OF A TYPICAL SOLAR COLLECTOR SYSTEM FOR BUILDING APPLICATION (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

TABLE 19: OVERVIEW ON SOLAR THERMAL COLLECTOR TYPES

Collector type	Absorber type	Temperature range [°C]	Usage	Cost range per m² [EUR]
Flat plate collector (FPC)	Flat plate	20-80	○ Domestic hot water (DHW) ○ Space heating (SH)	180- 240
Evacuated tube collector (ETC)	Flat plate or tubular	50- 110	○ Domestic hot water (DHW) ○ Space heating (SH) ○ Process heat (low temperature) (PH)	350- 600

TABLE 20: STRENGTHS AND WEAKNESSES ANALYSIS FOR SOLAR THERMAL COLLECTOR TYPES

Strengths	Weaknesses
○ Retrofit intervention to fulfil share of renewables ○ Residential and commercial applications in isolated regions ○ Financial incentives	○ Low efficiency in winter ○ Mostly heat exchanger needed ○ Degradation of performance with time. ○ Normally storage required ○ Normally need for back-up system by whole year use ○ Rapid drop in prices of competing technologies. ○ Competing technologies

	○ Already installed conventional systems in existing buildings (non-worthy replacement) ○ Bad installation practices that damage reputation.

5.7. Heat distribution systems

Heat is distributed through your home in a variety of ways: for instance, forced-air systems use ducts that can also be used for central air conditioning and heat pump systems, while radiant heating systems also have unique heat distribution systems.

5.7.1. Hot water radiators

Hot-water radiators are one of the most popular heat distribution systems. They are typically a baseboard-type radiator or an upright design that resembles steam radiators. The most common problem in hot-water systems is unwanted air in the system. At the start of each heating season, while the system is running, go from radiator to radiator and open each bleed valve slightly, then close it when water starts to escape through the valve. For multi-level homes, start at the top floor and work your way down.

U.S. Department of Energy asserts [43] that one way to save energy in hot-water systems is to retrofit them to provide separate zone control for different areas of large homes. Zone control is most effective when large areas of the home are not used often or are used on a different schedule than other parts of the home. A heating professional can install automatic valves on the hot-water radiators, controlled by thermostats in each zone of the house. Using programmable thermostats will allow you to automatically heat and cool off portions of your home to match your usage patterns.

Zone control works best in homes designed to operate in different heating zones, with each zone insulated from the others. In homes not designed for zone control, leaving one section at a lower temperature could cause comfort problems in adjacent rooms because they will lose heat to the cooler parts of the home. Zone control will also work best when the cooler sections of the home can be isolated from the others by closing doors. In some cases, new doors may be needed to isolate one area from another. Cooler parts of the home should be kept around 10°C to prevent water pipes from freezing. Never shut off heat entirely in an unused part of your home.

5.7.2. Fan convectors

Convectors are heat exchangers for room heating exploiting the mechanical hot air flow moving by using fans. The convector is connected to a central heating system, such as boiler, district heating or heat pump, and to electric supply needed for running the fans. Hot water from the central heating passes through a heat exchanger within the convector. The cool room air is drawn into the exchanger by the fans, and heat is passed to it within the exchanger. So, hot air is then extracted from the convector and pushed into the room.

Usually it's made up of several elements: galvanised sheet metal formwork, a heat exchange coil designed to maximise the natural convection effect, a closure panel and a head with fixed metal grille. The cover cabinet can easily be removed to thoroughly clean the internal parts. Installation is facilitated by reversible hydraulic connections, so the coil can be turned around during the installation phase.

5.7.3. UNDERFLOOR HEATING

Underfloor heating is far from a new concept, it was first used by the Romans whose dwellings were constructed with voids through which air, warmed by an open fire, would pass, thus heating the structure. Underfloor heating uses electrical resistance elements (old concept) or hot water pipes installed under the room floor. The heating elements can be cast in a concrete floor slab, or placed under the floor covering, or attached to a wood sub floor. The heating elements work as heat exchangers, releasing heat into the overlying room by radiation, conduction and convection mechanisms.

Utilising today's modern multilayer pipes, control systems and high efficiency boilers, the underfloor heating systems of today are extremely comfortable and controllable. Radiators are no longer needed so giving more room space. The heat is more evenly distributed and dust is not circulated.

Underfloor heating from the whole floor area of the house gently warms the air above, eliminating cold spots. The warm air convects from the floor surface losing approximately 2 degrees centigrade at 2.0 meters above the floor, which makes the system ideal for all ceiling heights.

Common installation configuration for assuring acceptable indoor climate is one in which the floor temperature ranges between 19-29°C and the air temperature at head level ranges between 20 and 24°C. With radiator or convector heating systems a vertical temperature gradient is produced; colder at foot level than at the head.

Underfloor heating has made it possible to reduce energy consumption by using low water temperatures. These systems, based on the development of complex and very high quality plastic pipe, such as the multilayer pipe, now account for over 60% of some European heating markets.

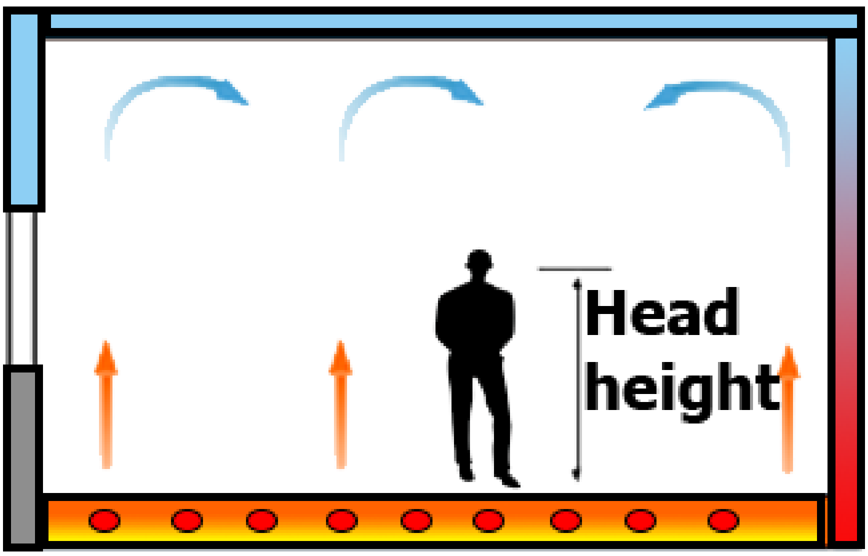


FIGURE 37: UNDERFLOOR HEATING (CREDIT BY © STAM S.R.L.)

5.7.4. Radiant heating

It is called radiant heating the effect that can be felt when you sense the warmth of a hot stovetop element from across the room. The systems depend mostly on radiant heat transfer, which is the delivery of heat from a hot surface to the objects in the room via infrared radiation.

The heating of radiant heating systems supply comes straight from panels installed in the wall or ceiling of a building; if the source of radiant heating is located in the floor, it is often called radiant floor heating or simply floor heating.

Radiant floor heating depends on convection, that is the natural circulation of heat within a room as air warmed by the floor rises. Radiant floor heating systems are significantly different from the radiant panels used in walls and ceilings.

- Radiant floor heat can be divided in the main categories:
- hot water radiant floors;
- radiant air floors (the medium for carrying the heat is air);
- electric radiant floors.

For a deeper understanding a further categorization of these types of systems can be made according with how they are installed:

- wet installations: make use of the large thermal mass of a concrete slab floor or lightweight concrete over a wooden subfloor;
- dry installations: it implies that the radiant floor tubing is put between two layers of plywood or attaches the tubing under the finished floor or subfloor.

Wall and ceiling-mounted radiant panels are usually made of aluminium and can be heated with either electricity or with tubing that carries hot water, although the latter creates concerns about leakage in wall or ceiling-mounted systems. Most common available radiant panels for houses are electrically heated.

Advantages of radiant heating are:

- A higher level of efficiency than baseboard heating and forced-air heating, because it eliminates duct losses;
- It doesn't distribute allergens like forced air systems, so it is suitable for people with allergies and respiratory diseases;
- Hydronic (hot water/liquid-based) radiant floors systems use little electricity and this is a huge plus for houses off the power grid or in areas where the electricity's expensive;

The huge variety of different energy sources that can be used to heat the liquid, (standard gas, oil-fired boilers, wood-fired boilers, solar water heaters, or a combination of these sources) in hydronic systems.

Like any type of electric heat, radiant panels can be expensive to operate, but they can provide supplemental heating in some rooms or can provide heat to a home addition when extending the conventional heating system is impractical.

Radiant panels have the quickest response time of any heating technology and -- because the panels can be individually controlled for each room—the quick response feature can result in cost and energy savings compared with other systems when rooms are infrequently occupied. When entering a room, the occupant can increase the temperature setting and be comfortable within minutes. As with any heating system, set the thermostat to a minimum temperature that will prevent pipes from freezing.

Radiant heating panels operate on a line-of-sight basis -- you'll be most comfortable if you're close to the panel. Some people find ceiling-mounted systems uncomfortable because the panels heat the top of their heads and shoulders more effectively than the rest of their bodies.

5.7.5. AIR CENTRAL HEATING

A common way to heat internal spaces, especially in North America, is to use a central furnace to provide heat. A furnace works by blowing heated air through ducts that deliver the warm air to rooms throughout the house via air registers or grills. This type of heating system is called a ducted warm-air or forced warm-air distribution system. It can be powered by electricity, natural gas, or fuel oil.

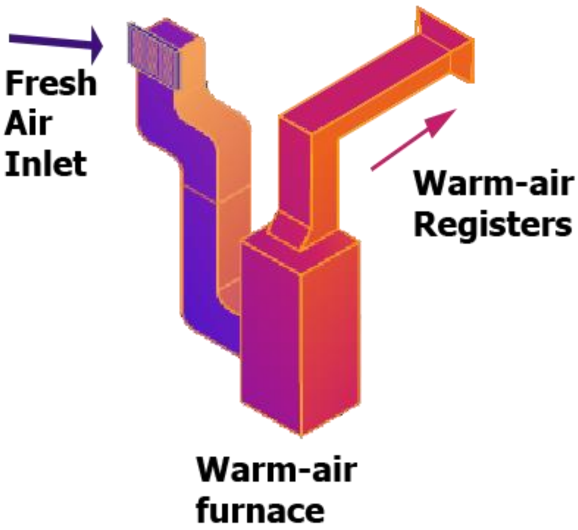


FIGURE 38: AIR CENTRAL HEATING WITH FURNACE, BASIC SCHEMA (CREDIT BY: © STAM S.R.L.)

Inside a gas- or oil-fired furnace, the fuel is mixed with air and burned. The flames heat a metal heat exchanger where the heat is transferred to air. Air is pushed through the heat exchanger by the "air handler's" furnace fan and then forced through the ductwork downstream of the heat exchanger. At the furnace, combustion products are vented out of the building through a flue pipe. Older "atmospheric" furnaces vented directly to the atmosphere, and wasted about 30% of the fuel energy just to keep the exhaust hot enough to safely rise through the chimney. Current minimum-efficiency furnaces reduce this waste substantially by using an "inducer" fan to pull the exhaust gases through the heat exchanger and induce draft in the chimney. "Condensing" furnaces are designed to reclaim much of this escaping heat by cooling exhaust gases well below 60°C, where water vapour in the exhaust condenses into water. This is the primary feature of a high-efficiency furnace (or boiler). These typically vent through a sidewall with a plastic pipe.

TABLE 21: STRENGTHS AND WEAKNESSES ANALYSIS FOR FORCED AIR CENTRAL HEATING SYSTEM

Strengths	Weaknesses
○ Can be used also for cooling with minor adaptation. ○ Can be coupled with many different heat source systems (furnace, heat pump, active solar heating, etc.)	○ Distributes allergens throughout the house. ○ Comfort and energy efficiency management in all the served rooms could not be guaranteed because of the centralised control.

5.8. Cold generation

Cold generation can be differing into mechanical and thermal cooling processes. Beside cold gas machines the most used systems are cold vapour machines. For this system the most common cold generation are the so called compression chillers. Another cold generation type are thermal driven sorption chillers, like AB- and ADsorption chillers. Those can use manifold heat sources as long the temperatures above 50°C and, depending on the stratification of the absorption chiller, up to 250°C. The stratifications of absorption chillers are single-effect, double-effect and triple-effect, which uses ones, twice or three times the heat to generate cold.

The generated cold for residential or office cooling devices is mostly distributed within the buildings by the heat transfer medium water. Several distribution systems are possible, depending on the user demand and the comfort requirements. Technologies like different air conditioning systems, active ceilings or fan coils are described more detailed in Chapter 5.11. Further technologies that can be used in combination with electrical and thermal driven chillers are different storages, which are explained in Chapter 5.10. Technologies that can only be joined with a specific chiller type is explained in each chapter of the respectively chiller type.

5.8.1. Vapour compression chiller

Compression chillers are electrically driven and, among others, cheap because of mass production. The main components of a compression chiller are the evaporator and condenser, where the refrigerant is evaporated by heat absorption at low pressure and then condensed again at higher pressure. Water is used to be chilled, that circulate in the cold supply systems of a building. For the condensation of the refrigerant a heat rejection system is necessary. This unit is usually placed on roof tops or on the building outside walls. A disadvantage of those chillers is the high global warming potential (GWP) of the refrigerants compared to thermally driven chillers (Figure 39).

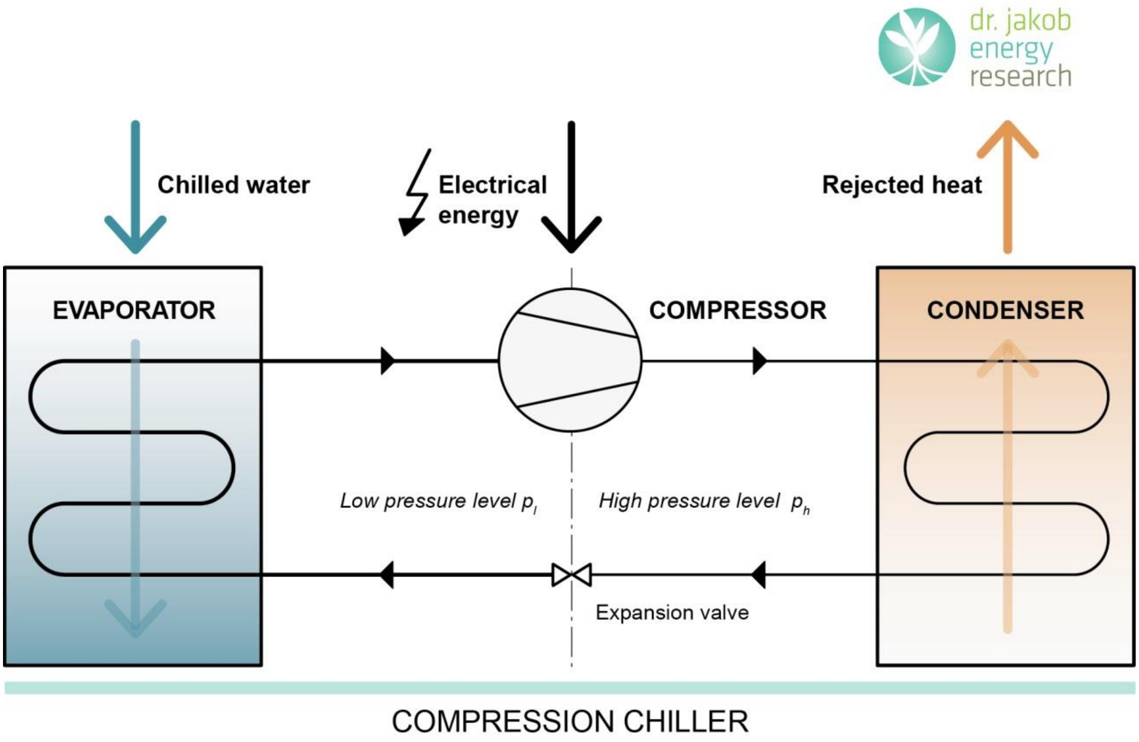


FIGURE 39: FUNCTIONAL SCHEME OF A VAPOUR COMPRESSION CHILLER (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

The efficiency of chillers, the coefficient of performance (COP), depends among others on the location of the chiller. The values for the COP are in between about 2.5 and about 6.0, while a higher value is better. The cold demand after the implementation of other energy efficiency measures needs to be calculated. By means of these results (cooling demand and capacity) the dimensions of the compression chiller has to be design properly before the substitution. The energy consumption in periods with high cooling demand can lead to peak loads in the grid.

The implementation of a compression chiller is economic above a cooling demand of 50 kW by a seasonal cooling demand of about 60 d/year (1.500 h/year) or constant cooling demands from technical devices (e.g. medical institution, server room, high comfort requirements, etc.). Compression chillers are comparatively cheap with costs between 75- 125 EUR/kW [44] (large scale), depending on the cooling capacity (small scale about 250-500 EUR/kW). These low invest cost lead to short amortisation durations up to 3 years. If a compression chiller is added later within the retrofit, the existing peripheral devices need to be adjusted. In case of an existing BMS further metering points should be installed and added on the BMS.

With an expected lifetime of 8-10 years' compression chillers need to maintain biannual by a qualified technician. The costs for the maintenance are about 1,000 EUR/year. Compression chillers have to be installed in closed rooms to prevent the system from environmental influences, wherefore there is no issue with the compatibility with historical buildings or any aesthetical issues. Small devices (10-50 kW), for instance VRF systems (variable refrigerant flow) can also be installed at the outside. Eventually the heat rejection unit at the outside can cause problems.

Possible combinations with other technologies are the implementation of cold water storage (short- or long-term) (Chapter 5.10) to buffer peak loads. The cold distribution provides a great band of technologies like ventilation systems, air conditioning, fan coils or chilled ceilings. The combination with photovoltaic modules (Chapter 5.12) can prevent peak loads from electricity demand from grid during summer (PV Cooling).

TABLE 20: STRENGTHS AND WEAKNESSES ANALYSIS FOR ELECTRICAL COOLING

Strengths	Weaknesses
○ Very good COP ○ Low space requirements ○ Moderate invest cost ○ Moderate energy consumption ○ Combination with photovoltaic modules can decrease the energy demand from grid ○	○ Use high-grade operation power with high primary energy factor ○ Frequently maintenance necessary ○ Very loud, noise insulation necessary ○ Installation location inside ○ High global warming potential of the used refrigerants

5.8.2. ABSORPTION CHILLER

Absorption chillers are one kind of thermally driven sorption chillers, beside adsorption chillers and desiccant cooling systems. Absorption chillers use thermal energy as source for cold generation by evaporating refrigerant and a solution mixture in a continuous cycle process. The refrigerant, mostly water or ammonia is absorbed and desorbed from the solution mixture, mostly water/LiBr solution or ammonia/water solution, respectively. The cold generation arises due the simultaneous evaporation inside the evaporator and the absorption of the refrigerant in the solution mixture inside the absorber. Heat is required to desorb the refrigerant from the solution mixture again. The cold is provided as chilled water (Figure 40) [45]. Due the fact that absorption chillers use heat as driving power, the sources are manifold and often cheaper than electricity. Besides gas boilers also solar thermal collectors, waste heat from CHPs and industrial processes can be used. The operating temperature levels depending on the type of the absorption chiller. The temperatures to evaporate the sorbent are between 60-250°C depending on the used absorption system. Important for this technology is the number of cooling days in the building, referring to the weather analysis, and the required user comfort. Especially in warm regions with a high number of cooling days and a high solar irradiation a combination with solar thermal collectors can be sinful.

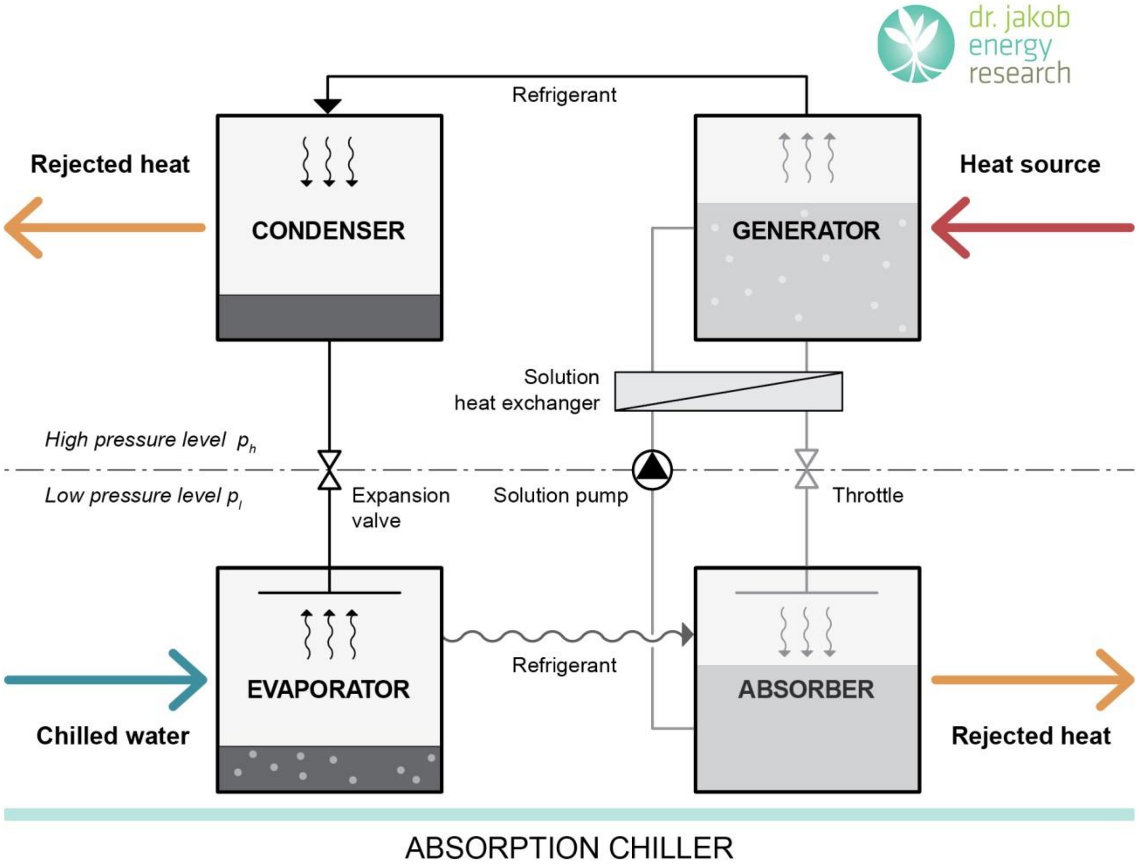


FIGURE 40: FUNCTIONAL SCHEME OF AN ABSORPTION CHILLER (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

There are three different kinds of absorption systems available: single-effect (COP 0.7), double-effect (COP 1.4) and triple-effect (COP 1.8), which divides in their efficiency. The advantage of the used natural refrigerants water and ammonia is that they have no GWP in comprehension to refrigerants of compression chillers. The range of the possible cooling capacities of absorption chillers is between 2.5 kW and 20 MW.

For the retrofit absorption chillers can be used for buildings with seasonal or constant cooling demand. The costs per kW cooling capacity for an absorption chiller is in between 1,000-1,500 EUR/kW (large scale), depending on the size of the chiller. On top of the invest costs, the yearly maintenance costs with about 500-1,000 EUR/year need to considered. The maintenance should be done by a qualified technician. The return of investment is about 5-10 years, while the chiller itself has an expected lifetime of about 15-20 years. If an absorption chiller is added later within the retrofit, the existing peripheral devices need to be adjusted. In case of an existing BMS further metering points should be installed and added on the BMS. Similar to the compression chillers, the absorption chillers are located in the plant room (or outside), which is why there is no conflicts with the compatibility with historical buildings or any aesthetical issues. Eventually the heat rejection unit at the outside can cause problems.

Referring to the other retrofit technologies within in this report, several come to consideration. The waste heat from a CHP unit can be used, then the system is called CHPC (Combined heat and power and cold generation). A more detailed description is in Chapter 5.8.5. Hot water from solar thermal collectors

(Chapter 5.4) can also be used as heat source, the so called solar cooling (Chapter 5.7). Depending on the stage type of the absorption chiller, the collector type needs to be selected with the respectively hot water output temperature. The implementation of a cold water storage (short- or long-term) (Chapter 5.10) to buffer peak loads is also possible.

5.8.3. Adsorption chiller

Adsorption chillers use, as well as absorption chillers, thermal energy as source for cold generation by the adsorption of water vapour. The cold generation process in an adsorption chiller is a quasi-continuous process. In contrast to absorption process, the sorbent is solid instead of liquid. Materials like zeolith or silica-gel are very common. These materials are unharmful to the environment and health. The liquid refrigerant is water. It is adsorbed on the solid surface (adsorber chamber) and provides cold through evaporation inside the evaporator. Once the solid is saturated with refrigerant, the process is reversed and the refrigerant is desorbed from the solid. The adsorption process is not continuous but alternates between adsorption and desorption. The generated cold is provided as chilled water [45]. The facts that adsorption chillers use heat as driving power, the sources are manifold and often cheaper than electricity. Besides gas boilers also solar thermal collectors, waste heat from CHPs and industrial processes can be used. These technologies can be considered within a retrofit and planned as a coherent energy concept. The operating temperature levels depending on the type of the adsorption chiller. The temperatures to evaporate the sorbent are between 50-95°C. The average COP is between 0.5-0.65. The range of the possible cooling capacity of adsorption chillers are between 5 kW and 430 kW.

For the retrofit adsorption chillers can be used for buildings with seasonal or constant cooling demand. The costs per kW cooling capacity for an absorption chiller is in between 250-350 EUR/kW (large scale) and 1,000 EUR/kW (small scale). On top of the invest costs, the yearly maintenance costs with about 500-1,000 EUR/year need to considered. The maintenance should be done by a qualified technician. The return of investment is about 5-10 years, while the chiller itself has an expected lifetime of about 15-20 years. If an adsorption chiller is added later within the retrofit, the existing peripheral devices need to adjust. In case of an existing BMS further metering points should be installed and added on the BMS. Similar to the compression chillers, the adsorption chillers are located in the plant room (or outside the building), which is why there is no conflicts with the compatibility with historical buildings or any aesthetical issues. Eventually the heat rejection unit at the outside can cause problems.

Referring to the other retrofit technologies within in this report, several come to consideration. The waste heat from a CHP unit can be used, then the system is called CHPC (Combined heat and power and cold generation). A more detailed description is in Chapter 5.8.5. Hot water from solar thermal collectors (Chapter 5.4) can also be used as heat source, the so called solar cooling (Chapter 5.7). Depending on the stage type of the adsorption chiller, the collector type needs to be selected with the respectively hot water output temperature. The implementation of a cold water storage (short- or long-term) (Chapter 5.10) to buffer peak loads is also possible.

TABLE 21: STRENGTHS AND WEAKNESSES ANALYSIS FOR AB- AND ADSORPTION CHILLER

Strengths	Weaknesses
○ Possibility of use the heat from RES ○ Wide range of cooling capacity ○ Eco-friendly operation fluids ○ Low electricity demand ○ Use of cheap (waste) heat possible ○ Use of several renewable heat sources (CHP, solar thermal collectors, (industrial process) waste heat in suitable heat range	○ High investment cost ○ When solar heat is the primary heat source an auxiliary heat system is required ○ Large space requirement ○ High payback period

5.8.4. HYBRID CHILLER

The hybrid chiller is a quite new invention. It combines the advantages of adsorption and compression chillers. The result is an eco-friendly and very efficient chiller. Beside the cost reduction for power the chiller is as 5.5 times more efficient that cooling only with compression. A possible combination with the chiller is a CHP engine for the use of waste heat for operating temperatures between 50 and 95°C. Another heat source could be solar thermal and photovoltaic collectors. With these energy sources, the amortisation time can be decreased. The savings of power of the hybrid chiller are up to 80% in comparison with the power consumption of compression chillers. Fluctuating ambient or load temperatures can fast and easy adjusted by the compression chiller cycle (Figure 42). The cooperation of the adsorption and compression process can moreover balance load peaks or operate just in one chiller mode, depending on the cooling load and the amount of waste heat.

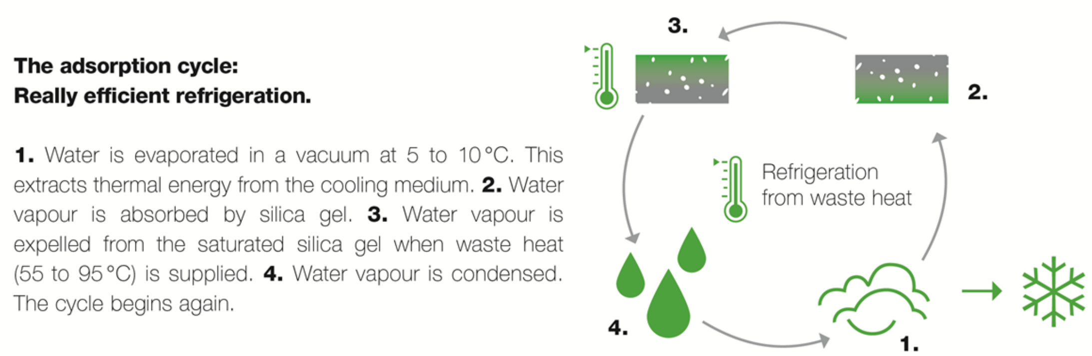


FIGURE 41: FUNCTIONAL SCHEME OF THE ADSORPTION CYCLE IN THE HYBRID CHILLER (SOURCE: GLEN DIMPLEX DEUTSCHLAND GMBH/RIEDEL KÄLTETECHNIK)

As operation material for the absorption process (Figure 41), silica gel is used. The output cold water temperature levels are between 8 and 20°C. The maximum cooling capacity is currently 32 kW. The expected lifetime of the chiller is about 15 years. The maintenance cycle is the same as for compression chillers (biannual). The chiller is also compatible with historical buildings and there are no aesthetical issues to consider.

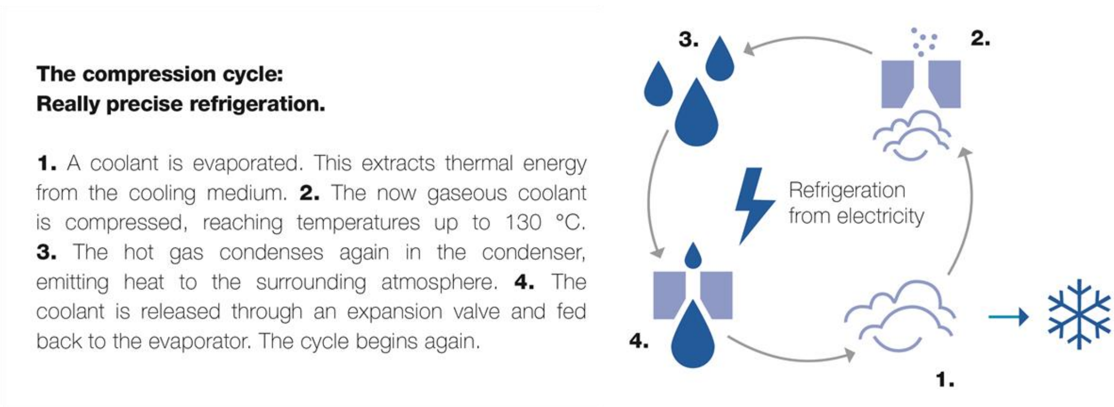


FIGURE 42: FUNCTIONAL SCHEME OF THE COMPRESSION CYCLE IN THE HYBRID CHILLER (SOURCE: GLEN DIMPLEX DEUTSCHLAND GMBH/RIEDEL KÄLTETECHNIK)

TABLE 22: STRENGTHS AND WEAKNESSES ANALYSIS FOR HYBRID CHILLER

Strengths	Weaknesses
○ High efficiency ○ Perfect operation balance between both systems ○ Less space demand ○ Eco-friendly operation material ○ Use of cheap waste heat ○ Use of renewable energy systems (solar thermal or CHP for adsorption chiller and PV for compression chiller)	○ Limited cooling capacity due new invention ○ Separate refrigerant for the compression chiller with high GWP ○ New invention and not many references so far

TABLE 23: OVERVIEW ABOUT CHILLER TYPES

Chiller type	Operation energy	Refrigerant	Sorbent	Chilled water temperature	COP	Cost range per kW [EUR]
Compression	Electricity	R134a R404A R407C R410A R507 NH_3	None	6-20 °C	2.0- 7.0	75- 125
ABsorption Single-effect Double-effect Single-effect	 Heat (60-100°C) Heat (130-160°C) Heat (75-150°C)	 H_2O H_2O NH_3	 LiBr LiBr H_2O	 6-20 °C 6-20 °C -30- +20 °C	 0.6- 0.7 1.1- 1.4 0.5- 0.7	 450- > 1,600 >500 500- > 1,500
ADsorption Single-effect Single-effect	 Heat (55-100°C) Heat (45-95°C)	 H_2O H_2O	 Silica gel Zeolithe	 6-20 °C 6-20 °C	 0.5- 0.6 0.5- 0.6	 400- >1,400

Hybrid	Electricity Heat (55- 95 °C)	R407C[4] R134a H_2O	Silica gel	8-20 °C	19,9[5]	ca. 900

5.8.5. Combined heat and power and cold generation (CHPC) / Tri-generation

Tri-generation or combined heat, power and cold generation (CHPC) describes the combination of a combined heat power system with an additional thermally driven sorption chiller. As chiller types mainly AB- and ADsorption chillers can be considered. In a tri-generation system the chillers are run with the waste heat of the CHP unit. The generated cold can be used for different cooling applications, which uses chilled water.

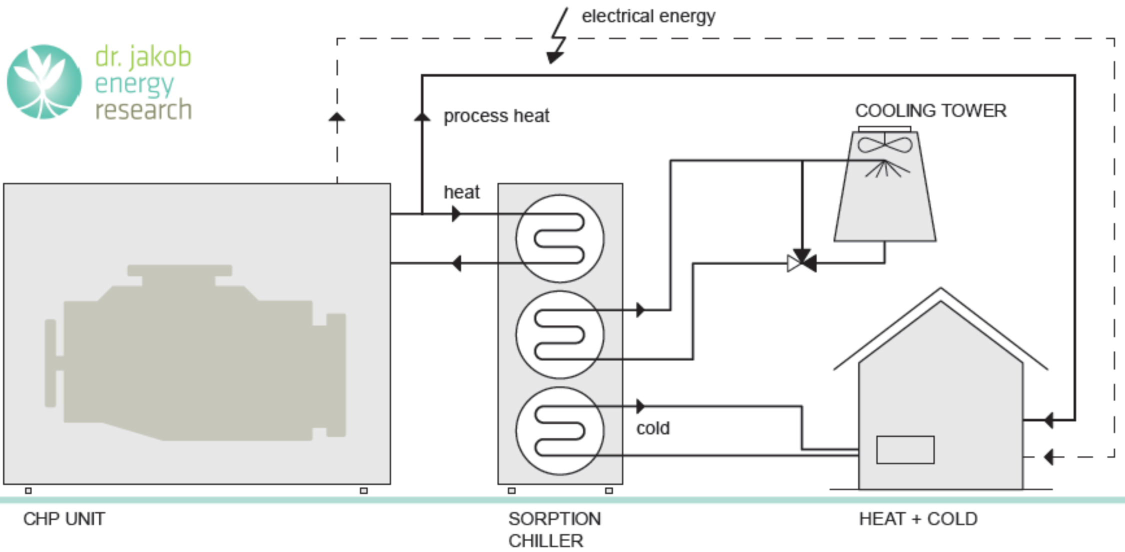


FIGURE 43: SYSTEM SCHEME OF A CHPC SYSTEM (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

CHPC systems can be used in buildings or neighbourhoods with a high and continual cooling demand. The integration of a CHPC system is easy and requires besides the space for the CHP unit only additional space for the sorption chiller and the heat rejection unit outside the building. Most CHP systems are controlled by the heat demand of the load, which has an economic background. In combination with a sorption chiller the heat demand is not only given in the heating period, but also while the cooling period, which means longer hours of operation of the CHP unit. The additionally generated power can be used for the operation of the chiller and auxiliary systems. The surplus can feed into the national grid.

[4] In this stage of the introduction on the market the chiller works with two refrigerants (R407C and R134a). Further versions of the chiller with other refrigerants are planned to introduce [46]:

[5] ESEER (hot water temperature 85°C & cold water temperature 20°C; [46])

TABLE 24: STRENGTHS AND WEAKNESSES ANALYSIS FOR CHPC

Strengths	Weaknesses
○ Compatibility with existing heating systems ○ Low emissions ○ Generation of power and heat simultaneously ○ High energy saving potential ○ Efficient use of fuel ○ Independent of energy market ○ For building sites or districts without infrastructure like in big cities ○ Feasible in regions / buildings with low solar irradiation but high cooling demand ○ Possibility of financial subsidies ○ Good for retrofit integration	○ Eventually need of planning permissions ○ High maintenance costs ○ High invest cost ○ Need of high operation hours (>5.000 h/year) for economy ○ Noise emissions

5.8.6. Solar cooling

Solar cooling describes the use of solar radiation for power or heat generation with solar thermal collectors or photovoltaic panels (PV Cooling). While electrically driven chillers are mainly vapour compressions chillers, the heat driven chillers can be described by three different systems: absorption und adsorption chillers and desiccant cooling systems. An advantage of solar cooling is the use of solar radiation instead of fossil fuels or expensive energy for cold generation. But the boundary conditions are very important: Referring to Chapter 2.2.3 a weather analysis, especially the geographic location and the intensity and duration of solar radiation is very important. Seasonal and daily variations of local climate determine the heating and cooling loads of a building [45]. For the retrofit this is especially important if, for instance, thermal insulation is added, the window area is in- or decreased or the glazing of the windows is changed. These retrofit measures have influence on the heat and cold demand and the time-base shift. Figure 44 shows the function scheme of a solar cooling system with an absorption chiller.

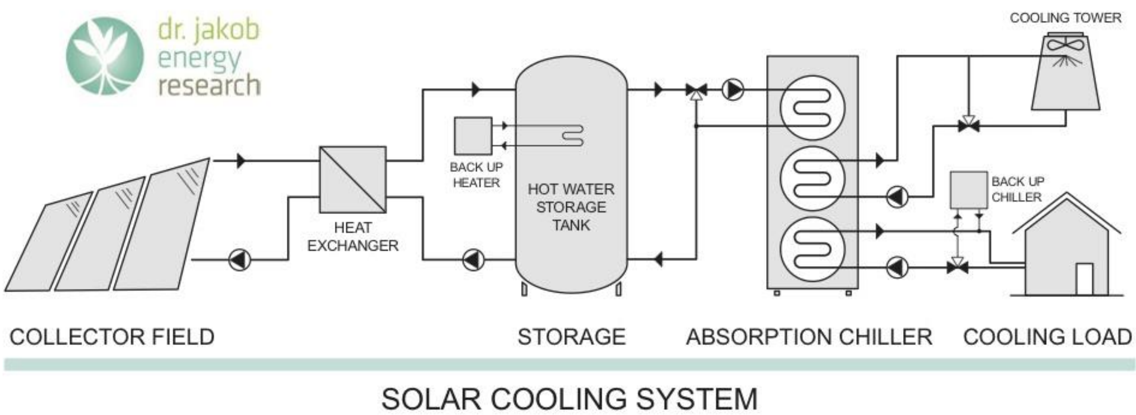


FIGURE 44: FUNCTION SCHEME OF SOLAR COOLING SYSTEM WITH AN ABSORPTION CHILLER (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

5.9. Heat Exchanger

A heat exchanger is a component to transfer heat from a medium to another. As media liquids or gas flows can be used. The most common materials for heat exchangers are steel or cast iron. For a better efficiency of the heat transfer the surface between the two fluids is maximized by ribbing the steel. There are two main building types of heat exchangers- plate heat exchangers and tube bundle heat exchangers. Plate heat exchangers are very compact, easy to expand and low maintenance. Tube bundle heat exchangers have a higher space demand, especially for maintenance, because of the space for the removal of the piping inside.

The flow of the fluids inside of the heat exchangers can be classified in two types: parallel-flow and counter-flow. Counter-flow heat exchangers are more efficient because of the average temperature difference along any unit length is greater. For instance, in retrofit heat exchangers can be used for the heat recovery from exhaust air from air conditioning, transfer station for district heating, domestic hot water or heat recovery from waste water. The installation of a heat exchanger has no influence on the shape of historical buildings, because of the usual installation in the plant room.

In NewTREND the main application for heat exchangers will be a transfer station for district heating or a local heat network. For fluid temperatures below 100°C plate heat exchangers are the most common technology. Due its structure they are very easy adjustable to higher capacities and easy to clean. Furthermore, they are easy to install and don't need much space and has no or very less influence on the inhabitants or building owners. By a regular maintenance, which depends of the grade of pollution of the media, a plate heat exchanger will have a lifetime up to 20 years.

A further heat exchanger type is the tubular heat exchanger. This technology is for media temperatures above 100°C or higher pressure, were the media is vaporous. Depending on the pressure and the type of media (acidic, polluted, etc.), the cost of a tubular heat exchanger is much higher than for a plate heat exchanger. In consequence of the construction, it has a higher space demand for installation and maintenance, because the pipes need to be extended in the whole length. Furthermore, the effort for the construction and used materials leads to higher costs.

TABLE 25: OVERVIEW ON HEAT EXCHANGER TYPES

Heat exchanger type	Media type	Temperature range [°C]	Usage	Cost range per kW_{th} [EUR]
Plate heat exchanger	Fluid, steam	40-80	○ Domestic hot water (DHW) ○ Heat transfer station for heating network with hot water (80°C)	15-35
Tubular heat exchanger	Fluid, steam	100- 130	○ Domestic hot water (DHW) ○ Heat transfer station for heating network with steam (130°C)	60-2010

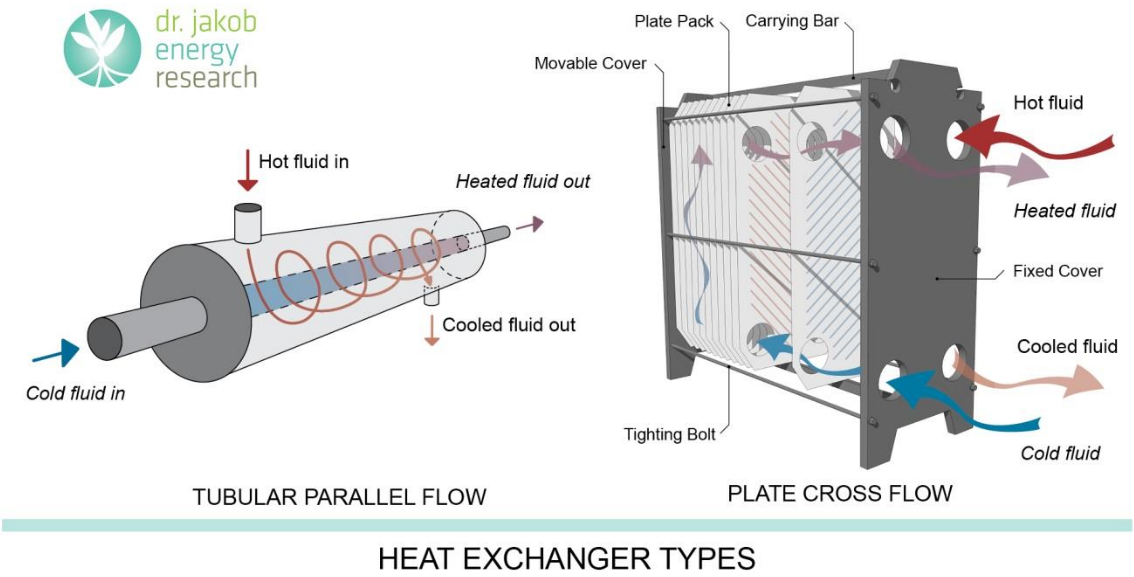


FIGURE 45: FUNCTIONAL PRINCIPLE OF A TUBULAR AND PLATE HEAT EXCHANGER (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

TABLE 26: STRENGTHS AND WEAKNESSES ANALYSIS FOR HEAT EXCHANGER TYPES

Strengths	Weaknesses
○ High efficiency ○ Easy installation ○ Compatible with many systems and fluids ○ Custom-sized for specific applications (materials, size, capacity) ○ Short amortisation	○ Process or system with lower heat demand than input heat required ○ Space demand for tube-bundle heat exchanger ○ Eventually cost intense ○ Not all kinds of temperature ranges are usable for the heat transfer via heat exchanger

5.10. STORAGE

5.10.1. ENERGY STORAGE

The purpose of energy storage is to storage generated (renewable) energy and uses it in a later point in time. The methods therefore are variegated, depending on the type of energy. For thermal storages fluid or solid materials can be used or the heat transformed into another type of energy. Electrical energy can be stored easy in batteries or converted into hydrogen and water, while hydrogen is the energy carrier. In the following both types will be explained more detailed.

5.10.2. THERMAL ENERGY STORAGE (TES)

Thermal energy storages buffer an amount of energy for a certain time, so it can be used at a later instant of time. The stored amount of energy can be released time delayed and create a balance between energy demand and energy supply. The duration of the delay can be hours, days or months and is defined in the storage period. Depending on that the size of the storage differs, which has also influence on the space demand of the storage. For storages a few parameters are important. The capacity informs about the stored energy and is dependent on the medium and the system size. How fast the stored energy can be charged and discharged is defined in the power of the storage and is in relation to the charge and discharge time, which describes how long the charge or discharge process needs. For heat or cold the energy is stored in thermal form in liquid or solid materials. In general, three different storage types are on the market- sensible, latent and thermochemical storages. The most common are sensible storages, which function principle is to store the energy in a liquid or solid material, like water, oil, sand or rocks. Latent storages use phase change materials that change their state of aggregation while charging and discharging, for instance from solid to liquid or gaseous. Typical materials for this storage type are paraffin, water or saline solution. Thermochemical storages (TCS) use reversible endothermic chemical reactions to store and release thermal energy.

Within NewTREND only storages for heat and cold with liquid storage materials, water, are investigated and described in detail. The temperature range for heat and cold storages with water as thermal storage medium is between 4-90°C. Heat storages for higher temperatures (100-300°C) needs to pressure checked, because the storage medium is then pressurized water or steam.

To minimize heat losses through heat transmission it's important to consider the thermal insulation of the storage. The usual insulation thicknesses for storages are between 8- 15 cm.

For short-term storages as well as for long-term storages the combinations with other technologies are manifold. Heat generation technologies (Chapter 5.3 until Chapter 5.7) like solar thermal collectors, gas boilers, CHP units or heat pumps can be combined with a storage tank. Cold generation technologies (Chapter 5.8) like compression chillers, ab- and adsorption chillers and hybrid chillers can also store the generated cold water in tanks, to delay peak loads.

5.10.3. Short-term storage (hot or cold water)

Short-term storages are the most common storage types on building scale. They are used very often to stock hot water for heating or domestic hot water. In combination with solar thermal collectors or CHP units energy from renewable energy sources can be utilised and save therefore fossil energy driven systems, like gas boiler with natural gas.

Storages for chilled water are actually only in buildings with cooling demand and corresponding chillers. Examples for the implementation of cold water storages are office buildings with cooling demand and distribution systems like activated ceilings.

Very important is the check of legionella measurements, especially if the water is used for domestic water in a temperature range between >20 °C up to 55 °C. Furthermore, the storage size is important to prevent stagnation in the tank over a few days. Besides the prevention of stagnation of the water in the piping and storage, the water can be heated up over 60 °C one time per day, which mortify the bacteria. Additional technical devices like ultraviolet light in the storage tank can also prevent legionella infection. Cold water storages with temperatures below 20 °C are not affected from legionella.

The costs for storages are between 0.1-10 EUR/kWh, depending on the volume of the storage. If a storage tank is installed within a retrofit it may be necessary to add the temperature sensors of the storage to the BMS system, if present. By an expected lifetime of 20 years, storage tanks itself are maintenance free and checked anyway within the annual check of operation pressure of the whole system.

Another point to consider if a short-term storage tank is added in a retrofit is the space demand of the storage in the plant room as well as the space demand for the installation and the transport in the plant room, which also reveals that there are no aesthetical issues and complications with historical buildings. An advantage of storages is that the volume can be adjusted to the local requirements in a certain extent.

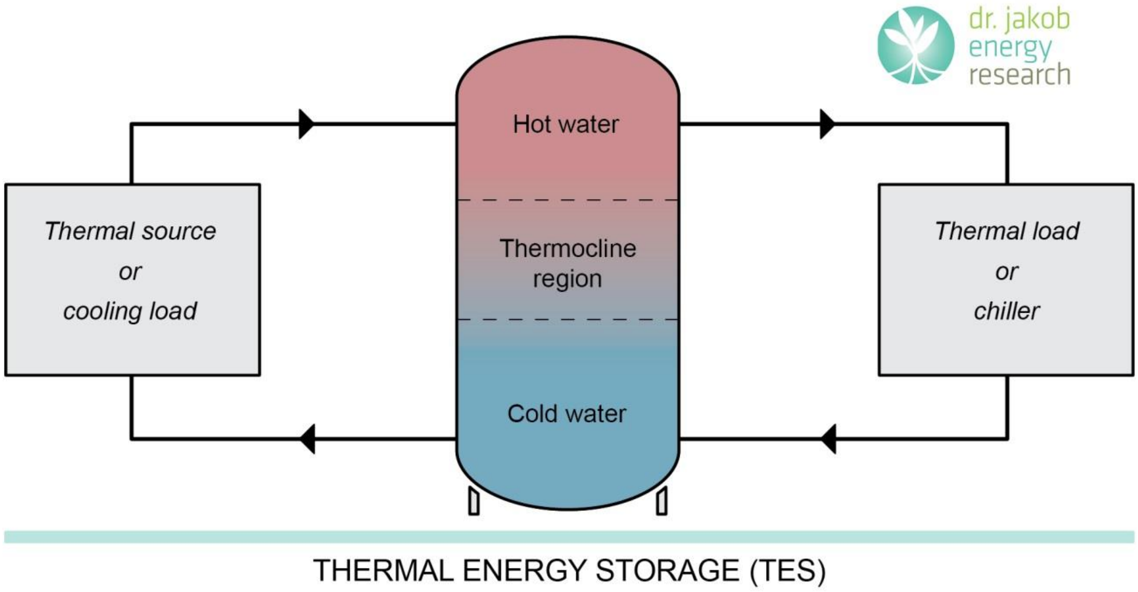


FIGURE 46: PRINCIPLE OF A THERMAL ENERGY STORAGE (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

5.10.4. LONG-TERM STORAGE (HOT OR COLD WATER)

In contrast to short-term storages, the volume of long-term storages is much bigger. Therefore, they can storage hot or cold water for longer periods (e.g. weeks, month or a season). The integration of long-term storages in a building in a retrofit process is almost unfeasible. The technical requirements are the same as for the short-term storages, except some differences. The size of the storage determines the location at the outside of the building.

FIGURE 47: LONG-TERM STORAGE INTEGRATED IN THE SHAPE OF THE BUILDING (SOURCE: S. BECKERLE)

There are two possibilities to implement a thermal long-term storage at the outside. The first possibility is the hiding of the storage under a mound and creates hence a park area. Further the surrounding earth on the storage envelope has further insulation effects. The second possibility is to integrate the storage conscious in the appearance of the building.

TABLE 27: OVERVIEW ABOUT THERMAL STORAGE TYPES

Storage type	Volume range [m³]	Temperature range[6] [°C]	Usage	Cost range per m³ [EUR]
Short-term	0.2- 1.5	50- 130	○ Domestic hot water (DHW) ○ Space heating (SH) ○ Process heat (low temperature) (PH) ○ Cold water	0.75- 1.8
Long-term	2.5- 45	50- 130	○ Domestic hot water (DHW) ○ Space heating (SH) ○ Cooling	2,015- 39,600

[6] Referring to the investigated buildings in NewTREND.

5.10.5. ICE STORAGE

Ice storage is a system for storing latent heat, which if used in a right way can significantly decrease energy cost for cooling (Figure 48). Cooling system freezes the water (or glycol mixture), during the period with lower price of electrical energy (example: night period), stored energy is then used later, when there is a need for cooling. Ice storage is more cost effective in buildings with significant differences in cooling need between day and night, such as office buildings. Additional benefit of ice storage is that it is possible to install cooling system with lower capacity then needed in peak times, this can lower the investment costs and energy cost by lowering demand charges. In this case ice storage covers the difference between requested cooling demand and capacity of cooling system. Furthermore, cooling system with lower maximum capacity (than the needed peak capacity) is going to work more time in higher efficiency domain. There are three basic work modes for ice storage with variants between them:

- **Chiller priority**: cooling system has priority while peak times are covered with the help of ice storage
- **Ice storage priority**: Ice storage has priority in consumption and after the storage has been depleted, cooling system covers the rest of the need
- **Optimal mode**: Is ideal control strategy (difficult to achieve), where ice storage is controlled in a way that minimal energy cost is achieved. To achieve it, control system should have to precisely predict future cooling demand [47; 48].

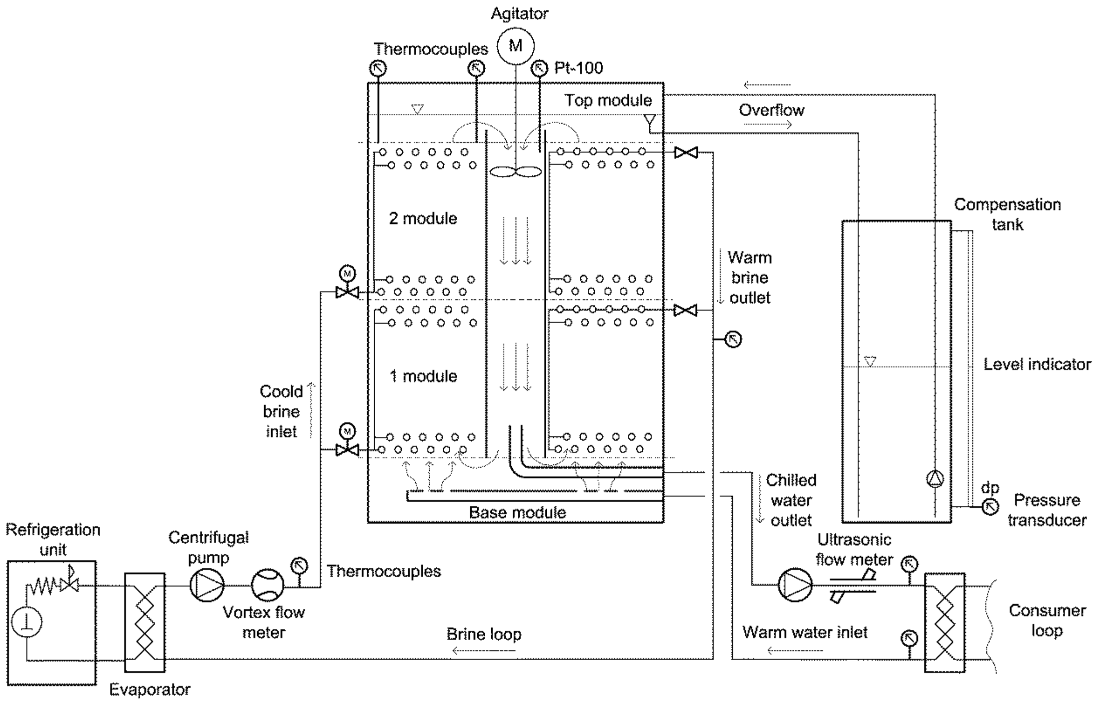


FIGURE 48: FUNCTIONAL SCHEME OF AN ICEBANK (SOURCE: M. GROZDEK, 2009)

TABLE 28: STRENGTHS AND WEAKNESSES ANALYSIS THERMAL STORAGES

Strengths	Weaknesses
○ Thermal stratification in the storage can improve the efficiency ○ Wide range of capacity ○ Low costs for storage medium (water) ○ Combination as buffer storage with renewable energy sources is manifold ○ Renewable energy systems can be better implemented in the energy supply system	○ Large space demand for large amount of energy storage, due the volume ○ Considering of space demand for transport and installation ○ Higher costs for high-quality storage insulation ○ Anti-legionella measurements if used for domestic hot water storage

5.11. Forced Ventilation

Ventilation is necessary in buildings to remove 'stale' air and replace it with 'fresh' air. This helps to:

- Moderate internal temperatures.
- Replenish oxygen.
- Reduce the accumulation of moisture, odours, bacteria, dust, carbon dioxide, smoke and other contaminants that can build up during occupied periods.
- Create air movement, which improves the comfort of occupants.

Very broadly, ventilation in buildings can be classified as 'natural' or 'mechanical'.

- Mechanical (or 'forced') ventilation tends to be driven by fans.
- Natural ventilation is driven by 'natural' pressure differences from one part of the building to another. Natural ventilation can be wind-driven or buoyancy-driven.

Mechanical ventilation systems can also include heating, cooling, humidity control and air filtration. These functions are often described collectively as HVAC (Heating Ventilation and Air Conditioning).

Natural ventilation is generally preferable to mechanical ventilation as it will typically have lower capital, operational and maintenance costs. However, there are a range of circumstances in which natural ventilation may not be possible:

- The building is too deep to ventilate from the perimeter.
- Local air quality is poor, for example if a building is next to a busy road.
- Local noise levels mean that windows cannot be opened.
- The local urban structure is very dense and shelters the building from the wind.
- Privacy or security requirements prevent windows from being opened.
- Internal partitions block air paths.
- The density of occupation, equipment, lighting and so on creates very high heat loads or high levels of contaminants.

Some of these issues can be avoided or mitigated by careful design, and mixed mode or assisted ventilation might be possible, where natural ventilation is augmented by mechanical distribution or extract.

5.11.1. Mechanical Ventilation

Where mechanical ventilation is necessary it can be:

- A circulation system such as a ceiling fan, which creates internal air movement, but does not introduce 'fresh' air.
- A pressure system, in which 'fresh' outside air is blown into the building by inlet fans, creating a higher internal pressure than the outside air.
- A vacuum system, in which 'stale' internal air is extracted from the building by an exhaust fan, creating a lower pressure inside the building than the outside air.
- A balanced system that uses both inlet and extract fans, maintaining the internal air pressure at a similar level to the outside air and so reducing air infiltration and draughts.
- A local exhaust system that extracts local sources of heat or contaminants at their source, such as cooker hoods, fume cupboards and so on.

In commercial developments, mechanical ventilation is typically driven by air handling units (AHU) connected to ductwork within the building that supplies air to and extracts air from the interior. Typically, they comprise an insulated box that forms the housing for; filter racks or chambers, a fan (or blower), and sometimes heating elements, cooling elements, sound attenuators and dampers. In some situations, such as in swimming pools, air handling units might include dehumidification. See Air handling units for more information. Where mechanical ventilation includes heating, cooling and humidity control, this can be referred to as Heating Ventilation and Air Conditioning (HVAC). Extracting internal air and replacing it with outside air can increase the need for heating and cooling. This can be reduced by re-circulating a proportion of internal air with the fresh outside air, or by heat recovery ventilation (HRV) that recovers heat from extract air to pre-heat incoming fresh air using counter-flow heat exchangers.

The design of mechanical ventilation systems is generally a specialist task, undertaken by a building services engineer. Whilst there are standards and rules of thumb that can be used to determine air flow rates for straight-forward situations, when mechanical ventilation is combined with heating, cooling, humidity control and the interaction with natural ventilation, thermal mass and solar gain, the situation can quickly become very complicated. This, along with additional complications, such as the noise generated by fans, and the impact of ductwork on acoustic separation means it is vital building services are considered at the outset of the building design process, and not seen as an add-on. Mechanical ventilation may be controlled by a building management system (BMS) to maximise occupant comfort and minimise energy consumption. Regular inspection and maintenance is necessary to ensure that systems are operating optimally and that occupants understand how systems are operated.

5.11.2. Fan

Ventilation fans are used to circulate the air in the buildings or houses. This type of ventilation is known as mechanical ventilation in which fans or blowers are used to create movement of the air. The other way to ventilate a house is using the natural ventilation where the air is moved by natural forces. A good design of a house will incorporate the natural ventilation as much as possible to reduce the electricity bill as well as the conservation of the environment. However, it is inevitable that suitable fans will have to be installed to ensure that the air quality in the house is fresh and safe for the people to stay.

The two most common type of fans that are used in buildings are the belt-driven and the direct-drive ones: the first one are usually more durable or for medium or heavy duty application, with the possibility of varying pitches and pulleys, while the direct-drive fans can be used for any kind of application and they offer more flexibility than the belt-driven in terms of size, performance and efficiency. Moreover, there are many different fan models and accessories, such as: build-in frequency driver, shutter-mount type, Venturi effect frame, cone frame, intake guard, wall or roof or ceiling mounting, tubeaxial or flush mounting.

In a mechanical ventilation system, extraction and intake fan speed can be automatically controlled by different parameters monitoring. Temperature, humidity and CO2 sensors can be connected in a fully integrated and automatic system in order to maintain optimal conditions for inhabitants comfort and health. Referring to the ventilation fans control, in particular, the system acts on their speed, increasing or decreasing the air flow as needed to keep temperature, humidity and CO2 values in the pre-defined comfort range.

5.11.3. Air conditioning

The use of the term 'air conditioning' (AC) can be confusing. In some of the strictest definitions, air conditioning is used to describe systems that control the moisture content of air, that is, its humidity. This can include humidification and dehumidification. Humidity control can be important for the comfort of building occupants, to reduce the incidence of condensation (both surface and interstitial), for specialist environments such as swimming pools, and where the protection of sensitive items requires particular conditions. However, dehumidification of air is generally achieved by cooling. As the temperature of air falls, it is less able to 'hold' moisture, that is, saturation water vapour density falls, and so relative humidity rises. When relative humidity reaches 100%, the air will be saturated. This is described as the 'dew point'. If the air continues to cool, moisture will begin to condense, dehumidifying the air. This means that humidity control and cooling are often considered together as 'air conditioning'. Cooling and dehumidification are important contributors to thermal comfort. This is because the ability to perspire, and so to lose heat by evaporation from the skin, is limited by the humidity of the air. As a result, remaining cool is dependent on both temperature and humidity. So a combination of reduced air temperature, and reduced humidity helps people to remain cool.

Within HVAC systems, ventilation, temperature (and humidity) can be regulated either by:

- Variable air volume (VAV), in which the temperature of the supply air remains constant, but the volume varies (also known as variable volume, constant temperature VV-CT).
- Constant air volume (CAV) in which the volume of air supply remains constant, but the temperature varies (also known as constant volume, variable temperature CV-VT, or constant volume CV).
- Variable volume, variable temperature (VV-VT sometimes referred to as variable volume and temperature - VVT).

Constant air volume (CAV) systems

Constant air volume (CAV) systems are becoming less common in new buildings as VAV systems tend to provide closer control of air temperature and require lower fan speeds, as a result of which they can use less energy and generate less noise. However, CAV systems are still used in small and medium-sized premises with straight-forward HVAC requirements, as they can be relatively simple to install, can have a lower capital cost and tend to be reliable. They are particularly common in simple systems where fan coil units are supplied with a constant volume of 'fresh' air. Simple, single-duct CAV systems which supply air at a single temperature and constant volume might be suitable for a large space with simple, uniform thermal demand, such as a gymnasium. This system can be enhanced by reheating the supply air in CAV terminal units to provide additional local control. This might be appropriate where there are some minor local variations to thermal demand. In this case, air is supplied to the system at the lowest temperature required and then its temperature is increased as necessary locally.

Alternatively, 'mixed-air' or 'dual-duct' systems can provide both heated and cooled air, the proportions of which are regulated locally in mixing boxes. This might be appropriate where there are significant differences in thermal demand. Air is supplied at the lowest and highest temperatures required and then mixed locally as necessary.

Variable air volume (VAV)

VAV systems tend to provide closer control of air temperature than CAV systems and require lower fan speeds, as a result of which they can use less energy and generate less noise. In simple VAV systems, air handling units (AHU) supply air through ductwork to spaces within the building, and the temperature of the spaces is moderated by adjusting the supply flow. In more complex systems, where spaces have different heating or cooling demands, there may be additional local control of the amount of air that enters each space. Typically, cool air is supplied by an air handling unit, and thermostatically controlled dampers regulate the amount of air that enters each space. The damper must always remain partially open to allow some 'fresh' air into the space. The fans in the air handling unit are adjusted (variable frequency drive VFD) to control the air pressure in the ductwork. Refrigerant flow is also adjusted to ensure that the air temperature remains constant. VAV terminal units may include fans that re-circulate a proportion of internal air along with the 'fresh' supply air to reduce the cooling load.

Where variations between spaces mean that some local heating is required in to maintain constant temperatures throughout a building, VAV terminal units may re-heat the supply air. Despite the apparent waste of re-heating previously cooled air, this can be more economic that providing a warm air supply from the air handling unit when there is only limited heating demand. Heat may be provided in VAV terminal units by electrical elements or by hot water coils.

Air conditioning terminal reheat

The air conditioning terminal reheat is a Variable Air Volume (VAV) device and consists of an air supply flow driven by a fan in a single duct, which is kept constant and at constant temperature. The supply air passes through in duct heating coils, which are thermostatically controlled in order to reheat the air to be delivered to areas not requiring the full cooling capacity of the air.

The reheating coils are water-air exchangers, and their heating water volume is controlled by room thermostats. Reheat is typically added to a few perimeter rooms or zones. Although it may seem that heating air that may have been previously cooled is wasteful, using reheat in a few locations may be more economical when both heating and cooling is required from a single air supply.

Air conditioning dual duct

It's a type of air distribution system and it's composed by a dual duct system. Because sometimes modern buildings, especially offices, use the area above suspended ceilings as the return air plenum, VAV efficiency is increased by pulling the warm plenum air into the VAV system and mixing it with the cooler supply air. With this configuration, there are two different supply ducts departing from the HVAC unit: one is for the cold air, the other one for heated air and they arrive in a parallel fan Variable Air Volume (VAV) or Dual-duct terminal units. Hot and cold air is mixed by damper systems in each zone according to the specific temperature required in the single areas.

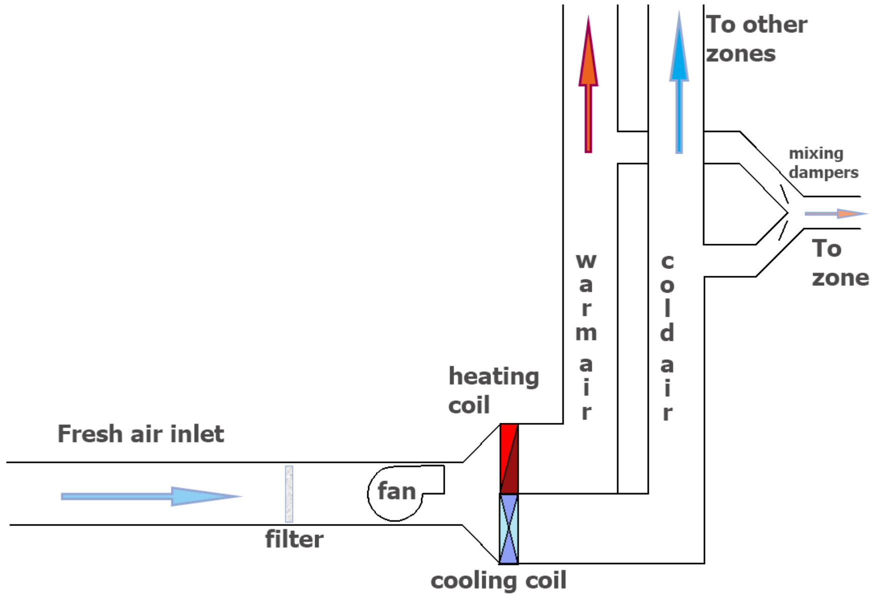


FIGURE 49: AIR DISTRIBUTION SYSTEM WITH DUAL DUCT CONFIGURATION (CREDIT BY: © STAM S.R.L.)

FAN COIL UNITS

Fan coil units (FCU) consist of only a fan and a heating or cooling element, are located within the space they are serving, and are generally not connected to ductwork. They may either just recirculate internal air, in which case a separate ventilation system is required, or may introduce s proportion of 'fresh' air that is mixed with the recirculated air.

Fan coil units can be wall-mounted, freestanding or ceiling-mounted and may be concealed in ceiling voids. They may be controlled by local thermostats or by a building management system (BMS).

Due to their simplicity, fan coil units are more economical to install than ducted air handling units. However, they can be noisy and can create vibrations because the fan is in the occupied space.

Where fan coil units are supplied with chilled water and hot water from central boilers and chillers they are generally referred to as two pipe (either heating or cooling) or four pipe (both heating and cooling) units.

Where the heating and cooling is provided locally, they may be referred to as variable refrigerant volume (VRV) or variable refrigerant flow (VRF) systems. Here, refrigerant is circulated between one or more fan coil units and is connected to an external heat exchanger. These systems may be more prone to refrigerant leakage than units that are connected to hermetically-sealed central chillers.

Fan coin units are relatively compact and straightforward to install. However, they require regular maintenance to ensure continued efficient operation.

When a fan coil unit cools air, it will generally cause condensation which must be collected and drained or pumped away.

5.12. PHOTOVOLTAIC

PV arrays convert sunlight to electricity. Systems are made up of modules assembled into arrays that can be mounted on or near a building or other structure. A power inverter converts the direct current (DC) generated by the system into grid-quality alternating current (AC) electricity.

Single Crystal solar cells are generally made from silicon and represent the most efficient PV cells (the efficiency is an indicator which shows performance conversion of sunlight to direct current electricity). Multi-crystal or Polycrystalline solar cells are made of different crystals and therefore less efficient. On the other hand, Thin-film solar cells are made from amorphous silicon or non-silicon materials such as cadmium telluride. These thin-film cells are composed by layers of semiconductor materials only a few micrometres thick. [49].

Most of the PV systems installed are in flat-plate configurations. This design is made from solar cells combined into modules that hold about 40 cells. Many solar panels or modules combined together create a solar array. The number of modules/arrays installed depend on the application; for large electric utility or industrial applications hundreds of arrays are interconnected to form a large scale PV system. These systems are generally installed fixed in a single position but can be mounted on structures that rotate toward the sun on a seasonal basis or from East to West over the course of a day. Figure 50 shows the components of a typical PV system [49].

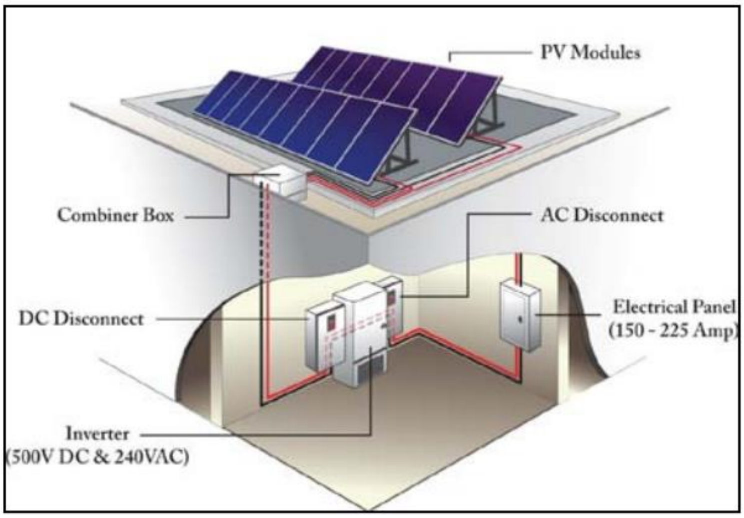


FIGURE 50: COMPONENTS OF A PV SYSTEM [49]

In terms of installation several factors need to be considered. PV facilities are installed in an unshaded, south-facing site with an optimized tilt angle and in places with a relevant electricity demand. Not all sites are suitable, some guidelines are as follows:

- It is important to identify an unshaded area during peak sun hours (between 9:00 and 15:00 for instance). Obstacles that create shades are trees, nearby buildings, and roof equipment or features (such as chimneys).
- In the case of fixed-mount panels, which does allow rotation, are due South in the northern hemisphere and due North in the southern hemisphere, another orientation will decrease efficiency. The location also has an impact on the total solar irradiation (Chapter 2.2.3) on the PV panels and therefore on the amount of produced electricity per year.

- Moreover, it is possible to maximize the annual energy production from fixed-mount PV systems by tilting the array to approximately match the latitude of where the system is located. However, a desired tilt angle is not always feasible because of factors such as roof pitch, wind, or snow loading considerations or because of the site features. One solution is to install panels at a different angle.

- Define well the best operation regime of the PV installation. PV systems can be designed to provide power simultaneously with the utility (grid-connected); independent of the utility (stand-alone, with batteries (Chapter 5.15); or to do either (dual mode). Several factors affect to this selection, such as the available connection to the grid, the electricity price form the utility or the level of autonomy of the building (flexible loads and storage systems). When considering a system that will be tied to the utility grid, or grid-connected, it is essential to understand the applicable standards and rules for the serving electric utility company.
- Efficiency and available space are two parameters that go always together. Therefore, if a project location has limited space, then a higher efficiency, and potentially higher cost, module may make the most sense. However, if space is not an object, then a lower efficiency, less costly module may be more suitable.

As mentioned before there are three types of solar panels; monocrystalline, polycrystalline and thin film. The monocrystalline panel may be the original solar PV technology, but it's being challenged by both established and emerging new technology on factors like price, efficiency and versatility. Solar PV modules made from polycrystalline silicon, as well as new generations of thin-film solar PV technology, are giving residential, commercial, industrial and utility clients a variety of options to fulfil their solar energy production requirements.

5.12.1. Monocrystalline silicon solar PV

Monocrystalline silicon solar PV is the best technology to deliver efficiency, however these panels are the most expensive in the market.

Monocrystalline solar cells are made by a single crystal. Because these crystals are usually an oval shape, monocrystalline panels are cut into the distinctive patterns that give them their recognizable appearance. As they are made by a single silicon crystal, these panels have a homogeneous colour, a dark blue colour with no grain marks, giving it the best purity and highest efficiency levels.

FIGURE 51: MONOCRYSTALLINE PANEL (SOURCE: KRANICH SOLAR)

5.12.2. Polycrystalline silicon solar PV

Polycrystalline solar cells are made by pouring molten silicon from different sources into a cast. Due to this manufacturing method, the crystal structure will form imperfectly, creating boundaries where the crystal formation breaks. That is way polycrystalline panels have a heterogeneous grainy appearance.

Because of these impurities in the crystal, polycrystalline silicon is less efficient when compared with monocrystalline. However, this manufacturing process uses less energy and materials, giving it a significant cost advantage over monocrystalline silicon.

FIGURE 52: POLYCRYSTALLINE PANEL (CREDIT BY: REGENERA LEVANTE, S.L.)

5.12.3. Thin-film solar PV

The technology that is more unusual is thin-film. It has several disadvantages, however it is a good option when high power requirements are not needed but there is a need for light weight and portability. Thin-film technologies produce energy at a maximum efficiency of 20.3%. Thin-film panels (Figure 53) can be manufactured from a variety of material such amorphous silicon (a-Si), cadmium telluride (CdTe) and copper indium gallium selenide (CIS/CIGS). Market price is more competitive than polycrystalline and monocrystalline technologies.

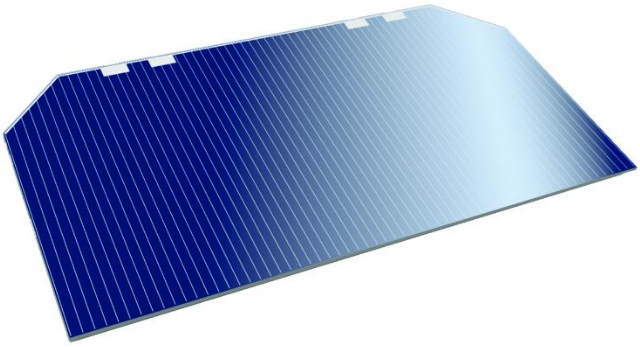


FIGURE 53: THIN FILM PANEL (SOURCE: SOLAERO TECHNOLOGIES)

TABLE 29: STRENGTHS AND WEAKNESSES ANALYSIS FOR PHOTOVOLTAIK PANELS

Strengths	Weaknesses
○ Flexible and modular system ○ Combination with other conventional or renewable energy systems ○ Long lifetime ○ Easy installation and implementation in retrofit ○ Profitable projects with low risks. ○ Low operating and maintenance cost ○ Increase of energy independency when combined with energy storage ○ Sites with high solar irradiation ○ Buildings or districts with energy autonomy (isolated regions). ○ Buildings or districts with demand of energy independency (isolated regions) ○ Very often financial incentives are available ○ Surplus energy can be sale and feed in the grid	○ Depending on the location and the weather conditions, low efficiency ○ Inverter is required ○ High initial investment ○ Low space efficiency. ○ DC/AC conversion generates energy losses ○ Decrease of efficiency by pollution of the collector panels ○ Regulation in some countries (Spain). ○ Long and complex legal procedures. ○ Depending on some materials like siliceous.

5.13. Micro Wind turbine

Wind energy technologies can be classified into two categories – macro wind turbines that are installed for large-scale energy generation such as wind farms, and micro wind turbines used for local electricity production, being suitable for applications at the building scale.

Micro wind turbines are mainly used for distributed generation, producing electricity at local level for on-site use. These are a small-scale alternative to solar panels, providing renewable energy to rural homes, farms and businesses where wind resources are available.

The main components of a wind turbine include blades, rotor, gearbox and generator. The generated power is affected by the air density, rotor area and the wind speed (Chapter 2.2.4) and the wind speed is affected by topography and the structure of the land nearby.

Within the micro turbines group there are two types: Horizontal axis wind turbine (HAWT) and Vertical axis wind turbines (VAWT).

Horizontal axis wind turbine (HAWT) are the most common micro wind turbine type **(**Figure 54**)**. As an installation requirement, HAWT turbines need to be pointed into the wind direction to generate power, that is why they can rotate easily depending on the wind direction. Simpler models do this by a weather vane behind the blades, more complex models have wind sensors connected to the motor that will move the turbine to face the wind. On the other hand, some new models can generate more power with fewer rotations per minute (RPMs) of the blades, making them more efficient and reducing both noise and disturbances, others have blades with a curved design that further reduces noise levels [50].

FIGURE 54: HORIZONTAL AXIS WIND TURBINE (HAWT) (SOURCE: AEOLOS)

Vertical axis wind turbines (VAWT) (Figure 56**)** have a totally different design than (HAWT), especially in their blades system which rotate around a vertical shaft instead of a right angle. These turbines have several advantages; they can operate at lower speeds, be installed lower to the ground and require smaller space requirements than HAWT ones. Due to their design, VAWTs can generate power from wind blowing in any direction. The generator is located at the bottom of the shaft, making easier maintenance tasks. However, as they operate at low wind speeds, they generate significantly less power than horizontal axis turbines. In general lines, HAWTs are far more common due to their better efficiency and generation capabilities. Nevertheless, VAWTs could be a good option in locations with less available space, or where wind speed and direction are inconsistent.

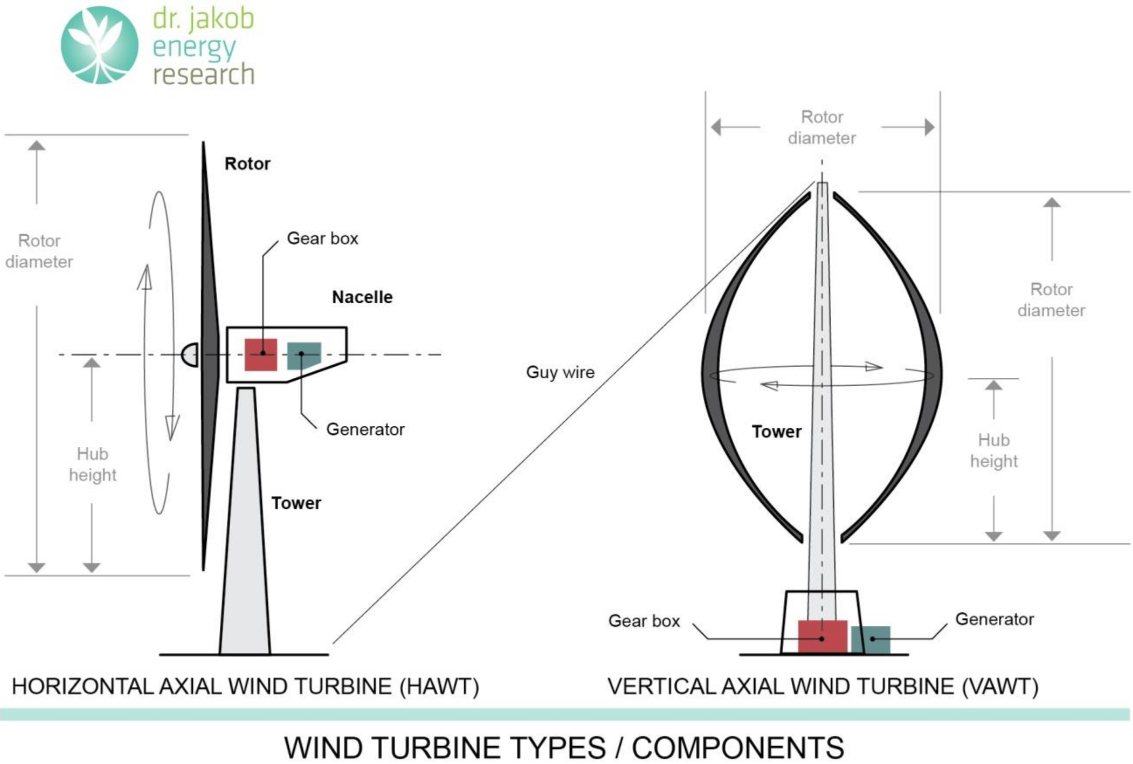


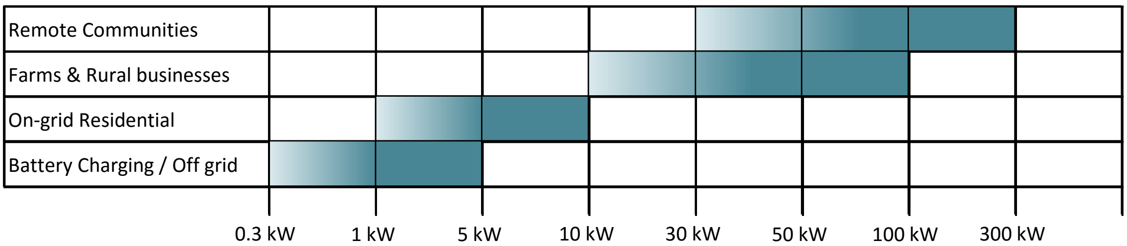
FIGURE 55: WIND TURBINE TYPES AND COMPONENTS (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

FIGURE 56: VERTICAL AXIS WIND TURBINE (VAWT) (SOURCE: WWW.UGEI.COM.)

In terms of applications, micro wind turbines can be grid-connected or off-grid. Off-grid systems require storage systems to store the surplus of electricity and supply energy in scarcity periods, providing a stable electricity supply as much as possible. Their application is most suitable for rural and remote areas (such as remote villages and small isolated islands), in other words, where grid power is not available.
On the contrary, grid-connected systems do not need storage system but require power converters to convert the generated DC electricity to AC electricity, in order to be compatible with both the main grid and AC electrical appliances. In newer models, wind turbines can also directly generate AC power.

Type of applications depending on the power, for residential ones (the one that concern in this project) micro wind turbines ranges from 300 W to 10 kW.

TABLE 30: WIND TURBINES APPLICATIONS (SOURCE: CANWEA, CANADIAN WIND ASSOCIATION)



Further developments in wind technologies have been deployed, improving reliability and efficiency at low wind speeds and lowering capital cost. Wind turbine blades are currently designed with lightweight materials and aerodynamic principles, so that they are sensitive to low wind speeds. Another issue to be solved is to reduce/eliminate noise associated to blade rotation. This can be achieved by using low-noise blade designs, vibration isolators to reduce sound and sound absorbing materials around the gearbox and generator.

Regarding technical characteristics of micro wind turbines, their blades are usually 1.5 to 3.5 metres in diameter and produce 1-10 kW of electricity at their optimal wind speed. Some units have been designed to be very lightweight in their construction, allowing sensitivity to minor wind movements and a rapid response to wind gusts and easy mounting. Dimensions depend on the total power of the turbine, below there is an image with the main models.

The size of the turbine depends on the wind resource and how much power is needed to generate. Manufacturers typically provide a power curve or energy curve indicating the turbine’s expected power output or energy production at various wind speeds. That power curves are not standardized and only provide an approximation of how much electricity a turbine will generate. In general, the larger the “rotor swept area” (the diameter of the circle defined by the rotating blades), the more power a turbine will produce at a given wind speed.

Before installing a wind turbine, it must be established that the wind resource in a specific location is adequate. Wind resource maps can determine if an area of interest should be further explored, but wind resource at a micro level can vary significantly. Therefore, it is important to evaluate the specific area of interest before deciding to invest in wind systems.

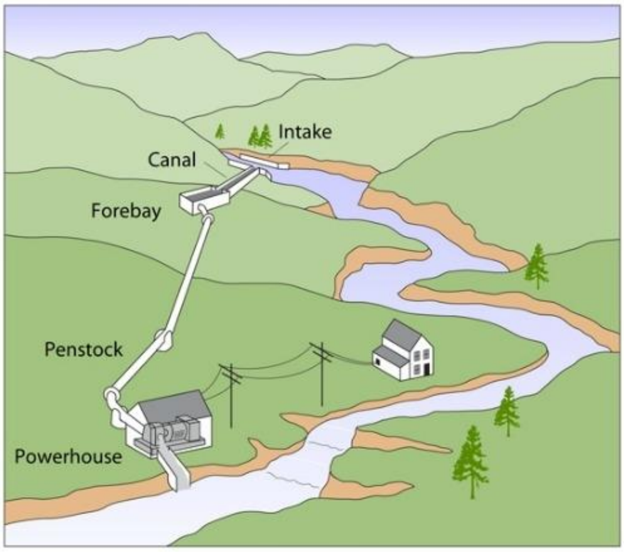
Once wind potential has been evaluated, technical requirements such as size and premises to be installed can be determined. The height of the turbine tower is a key factor determining the operational efficiency of the turbine because wind speeds generally increase with height above ground (with wind energy increasing exponentially as a function of wind speed), and because there should be sufficient clearance between the lowest tip of the turbine blade and any nearby natural or man-made structure to minimize local air turbulence. As a rule of thumb the wind farm should be 650 m away from habitation. "Putting a turbine on too short a tower is like putting a solar panel in the shade" [51]

Most wind turbines are designed for an operating life of up to 20 years and require little maintenance during this period. Wind turbines require land area, so on-site wind power generation usually occurs for projects having space for installing the turbines. Roof-mounted wind systems are beginning to be used in some building projects.

TABLE 31: STRENGTHS AND WEAKNESSES ANALYSIS FOR WIND TURBINE

Strengths	Weaknesses
○ Locations with high wind speed (seaside, mountains or hills, etc.) ○ High recognisable signal for use of renewable energy production and therefore upgrading of the retrofitted building or district ○ Simple technology ○ Mature technology ○ Buildings or districts with demand of energy independency (isolated regions) ○ Small wind turbines are easy to install in retrofit ○ Locations with high wind speed ○ Surplus can be feed in the grid or stored	○ Intermittent resource (difficult to predict when wind will blow) ○ Production uncertainty ○ Technology is dependent on the wind speed (no use in urban districts or cities) ○ Space demand for installation ○ Local grid capacity should be checked for stability of feed in is planned ○ Elaborative installation ○ Use of high value materials for generator (copper, semiconductors, etc.) ○ Opponents from the public against this technology ○ Environmental impact

5.14. Small hydro power



In this microhydropower system, water is diverted into the penstock. Some generators can be placed directly into the stream.

FIGURE 57: EXAMPLE OF A MICROHYDROPOWER SYSTEM (SOURCE: U.S. DEPARTMENT OF ENERGY (SOURCE: ENERGY.GOV/ENERGYSAVER/MICROHYDROPOWER-SYSTEMS)

Small scale hydropower is hydropower of capacities up to 10 MW (in some countries definition goes up to 30 MW). Small hydro can be further divided into mini hydro (up to 500 kW) and micro hydro (up to 100 kW). Small scale hydropower works on the same principle as a large hydro. It captures the energy in flowing water and converts it to electrical energy. Potential for small hydro depends on the availability of suitable water flow and where it exists it can provide clean and cheap electrical power.

Electricity produced by small hydro plants can be used directly, stored in batteries or inverted to produce electricity for power network. Since they usually have small reservoirs and small civil construction work required, they have relatively low environmental impact, especially compared to larger hydro plants. Small hydro plants can be built on existing structures, such as existing dams for controlling river and lake water level [52]:

TABLE 32: STRENGTHS AND WEAKNESSES ANALYSIS FOR SMALL HYDRO POWER

Strengths	Weaknesses
○ Energy source is free and maintenance costs are low ○ No carbon dioxide (as well as other pollutants) emissions from electricity generation ○ Usually more stable energy source compared to solar and wind renewables ○ Increase in fuel prices, lowers the ROI ○ As more small hydro plants are installed, prices might decrease	○ High investment costs ○ Installation possible only on certain locations, where hydro power potential exists ○ Impact on flora and fauna of a stream where small hydro is installed and the area around it ○ Decreased electricity generation during drought periods ○ Installation of dams and additional hydro power plants upstream decreases the water potential and electricity generation in locations downstream

5.15. ELECTRICAL BATTERY STORAGE (SHORT-TERM / LONG-TERM)

Home batteries and other storage systems could be charged using electricity generated from solar panels, and/or when utility rates are low, and powers homes in the evening. These technologies enable prosumers/consumers to maximize self-consumption of solar power generation. This bridges the gap between peak solar and peak demand, allowing consumers to use their energy when necessary.

Applications fall into two broad categories: energy applications and power applications. Energy applications involve storage system discharge over periods of hours (typically one discharge cycle per day) with correspondingly long charging periods. Power applications involve comparatively short periods of discharge (seconds to minutes), short recharging periods, and often require many cycles per day. Within energy application we can find short and long term storage systems depending on the capacity and the usage, usually long term storage systems cover large time periods of charging and discharging meanwhile short term storage applications are sized to cover shorter periods (hours).

The main application in buildings for these systems is when storing the energy from the renewable sources, which is intermittent. Lead-acid batteries are most often used in renewable energy systems. Lithium batteries, though more expensive than lead-acid, can have a much longer life. Nickel iron batteries are harder to find and less efficient than lead-acid or lithium ion but have very long lives. Flow batteries (zinc bromine and vanadium redox) and flywheel batteries can be used in renewable energy systems but are complex and expensive. However, there are more applications than just hosting renewables such as peak shaving and load levelling (energy applications) as well as frequency and voltage regulation, power quality, renewable generation smoothing and ramp rate control (power applications). The former ones are more related to provide services to the grid (not applicable in NewTREND).

FIGURE 58: BATTERY STORAGE (LI-ION) (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

In the following table there are all the technologies available in the market, with their corresponding technical and economic features:

TABLE 33: CHARACTERISTICS OF STORAGE TECHNOLOGIES AVAILABLE IN THE MARKET (SOURCE: FORSKEL PROJECT)

Property / Technology	Flywheel	Battery	CAES	Hydro	Supercap	Hydrogen	SMES
Start up time / response time	Instant	Instant	Few seconds	Few seconds	Instant	Seconds (if warm and running)	Instant
Ramp time- % of power capacity per second	25%	Program mable	0.2 (100% in 14 min.)	4% (50% in 12 sec.)	Programmable	5 %	Very high
Cyclability (with reference to the needs described in Section 2) and influence on lifetime	12,5000	10- 20.000	Capacity independ ent of cycling	Capacity independent of cycling	Millions	Cycles to 80% capacity: thousands	Unknown
Round cycle efficiency (electricity out over electricity in), %	85%	85% (Li-Ion based)	80	75- 85%	90 %	35 %	Unknown
Power capacity	100 kW-modular	MW on modular base	Multi MW	Multi MW	Up to 100 kW unit available	Modular	Variable
Energy capacity	25 kWh in 100 kW unit	MW on modular base	Depends on reservoir	Depends on reservoir	300 kWh in unit	Modular	Variable
Investment, EUR per kW	2,200 EUR/kW	300- 450 EUR/kW	750	800- 1,000	250	3,500 (FC) and 230 (EC)	1,134
Investment, EUR per kWh	8,800 EUR/kWh	400- 1,500 EUR/kWh	10	80- 100 EUR/kWh	6,000	n.a.	90 kEUR/kWh

Batteries applications make sense in the following situations:

- When shifting loads to avoid energy consumption from the grid during peak times.
- When main consumptions do not coincide in time with renewable energy production.
- When EV charging points integration with renewable energy production.

There are several types of batteries depending on the technology and its application. Right below there is a table which guides in the technology selection depending on the usage. In smart houses mainly lead acid systems are used currently, but in the future Li-ion or NaNiCl batteries in particular may be installed because of their high cycle lifetime and their ability to deliver high peak power [54]

TABLE 34: STORAGE TECHNOLOGIES PER APPLICATION TYPE (SOURCE: INTERNATIONAL ENERGY AGENCY, ELECTRICAL STORAGE WHITE PAPER)

Storage technologies	Characteristics	Hydro storage	Compressed air	Flywheel	Lead acid	NiMH	Li-Ion	Metal-air	NaS	NaNiCl	Redox flow	Super capacities	SMES
Consumer usage	Temporal load shifting				•••		••		•••		••		•
	Grid quality			•••	•••		••		•••			•••	•
	Electrical Vehicles					•••	•••	•		•••			
Renewable energies integration	Temporal load shifting	•••	••		•••		••		•••	••	••		•

5.15.1. Short term batteries

Energy and power need to be supplied in buildings at both night and sun hour's periods. In order to enable this, short-term storage solution that allows excess energy to be transferred from day to night are the best option, overall when self-consumption or there is no connection to the main grid. These short-term storage systems have many advantages. It enables a significant increase in self-consumption which helps to reduce electricity bills – something that is becoming increasingly attractive given the constant increases in energy costs.

Furthermore, short-term storage solution definitely helps to smooth out the peaks that result from the generation of solar power, or to balance them by shifting the time at which load peaks occur within the household. Another advantage is the increase in the home energy autonomy when power cut occur.

Regarding installation issues, the battery can be connected directly to the photovoltaic inverter, which has a DC input for connecting a battery. By connecting doing this a high total efficiency is achieved, because there are no multiple conversions it is with corresponding losses. The inverter is then the device that controls the various energy flows – between the solar modules, battery, network and consumers – and ensures optimal energy management. [55]

5.15.2. Long term storage systems

While short-term storage solutions create a balance between day and night, long term ones attain a balance between periods with high levels of insolation (summer) and those with less (winter), covering weekly and monthly demand. That make sense in places at central European latitudes, where insolation in winter is up to 85 percent less than in summer. In terms of storage capacity and loss-free long-term storage, this is a challenging task for storage technology. In practical terms, a solution cannot be achieved with batteries, then the use of other technologies with larger capacity. [55]

There are several types of large capacity technologies, most frequent are Compressed air energy storage (CAES) and Hydrogen (H2). Locations and situations in which they could be installed are the following: in order to host renewable energies at the grid by ensuring a smooth injection of the electricity in it, to offer balancing and ancillary services, to integrate large scale of EV charging stations and, as mentioned before, to cover weekly and monthly demand during low production periods.

Hydrogen technology

When excess power is present, this is fed to the electrolyser in an energy cell. The electrolyser breaks down water (H_2O) into its component parts of hydrogen (H_2) and oxygen (O_2). Hydrogen is then stored under pressure in a gaseous state in steel cylinders. The size of the tank determines the amount of energy that can be saved for the winter during the summer months. In winter, the stored hydrogen is converted back to electricity using the fuel cell function. These conversion processes also produce waste heat that can be used to provide hot water and heating back-up. [55]

Compressed Air Energy Storage

Working principle Compressed Air Energy Storage (CAES) is based on storing energy as potential energy in pressurized air. When compressing gases (air) the pressure increase is accompanied by an increase in temperature. The temperature raise is highly depending on the pressure ratio (the ratio between out- and inlet pressure of the compressor) and the compressor outlet temperature has to be cooled before storing. When utilizing the stored energy by re-expansion, the heat has to be added again in order not get freezing. Different technologies/concepts exist all based on CAES being at different stages of development: 1) Compressed air stored underground and combined with gas turbine 2) Compressed air stored over ground and combined with gas turbine 3) Compressed air stored underground incorporating heat storage (AACAES).

This system has a common compressor motor/generator-expander train. The system can be considered as a traditional type gas turbine having the compressor (1) and turbine (3) separated by the motor/generator (2), connected by clutches making separated operation possible. Compared to a traditional gas turbine the operating pressure is much higher and multi stage compression having intercoolers are needed when charging the caverns (4). When discharging, the natural gas is heating the compressed air before expanding through the turbine (3) driving the generator (2) and delivering electrical power to the grid. [56]

Long term batteries are used in

- Price arbitrage
- Balancing energy (supply &demand)
- Higher utilization and greater integration of renewable energy
- Ancillary services including, regulation, spinning reserve & MVAR generation
- Provision of black-start services

5.16. Electric and motors

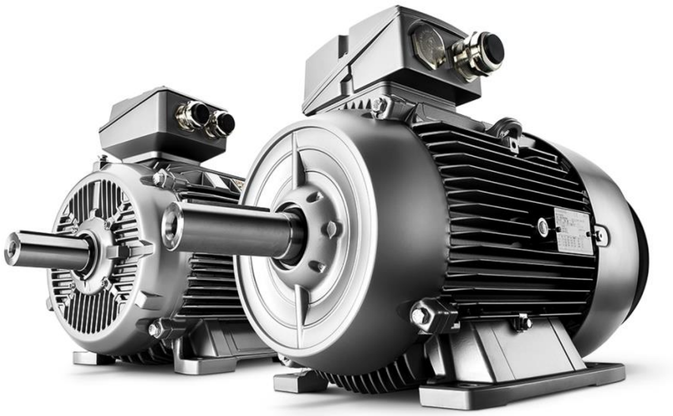


FIGURE 59: AC ELECTRIC MOTOR (SOURCE: SIEMENS AG 2016, AUTOMATION.SIEMENS.COM)

5.16.1. Standard efficiency electric motor

Standard efficiency electric motor is an AC powered induction electric motor. By IEC 60034-30-1 standard, standard efficiency motor belongs to IE1 class. Depending on power output of the motor, average nominal efficiency varies from 73 % to 93 %. Usually this kind of motors are made for constant speed (On/Off control, versions with selection between 2 or 3 speeds, but it is possible to retrofit them with VFD (variable-frequency drive), if they are compatible. VFD allows the control of the motor speed by the demand, which in long-term can save energy and money [57; 58].

5.16.2. High efficiency electric motor

High efficiency electric motor is an AC powered induction electric motor. By IEC 60034-30-1 standard, high efficiency motor belongs to IE2 class. Depending on power output of the motor, average nominal efficiency varies from 83 % to 95 %. The improved efficiency for high eff. motors is mainly due to better design with the use of better materials to reduce losses. However, this improved efficiency comes with 10 – 30 % higher price. Usually this kind of motors are made for constant speed (On/Off control, versions with selection between 2 or 3 speeds), but it is possible to retrofit them with VFD (variable-frequency drive), if they are compatible. VFD allows the control of the motor speed by the demand, which in long-term can save energy and money [57; 58].

5.16.3. DC ELECTRIC MOTOR

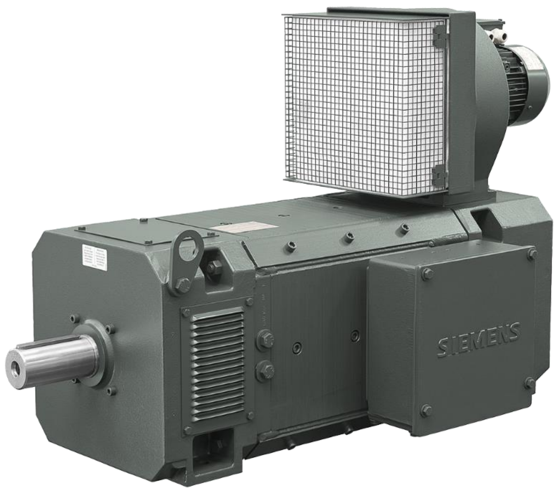


FIGURE 60: DC ELECTRIC MOTOR (SOURCE: SIEMENS AG 2016, AUTOMATION.SIEMENS.COM)

DC motor is electric motor which runs on direct current, most common types of DC motors are brush and brushless motor. Classical DC motors are with the motors with brushes, which are located on the stator and have function to carry the electric contact between commutator and rotor. Resulting friction wears brushes over the time and because of it, regular maintenance is necessary. Later brushless DC motors were invented, even though they are more expensive than brushed motors, but because they are maintenance free and more efficient they are becoming more popular. Traditionally in HVAC field AC motors are used, but nowadays growing trend is to use brushless DC motors, with most significant reason of dramatic reduction in required power for operating brushless DC versus typical AC motor. Speed control of brush DC electric motors is easier than with AC drives, as it requires only to variate the voltage, which is simpler than variating frequency. On the other hand, brushless DC motors require inverter, as the speed of rotation is controlled by pulse frequency [59; 60; 61].

TABLE 35: STRENGTHS AND WEAKNESSES ANALYSIS FOR ELECTRIC MOTORS

Strengths	Weaknesses
○ Reliable ○ Efficient ○ Easy to control (via VFD or directly in case of DC motor) ○ Possibility of installing VFD on old electric motor to enable demand control ○ Prices of VFDs and brushless DC motors are decreasing with every new generation	○ For high efficiency it requires expensive control system which needs to be configured by professional ○

5.17. LIGHTING

5.17.1. TUNGSTEN INCANDESCENT LAMPS

Tungsten lamps are the most classical lighting source, historically the most used in residential homes, public buildings and offices during the last decades. The technology exploits the high resistivity features of tungsten in two different ways. The most traditional tungsten incandescent (15 lm/w) electric lights is a technology directly based on the high resistivity of tungsten material. When electric current flows through the very thin tungsten filament, the Joule effect coupled with the high resistance (tanks to both the high intrinsic material resistivity and the low wire thickness) causes a very high temperature into the wire itself. The incandescent effect of the high temperature metal causes lighting. The tungsten halogen Incandescent lamp contains a small amount of halogen such as iodine or bromine added. The chemical reaction between tungsten and halogen re-deposits the evaporated tungsten back on the filament, increasing its life. The working temperature can be very high, with higher luminosity efficacy. Halogen-based lamps are more compact than traditional ones. Lamps of both typologies are covered by a glass bulb, which protects the filament and prevents users from electric and thermal accidents.

5.17.2. Fluorescent incandescent lamps

Compact fluorescent (60 lm/w) lamps technology is based on light-emitting properties of certain gases as phosphors. A glass bulb contains a mix of phosphors, and the standard threaded ferrule can be mounted on any electric lamp. When electric current is applied, the phosphor mix emits fluorescent light. This technology uses one fifth of electric power absorbed by conventional incandescent lamps.

Other kinds of fluorescent, non-compact lamps are Fluorescent T8 (90 lm/w) and Fluorescent T5 (100 lm/w): these lamps are tubes containing low-pressure mercury-vapour. An electric current in the gas excites mercury vapour, which produces short-wave ultraviolet light causing the glowing of a phosphor coating inside the lamp.

5.17.3. LEDs

In LED lamps for electric illumination solutions, LED (light emitting diode) technology is exploited in LED arrays for rooms lighting. A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode, where "p" (positive) side contains an excess of electron holes and the "n" (negative) side contains an excess of electrons, which emits light when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons (light). This effect is called electroluminescence, and the colour of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor. The luminance efficiency of LED array lamps can cover a wide range of values (namely, 60 - 120 lm/W). The first applications of this technology were not related to building lighting: they were used as indicator lamps for electronic devices, replacing small incandescent bulbs. They were soon packaged into numeric readouts in the form of seven-segment displays, and were commonly seen in digital clocks.

Recent developments in LEDs permit them to be used in lighting. LEDs have many advantages over incandescent light sources including lower energy consumption, longer lifetime, improved physical robustness, smaller size, and faster switching. Light-emitting diodes are now used in applications as diverse as aviation lighting, automotive headlamps, advertising, general lighting, traffic signals, camera flashes and lighted wallpaper. LEDs powerful enough for room lighting remain somewhat more expensive, and require more precise current and heat management than compact fluorescent lamp sources of comparable output.

5.17.4. OLEDs

What OLED stands for is organic light-emitting diode, in which the emissive electroluminescent layer is a film of organic compound that emits light in response to an electric current. This layer of organic semiconductor is settled between two electrodes; in the majority of instalments at least one of these electrodes is transparent.

Normally OLEDs are used to create digital displays in devices such as screens for televisions and computers, mobile phones, game consoles and tablets, etc.

Recently an area of research is the development of white OLED devices for use in solid-state lighting applications.

There are two main types of OLED, depending on what they employ:

- small molecules
- polymers.

Adding mobile ions to an OLED creates a light-emitting electrochemical cell (LEC) which has a slightly different mode of operation.

TABLE 36: STRENGTHS AND WEAKNESSES ANALYSIS FOR OLED

Strengths	Weaknesses
○ Generally, mature and well-known technologies ○ Low prices for purchasing standard light source ○ No need for maintenance or high qualified personnel for installation ○ Achieving very long lifetime and low energy absorption with innovative light technologies under development ○ Coupling with dimming and automatic control technologies for energy saving	○ High energy absorption and heat dissipation for tungsten incandescent lamps ○ High prices for OLEDs technology ○ Non-recyclable waste material production

5.18. Light Control

5.18.1. Manual switching

In building wiring, a manual light switch is a very simple device commonly used to operate electric lights, permanently connected equipment, or electrical outlets. Portable lamps such as table lamps will have a light switch mounted on the socket, base, or in-line with the cord. The working principle is simply based on opening or closing a certain arc of the electric network of a building. When the circuit is closed, electric current flows to the installed lighting source. Manually operated on/off switches may be substituted by remote control switches, or light dimmers that allow controlling the brightness of lamps as well as turning them on or off.

5.18.2. Standalone occupancy switching

Light sources can be automatically controlled in order to optimize the energy consumption, by the use of different technologies aimed to dimmer or switch on/off the various lamps in a building area.

One of these technologies is represented by occupancy sensors, whose working principle is based on motion of objects and people in the surrounding area. If no motion is detected, it is assumed that the space is empty, and thus does not need to be lit. Turning off the lights in such circumstances can save substantial amounts of energy. On the other hand, when people move and walk close to the sensor, the room gets automatically illuminated. Some more complex occupancy sensors also classify the number of occupants, their direction of motion, etc., through image processing principles.

5.18.3. Standalone daylight harvesting

Daylight harvesting is an energy management technique that reduces lighting use by utilizing the ambient (natural & artificial) light present in a space. They use daylight to offset the amount of electric lighting needed to properly light a space, in order to reduce energy consumption. This is accomplished using lighting control systems that are able to dim or switch electric lighting in response to changing daylight availability. They are designed in order to maintain a minimum light level.

The system main components are photo sensors and control modules. The photo sensors are aimed to constantly detect the ambient light intensity, outside (in an open-loop system) or within the space (closed-loop). The signal from the photo sensors is taken as input by a control module, which dimmers or switches the light on/off according to the real need and the pre-defined minimum light level.

Obviously, the working mode also depends on the light source features: if it is dimmable, then the artificial lighting may be continuously adjusted in proportion to the amount of daylight available. If the electric lighting is on-off only, then an electric lighting fixture or lamp must remain on at full output until daylight can meet the entire recommended light level for the space.

5.18.4. Light control combinations

Light control technologies can be differently combined in order to optimize their potentialities in different situations and applications. Examples of possible combinations are the following.

Standalone zone switching and daylight harvesting: light is automatically switched on/off on the basis of presence of people in a certain room of the building, while daylight harvesting reduces lighting use by utilizing the ambient (natural & artificial) light present in the controlled space. As previously seen, ambient light is detected by photo sensors and used to decide if dimming or switching OFF electric lighting. Networked switching, daylight harvesting, smart scheduling & load shedding: ambient light is detected and used to decide if dimming or switching OFF electric lighting; the light control is performed at a network level, with light information shared in an integrated automation/domotic system. The light control scheduling is programmable on the basis of comfort requirements with different features in different day periods. Load shedding functionalities allow an optimization of energy consumption by switching off electrical devices which are not essential for inhabitants' needs in a certain moment.

The combination of these technologies, also coupled with zone by zone standalone light controls, can help to decrease energy consumption for illumination.

5.19. User specific control

5.19.1. Thermostatic radiator valves

Thermostatic radiator valves are used in connection with hot water heating radiators. They are self-regulating on the basis of the surrounding temperature. The working principle can be passive, with a wax plug contracting or expanding according to the environment temperature. The plug moves a pin which closes the valve when the surrounding temperature increases. Otherwise, active valves are available on the market, having electronic temperature sensing and programmable logics.

5.19.2. Room thermostats

A room thermostat is a system designed to keep the desired temperature within a room, by acting remotely on heating and cooling systems. Occupants can easily manually set the temperature on the control unit (a command interface based on buttons, or a roller), and an integrated temperature sensor is used to evaluate if the heating, or the cooling system, has to be switched on in a thermostatic cycle. The system can only work manually, without programmable heating/cooling cycles. Digital versions can display error messages and codes to the user.

5.19.3. Programmable room thermostats

A programmable room thermostat is, as the standard manual room thermostat, a system designed to keep the desired temperature within a room, by acting on heating and cooling systems. Occupants can set the temperature on the interface module, and an integrated temperature sensor is used to evaluate if the heating, or the cooling system, has to be switched on in a thermostatic cycle. The main peculiarity of these more complex systems is that the operator can set different temperatures in different day periods, and the system will automatically work controlling the heating and cooling plants.

More complex thermostats may have also an external temperature probe and it may provide a progressive regulation of the heating, if the associated heating system is able to manage modulating energy request.

5.19.4. Zone & thermostatic controls

This kind of system is designed to keep the desired temperature within a house, room by room, and the desired level of stored hot water. Occupants can set the desired temperature for each room on the interface module (also remotely), and an integrated programmed logic is used to evaluate if the heating, or the cooling room units, have to be switched on in a thermostatic cycle. Different temperature in different day periods can be set by the operator, then the system automatically controls the plants.

This system is composed by a smart thermostat control with associated several temperature probes; nowadays, smart controls combine a touch screen programmable thermostat with Wi-Fi connectivity and intuitive free mobile App to allow busy households to monitor and adjust home comfort and energy consumption while on the go.

Thanks to web connection, some smart thermostat may modify adaptively the set points according to weather forecast condition.

Finally, it can monitor and adjust not only home heating and hot water conditions, boiler design settings but even energy consumption via the mobile App anywhere in the world via a Wi-Fi or cellular connection.

5.20. General control

5.20.1. Weather compensation

Is an intelligent system integrated with a Building Management System. It is aimed to control acclimatisation plants (heating, cooling, humidity control, temperature control) on the basis of data coming from one or more connected weather prediction stations, or temperature sensors. The aim of such a system is the fully automatic optimization of plants utilization, with proactive response to external climate stimuli.

The working principle is based on the signals coming from outdoor sensors, registering temperatures and other key factors as humidity. The electronic controller adjusts, if necessary, the heat supply (flow temperature) to reflect the new conditions. The controller will also adjust the heat supply to the radiators and ensure that room temperatures are kept constant. Thermal comfort for inhabitants is then ensured also during weather changes.

5.20.2. Optimisers, compensation

Optimisers are heating plants control systems based on the compensation of the external temperature. Changes in the outside temperature are detected by an intelligent electronic controller, which is integrated into the heating plant control system and pro-actively sets the optimal parameters to meet the correct heat demand, without exceeding the right energy consumption. Such systems are programmed to follow a self-adaptive heating curve, in order to optimize the energy absorption during the heating phase, with the smoothest trend without affecting the system performance (e.g., the optimal temperature reaching time). To do this, a set of outdoor temperature sensors is installed on the building, and the controller ensures that room temperatures are constant.

The most advanced versions of this kind of control system are also integrated with domestic hot water control, and can have weekly programmable clocks for heating and hot water control, holiday programme and automatic summer/winter operation switch.

5.20.3. BEMS

A Building Energy Management System (BEMS) is a computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical equipment such as heating, air conditioning, ventilation, lighting, power systems, according to the building needs.

A BEMS consists of software and hardware; the software program, usually configured in a hierarchical manner, can be proprietary, using such protocols as C-bus, Profibus, and so on. Vendors are also producing BEMSs that integrate using Internet protocols and open standards such as DeviceNet, SOAP, XML, BACnet, LonWorks and Modbus. Building Energy Management Systems can be installed on different building typologies, such as: residential homes, retail shops, schools, small and large offices, hotels, healthcare structures. At the time being, the BEMS are most used in large buildings rather than in small ones or homes, where 90% of the buildings have no Building Energy Management System (USA data). On the other hand, 50% of large offices, healthcare structures and hotels have a BEMS.

The most user-friendly feature of a BEMS is the interface, which can be used to only monitor or actively control heating, cooling, ventilation, lighting and other plants, which can be critical under the energy consumption point of view. Control and scheduling of different plants working are achievable by customizable dashboards and local/remote access, thanks to web-based applications, which are directly developed by the BEMS providers. These innovative interfaces allow the end user (the building owner, or inhabitants, according to the building typology) to control the system remotely by a computer or a mobile device, thus making the BEMS key parameters settable from theoretically every part of the world.

In a scenario where energy costs are one of the highest expenses for many small businesses, and HVAC and lighting represent about 70% of energy consumption, a BEMS can easily improve the comfort with a minimal impact on operation, by saving up to 30% on energy expenses for the building owner or user. This high energy saving potential contributes to a quick Return On Investment after the system purchasing and installation. The highest energy savings are achieved by acting on lighting and HVAC systems, in particular by switching on/off and dimming lights according to occupancy detection and scheduling processes, further than controlling blinds. HVAC system working can be e.g. scheduled and controlled according to occupancy detection.

FIGURE 61: SCHEMATIC REPRESENTATION OF BEMS ARCHITECTURE (CREDIT BY: © STAM S.R.L.)

Between the low-hardware level of plants to be controlled (HVAC, heating, lighting, etc.) and the high-level control and monitoring application, there is a middle-level controller, which integrates the control programmable logics and the web server capabilities for remote connection. Communications to this controller can be wired or wireless, inputs and outputs can be both analogue and binary. In the low-level layer, plants are monitored by integrated sensors sending real-time information about their key parameters to the control unit.

TABLE 37: STRENGTHS AND WEAKNESSES ANALYSIS FOR CONTROL

Strengths	Weaknesses
○ Energy savings thanks to optimal plant control ○ Status monitoring ○ Local and remote user interface ○ Easy user interface ○ Increase of property rental values ○ Enhancement of property marketability ○ Integration with a wide range of technologies	○ Complex installation and configuration ○ Informatics/electronic skills required during installation phase

6. Passive retrofit Technologies on neighbourhood scale

In the following is a list of suggested passive retrofit technologies that are applicable to the neighbourhood scale and have not already been described in the previous chapters.

6.1. Increase on Green Spaces

Ponds and trees were suggested to influence the micro climate within a neighbourhood or district and prevent the heat island effect. On grounds of technical issues for the necessary calculation and simulation in the NewTREND tool, these technologies cannot be realized.

6.2. Noise protection wall

To increase the acoustic comfort for inhabitants in buildings on noisy roads, near industrial areas or other noise sources, the adding of noise protection walls in the district information building (DIM) was contemplated. The calculation and simulation is too extensive to carry out in the scope of NewTREND. Therefore, no viable retrofit technologies are considered on district scale.

7. Active retrofit Technologies / interventions on neighbourhood scale

7.1. Local Heating Grids for neighbourhood retrofitting

Heating grid technology describes a heat distribution system with centralized heat generation, providing heat for residential, commercial such as industrial heating requirements. For the NewTREND scope the scale of district heating refers on small building neighbourhoods (max. 10 buildings), also called local heating communities. Heating grids in general are profiting by the effect of local load shifts, which can be displayed by the factor of simultaneity. The energy efficiency significantly depends on the number of dwellings and the type of heat consumers as well as the heat supply source. Furthermore, the installation of central heat supply systems enables the possibility of larger heat supply systems with enhanced efficiencies compared to building scaled technologies. The integration into a local heating network requires only a small amount of floor space for installations at each dwelling (house transfer station). The installation of a central heat supply station however does occupy additional space and an integrated design process. Heat supply for district heating

In the following chapters different heat generation types on neighbourhood scale are explained. Thereto the following six technologies were investigated.

- Gas boilers (Chapter 7.1.1)
- Geothermal (Chapter 7.1.2)
- Solar thermal collectors (Chapter 7.1.3
- Heat pumps (Chapter 7.1.4)
- CHP (Chapter 7.1.5)
- Combined cycle gas turbine (CCGT)(Chapter 7.1.6)

This chapter treats the heat generation systems on neighbourhood scale. The described technologies are in principle the same as on building scale. Therefore, special attention is placed on the differences and special aspects regarding district scale heat supply systems, which will be explained in the following chapters. For each technology given, there is a reference to the technology description in the chapters of building scale mentioned. Furthermore, the descriptions on district scale characterise the combination of several technologies to illustrate the potential on NewTREND scale in retrofit.

The heat generation on district scale point out different systems for district heating. District heating networks are designed to supply several buildings within a neighbourhood or a district. For the design mostly auxiliary heating system are not planned. The heat distribution from the heat generation to the consumers is handled by piping systems, while the transfer to the consumers in each connected building is done by a heat exchanger (heat transfer station). The efficiency and feasibility of district heat networks relates to several factors, which are shortly explained in the following:

- **Heat density [(MWh/a)/$m_{heat\ net}$]**

  At low district density, the length of the heat net is usually longer than in dense neighbourhood structures. The length is one criterion that affects the heat density of a district. The other one is the total annual amount of heat demand. A general threshold value is about 1.5 MWh/($m_{heat\ net}$ x a). This value mainly bases on the design of conventional heating grids T >90°c. Heating grids with lowered mean temperatures may already be feasible at heat densities

< 1 MWh/($m_{heat\ net}$ x a). A more detailed examination of heat density thresholds regarding heat grid temperatures can be found in deliverable D2.3 of the NewTREND project.

- **Characteristics of piping**
  Besides the length of the heat network, which is crucial for the determination of heat losses by transmission, also the dimensioning and type of insulation for the piping (Chapter 4.2.8) are important aspects which need to be considered. Moreover, the selection of the piping material may affect the general efficiency of the grid, as well as the fact whether piping is buried or not. Further the length of the heat net is important for the overall design of the heat grid including pumps or horseshoe bends for extends.

- **Availability of a storage system**
  The availability of an existing storage system is important for the design of the heat generation system. The installation of storage capacities supporting the heat supply system can have a significant impact on runtime hours and efficiencies of the heat supply technologies. However, especially for the retrofit of a district the space demand for the integration of a (long-term) storage (Chapter 7.3) needs to be wisely considered.

- **Height difference between generation and highest consumer transfer station**
  The height difference between the lowest and highest point in the heating network is clearly determining the dimensioning for installed pump power (Chapter 5.16).

- **Mean heat grid temperature [°C]**
  The mean temperature of a heating grid should be as low as possible to reduce heat losses. Further the spread of supply and return flow temperatures should be as high as possible to increase the heat network efficient.

- **Design of heat generation/supply system**
  Besides general efficiency factors for different heat supply technologies, especially a reasonable design and dimensioning of heat supply systems is significant for runtime hours and operation grades of the system. For this it is crucial to determine precisely the total heat load by considering the number of dwellings connected to the grid and the effect of time-based load shifts. The so called simultaneity factor may reduce the maximum peak load of the district up to ~40%. Further the coverage of different heat load factors (base load, medium load, peak load) needs to considered in the design of heat supply system (combination of several supply technologies).

- **Type of used fuel**
  For conventional and energy efficient heat supply technologies, running on fossil fuels, it is important to consider the used fuel and its impact on CO2 emissions. Regarding efficiency factors the specific caloric value of the fuel also effects the incineration process any by that the overall efficiency of a system. Other points to consider within the selection of the fuel are the storage or supply piping and eventually the planning for an access road.

The types and technologies of heat generation are described in the following sections. Usually heat supply systems for heating grids do not only consist of a single heat supplier but rather different suppliers to meet the variable heat loads in the neighbourhood. Therefore, it is useful to apply to the following characteristics of heat loads:

Base Load:

- operation at design load point
- high number of operating hours
- rare load changes
- includes annual domestic hot water generation.

To cover base load demands the usage of CHP (Combined Heat Power Systems) can be a quiet suitable and energy efficient heat supply system.

Medium Load:

- main heat supply system (advanced base load)
- 50% of load serves ~ 90% of total work energy sum (base + medium load)
- alternating heat loads point out potentials for design storage capacity

To cover medium load demands the usage of HP (Heat Pump Systems) can be a quiet suitable and energy efficient heat supply system, which largely enables the implementation of RES (Renewable Energy Sources) to the heat supply system.

Peak Load:

- Operation at partial load range
- low amount of operating hours
- frequent load changes
- fast demand-load response
- very high availability

To cover peak load demands usually only the usage of boiler system (natural gas, biomass) is possible, due to the fast demand load responses.

7.1.1. Local heating grids with gas boilers (natural gas or bio gas) or biomass

Gas boilers (Chapter 5.3) with natural (Chapter 5.1) or biogas (Chapter 5.2) on neighbourhood level have much more capacity than on building scale. For a higher efficiency the gas boiler is placed in a local plant building in the centre of the neighbourhood or as near as possible to prevent long piping distances between heat generation and consumers. The efficiency of the local heating network can be increased by the implementation of storage capacities (Chapter 7.3). The firing of natural gas provides heating values of 8.5 - 13.5 kWh/m³ depending on varying gas types. In the case of biomass, it can be distinguished between solid and liquid forms. They are showing different characteristics in its heating values, solid biomass 5.1 kWh/kg and liquid biogases 10.2 kWh/kg. To generate heat for district heating biomass is combusted with an efficiency rate of (η = 0.85). In case of the use of boilers that use biomass (Chapter 5.2) the place demand for the storage and access road for the delivery of the biomass needs to be considered. Another point is the exhaust fumes that are generated by the incineration of the biomass. Modern exhaust filter systems and the height of the chimney are necessary to prevent problems with surrounding buildings and their inhabitants. In relation to the weather data (Chapter 2.2), the main wind orientation needs to be considered into the planning process for the movement of exhaust fumes.

7.1.2. GEOTHERMAL HEAT SUPPLY

The geothermal potential can be diverted in to shallow and deep geothermal potentials. Shallow geothermal installations refer to depths up to 400 m below the surface, whereas the deep geothermal potential refers to depths between 400 m – 5,000 m. For the utilisation of low enthalpy geothermal energy, it is intended to exploit the ground as a source/sink for thermal energy exchange employing a heat pump for the thermal conditioning of buildings, see Chapter 5.5.2. Below a depth of about 15 – 20 m the geothermal temperature is not affected by specific surface conditions anymore. Shallow geothermal applications are suitable for residential heating and cooling issues.

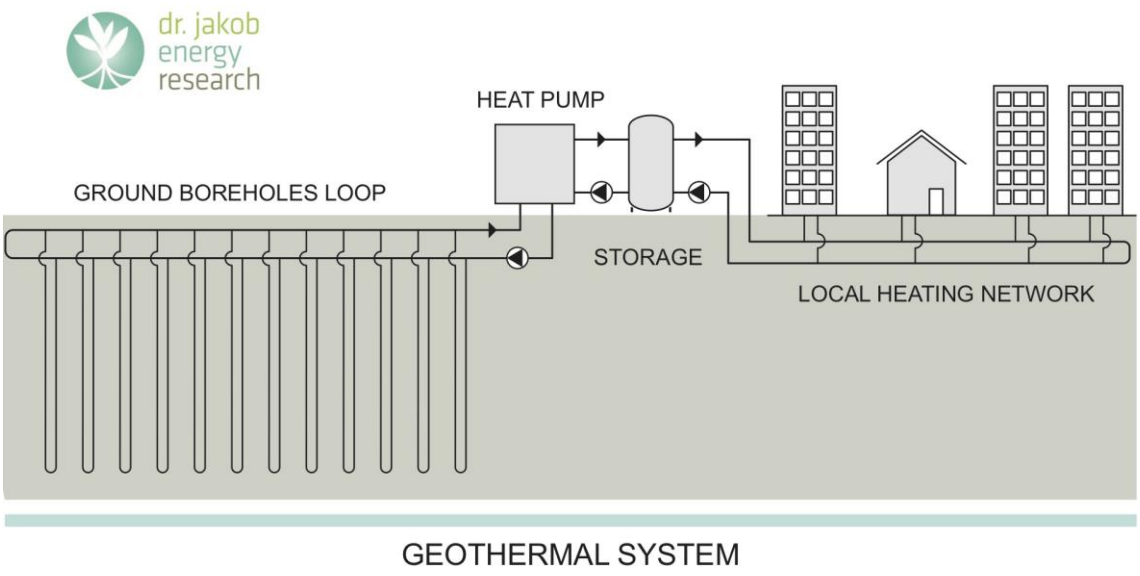


FIGURE 62: FUNTIONAL SCHEME OF A GEOTHERMAL HEATING NETWORK (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

Deep geothermal installations however can also be used for industrial and large scale heat generation as well as power generation systems (ORC). The shallow geothermal potential is usually not differing much between locations all over Europe, whereas deep geothermal potential depends moreover on geological characteristics. For the purpose of a direct neighbourhood heat supply via geothermal probes only deep geothermal applications are useable. The existence of hot sedimentary aquifers and other reservoirs can be found all over Europe. There are for example places which are showing temperatures > 50°C at 1000 m and others > 90°C at 2000 m. This range of temperature level is substantial for the application in local heating grids. The supply of local heating networks by deep geothermal applications has to examine closely in any case. The scope of supplying only a small neighbourhood by a deep geothermal application might be not economic for small scale purposes.

7.1.3. SOLAR THERMAL COLLECTORS FOR LOCAL HEATING NETWORKS

Local heating concepts with solar thermal collectors require larger collector areas than on building scale. The technology and functionality behind the collectors is the same as described in Chapter 5.6. Both of the described collector types in this chapter can be used and installed either on free ground or roofs of the surrounding buildings of the network and district. Solar district heating systems can supply an existing local heating network or feed a separate heating network. For the increase of the efficiency of solar district heating(SDH) network a seasonal storage (Chapter 7.3) can be integrated, which may lead to a solar fraction up to 50% of the total heat supply of the SDH network. Besides the total head demand, which depends on building standards and retrofit interventions, also location characteristics with its solar radiation (Chapter 2.2.3) has an impact on the feasibility of solar heating networks. Depending to the specific heat distribution system supply temperatures are often lower after building retrofitting, which is favourable for solar thermal plants.

In general there are two different connection types of solar district heating networks- central and peripheral (Figure 63).

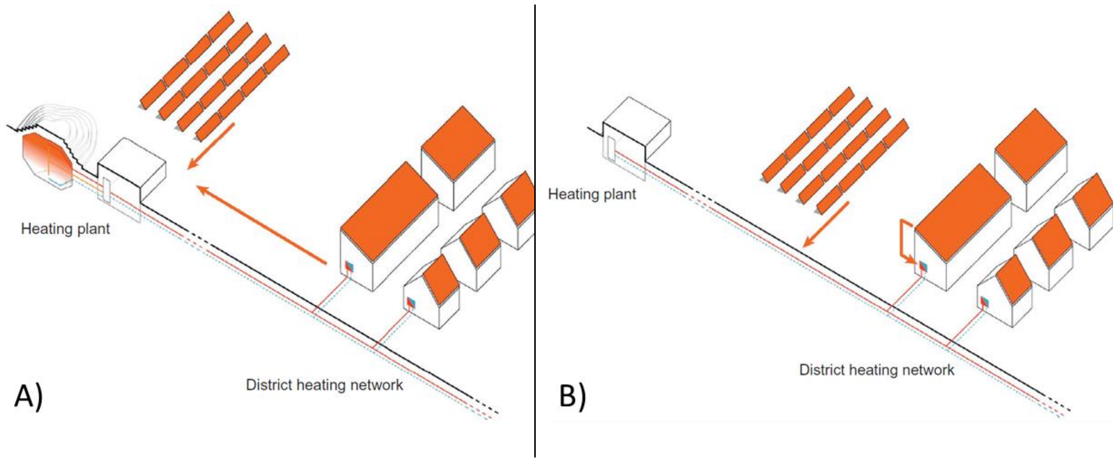


FIGURE 63: CENTRAL (A)) AND PERIPHERAL (B)) INTEGRATION TYPES OF SOLAR THERMAL COLLECTORS INTO A LOCAL HEATING NETWORK (SOURCE: SOLITES ,STEINBEIS RESEARCH INSTITUTE SOLITES)

An important aspect to consider at the dimensioning of SDH systems referring to the contribution of solar heat to the total heat load is the so-called solar fraction. While large solar thermal plants can be used as a preheater with solar fractions up to 5%, systems with about 15% annual solar fraction can reach a 100%-coverage during summer [62].

The different types of SDH systems are the following. For the scale of NewTREND only the first three system types are appropriate:

- **SDH for block heating in quarters**
  A valid option for heat supply in retrofit or new construction of urban districts, the heating networks are often planned as block heating systems. The solar fraction of such systems is up to 20%. The remaining 80% are often supplied by fossil fuel or biomass-fired boilers [62]. Due the lack of free areas for the installation of solar thermal collectors a possibility is to integrate the collectors on the roofs of the connected buildings within the district. Furthermore, the implementation of heat storage requires respectively space demand.
- **SDH with long-term heat storage and high solar fraction for block heating in quarters**
  An optimized variation of type 1 is the implementation of long-term seasonal heat storage (Chapter 7.3). Given that the solar fraction of the total heat demand of the district can reach up to 50%. The solar thermal heat is stored from summer to the heating period in winter [62]. A problem is the space demand for the integration of the long-term seasonal storage within a retrofit, because of the large space demand. The volumes of such storages are between 1,000 and 100,000 m³.
- **Decentral integrated solar thermal plant for quarters**

A possibility for districts with an existing district heating network can use as the grid as storage. The installation of the thermal collectors can be on the roof or on free spaces within the district. Instead of a separate storage the surplus of the generated heat is feed into the existing DH system. In comparison with the system of type 3 it is less cost intense due the saving of the storage costs. The remaining heat demand of the heating network is covered by the standard substation of the DH system.

- **SDH systems for small cities and communities**
- **SDH systems with combined electricity and heat supply for small cities and communities**
- **Large-scale solar thermal plants with decentral integration into large urban district heating systems**
- **Large-scale thermal plants with central integration into large urban district heating systems**

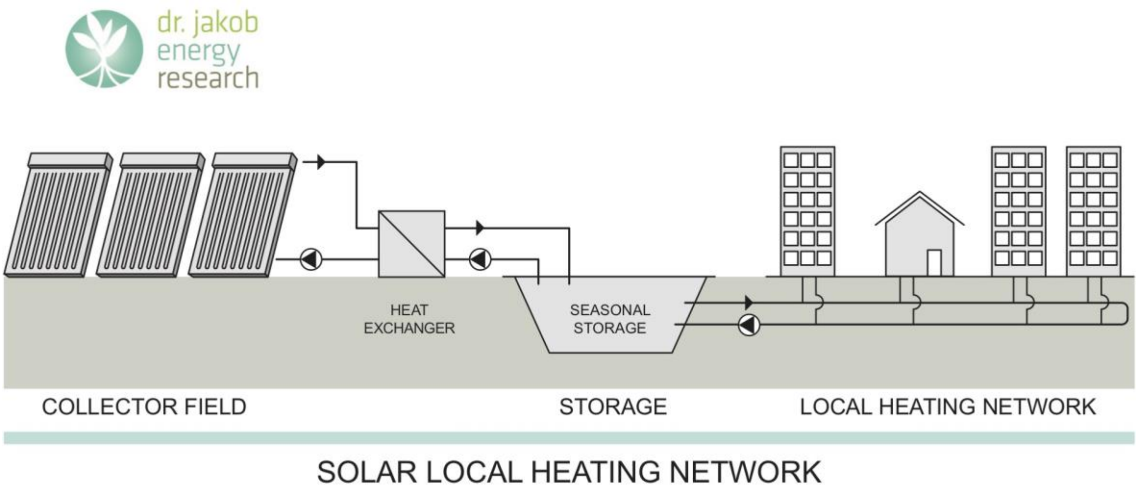


FIGURE 64: FUNTIONAL SCHEME OF A SOLAR LOCAL HEATING NETWORK (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

7.1.4. HEAT PUMP FOR LOCAL HEATING GRIDS

Nowadays trend exists to integrate heat pumps in a local heating network. Those are primarily large scale heat pumps usually ground source, water source or even use heat from sewage system as a source. Additional benefit of using heat pumps in a district scale is that there is the possibility of using it as a centralized local cooling system.

Performance (COP) of the heat pumps depends on a temperature difference between heat source and sink. Existing local heating systems usually have high temperature and adding heat pump to that system wouldn't be as efficient as expected. Therefore, retrofitting buildings and their heating systems should be done in a way which would lower the in/out temperatures of the circulating hot water. (COP will increase by typically 5 % if the supply temperature is lowered by 5°C). Alternatively, it is possible to install multiple heat pumps in a series, in such a case each heat pump then can operate with a smaller temperature difference.

Interesting example with sea water heat pumps as a source for local heating was done in The Hague, Netherlands. System takes heat from seawater and supplies it to low temperature network with primary heat pump maintaining temperature range between 11°C and 18°C. In every of 789 apartments which are supplies with this network secondary water to water heat pump is installed. Secondary heat pumps use the low temperature network as their heat source and raise the temperature to 45°C for underfloor heating and to 55-65°C for DHW. This solution allows relatively high COP (two-stage heat pumps), low heat losses from distribution network and no need for antifreeze in secondary heat pumps. Alternatively, in summer this system can be used for cooling of the apartments.

Using air source heat pumps on a local scale is more problematic as large heating need in a district would require a lot of space available for installation of outdoor air heat exchangers and there would be a noise issue as well. For using waste air heat pump on a local scale, large amount of waste air is needed and probably waste air volume from a single building exhaust is not a significant amount. District with industrial sites could have higher potential for including waste air heat pumps into local heating network [63; 64].

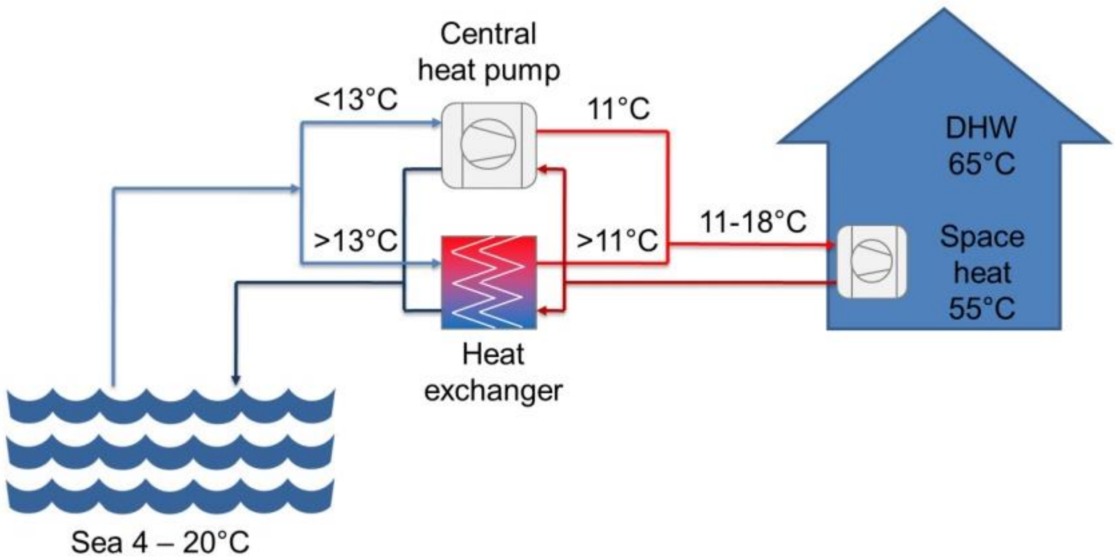


FIGURE 65: SIMPLE SCHEMATIC OF LOCAL HEATING SYSTEM IN THE HAGUE, NETHERLANDS [65]

7.1.5. CHP (BIOMASS AND NATURAL GAS) FOR LOCAL HEATING GRIDS

CHP (combined heat power) plants for local heating are providing heat and power with partial efficiencies. In general the same boundary conditions for CHP units are valid on local scale like they are on building level, see Chapter 5.4. An overall efficiency for large scale CHP is given with (η = 1.64). The technology serves a wide range of performance rates (5 kW - 10 MW). Continuous and long periods of annual operation are having a significant positive effect on its economic efficiency. Besides the storage of thermal energy in short- or long-term storages, to optimize runtime hours of the CHP, also the possibility of storing electrical power can be considered. Depending on the consumers within the heat network a local network for electricity can be installed. To better meet time-shifts between generations and demand battery storage (Chapter 5.15) can be installed in the neighbourhood. Another possibility is the feed-in of surplus in the local grid. Due to the combined heat & power generation CHP are very suitable for the usage in district heating and smart grids.

In principle the firing of CHPs can be realized with different fuels, like biogas and natural gas. Even the incineration of solid biomasses, like wood chips and pellets can be considered. Practically this means different designs of model types for CHPs. The firing of natural gas provides heating values of 8.5 - 13.5 kWh/m³ depending on varying gas types. In the case of biomass, it can be distinguished between solid and liquid forms. They are showing different characteristics in its heating values, solid biomass 5.1 kWh/kg and liquid biogases 10.2 kWh/kg. To generate heat for local heating biomass is combusted with an efficiency rate of (η = 0.85). The availability of biomass depends on local conditions and its storage can be quite extensive and spacious.

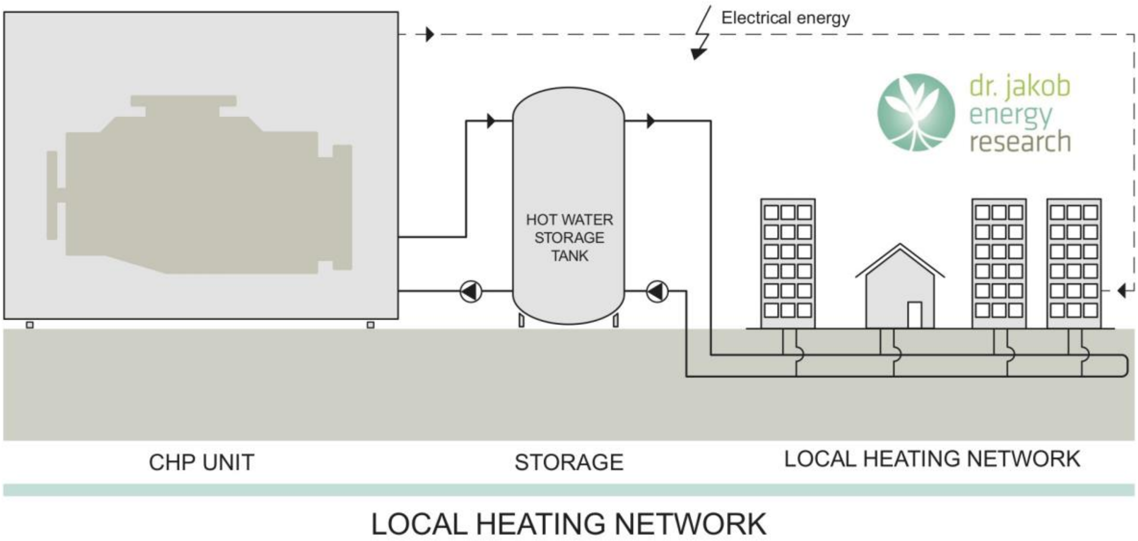


FIGURE 66: LOCAL HEATING NETWORK WITH COMBINED HEAT AND POWER SYSTEM (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

7.1.6. LOCAL HEATING WITH GAS CCGT (COMBINED CYCLE GAS TURBINE)

The installation of a central heat supply station however does occupy additional space and an integrated design process. CCGT (combined cycle gas turbine) (Figure 67) plants for local heating are providing heat and power with different efficiencies. An overall efficiency for this technology is given with COP 2.22. Continuous and long periods of annual operation are having a significant positive effect on its economic efficiency. Due to the combined heat & power generation CHP are very suitable for the usage in local heating and smart grids.

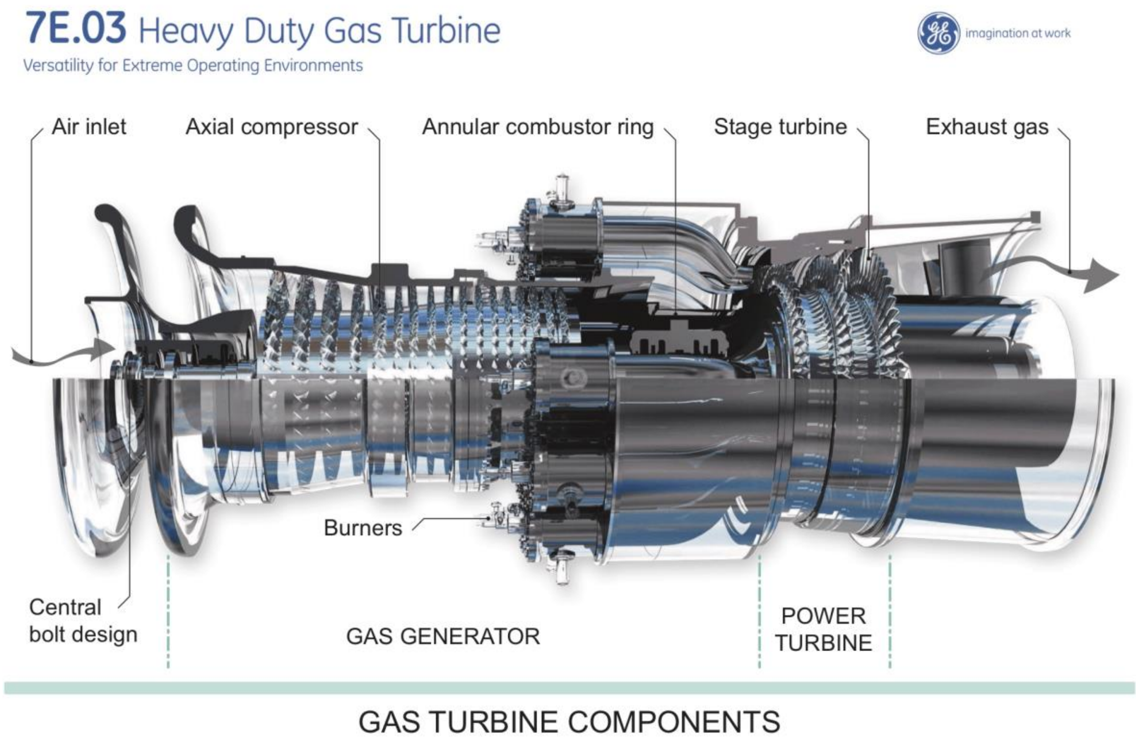


FIGURE 67: SCHEME OF A GAS TURBINE (CCGT) (SOURCE: PHOTO CREDIT: GE)

A combined cycle gas turbine consists of a gas turbine with heat recovery steam generator. This generator runs the steam turbine by a back pressure or a steam extraction system. Most frequent usage sites are in the industry or meanwhile for the energy supply of districts or neighborhoods. One benefit of CCGT is the higher electrical efficiency (min. 40%). The costs of a CCGT plant are about 1,000- 1,600 EUR/kW_{el}. Combined cycle gas turbines can be driven in two operation modes:

- **Back-pressure steam turbine operation:** The steam turbine is a non-condensing machine where all the exhaust steam is utilized for heating or processing at a lower pressure level. In this mode the turbine can be run fired by boiler or unfired.
    - **Controlled extraction steam turbine operation:** The steam extraction depends on the steam demand, while the remaining steam is condensed. This operation mode is more feasible for district heating plants. [66].

The exhaust steam from the steam turbine can be used efficiently for district heating plants by heating up water in steam condensers. Therefore, are two possible systems. One is the back pressure mode. More efficient is heating up the return water of the district heating grid in an economizer after the heat recovery steam generator [67].

TABLE 38: STRENGTHS AND WEAKNESSES ANALYSIS FOR LOCAL HEATING

Strengths	Weaknesses
○ High efficiency ○ Central heat generation with small heat losses ○ Reduced supply temperatures of heating grid positively affects the inclusion of RES for local heating grids enables the implementation of waste heat sources (neighbourhood) ○ Acquisition of subsidies possible (depending on the location and boundary conditions)	○ Retroactive installation might be elaborative referring to installation of the piping system ○ Additional space requirements for central heating station ○ Incorrect design of CHP dimensioning may lead to unfavourable operation loads (→ low efficiency) ○ Feed-in rates as design aspect for CHP: legal changes may deteriorate rates for feed-in into power grid

7.2. Local cooling networks for neighbourhood retrofitting

7.2.1. Local cooling grid with electrical and absorption chillers

Besides local heating networks, such thermal networks can also be installed for local cooling. Especially in regions with a high cooling demand and a high number of cooling hours per year referring to the weather analysis (Chapter 2.2), suchlike networks with a central cold generation are feasible. Possible systems for the cold generation are electrical or thermal driven chillers (Chapter 5.7).

For electrical driven chillers (Figure 68), like vapour compression chillers, the potential of the combination with photovoltaic panels (Chapter 5.12) on neighbourhood scale is given. The panels can either be installed on the roofs of the buildings or on free areas within in the neighbourhood.

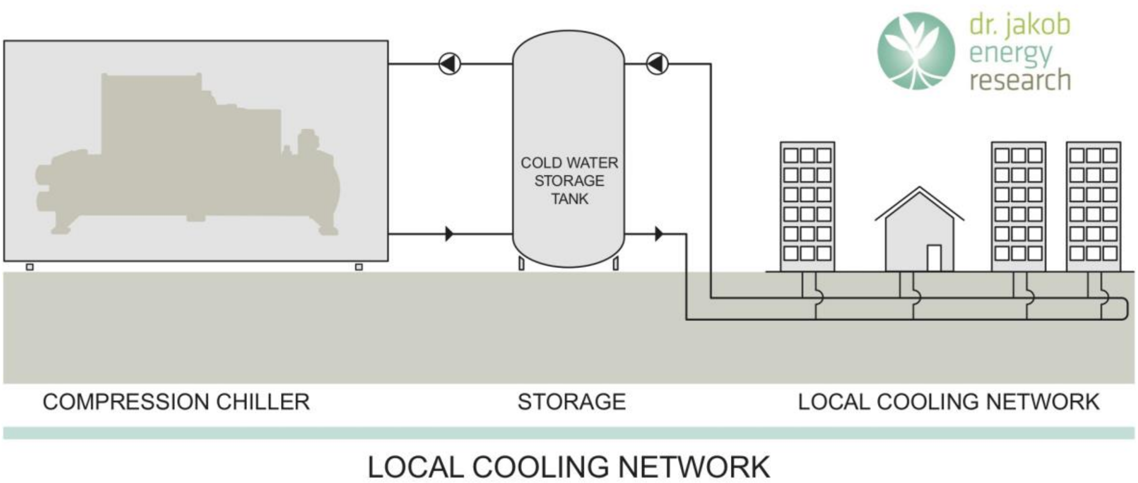


FIGURE 68: LOCAL COOLING NETWORK WITH ELECTRICAL DRIVEN CHILLER (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

Thermal driven chillers (Figure 69), first of all absorption chillers, are very feasible for the cold generation within a local cooling network. In combination with solar thermal collectors they are very efficient (Chapter 5.7). In summer the generated heat from the collectors can be used for cold generation and DHW, while in winter the heat is used for DHW and heating.

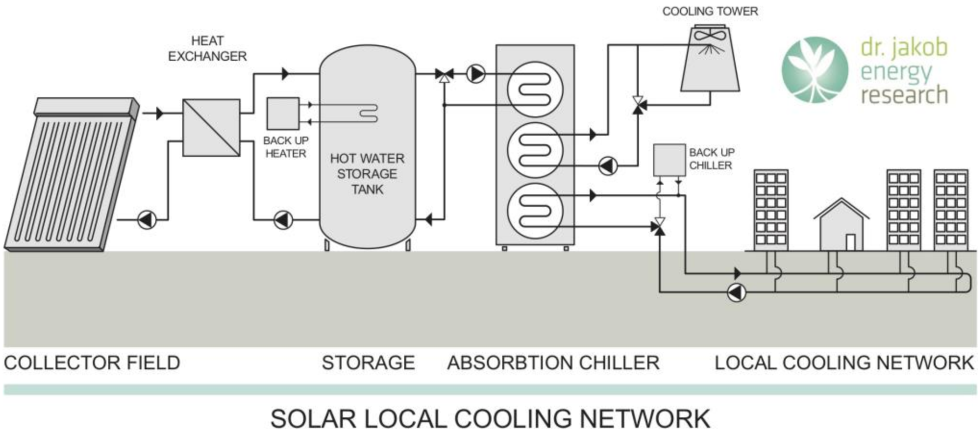


FIGURE 69: LOCAL COOLING NETWORK WITH SOLAR THERMAL DRIVEN CHILLERS (CREDT BY: ©DR. JAKOB ENERGY RESEARCH GMBH & CO. KG)

For both mentioned systems the space demand for the chiller and eventually the panels or collectors needs to be considered. As aforesaid in Chapter 7.1 the boundary conditions are nearly the same as for the design of a heating network, except the heat density. Instead of this criterion the total cold demand of the neighbourhood is the crucial factor.

TABLE 39: STRENGTHS AND WEAKNESSES ANALYSIS FOR LOCAL COOLING

Strengths	Weaknesses
○ Substitution of peripheral chillers and small, inefficient air conditioning units ○ High operation efficiency of large central chiller ○ Reduced maintenance effort ○ Use of cheap waste heat (for thermal driven HPs) ○ Usable in regions with very long cooling periods or districts with constant cooling demand ○ Use of renewable energy systems (solar thermal or CHP for adsorption chiller and PV for compression chiller) ○ Thermal driven chillers may relieve electrical ○ grid in peak hours of cooling demand	○ Rather high investment costs ○ Changing cooling demand due to retrofit interventions can cause bad influence on efficiencies.

7.3. Storage

7.3.1. Sensible thermal storage

Sensible thermal storage is based on the temperature change in the material. Storage capacity depends on heat capacitance and temperature change. Possible sensible heat storage media are liquids (typically water) and solid materials (soil and gravel) which can be used in several forms, listed in following sections.

7.3.2. Water

Water is the most common used storage due to its high thermal capacity and low cost. It main inconvenience is its limited temperature range (20-80°C), which doesn't affect residential applications for space heating and DHW. Water as a thermal storage is used usually in these forms:

- **Water tanks:** Either artificially constructed or using geological cavities. Constructed tanks can have different heat transport configurations, such as: immersed coils exchanger, external heat exchanger or mantle-heat exchanger (double walled storage tank). Largest differences between water tank types are in temperature stratification, performance and price.
- **Aquifer:** Wells are used to carry water to/from the aquifer, allowing the transport of heat (as shown in Figure 70). Aquifer storage has potential for economical large scale and long term energy usage and it is best suited for high capacity systems. Designer need to take in consideration potential environmental consequences.
- **Solar ponds:** Surface water (ponds or lakes) can be used to collect and store solar heat. Solar ponds contain salt solutions. Higher salt concentration is located at the bottom of the pond (salinity gradient), what keeps the absorbed heat at the bottom. At the surface of water, cooler water is located which serves as insulating layer to stored heat. Solar ponds are economically viable in regions with little snow fall and where land is readily available.

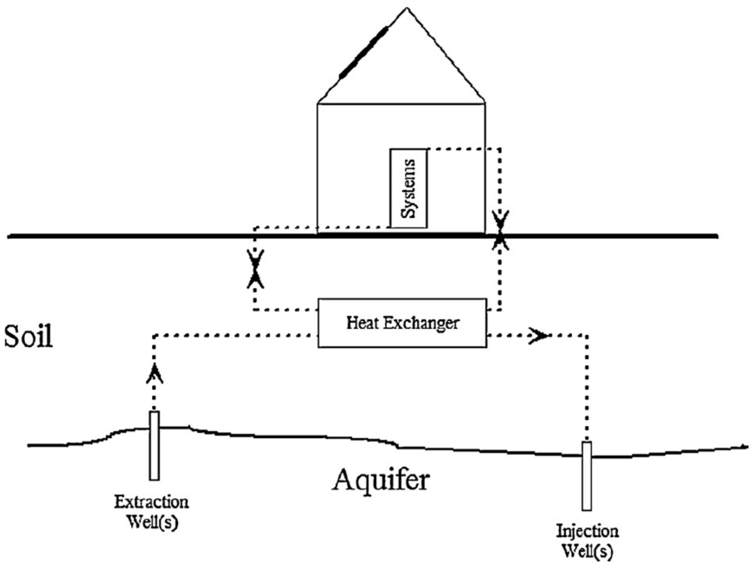


FIGURE 70: AQUIFER STORAGE (SOURCE: PINEL P., ET. AL., 2013)

7.3.3. Rock beds (Gravel)

Rock bed storage consists of having heat transfer fluid (usually water or air), circulate through a bed of rocks, discharging/charging heat to/from it. If air is used as a heat transfer fluid, rocks are the only storage medium, while water as heat transfer medium contributes to the storage as well. Rocks have lower thermal capacity than water (requires three times more space for storage of same amount of energy), but can contain higher temperatures and are easier to contain. Cost of rock bed storage is proportional to the size of system (excavation and insulation), so for this reason it should be considered for seasonal storage mostly when geological conditions favour this type of system. On following figure rock bed storage system is presented.

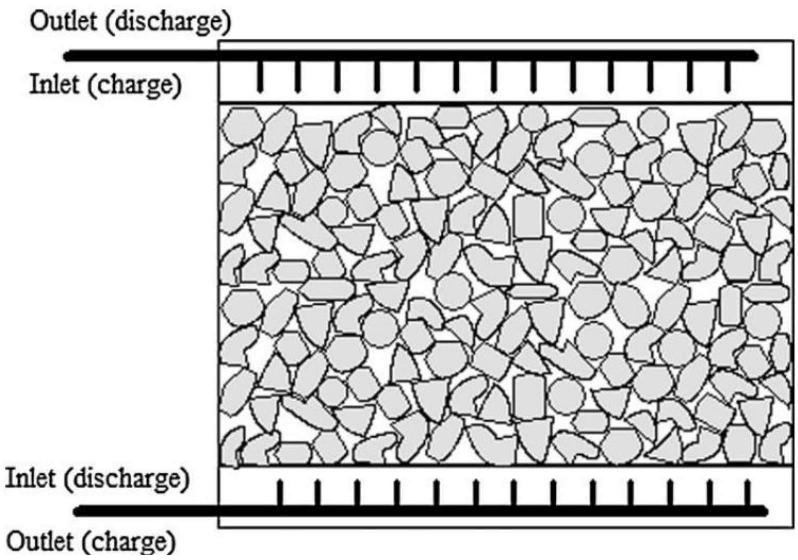


Figure 71: Rock bed storage system (Pinel P., et. al., 2013)

7.3.4. Ground (Soil or solid rock)

The use of ground as a passive storage medium uses soil or solid rock, which is free medium. System needed for storage is similar to ground-source heat pumps, where ground is drilled or excavated to insert tubes, in which transport fluid circulates, injecting/extracting heat in/from the ground material (Figure 72). Even though medium is free, excavation or drilling and installation of system parts have a significant cost.

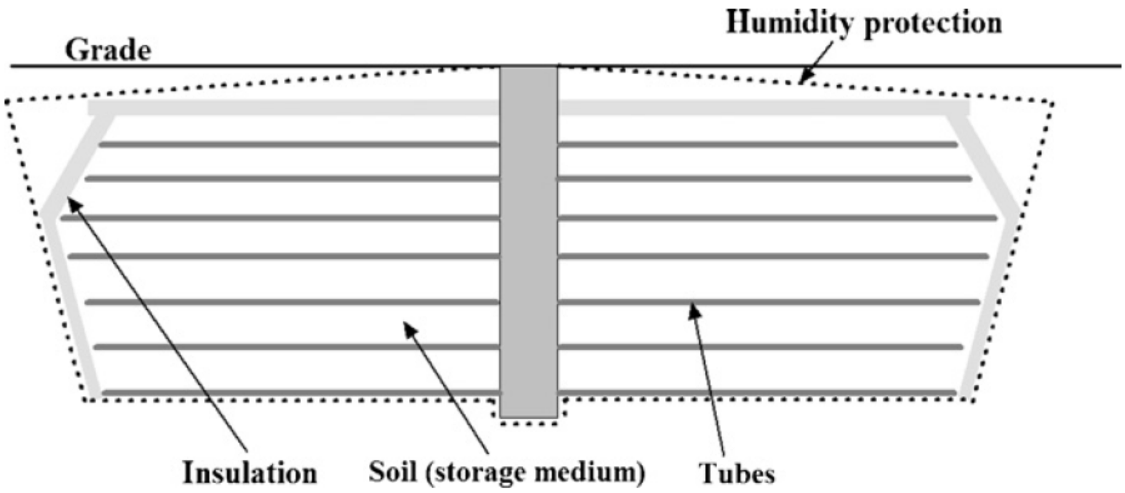


FIGURE 72: GROUND PASSIVE STORAGE SYSTEM WITH VERTICAL TUBES (SOURCE: CHUARD & AL)

7.3.5. LATENT HEAT STORAGE

Latent heat storage is based on absorption or release of heat when storage medium undergoes a phase change from solid to liquid, liquid to gas or vice versa. Mediums in latent heat storage are called phase change materials (PCM). Unlike traditional medium used in sensible storage, PCMs absorb and release heat at a nearly constant temperature and they store 5-14 times more heat per volume unit than sensible storage mediums.

Three categories of PCM materials used for latent heat storage exist:

- Organic PCMs (paraffin, fatty acids, alkanes)
- Inorganic PCMs (salts)
- Eutectics

Inorganic PCMs have characteristics if being non-toxic, non-flammable and economical, while they have corrosion difficulties to storage container, phase separation and segregation and lack of thermal stability. Organic PCMs can be toxic, flammable and expensive, but they have infinite life cycle.

Latent heat storage can be in form of container, where heat is absorbed or released by heat transfer between PCM and heating/cooling medium or it can be as a part of a building (PCM in walls, floors, ceilings, shutters...) [68; 69].

TABLE 40: STRENGTHS AND WEAKNESSES ANALYSIS FOR STORAGE ON DISTRICT SCALE

Strengths	Weaknesses
○ Lower energy costs ○ HVAC system can be smaller in capacity than the required peak ○ HVAC system works with higher efficiency ○ Possible to store free energy and use it when it is needed ○ Possible to implement it as a seasonal storage	○ District scale storage system requires a lot of space ○ Some types require certain environment available near the site (aquifer, rock bed) ○ Some types of latent storage can be toxic and flammable ○ Possible legal restrictions and permits needed ○ The systems can have high price ○ Problematic to extend underground storage if more capacity is needed ○ Neighbouring underground seasonal storage or heat pump can decrease capacity of the storage

7.4. Electricity

7.4.1. Photovoltaic

As mentioned before (Chapter 5.12) Photovoltaic technologies are based on PV panels/units and therefore it is a scalable solution that can be installed at any scale (both building and districts). The only difference is the total power installed; obviously for district application the power should be bigger than plants that are bound to cover partially a building demand. In terms of installation, PV facilities can be ground or roof mounted depending on the space availability.

In terms of installation, a solar panels can be *mounted on rooftops*, *Ground-mounted or directly integrated in the building features,* depend on the application and the space available.

Regarding those arrays which are installed at roofs, if the rooftop is horizontal, the array should be mounted with each panel aligned at an angle. In the case of already constructed buildings, it is relatively easy to install panels directly on top of existing roofing structures. However, in small some roofs that are designed so that it is capable of bearing only the weight of the roof, installing solar panels demands that the roof structure must be strengthened before. As an alternative solution, there are some low-weight designs for PV systems that can be used, made by light materials such as extruded aluminium or plastic. In other cases, the weight of the removed roof materials can compensate the additional weight of the panel structure. Therefore, there are multiple roof-mounted configuration and its selection will depend on the technical characteristics of the building at hand.

Ground-mounted PV systems are used in large photovoltaic power stations, when it is required large land surface. In order to ensure their stability, land should be prepared to support the weight of the whole structure and foundations are also required.

Building-integrated photovoltaics (BIPV) are photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades. They are becoming more popular in new buildings or in existing buildings during major renovations. Figure 73 shows an example of this technology integrated into shingles. In some cases, BIPV can add cost and complexity to a project and may not be universally available, but may help enhance acceptance of a project on a visible surface [52]

FIGURE 73: THIN-FILM SOLAR PV SHINGLES (SOURCE: PHOTO BY UNITED SOLAR OVONIC, NREL 13572).

7.4.2. WIND TURBINE

Wind energy for district applications is not usual. Large wind turbines or wind parks are no applicable to residential areas, as they are usually installed in high and remote locations due to noise levels and required weather conditions. However new smart grids systems consider an area with energy resources (that could be a district of buildings) as whole energy systems, managing the surplus of energy production between buildings. At the same time, in small settlement with ideal conditions for wind turbine installation and enough room to meet distance requirements from these systems to buildings, small wind turbines (around 100 kW) make sense. These are not residential turbines but are community-sized wind turbine that produces the right amount of power for school and university campuses, residential developments, farms, municipalities, and a variety of businesses.

The height of the turbine tower is a key factor determining the operational efficiency of the turbine because wind speeds generally increase with height above ground (with wind energy increasing exponentially as a function of wind speed), and because there should be sufficient clearance between the lowest tip of the turbine blade and any nearby natural or man-made structure to minimize local air turbulence. As a rule of thumb the wind farm should be 650 m away from habitation. "Putting a turbine on too short a tower is like putting a solar panel in the shade" [51]

In complex terrain, selecting the installation site is a challenge. If the wind turbine is installed on the top of or on the windy side of a hill, for example, it will be more access to winds than in valley or lower ground on the same property. In addition to geologic formations, it is important to consider existing obstacles such as trees, houses, and sheds, and plan for future obstructions such as new buildings or trees that have not reached their full height. Turbine needs to be sited upwind of buildings and trees, and it needs to be around 10 metres above anything within 100 metres.

HYBRID SYSTEMS

Hybrid wind and PV systems are potential to be applied in some situations. These systems can provide reliable off-grid power for homes, farms, or even entire communities that are far from the nearest utility lines. In some locations, wind speeds are low in the summer when the sun shines brightest and longest. The wind is strong in the winter when less sunlight is available. Because the peak operating times for wind and PV occur at different times of the day and year, hybrid systems are more likely to produce power when you need it. [70]

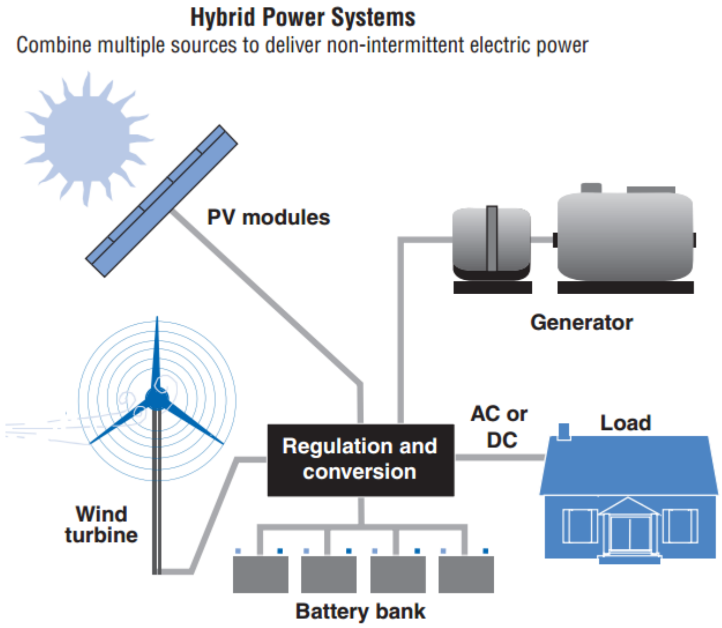


FIGURE 74: HYBRID POWER SYSTEM (SOURCE: CANWEA)

When neither the wind turbine nor the PV modules are producing, most hybrid systems provide power through batteries and/or an engine-generator powered by conventional fuels such as diesel. If the batteries run low, the engine-generator can provide power and recharge the batteries. Storage capacity must be large enough to supply electrical needs during non-charging periods. Battery banks are typically sized to supply the electric load for one to three days (see Chapter 5.15 Storage, Sub Chapters short and long term systems). An off-grid hybrid system may be suitable when the following situations: [70]

- The area to install the turbine has average annual wind speed of at least 4.0 m/s.
- A grid connection is not available or can only be made through an expensive extension.
- To gain energy independence from the utility.

7.4.3. Electric Vehicle (EV) Charging station

When talking about EV charging infrastructure it is important to distinguish between type of plugs or connectors, charging types and charging modes [71]

There is no standardization of connector types, then there are different models depending on the country and the manufacturer. Find below some types already in the market in Europe:

- Domestic plug **"Schuko"** type which responds to the standard CEE 7/4 and it is compatible with European electrical outlets. They work until electrical currents of 16 Amperes, for slow charging and they are not equipped with communications.
- **Single Combined Connector or "CSS"**, proposed by German and Americans as a possible standard solution. They have five clamps for both electrical connection and communications. These models allow slow and fast charging types.
- **"Scame or Type 3"** connector, also known as EV Plug-in Alliance proposed by French manufactures. It has from five to seven clamps depending on the current type (one or two - phases). It allows currents up to 32 Amperes and it is used for semi-fast charging type.
- **CHAdeMO Connector** is the Japanese manufactures standard (Mitsubishi, Nissan, Toyota). It is only used in fast charging types. They have ten clamps so they are created for three phase current

and communication. They allow up to 200 Amperes currents. Regarding applications, they are only used for very fast charging types.

Regarding charging types, we can find two depending on charging time;

- **Slow or traditional charging**. The charging is performance at 16 Amperes and 230 V, and require 3,6 kW of power (residential applications). The charging time is generally from six to eight hours therefore, this type is suitable for charging the electrical vehicle overnight within the consumer premises.

FIGURE 75: RESIDENTIAL CHARGING POINT (SOURCE: CIRCUTOR)

- In **fast charging types** the required power is quite high (between 44 and 50 kW), comparable to a building of approximately 15 homes. They may be used regularly by commuters in metropolitan areas, and for charging while parked for shorter or longer periods. As for the charging time, it is between 10 and 30 minutes.

The last but not least feature that characterizes EV charging points is the charging mode. This is related to level of communication between the EV and the charging infrastructure and the level of control over the load.

- **Mode 1**: This mode does not have communication with the main grid. It would be a conventional outlet with a “Schuko” connector, usual in residential applications.
- **Mode 2**: Low level of communication with the grid is available in this mode. The wire is equipped with an intermediate control device in order to check the correct connection between the vehicle and the charging grid. Schuko connectors still used in that mode.

- **Mode 3**: High level of communication with the grid. Protection and control equipment are necessary within the charging point. The wire includes a communication line integrated. CSS and Scame connectors are typical in this mode.

- **Mode 4**: The level of communication with the main grid is the highest one. There is always a converter from AC to DC to enable fast charging. One example of connector compatible with this mode is the CHAdeMO one.

In general lines the categories described above provide an overall methodology to classify and characterized current charging infrastructure, despite the lack of standardization. The selection of each connector, charging and mode type will depend on the application. For public infrastructures (district applications) fast charging and Modes 3 and 4 are required when designing it as well as connectors which are compatible with that type of charging. On the other hand, at building and home level; slow charging, Modes 1 and 2 and connectors Schuko type may be enough and suitable.

TABLE 41: STRENGTHS AND WEAKNESSES ANALYSIS FOR CHARGING POINTS

Strengths	Weaknesses
○ Low running costs for maintenance and recharge. ○ Environmental friendly (more efficient and less emissions). ○ Autonomy of fossil fuel. ○ Promote sustainable transport in cities (low noise levels and emissions). ○ Government aids. ○ Contribution to grid management (services to the grid when hosting RES). ○ Creation of new markets agents. ○ Contribution to demand peak management. ○ Incentives and tax reductions.	○ High charging time periods. ○ Lack of related services (repair, recharging). ○ Low Electrical Vehicles Autonomy. ○ Energy price uncertainty. ○ Lack of standardization (several systems and plugs types in the market). ○ Lack of public charging infrastructure. ○ High battery prices. ○ Low battery lifetime.

7.5. Neighbourhood energy control

At a neighbourhood scale, a Building Energy Management System (BEMS) is a computer-based control system that controls and monitors the different buildings' mechanical and electrical equipment such as heating, air conditioning, ventilation, lighting, power systems, according to the real time needs. This kind of neighbourhood control system is based on the same principles and technical solutions as seen in Chapter 5, with a single integrated control unit for each building within the district. The users' interfaces are locally or remotely accessible via web-based applications and computer or mobile devices. The main difference between a building-scale and a district-scale BEMS is the possibility to create a synergic system among the various buildings of the neighbourhood, in order to properly share the energy loads by mean of a real time monitoring and control algorithm. In this context, a web-based application runs "over" the various BEMS which are not physically connected to each other, and its scopes are monitoring energy consumption trends and consequently managing the resources within the district. A gateway with a webserver is used for this purpose, letting the end user the possibility to export and offline analyse the relevant energy data.

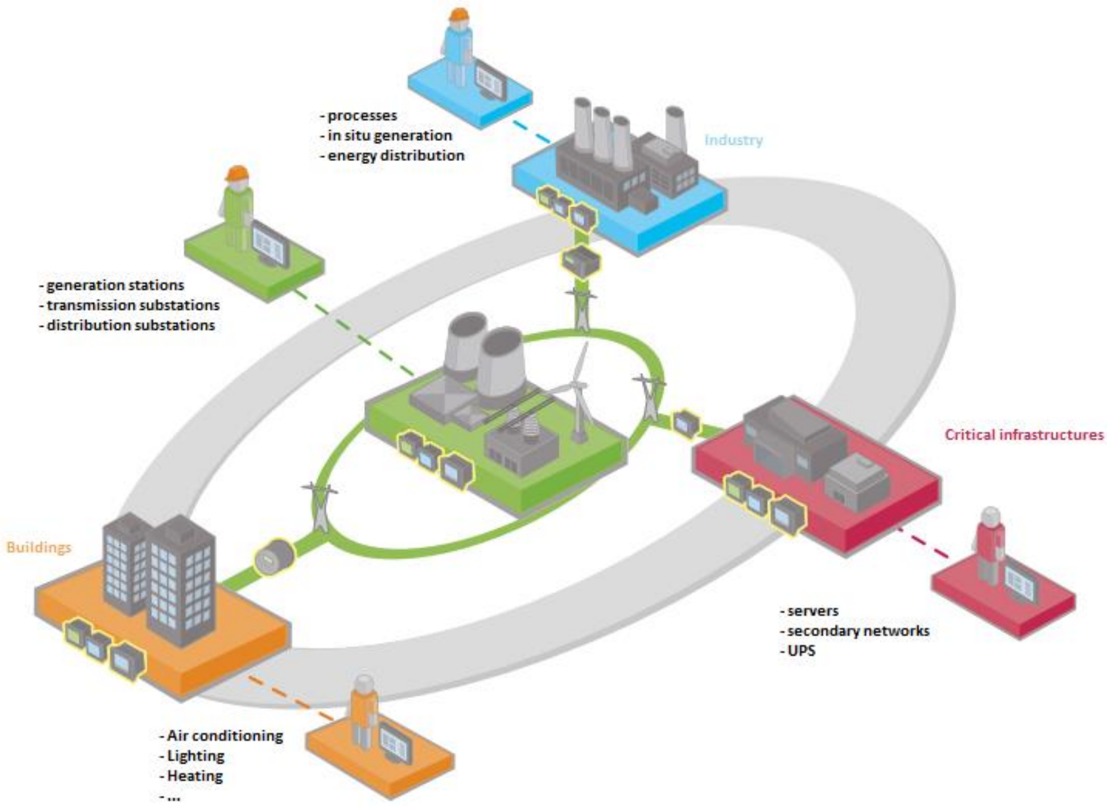


FIGURE 76: EXAMPLE OF NEIGHBOURHOOD SCALE BEMS ARCHITECTURE (CREDIT BY: © STAM S.R.L.)

In particular, energy resources come from conventional energy grid connected to standard production plants (i.e. fossil fuels and nuclear plants, according to the national energy policies), and also from renewable microgeneration systems such as: photovoltaic panels, wind turbines and other solutions connected to the district buildings in a smart grid concept. The neighbourhood scale BEMS can manage the energy sources and loads in order to real-time distribute the needed power to the various users in the different day and year periods, according to the building typologies. Such a solution prevents overloads and blackouts during the energy consumption peaks in the different buildings of the district.

Building owners and users can also analyse the detailed trends calculated by the BEMS in order to optimize the energy purchasing contracts on the basis of their needs, obtaining further money savings.

8. Conclusion and Next Steps

In summary, through deep research, this task has collected, as much as possible, the relevant information related to the available retrofit technologies both at building and district level. Both passive and active technologies have been considered and characterised in terms of technical parameters, suitability for different building typologies and climatic conditions, ease of application, specific installation procedures and criteria for applicability.

A list of fields has been defined in order to facilitate the use of this information by the Simulation and design hub (T4.4). During the data collection phase, all of the information gathered for the technologies was either entered into Technology Description templates, or into an Excel file to be used in later deliverables as required.

The final part of the analysis was to complete and strength and weakness assessment of each high level technology, and it is planned that is taken further into a full SWOT analysis as part of task 4.2 that follows this one.

The main outcome of the deliverable is to show the potential and feasibility of energy saving technologies in retrofit for buildings and neighbourhoods. With the help of this guideline the user of the simulation and design hub of NewTREND can get more information about the retrofit technology itself and recessed information about boundary conditions, for instance climate or location conditions. For district level technologies, criteria for connecting different buildings as part of a single energy network has also been analysed and quantified according to the different available technologies in order to be easily taken into account in the decision making phase.

Referring to Figure 1 in Chapter 1 the following structure shows the sub-tasks, which have been realized within in Task 4.1 and how other tasks are connected.

The brown highlighted boxes are the tasks and connections that were realized, while the grey boxes and the struck through technologies are not implemented in Task 4.1. The green highlighted boxes show the following tasks, which are tied to Task 4.1.

Task 4.2 will implement the technology library and adjust the excel file for a suitable implementation as a stand-alone tool as a help for the Simulation and Design Hub.

Task 4.4 will integrate the mentioned technologies (Figure 9 & Table 3) of Task 4.1 and provide the base to realize the simulation and application of the technologies in the Simulation and Design Hub.

Therefore, the structure and type of content were discussed intensive with the leading partners of Task 4.2 (STAM) and Task 4.4 (IES).

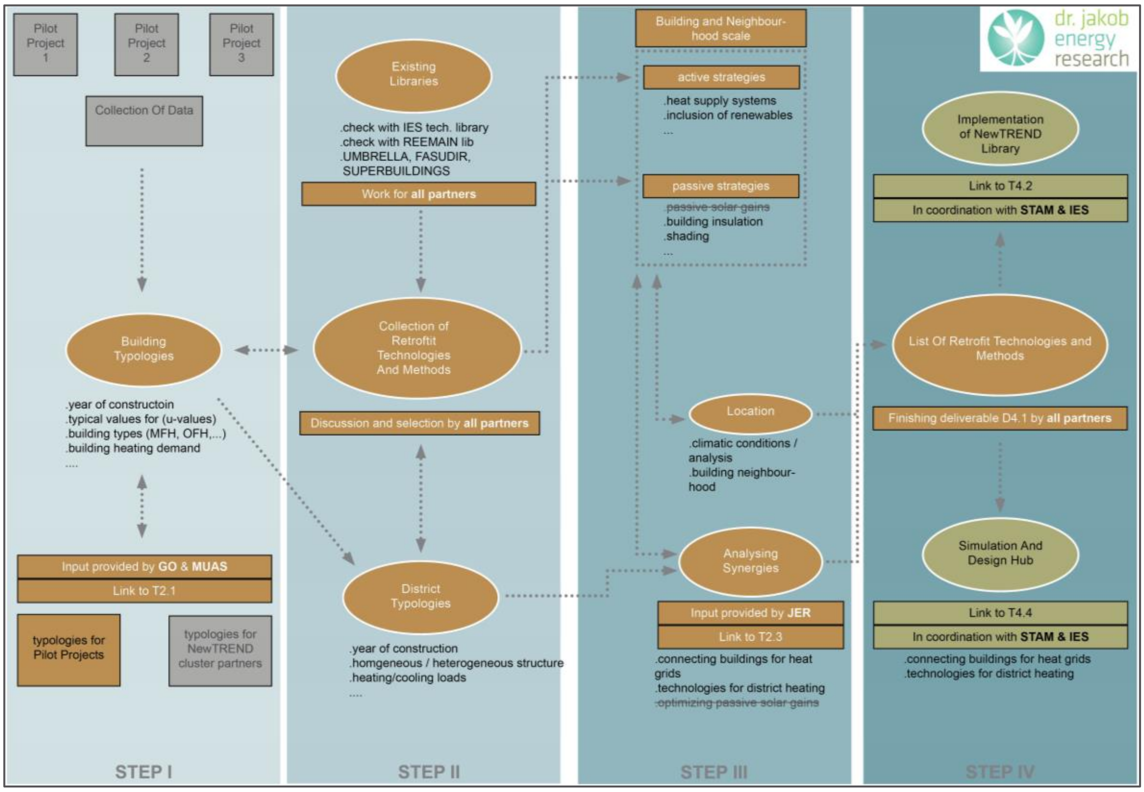


Figure 77: Realized structure of Task 4.1 (Credit by: ©dr. jakob energy research GmbH & Co. KG)

9. ANNEX 1 – EXAMPLE TECHNOLOGY DESCRIPTION SHEETS

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

Technology description - building scale / neighbourhood scale

Name of the technology / material:

Over rafter insulation

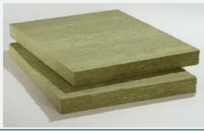
Category referring to technology library:

Building envelope: Slopped roof

Images:

of the technology / material

Source: Rockwool



of use / built-in

Source: Rockwool

Short description:

WHAT

Over-rafter insulation is used to reduce heat loss of sloped roofs. As the insulation is installed above the rafters, thermal bridges can be competely avoided compared to between-rafter insulation. Depending on the type of insulation it may be neccessary to install roof boards on the rafters before adding the insulation panels. Alternatively, there are rigid insulation boards which can be directly attached to the rafters. Usually materials like rigid boards made of polyurethane, extruded polystyren, resol and wood fibres or glass wool and rock wool in combination with roof boards are used. The insulating material is installed from the outside of the roof. Therefore, the top floor rooms stay inhabitable during construction works. To prevent structural damage the insertion of a steam brake on the underside of the insulation is neccessary. The insulation itself has to be protected by a sub-roof that ensures water- and windproofness. The installation of over-rafter installation is always accompanied by the renewal of the roof covering. Over-rafter insulation is often used in combination with between-rafter insulation to achieve a higher insulating effect.

Advantages, disadvantages:

WHY

Pro:
No loss of room height and living space
No thermal bridges
No impact on inhabitants by an installtion from the outside
Suitable for historic buildings under certain conditions

Contra:
Complex execution
Only possible in combination with renewal of roof covering
Bigger roof height and smaller distance between buildings.

Specific applications / where to use it:

WHERE

It is a suitable solution for rafter roofs if the roof covery is in bad condition and also has to be renewed. Therefore the condition of the roof covery has to be checked in advance in order to choose the best solution. Moreover the compatibility of the bigger roof height and buildings regulations should be reviewed.

Under which conditions can it be used:

WHEN

It is suitable for all climate zones and types of buildings. The general condition of the rafters and the load-bearing capacity should be checked before adding over-rafter insulation.

Typical technical characteristics

> Thickness of material [0,06-0,20m]
> Coefficient of thermal conductivity λ [0,035 W/(m*K)]
> Fire class acording to the European standard A1 not inflammable

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

40 Euro/m²

Influence on inhabitants / building owners / building management:

The measure has low influence on inhabitants of the top floor as the insulation is installed from the outside. However, a scaffolding is needed.

Impact on the environment:

Less energy consumption for cooling and heating.

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

The roof should be inspected regularly in order to prevent structural damage through mould, fungi or moisture.

Expected lifetime:

30-40 years

Aesthetical issues:

No visual impact inside the building. Certain visual impact outside the building as the roof height increases.

Ease of application:

4

Restriction criteria of applicability:

Physical issues need to be considered
The roof layer needs to be able to be rebuilt

Potential of combination with other technologies:

can be combined with between-rafter insulation

Hint for suboptimal practies:

Compatibility with historical buildings: ☐ Compatibile

Outer interventions may be banned in historic buildings if the exterior aspect is altered.

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

Technology description - building scale / neighbourhood scale

Name of the technology / material:

Secondary glazing

Category referring to technology library:

Building envelope: Window

Images:

of the technology / material

SCredit by: ©University of Applied Sciences Munich

of use / built-in

Credit by: ©University of Applied Sciences Munich

Short description:

WHAT

Secondary glazing is the installation of a of an independent window system on the room side without altering the existing window. Secondary glazing is used cut down the heat loss and provides some acoustic insulation to the existing window opening.Secondary glazing can reduce heat loss as well as reducing the air draughts. Usually it is preferred to leave the outer windows without draught-proofing so that there is a degree of ventilation to the air space between the outer windows and the secondary glazing. This help preventing the buildup of condensation. Secondary glazing can be built as movable or fixed units. Opening of both the external windows and secondary glazing is required for ventilation. This solution is usually preferred in historic buildings.

Advantages, disadvantages:

WHY

Pro:
Useful for heritage buildings.
Highly effective at reducing noise transmission.
Airtightness is achieved
Improving the thermal performance

Contra:
Visibility can be reduced.
Possible formation of condensations.

Specific applications / where to use it:

WHERE

On the room side of existing window. Application can be done in all countries and all climate zones.

Under which conditions can it be used:

WHEN

Historical and heritage protected buildings. It is also a good solution for those rustic buildings that want to preserve its aesthetical aspect. Aslo can be used as an acoustic insulation.

Typical technical characteristics

The installation of a secondary glazing can result into a combined window thermal insulation U value between 1.8 to 1.5 W/m²K

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

200 Euro/m

Influence on inhabitants / building owners / building management:

This intervention have a moderate impact on the user as it is usually takes a number of days and might render some rooms unusable for a some time

Impact on the environment:

Heat loss reduction. Less power is needed for heating or cooling.

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

Normally the cleaning is more time consuming due to the nature of the solution. It is convenient to ventilate the inner space when condensation appears and to check the sealing to avoid the possible air infiltration

Expected lifetime:

25 Years

Aesthetical issues:

There is an evident interior visual impact, however,the exterior visual impact is usually unnoticeable

Ease of application:

3

Restriction criteria of applicability:

The opening system of the existing window can limit its application. Functionality of the fenestration is reduced.

Potential of combination with other technologies:

Can be combined with shutters, blinds.

Hint for suboptimal practies:

Thermal bridges due to incorrect execution must be checked

Compatibility with historical buildings: ☑ Compatibile

This system is usually compatible with historic buildings.

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

NewTREND

Technology description - building scale

Name of the technology / material:

Evacuated tube collector

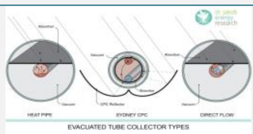
Category referring to technology library:

Building services, Replacement, Renewable energy system, Heat

Images:

of the technology / material

Credit by: dr. jakob energy research GmbH & Ko. KG



of use / built-in

Credit by: dr. jakob energy research GmbH & Ko. KG

Short description:

WHAT

A solar collector converts solar energy from solar radiation into thermal energy. The heat can be used for the heating of water or air. By the absorption of the sunlight on the surface of the collector the fluid in the collector gets heated up and can then be used for domestic hot water (DHW), heating supply or even process heat.
An evacuated tube collector is an improved version of a flat plate collector. The output temperatures of such a collector are between 50-110°C. The absorbers are single glass pipes, which are all connected at on end where the heated fluid is collected and transferred to a heat exchanger. It has lower thermal losses due the vacuum inside the tubes and can generate higher temperatures. For building scale collector areas from 5m² up to 200m² are feasible.
Evacuated can divided in three categories:
1. Heat pipe: The solar radiation is collected by an absorber on top of the pipe. The heat of the liquid is transferred at the heat pipe to a separate fluid cycle that transfers the heat to the thermal storage.
2. Sydney CPC: Piping loop within an evacuated glass tube. On the inside of the tube a special absorption coating is plotted. On the outside of the tube an additional compound parabolic concentrator is installed to increase the efficiency of the collector.
3. Direct flow: In the direct flow collector the heat-carrier-fluid flows in a coaxial pipe. In the inner pipe the cold liquid flows to the bottom of the pipe and absorbs the heat on the way back to the top of the pipe.

Advantages, disadvantages:

WHY

Pro:
- No moving parts
- Higher temperatures
- Lightweight and easy to install
- Modular system
- Compatibility with conventional heating systems

Contra:
- Mostly heat exchanger required
- Higher costs
- Low efficiency in winter

Specific applications / where to use it:

WHERE

Very widespread use in climate conditions with high solar radiationfor the use of heat generation for DHW, heating supply or low temperature processes up to 120°C.

Under which conditions can it be used:

WHEN

Roof construction should be checked before on static specifications. If the solar hot water can implement in the existing or new DHW or heating system. The highest efficiency of solar thermal collectors is in south or west orientation. For DHW an aperture angle of about 20°-50° is the best, while for heat supply 45°-70° are feasible.

Typical technical characteristics

-> modul area [m²]; coefficient of performance (CoP); costs [€/m²]

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

Between 500- 600 €/m² depending on efficiency, construction and availbility of the collector.

Influence on inhabitants / building owners / building management:

No or very low influence on the inhabitants. Eventually is the need for a momentary need of a scaffolding. This influence can be minimised when done in combination with roof retrofit.

Impact on the environment:

Use of sunlight for heat generation. Reduction of fossil fuel consumption.

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

Biennial visual testing. Installations below a slope of 30° eventually needs to be cleaned in dusty locations to keep the efficiency high.

Expected lifetime:

18 years.

Aesthetical issues:

Eventually artistic issues due the technical character of the installation on the roof or facade.

Ease of application:

2

Restriction criteria of applicability:

Maybe static issues of the roof or facade

Potential of combination with other technologies:

Combination with short- and long-term storage, AB- and ADsorption chillers on building level

Hint for suboptimal practies:

Compatibility with historical buildings: ☑ Compatibile

Impairment of the historical and monumental appearance. The grade of impairment needs to reviewed.

10.

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

NewTREND

Technology description - neighbourhood scale

Name of the technology / material:

Heat pump geothermal

Category referring to technology library:

Renewable Energy Systems (RES)

Images:

of the technology / material

of use / built-in

Source: www.thermia.fi/varmepump/Thermia_Hus_Bergvarme_cmyk.gif

Short description:

WHAT

Geothermal heat pump is a heat pump which uses earth as a heat source (for heating) or as a heat sink (for cooling). It takes advantage of relatively stable temperatures of ground throughout the year; where ground is usually warmer than outside air in heating season while colder than air during cooling season. Geothermal heat pump is able to provide several times (3-6) more heating/cooling energy than the provided electrical energy to the heat pump. This is determined by the coefficient of performance (COP) which depends on heating pump model and on the temperatures of heat sink/source. There are two types of installation: vertical and horizontal. Vertical installation means that heat exchanger (pipes) is placed vertically and reaches depths of several hundreds of meters. In horizontal installation, pipes are placed underground on a horizontal plane through the yard.

Advantages, disadvantages:

WHY

Pro:
- Environmentally friendly energy source
- Low running costs
- Long life span
- Very silent in their work

Contra:
- high investment costs
- requires high expertise in design and installation phase
- in the case of horizontal installation, geothermal heat exchanger can have an effect on flora above

Specific applications / where to use it:

WHERE

In places with significant heating/cooling costs, where ground drilling work is possible.

Under which conditions can it be used:

WHEN

In building retrofit it is recommended to perform measures for decreasing thermal need of the building, because heat pumps are more efficient in low temperature heating applications.

Typical technical characteristics

-> Coefficient of performance (COP)/Seasonal coefficient of performance (SCOP)
-> Heating/cooling capacity of the heat pump

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

1058 €/kW

Influence on inhabitants / building owners / building management:

Reduction in energy bill and minimal maintenance

Impact on the environment:

Heat pump's environmental impact is depending on the source of electricity used for powering HP.
Refrigerants used in HPs nowadays are not harmful for Ozone-layer but they have potential for global warming, which can be an issue in the case of refrigerant leakage (which is rare in properly installed and maintained HPs).

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

Minimal maintenance is required, yearly checks of water pump, external pipes, fittings and electronics. Many of checks can be performed by user, but every few years heat pumps should be checked by professional installer.

Expected lifetime:

25 years

Aesthetical issues:

Heat pump unit can be placed in basement or other space where it is not visible, ground heat exchanger and relating pipes can be installed in a way which hides them completely

Ease of application: (easy=1; elaborative=5)

Requires expensive and labour intensive operation of ground drilling, possible legal permit required

Restriction criteria of applicability:

Applicability depends on geothermal potential of ground, existing geothermal HPs nearby, possible legal restrictions

Hint for suboptimal practies:

After installation it is recommended to monitor HPs performance (often problematic and inaccurate control setup)

Compatibility with historical buildings: ☑ Compatibile

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

Technology description - building scale

Name of the technology / material:

Tri-generation: combined heat, power and cold generation (CHPC)

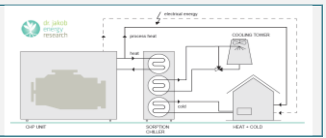
Category referring to technology library:

Building services, Replacement, Tri-gen

Images:

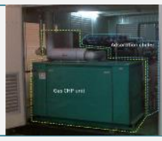
of the technology / material

Credit by: dr. jakob energy research GmbH & Ko. KG



of use / built-in

Credit by: dr. jakob energy research GmbH & Ko. KG



Short description:

WHAT

Tri-generation (tri-gen) describes the combination of a CHP engine (natural gas/ oil, biogas, biomass) with a thermal driven sorption chiller (absorption or adsorption chiller). The compound of these two systems is very efficient. Besides the normal use of power and waste heat for DHW or heating supply, the heat is used for cold generation by an absorption chiller. While a heating energy driven CHP unit operates mostly in winter for heating supply, the operating hours in summer are extended by the heat demand of the absorption chiller. The generated energy from the CHP unit can be used for the energy demand in the building or auxiliary power of the chiller. The surplus or can be fed in the grid.
A tri-generation system is practical with small CHP units (5.5kWe) up to gas turbine turbo CHPs with 400kWe. As absorption chillers single-effect chillers will fit the best, due the equality of the waste heat temperatures of the CHP and the hot water temperature of this type of chiller.

Advantages, disadvantages:

WHY

Pro:
- Chiller can be added to an existing CHP unit
- Tri-generation of electricity, heat and cold
- Possibility of addition of other RES (solar thermal collectors)
- Fast amortisation due long operation hours
- Compact system in comparison to single systems (electricity, heat and cold)

Contra:
- For the improvement storages are needed
- Space requirement for several units needed (CHP, ab-/adsorption chiller, storage)
- High invest cost
- At low power range not lucrative

Specific applications / where to use it:

WHERE

In buildings with an existing CHP unit and cooling demand (replacement of conventional chiller). Buildings with seasonal heat and cold demand.

Under which conditions can it be used:

WHEN

Buildings with great space demand in plant room.

Typical technical characteristics

-> CoP of the CHP unit [-]; CoP of the sorption chiller [-]; heat and cold demand of the building [kWh];

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

The typical payback time is <10 years.

Influence on inhabitants / building owners / building management:

The implementation of an CHPC unit hasn't any direct influence on the inhabitants or the building owner. The CHP engine, sorption chiller and auxiliary units needs to be connected to the BMS system for an optimal operation.

Impact on the environment:

Saves energy by an increased efficiency and reduces CO_2 emissions.

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

The combination of different systems requires for each system his own maintenance frequncy and costs. The complexitivity of the system requires the commitment of a qualified technician.

Expected lifetime:

25 years.

Aesthetical issues:

Depending on the installation of the chimney (inside or outside) it might could have aesthetical issues.

Ease of application:

4

Restriction criteria of applicability:

The CHP and absorption unit itself are no problem. The static issues for the weight, vibrations and space demand needs to considered.

Potential of combination with other technologies:

Combination with gas boiler for back up heating system

Hint for suboptimal practies:

Compatibility with historical buildings: ☑ Compatibile

The CHP and absorption unit itself are no problem. The static issues for the weight, vibrations and space demand needs to

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

NewTREND

Technology description - neighbourhood scale

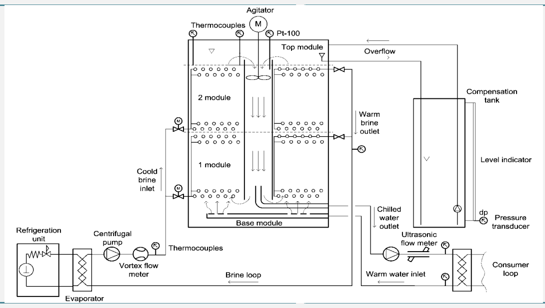
Name of the technology / material:

Ice storage

Category referring to technology library:

Renewable Energy Systems (RES)

Images:



Source: Grozdek, M. (2009). Load shifting and storage of cooling energy through ice bank of ice slurry systems-modelling and experimental analysis. Doctoral Thesis. Royal Institute of Technology.

Short description:

WHAT

Ice storage is a system for storing latent heat, which if used in a right way can significantly decrease energy cost for cooling. Cooling system freezes the water (or glycol mixture), during the period with lower price of electrical energy (example: night period), stored energy is then used later, when there is a need for cooling. Ice storage is more cost effective in buildings with significant differences in cooling need between day and night, such as office buildings. Additional benefit of ice storage is that it is possible to install cooling system with lower capacity then needed in peak times, this can lower the investment costs and energy cost by lowering demand charges. In this case ice storage covers the difference between requested cooling demand and capacity of cooling system. Furthermore cooling system with lower maximum capacity (than the needed peak capacity) is going to work more time in higher efficiency domain.
There are three basic work modes for ice storage with variants between them:
- Chiller priority – cooling system has priority while peak times are covered with the help of ice storage
- Ice storage priority – Ice storage has priority in consumption and after the storage has been depleted, cooling system covers the rest of the need
- Optimal mode – Is ideal control strategy (difficult to achieve), where ice storage is controlled in a way that minimal energy cost is achieved. To achieve it, control system should have to precisely predict future cooling demand

Advantages, disadvantages:

WHY

Pro:	Contra:
- Possibility to decrease energy and investment costs	- Ice storage increases energy consumption (storage losses), but with proper design and control of the system costs will decrease

Specific applications / where to use it:

WHERE

In buildings with significant variation in cooling needs throught the day and large demand for cooling

Under which conditions can it be used:

WHEN

If there is enough space available in the building, as ice storage tank requires a lot of space

Typical technical characteristics

Ice storage capacity

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

Inv.cost=1020*Capacity[kWh]^0.64 [EUR], valid for capacity over 250 kWh

Influence on inhabitants / building owners / building management:

If it is properly controlled it can lower energy costs

Impact on the environment:

Depends on rest of the cooling system

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

As ice storage has no moving parts it requires minimal maintenance. Once or twice a year quality of water should be checked, while additional equipment needed can require maintenance (pumps, etc.).

Expected lifetime:

Aesthetical issues:

Ice storage tank requires a lot of space, but it can be placed undergound, so it wouldn't affect aesthetics of a building

Ease of application: (easy=1; elaborative=5)

Storage is not problematic to install, but installation and setup of control system can be difficult

Restriction criteria of applicability:

Hint for suboptimal practies:

Special attention is required for designing HVAC system and control system to insure most efficient operation of storage

Compatibility with historical buildings: ☑ Compatibile

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

Technology description - building scale / neighbourhood scale

Name of the technology / material:

Polycristalline PV

Category referring to technology library:

Building/district service

Images:

of the technology / material	**of use / built-in**
	

Short description:

WHAT

A PV array is made up of a number of modules in series or parallel, corresponding to the input characteristics of the inverter. Poli cristal panels are composed of several cristal silicon cells linked and less sentitive to shades, being able to generate energy when low levels of irradiance. Polycrystalline cells were previously thought to be inferior to Monocrystalline because they were slightly less efficient, however, because of the cheaper method by which they can be produced coupled with only slightly lower efficiencies they have become the dominant technology on the residential solar panels market.

Advantages, disadvantages:

WHY

Pro:	**Contra:**
Lower price comparing to other PV technologies (thin film and mono cristal).	**Lower efficiency.** The efficiency of polycrystalline-based solar panels is typically 14-16%. **Lower space-efficiency;** it is necessay to cover a biger surface to output the same electrical power as you would with a solar panel made of monocrystalline silicon.

Specific applications / where to use it:

WHEF

In any building or premises with relevant electricty consumption.

Under which conditions can it be used:

WHE

when there is a surface available free from shades and near to the electricity network.

Typical technical characteristics

Shading of 10% of the surface area of a string may cause more than a 30% reduction in output. It is therefore important to eliminate direct shading

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

1.2 Euro/ Watt peak

Influence on inhabitants / building owners / building management:

Reduction in the energy consumped from the grid and therefore in the consumer electricity bill (cost savings). In the case of the building owner PV facilities increase the property value but increase the maintenance costs.

Impact on the environment:

Production of polluting substances during the manufacturing process of the modules.

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

The maintenance cycle is one year for small facilities and six months for big ones (more than 100 kW installed). And the preventative maintenance activities are the following: module´s cleaning, check out of the PV inverter fuses and terminal boxes (to verify that all strings are connected) and current checking.

Expected lifetime:

Photovoltaic installation are usuallty built for a lifetime of 25 years.

Aesthetical issues:

Monocrystalline and thin-film solar panels tend to be more aesthetically pleasing than polycrystalline since they have a more uniform look compared to the speckled blue color of polycrystalline silicon.

Ease of application:

When installing a PV array on a roof, panels need to face in different directions, it is essential to assemble at least one string per direction and ensure each string is facing in just one direction to ensure optimised supply. Each string must be connected to a specific inverter (or to inputs of a multi-MPPT inverter).
If this instruction is not observed, the array will not be damaged but supply will be reduced, thus increasing the time needed for a return on investment.

Restriction criteria of applicability:

Legal restrictions in Spain: more than 100 kwp facilites requires a legalization processess in order to be included in the energy production regimen.

Potential of combination with other technologies:

PV technologies can be installed coupled with batteries to adjust consumption and generation.

Compatibility with historical buildings: ☑ Compatibile

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

Technology description - building scale / neighbourhood scale

NewTREND

Name of the technology / material:

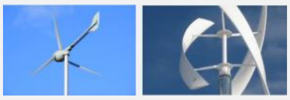
Micro wind turbine

Category referring to technology library:

Building service

Images:

of the technology / material



of use / built-in

Short description:

WHAT

Small scale turbines for residential applications are available. Their blades are usually 1.5 to 3.5 metres (4 ft 11 in–11 ft 6 in) in diameter and produce 1-10 kW of electricity at their optimal wind speed. Some units have been designed to be very lightweight in their construction, e.g. 16 kilograms, allowing sensitivity to minor wind movements and a rapid response to wind gusts typically found in urban settings and easy mounting much like a television antenna. There are two types ; horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT)

Advantages, disadvantages:

WHY

Pro:
Small wind turbines do not require strong winds to start working, some technologies are able to generate electricity with **low start-up speeds** around 1meters per second. **Space-efficiency**, these turbines does not need large surfaces and can be installed in small locations. **Low operational and maintenance costs.**

Contra:
They could cause noise, vibrations and turbulences. In urban enviroments, wind finds too many obstacles (other buildings, trees..) which means high turbulences and therefore low performance levels.

Specific applications / where to use it:

WHERE

In locations with high wind potential and without too many obstacles around that could provoque turbulences.

Under which conditions can it be used:

WHEN

When there is a relevant electrical consumption and wind potential.

Typical technical characteristics

Rooftop models vary from 0.5kW to 2.5kW in size while pole-mounted domestic turbines are often about 5kW to 6kW. The regulation that cover the requirment for wind turbine design is the EN 61400-2:2006

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

The cost of one unit of 1.5 kW range from 2000 to 3000 euros.

Influence on inhabitants / building owners / building management:

Consumers can reduce their energy bill, however some turbines could impinge on inhabitants comfort due to the noise generated. In the case of the building owner, Wind power facilities increase the property value but increase the maintenance costs.

Impact on the environment:

Due to their small size they have a low impact on the enviroment.

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

All wind turbines require regular maintenance, at least once but ideally twice a year. Most maintenance is centred on thorough inspections of the turbine and tower. The tower needs to be designed to allow access for servicing mechanical components, such as bearings.

Expected lifetime:

Lifetime of micro wind tubines is between 20 and 30 years, in order to pay off the investment and considering energy performance.

Aesthetical issues:

Small turbines have a small visual impact.

Ease of application:

Turbines are often mounted on a tower to raise them above any nearby obstacles. One rule of thumb is that turbines should be at least 30 ft (9.1 m) higher than anything within 500 ft (150 m). Better locations for wind turbines are far away from large upwind obstacles. A small wind turbine can be installed on a roof. Installation issues then include the strength of the roof, vibration, and the turbulence caused by the roof ledge.

Restriction criteria of applicability:

Wind turbine installations in buildings depend on the municipality legislation

Potential of combination with other technologies:

Wind turbines can be installed coupled with batteries to adjust generation to consumption.

Hint for suboptimal practies:

Compatibility with historical buildings: ☑ Compatibile

V

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

Technology description - building scale / neighbourhood scale

Name of the technology / material:

Light control combinations

Category referring to technology library:

Lighting controls

Images:

of the technology / material

Source:

of use / built-in

Source:

Short description:

WHAT

Light control technologies can be differently combined in order to optimize their potentialities in different situations and applications. Examples of possible combinations are:

Standalone zone switching and daylight harvesting: light is automatically switched on/off on the basis of presence of people in a certain room of the building.
Daylight harvesting is an energy management technique that reduces lighting use by utilizing the ambient (natural & artificial) light present in a space.
Ambient light is detected and used to decide if dimming or switching OFF electric lighting.
Other data as distance from ambient light sources (windows, etc) can be used to tune the dimming too.

Networked switching, daylight harvesting, smart scheduling & load shedding: ambient light is detected and used to decide if dimming or switching OFF electric lighting; the light control is performed at a network level, with ligh information shared in an integrated automation/domotic system. The light control scheduling is programmable on the basis of comfort requirements with different features in different day periods. Load shedding functionalities allow an optimization of energy consumption by switching off electrical devices which are not essential for inhabitants' needs in a certain moment.
Other data as distance from ambient light sources (windows, etc) can be used to tune the dimming too.

With these technology combinations, also coupled with zone by zone standalone light controls, different values of energy savings can be achived, from -30% up to -55% of energy consumption for illumination.

Advantages, disadvantages:

WHY

Pro:
From 30% up to 55% eenergy saving, with consequent environment and cost advantages

Contra:
Complex automatic system to be installed and configured; in the case of network switching, complex network integrated system has to be installed and configured, with the intervention of an informatic/automation skilled technician.

Specific applications / where to use it:

WHERE

These combined control systems are aimed to manage the artificial illumination intensity and consequently the energy demand for areas of the building which are not constantly occupied by people. Moreover, the daylight harvesting tecfhnology is focused on zones with high natural light intensity.

Under which conditions can it be used:

WHEN

Lighting automatic control system can be installed in every situation in which sensors can be used. The possibility of connecting the different elements into a network is needed for such a system.

Typical technical characteristics

Movement sensors are used in order to detect presence of people in the controlled areas, with a switching control automatic system to use artificial illumination only when really required. Dimming system integrated in the control based on the ambient light stimuli.

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

An estimation of purchasing cost range of 14-21 €/ floor m^2 can be considered for these light control systems.

Influence on inhabitants / building owners / building management:

Energy savings due to proper lighting control are advantageous for building owners due to the lower electricity bills if compared to a non-controlled lighting plant.

Impact on the environment:

The energy savings due to artificial lighting control has a reduction of CO2 emissions as an indirect consequence. Moreover, a more focused utilization of lighting elements (e.g., incandescent lamps) increases their lifetime, thus reducing the waste production due to theuir end of life.

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

Automation/domotic system to be maintained by periodical interventions of strongly skilled technicians; electronic parts to be substituted and updated.

Expected lifetime:

15 years before a complete system refitting; single elements such as lamps and sensors have to be periodically substituted during the system lifetime.

Aesthetical issues:

Inhabitants have the only internal aesthetical impact of sensors in the controlled areas. They are usually very little elements. In the daylight harvesting case, outside elements are present too, often on the roofs.

Ease of application: (easy=1; elaborative=5)

3 - a proper system design and qualified personnel is required for installation and configuration of such systems, with both "practical" skills (cables drawing, connections, sensors mounting) and informatic skills for network configuration.

Restriction criteria of applicability:

These technologies are applicable in any building with a proper electrical plant for sensors and network elements feeding.

Potential of combination with other technologies:

tungsten incandescent lights, tungsten halogen, compact fluorescent, fluorescent, led lights, neon lights

Hint for suboptimal practies:

Compatibility with historical buildings: ☑ Compatibile

New integrated methodology and **T**ools for **R**etrofit design towards a next generation of **EN**ergy efficient and sustainable buildings and **D**istricts

Technology description - building scale / neighbourhood scale

Name of the technology / material:

Programmable room thermostats (setback)

Category referring to technology library:

Control

Images:

of the technology / material	**of use / built-in**
 Source:	 Source:

Short description:

WHAT

System designed to keep desired temperature within a room, by acting on heating and cooling systems. Occupants can set the temperature on the interface module, and an integrated temperature sensor is used to evaluate if the heating, or the cooling system, has to be switched on in a thermostatic cycle. Different temperature in different day periods can be set by the operator, then the system automatically works.
More complex thermostat may have also an external temperature probe and it may provide a progressive regulation of the heating, if the associated heating system is able to manage modulating energy request.

Advantages, disadvantages:

WHY

Pro:	**Contra:**
Energy saving with reference to a conventional heating or cooling system, with comfort improvement thanks to the constant temperature. Easy to use.	Relatively limited number of programmable periods; battery power supply; no kind of auto adaptive set point modification

Specific applications / where to use it:

WHERE

Rooms in houses, offices, public buildings, where at least one compatible heating and domestic water heating circuit is present and it could be connected to the smart thermostat.

Under which conditions can it be used:

WHEN

It may be installed in private houses/appartment when more relevant energy retrofitting interventions are not planned.

Typical technical characteristics

digital controls, lcd screen, ON/OFF control, weekly and daily set up, holiday mode, battery electrical source.

Average/general cost or return of investment (Euro/m²; Euro/kW; Euro/unit):

130 Euro/unit

Influence on inhabitants / building owners / building management:

Improved comfort and easy control of temperature

Impact on the environment:

CO_2 emissions reduction thanks to energy saving in heating and cooling systems

Maintenance / Operation aspects (frequency, timing, auxiliary resources, qualified technicians, etc.):

The component is cheap, so maintenance is much more expensive than replace the entire device once is broken.

Expected lifetime:

12 years

Aesthetical issues:

The small dimension of this device does not create any kind of visual issue.

Ease of application: (easy=1; elaborative=5)

2

Restriction criteria of applicability:

Potential of combination with other technologies:

Water heating radiators, heat pumps, conventional cooling systems, more complex BMS

Hint for suboptimal practies:

Compatibility with historical buildings: ☑ Compatibile

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