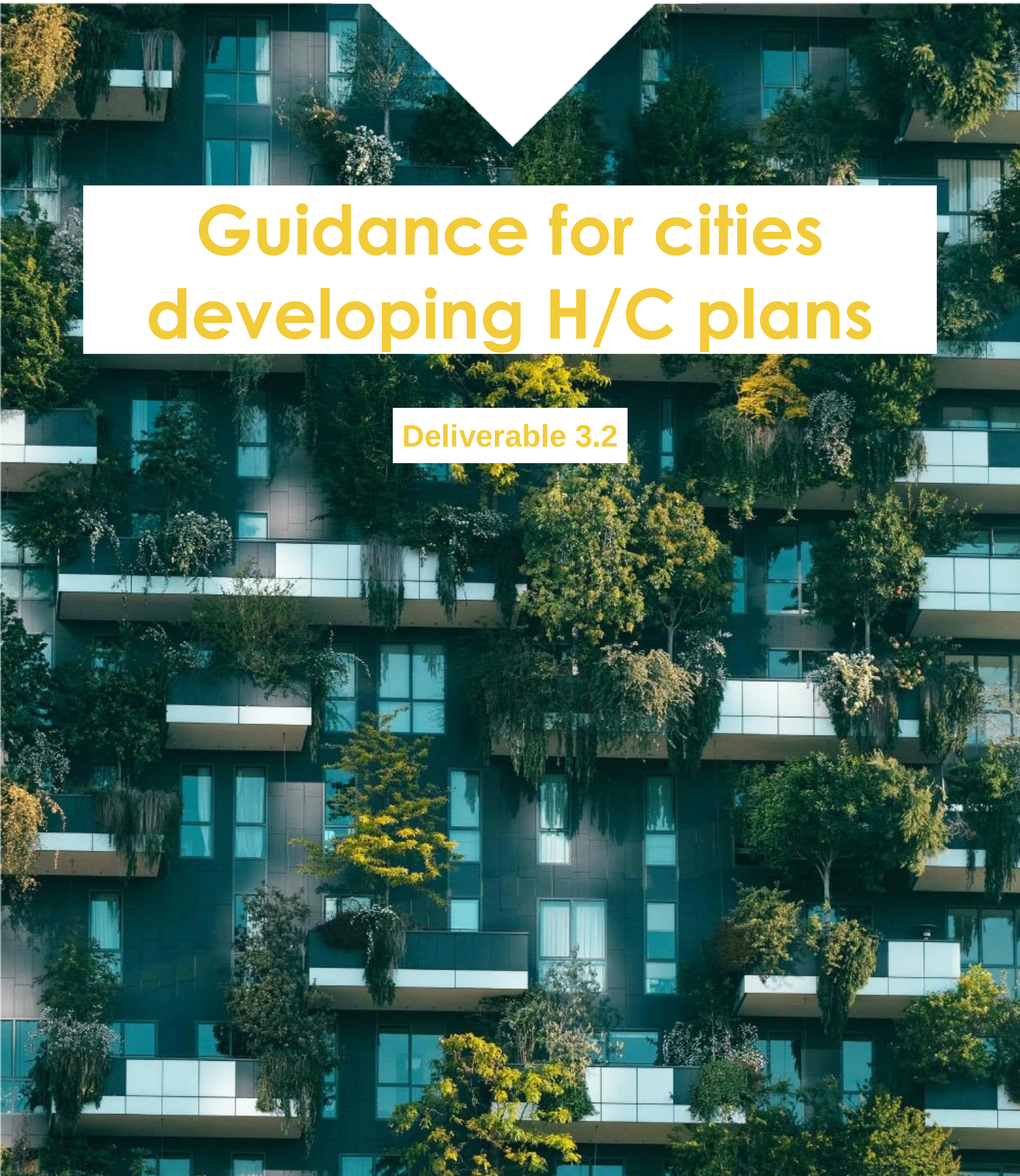
DECARB CITY PIPES 2050

Guidance for cities developing H/C plans

Deliverable 3.2



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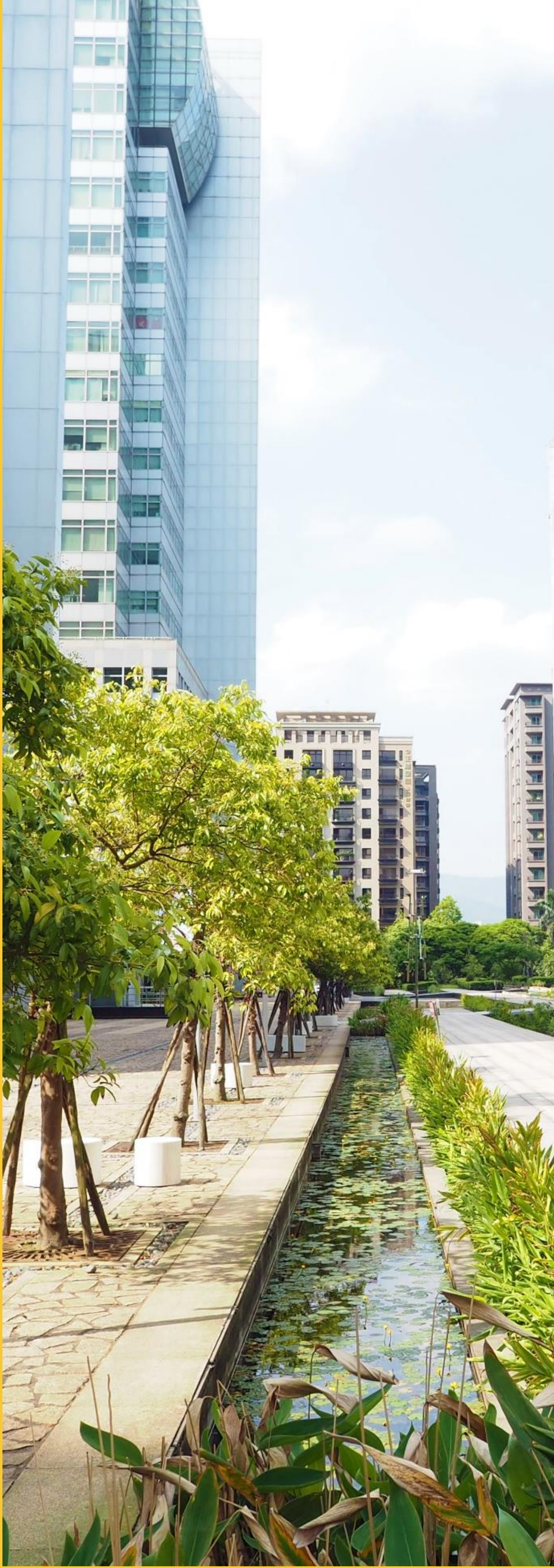

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Introduction

This guide explains possible procedures for creating a Heating and Cooling Map (H/C Map) and the necessary base maps. The documented procedure in this document is based on the city of Winterthur's approach towards creating its H/C-plan. There are, of course, several other ways to elaborate an H/C-plan, depending on local framework conditions and taking into account local laws, economic aspects, building structures etc.

An important basis for all approaches involves knowledge of the existing heat infrastructure, heat demand, and available renewable energy sources (RES). Three basic maps are therefore considered essential for an H/C map:

- the infrastructure map,
- the heat demand density map or another approach to map the heat-demand and
- the potential map.

The **infrastructure map** shows existing heat networks and other infrastructures to be considered. The current and future heat demand density in accordance with the expected settlement development is presented in the **heat demand map** in order to assess whether a district heating supply is economically feasible or not. The **potential map** shows the spatial distribution of potential supply of heating and cooling. Ideally, the potentials of the various available energy sources are quantified spatially.

By combining and prioritizing the inputs from these maps, the H/C-map is created (see Figure 1).

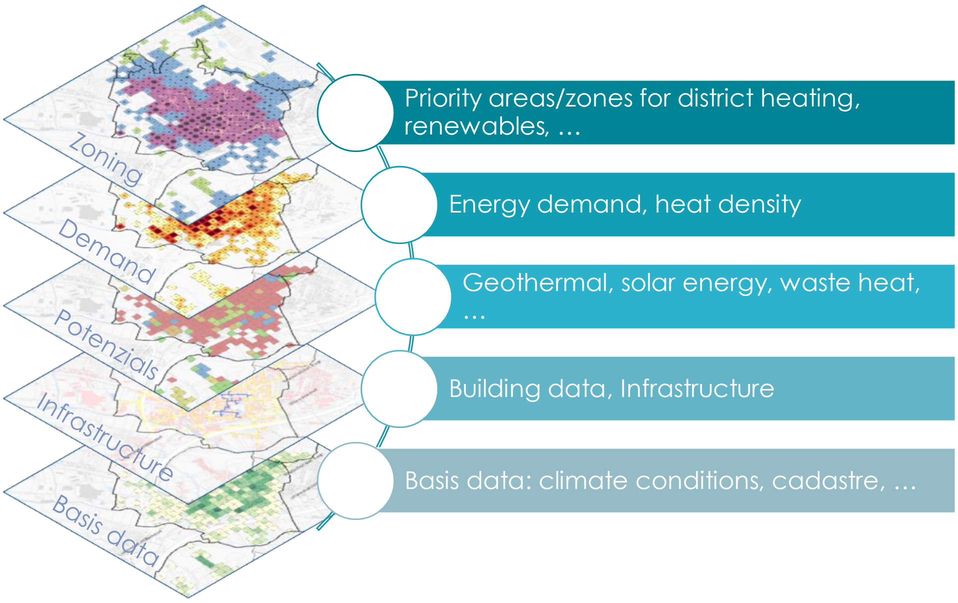

FIGURE 1: WINTERTHUR´S PROCEDURE FOR THE PREPARATION OF ITS H/C-PLAN, SOURCE: AEE INTEC

How the basic maps can be developed is described using the example of the city of Winterthur (chapters "H/C-data" to "Potential map").

The creation of the H/C map also requires knowledge of the economic framework conditions for heat networks. The basics are described in the chapter "Economic aspects".

The procedure strongly depends on the available data basis and its quality.[1] Statements about data quality can only be made on a case-by-case basis, which is why it is recommended to clarify in advance the quality of the data directly with the data owners responsible. This report takes into account country- and site-specific characteristics with regard to the data basis by explaining the procedure on the basis of three variants. The differing starting settings are defined as follows:

- Case 1: Hardly any data is available, a complete estimation is necessary.
- Case 2: Partial consumption data and/or combustion data is available.
- Case 3: A digital twin is available (each building is mapped, if possible with measured data)

In reality, the transitions between these three variants are fluid, which means intermediate stages are also possible.

Scope of this report

This guide focuses on heating and cooling. In light of increasing electrification, this, however, also needs coordination with the power grid. Since central heating systems require more power than decentralized heat pumps, the availability of capacity needs to be clarified. The links to the electricity and mobility sectors are discussed in the chapter “sector coupling”.

[1] Data quality can include the following aspects: Completeness, correctness, consistency, reliability, accuracy, timeliness, lack of redundancy, relevance, uniformity, unambiguity, and comprehensibility.

H/C-Data

Data availability and determination

This section provides an overview of the data basis and the contact points from which the data[2] can be obtained (see Table 1).

In general, it is advisable to sign a non-disclosure agreement for data procurement if no legal basis exists. This applies in particular to the procurement of building-specific consumption data from energy service providers[3]. In general, the data protection laws of the respective country must be observed.

TABLE 1: OVERVIEW OF THE DATA BASIS, PURPOSE OF USE, AND POINTS OF CONTACT FOR OBTAINING DATA.

Case	Data	Specification	Source	Usage	
1	Pan European Thermal Atlas (PETA)	– heat demand density – cold density – potentials	available online[4]	Heat, cold, potentials, costs, scenarios	Actual demand
1	Hotmaps Toolbox	– heat demand density – cold density – potentials	available online[5]	Heat, cold, potentials, costs, scenarios	
2	Heating / Combustion	– installed power – operating hours (average value)	Authority, chimney sweepers	heat	
2	Heat pump	– electric power – electricity demand – mean Operating factor (average value)	Energy service provider	heat	
2	Boiler (warm water)	– electric power – electricity demand – operating hours (average value)	Energy service provider	heat	
2	Refrigeration plant	– power – operating hours (average value)	Owner / Authority (register)	cold	
2	Metered data per building	– measured gas consumption for heat generation	Energy service provider	heat	

[2] A detailed description of data procurement and availability can be found in deliverable D2.4 (to be published).

[3] e.g. energy provider or grid operator

[4] https://www.seenergies.eu/peta5/

[5] https://www.hotmaps.eu

Case	Data	Specification	Source	Usage	
		– measured electricity consumption for heat generation			
2	Sectors	– classification of commerce/industry by sector – full-time equivalent	Authority	cold	
2	Building and housing register	– building age – living or energy reference areas – energy source	Authority	Heat, cold	
3	Digital twin	– data from twin-software	Authority / energy service provider (Data owner)	Heat, cold	
1 - 3	Retrofitting rate and success	– number of refurbished buildings with comprehensive building refurbishments per year in relation to the total stock. – average values	authority: statistic office	heat	Future demand
1 - 3	Settlement development	– development Areas – undeveloped areas	authority: spatial planning office	heat	

The three data sets to estimate heat demand (PETA, Hotmaps, and Building and Housing Register) are described in further detail below. Still, there may be more tools available on national and international level, which are not listed here.

Pan European Thermal Atlas (PETA 5.2)

If no data is available, the heat demand density maps from the Pan European Thermal Atlas (PETA) can be consulted for all EU countries. In addition to the heat demand density maps, the tool provides maps on cooling demand and waste heat potential, on possible district heating networks and on the availability of renewable energy resources such as geothermal energy, solar radiation, and biomass. Also, scenarios are integrated as well as capital costs on district heating (DH) distribution (Heat Roadmap Europe, 2022).

Hotmap Toolbox

As an alternative to Peta, the Hotmap Toolbox is available for EU countries, Iceland, Norway, Switzerland and the United Kingdom. Hotmaps is a GIS-based online software that provides a wide range of relevant data for heating and cooling planning. The data can be visualised with the toolbox. In addition to heat demand density maps, this platform also offers additional map material on cooling demand and waste heat potential as well as on the potential of renewable energy. Furthermore, a cost estimate and comparison between heating and cooling supply as an individual solution or in thermal networks can be made and scenarios for the transformation and reduction path can be developed (Hotmaps Toolbox, 2021).

Building and housing register

An important data basis is the building and housing register, which should be available in all EU countries. Ideally, it contains important building information such as construction period, building dimensions (area, volume), building structure (number of floors) and heating systems.

A basic survey for the registration of existing buildings can be done, for example, by a mandatory survey of the building owners (heat generation, gross floor area, energy demand area, number of floors, apartments, rooms incl. area data, etc.).
In the long term, regular updating of the register should be envisaged (e.g. linked to approval and notification procedures in the construction process) in order to obtain a better data basis and to be able to monitor the implementation of the H/C-map.

Processing

This chapter outlines how to process the basic data and prepare it for the subsequent creation of the hectare grid.

As described in the introduction, three different variants of data availability were assumed. Based on these, the procedure of data processing also differs:

- Case 1: If no baselines are available, then the hectare grids of existing tools should be used (Heatmap and PETA). The next step is to estimate the future heat demand. [6]
- Case 2: Some baseline data is available, but incomplete. In the next two sections, the procedure is explained by using building data as an example.
- Case 3: If a digital twin of the heating and cooling supply of the study area is already available, the current consumption data can be taken directly from it. The next step is to estimate the future heat demand.[7]

Heat modeling Case 2

The priority of the data used depends on the accuracy of the available data. First, measured data must be considered, followed by an analysis of extrapolated data based on installed capacity. Finally, estimates based on building data are considered. If data gaps remain, either Peta or Hotmap data can be used.

The procedure is shown in Figure 2.

[6] chapter heat demand density – Scenario 2035

[7] chapter heat demand density – Scenario 2035

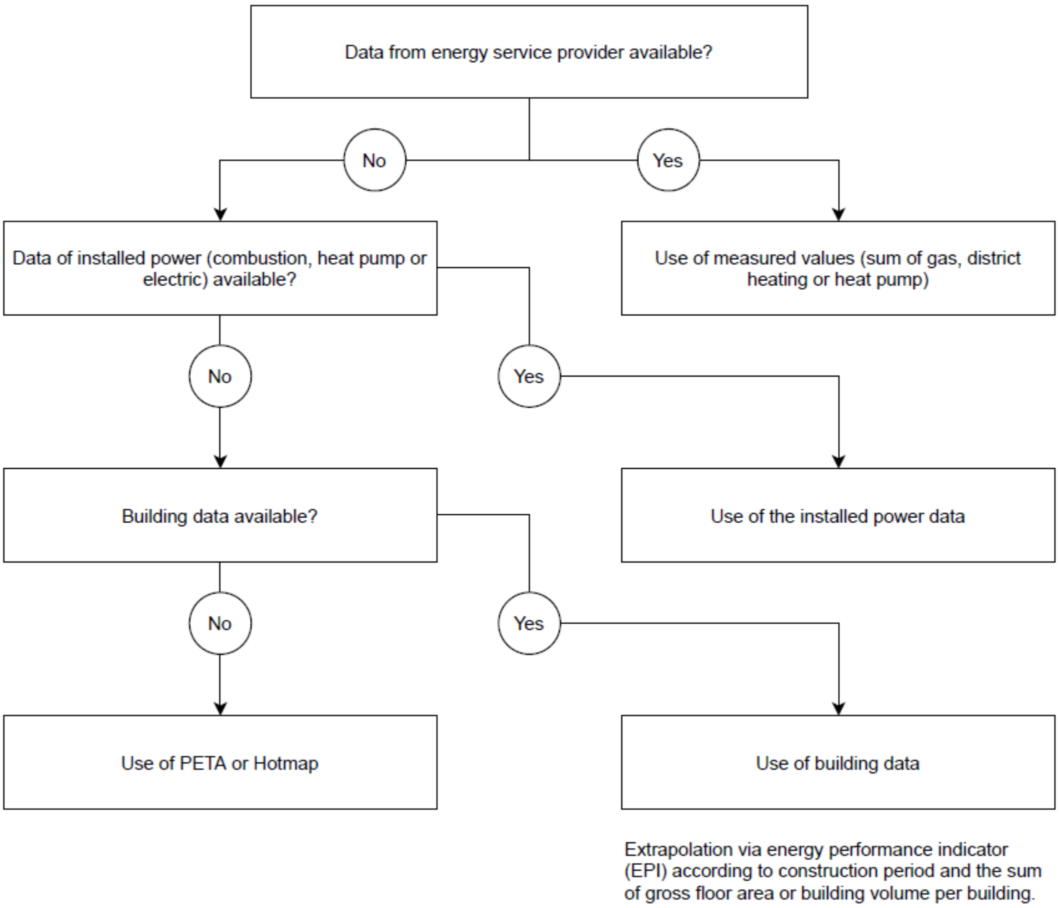

FIGURE 2: PROCEDURE FOR CALCULATING THE HEAT DEMAND PER BUILDING. THE PRIORITY CASCADE CAN BE MODELLED IN THE GIS SO THAT THE QUALITATIVELY BEST DATA SET IS CONSIDERED ON EACH BUILDING.

If heat demand must be extrapolated from installed capacity, a state-specific number of full-load hours for combustions has to be used. For heat pumps, in addition to the amount of full load hours, the seasonal performance factor (SPF)[8] is also decisive.

The following data is needed to estimate the heat demand by using building data:

- Average specific heat demand (ASH) per construction period and energy demand area (kWh/m^2 energy reference area per year),
- Energy reference area or as an approximation the gross floor area or building volume.

The ASH provides information on the energy consumption for heating and hot water per m² of energy demand area. Since the ASH varies depending on the year of construction of the building, it is also differentiated according to the construction period.

The process is described below using the city of Winterthur as an example.

If no ASH is available, the values can be taken from an area with comparable climatic conditions and a similar construction method. Alternatively, for the estimation of the local

[8] The seasonal performance factor (SPF) varies depending on the area. The site-specific value can be determined by standard data of the country or by means of surveys.

energy performance indicator, a survey of random samples can be done (analogous to the procedure of the canton of Zurich, see next section).

The statistical office of the canton of Zurich analyses measured data for final energy and useful energy for space heating and hot water of residential buildings. For 2018, for example, around 21,000 single- and multi-family homes with purely residential use were included. (AWEL, 2018). The energy consumption per construction period is divided by the energy demand area, which determines the construction period-specific ASH (Table 2).

TABLE 2: THE ENERGY PERFORMANCE INDICATOR OF A BUILDING ACCORDING TO ITS CONSTRUCTION PERIOD.

Construction period	Before 1919	1919 – 1945	1946 – 1960	1961- 1970	1971 – 1980	1981- 1985	1986 – 1990	1991- 1995	1996 – 2000	2001 – 2005	2006 – 2010	2011 – 2015	After 2015
Indicator 2019 (Zurich) [kWh/m^2]	121	137	137	136	136	110	110	90	90	95	95	95	95

Example: City of Winterthur

A wide range of data was used to create the heat demand density map for the city of Winterthur. A large part of the data was obtained directly from the utility on the basis of a non-disclosure agreement, while the remaining data was supplied by the relevant specialist agencies (at municipal, cantonal and national level) depending on the scope of responsibility.

In order to calculate the heat demand per building, the existing measured consumption data (gas, district heating, heat pumps - often per dwelling) were first geo-referenced, and summed up in the GIS per building (point data).

If no measured values were available for a building, the consumption was extrapolated via the installed power of combustion/heat pumps. Table 3 gives an overview of the data used and their extrapolation.

TABLE 3: BASIC DATA AND THEIR USE FOR THE CALCULATION OF HEAT DEMAND DENSITY USING THE EXAMPLE OF THE CITY OF WINTERTHUR. MEASURED VALUES CAN BE OBTAINED FROM THE ENERGY SERVICE PROVIDERS, THE REMAINING DATA FROM RESPECTIVE AUTHORITIES.

Energy source	Accuracy	Source	Calculation heat demand
Gas	High – metered	Utility	Measured value per dwelling
District heating	High – metered	Utility	Measured value per dwelling
Heat pump	High – electricity metered	Utility	Electricity metered * SPF[9]
Fuel oil	Medium – installed power	Heating control (chimney sweeper)	Installed power * full load hours[10]

[9] Seasonal performance factor (SPF) for Winterthur the SPF = 3.9 was used (provided from the emission register).

[10] The full load hours depend on the local climate and can usually be obtained from the local heating farmers. For Winterthur the following average full load hours were used: 1,629 h/a (Fuel oil < 1 MW, Wood < 70 kW), 2,000 h/a (Fuel oil > 1 MW), 2,580 h/a (Wood > 70 kW), 1,750 h/a (electricity heating).

Energy source	Accuracy	Source	Calculation heat demand
Wood	Medium – installed power	Heating control (chimney sweeper)	Installed power * full load hours
Electricity heating	Medium – estimation	Utility	Installed power * full load hours

For buildings without data on the heating system (neither installed power nor measured values), the heat demand was calculated by using GWR[11] data. This is calculated by multiplying the energy demand area by the energy performance indicator. For the calculations in Winterthur, the energy performance indicators of the Canton of Zurich could be used. As an approximate value for the energy demand area, the sum of the dwelling areas per building was used for Winterthur. The areas were taken from the building register (GWR).

Heat demand density

The heat demand density is needed to estimate whether an area should be developed by means of a thermal network or not.

Actual heat demand density

In a next step, a hectare grid is created in the GIS and the previously calculated or measured heat demand per building within a hectare is summarized or added up and classified.

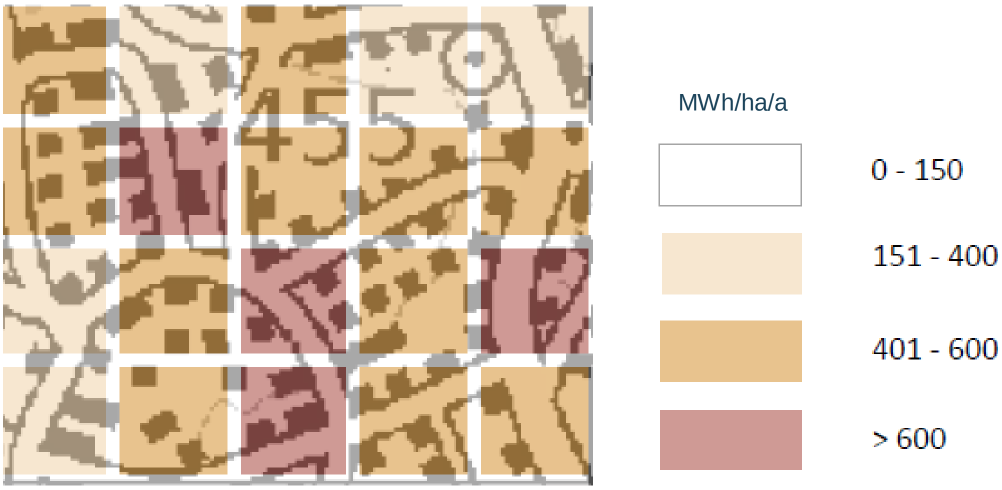

FIGURE 3: HEAT DEMAND DENSITY 2019 USING THE EXAMPLE OF WINTERTHUR (SOURCE: PLANAR 2021)

[11] GWR: Gebäude- und Wohnungsregister der Schweiz (=Building and Housing Register of Switzerland)

Future scenario

Based on the heat demand for the current year, an estimation can be made for a future year (2035 in the case of Winterthur). For this purpose, the average annual retrofitting rate is included in the calculation (view next section). The retrofitting rate refers to the number of buildings with comprehensive retrofitting of energy relevance per year in relation to the total stock of the study area. This value is to be adapted to the municipal or national specifications and goals.

In addition to the reduction in consumption due to retrofitting, there will be an increase in consumption in today's undeveloped areas or in areas with low utilization due to construction activities and densification. For this reason, the next step is to record settlement development with urban planners and estimate the future consumption of these areas. The detailed procedure is explained in the next two sections.

Retrofitting success of existing buildings

The annual retrofitting rate and scope is not the same for all buildings and differs depending on the age of the building (and therefore the construction period). Due to the protection of historical monuments, very old buildings have a lower energy retrofitting potential than buildings built between 1960 and 1980. Thus, the younger the buildings, the less retrofit work has been done or is required.

For the calctulation of the future heat demand (Qf) following data are needed:

- age of the building (construction period) as the retrofitting rate depends on the construction method which were similar within a construction period and of the age of the buildings.
- Q1: sum of heat demand per construction period.
- Rr: Retrofitting rate.
- T: The time period regarded (T = 2021-2035 = 14 a).
- Rs: Retrofitting success (e.g. remaining 60% of energy after retrofitting).

Formula for estimating future heat demand per construction period:

$$Q\mathrm{f} = Q1 * \left((Rr * T * Rs) + (1 - Rr * T)\right)$$

In the absence of the relevant data on construction times, the reduction in heat demand in the study area due to energy-efficient retrofittings can be estimated as a lump sum or on an area-by-area basis and offset against today's demand. Political control mechanisms such as subsidy standards (practiced in Munich) can also be taken into account.
When choosing the retrofitting success, it is important to consider a rebound factor, since theoretical savings are never realized. In a Dutch study, a rebound factor of 25 or 30 % was determined (depending on whether the building was owned or rented).

Savings through retrofitting of existing buildings using the example of the city of Winterthur

In Switzerland, the energy-related renovation rate is currently one percent per year. Within the national climate strategy, an annual retrofitting rate of 1.2% is targeted until 2040. Since the areas for district heating are based on the future heat demand density, an annual retrofitting rate of 2% is chosen for Winterthur, which, however, is likely to be overestimated (Table 4). n this way, however, district heating can be operated profitably in the future. Otherwise, there is a risk that the density will be too low.

TABLE 4: CALCULATION OF THE FUTURE HEAT DEMAND IN THE CITY OF WINTERTHUR ACCORDING TO THE FORMULA SUBDIVIDED BY CONSTRUCTION PERIOD. RR = 2%, T = 13. RS IS AN ESTIMATION OF PLANAR AG.

Construction period	Q1: Heating 2019 (MWh/a)	(Rs): remaining heat per retrofitted building	Qf: Heating 2035 (MWh/a)
< 1919	153,194	70%	141,245
1981 - 1985	43,752	50%	38,064
2011 - 2015	43,175	90%	42,053
< 2015	32,953	100%	32,953

Settlement development

This section focuses on how the residential development of the study area can be captured and integrated into the planning process. Special emphasis is placed on currently undeveloped areas and on large areas where major conversion or redevelopment with replacement buildings is foreseeable.

The effect of inner densification in existing settlement areas on the heat demand depends on the legal building regulations. In the case of high legal efficiency requirements, experience shows that internal densification is negligible, because it does not significantly influence the heat consumption within a hectare cell (modern new buildings and extensions hardly require any more heat). Depending on the available data, however, it may be worthwhile to consider the utilization reserves as well.

The data can be collected in qualitative and/or quantitative form and spatially represented in the GIS in cooperation with the urban planners. Depending on the data basis, it should be estimated how high the future consumption will be in these development areas. This estimation can be made, for example, via the newly added or eliminated residential areas in m², the number of future apartments or via the increase or decrease in residents.

Example of the city of Winterthur

In close cooperation with the Office of Urban Development, the development areas of the city of Winterthur were defined and their energy reference area was estimated. The city directs the focus of future development to the so-called "urban backbone" (Figure 4).

The future heat demand is the product of this energy reference area and the parameter of 35 kWh energy demand per m² of new building area (expected ASH). This value depends on the construction method and climatic conditions and therefore differs depending on the region. The estimation of the energy reference area in Winterthur is based on municipal geodata, which include the following information:

- Areas with forecasted construction activities (number of apartments added);
- Land reserves for construction (maximum permissible plot utilization);
- Areas with special conditions ("special planning" with maximum permissible plot utilization).

FIGURE 4: DIRECTION OF SPATIAL DEVELOPMENT 2040 OF THE CITY OF WINTERTHUR (STADTENTWICKLUNG WINTERTHUR, AMT FÜR STÄDTEBAU, 2019)

Future heat demand density

In a final step to determine the future heat demand density, the previously calculated data of the renovated stock[12] and the settlement development[13] are combined in the GIS and summed up again on a hectare grid. In addition, corresponding classes are formed.[14]

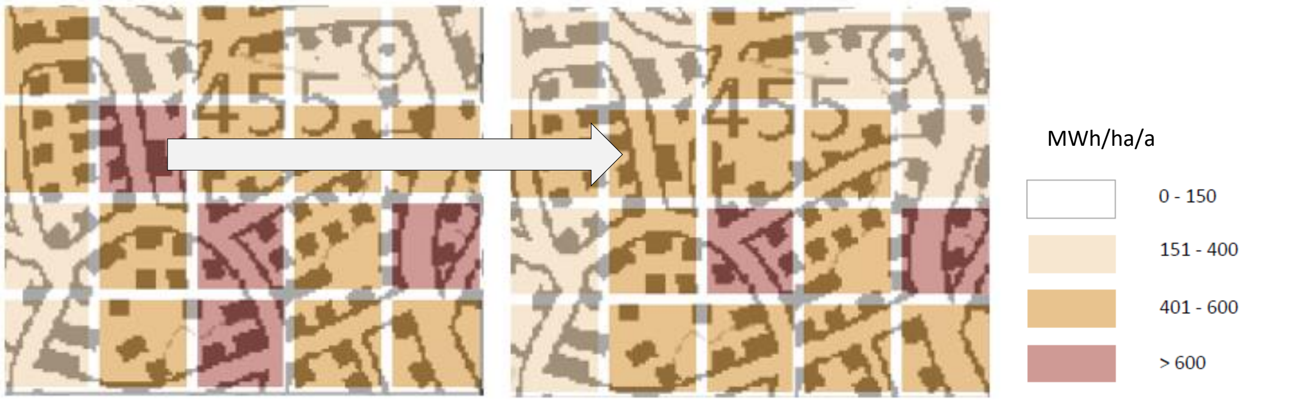

FIGURE 5: HEAT DEMAND DENSITY IN 2019 (LEFT) AND 2035 (RIGHT) BASED ON THE EXAMPLE OF WINTERTHUR (SOURCE: PLANAR 2021). DUE TO RETROFITTINGS, THE FUTURE DEMAND DECREASES. AN INCREASE IN DEMAND CAN OCCUR IN DEVELOPMENT AREAS.

12 Section "retrofitting success of existing buildings"

13 Section "settlement development"

14 Section "actual heat demand density"

Cooling density

With the increase of cooling demand days, efficient cooling solutions become more and more important. Thus, and first and foremost, climate adaptation measures need to be applied in urban planning and building permits to enable a comfortable urban climate. This includes preserving a good ventilation of the city, vegetated open spaces as cooling spots and sponge city elements to cool urban spaces. On the building itself, attention should be paid to summer thermal protection, roof greening (PV and greening combined), facade greening and other measures.

According to Heat Roadmap Europe 4 (2017), energy use for space cooling is nowadays dominated by southern countries, mainly Italy and Spain (Figure 6).

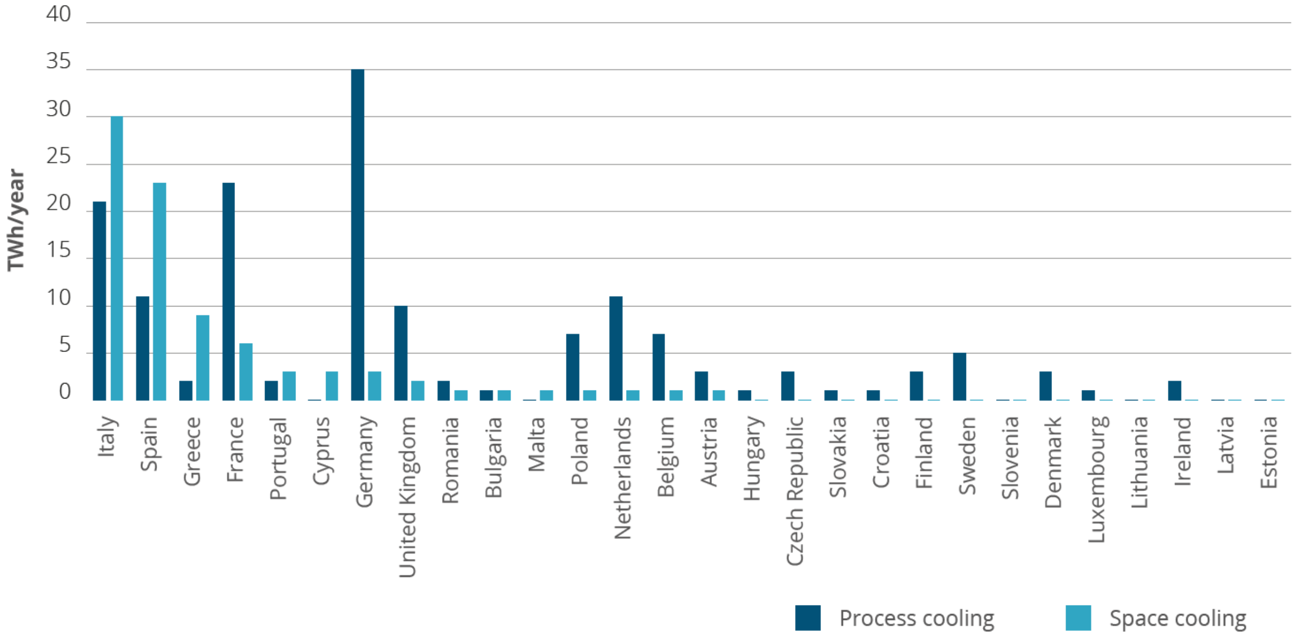

FIGURE 6: ELECTRICITY CONSUMPTION FOR COOLING BY COUNTRY (HEAT ROADMAP EUROPE 4 (HRE4), 2017).

A study by EMPA[15] assumes that in 2050 the cooling demand in Switzerland in summer will be as high as the heating demand in winter today. If this cooling is generated individually with air conditioning systems, the future electricity demand will be enormous. It is therefore necessary to develop efficient systems at least at the building level, and even better on heat grid level. To take this into account in energy planning, it is necessary to estimate the cooling demand and show possibilities in the H/C map. The procedure will be described in the next chapters.

[15] R Mutschler, M Rüdisüli, P Heer, S Eggimann; Benchmarking cooling and heating energy demands considering climate change, population growth and cooling device uptake; Applied Energy (2021)

Data

The data basis for cooling demand seems to be even more difficult to collect than for heat demand. A more detailed analysis would require data on the installed capacity of cooling systems, which is often lacking. Where applicable, environmental protection departments have data on the amount of refrigerants used in larger cooling systems. However, a method for estimating the amount of cooling produced per refrigeration unit is still lacking.

For the H/C map, the following data is available or has been used for estimation:

Qualitative estimation via industries and commercial

If a geo-referenced data set on the sector affiliation of commercial and industrial enterprises is available, a qualitative estimate of the cooling demand can be made. Based on this data, areas for possible cooling networks can be identified.

To locate cooling-affine uses, qualitative cooling scores (0 for no cooling demand and 5 for high cooling demand) are assigned to different branches[16]. The sum of all cooling values per hectare is then divided into equal quantiles so that clusters of cooling-affine uses can be visually identified and categorized from low cooling demand to very high cooling demand.

Example Winterthur: The data used is taken from the statistics of business structure (STATENT), which classifies trade and industry according to specific sectors (NOGA)[17]. Cooling demand for residential use is currently negligible in Switzerland.

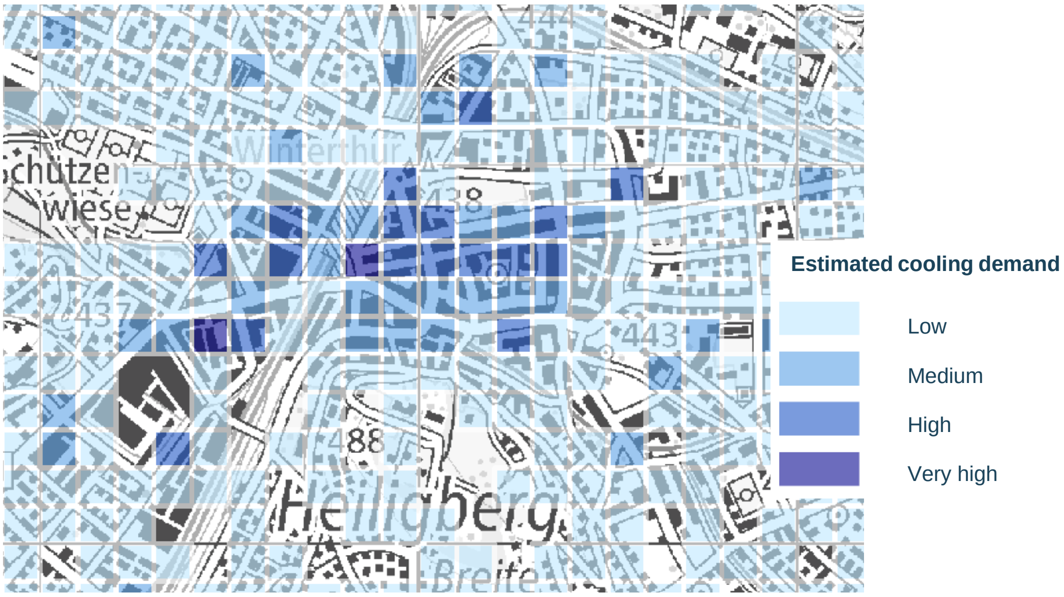

FIGURE 7: COOLING DEMAND IN THE CITY CENTRE OF WINTERTHUR, ESTIMATED VIA THE INDUSTRY AFFILIATION OF THE COMPANIES (PLANAR, 2021)

[16] For example, the refrigeration demand of the "Wholesale" category was rated 5, while the "Retail" category was rated 3.

[17] https://www.bfs.admin.ch/bfs/de/home/statistiken/industrie-dienstleistungen/erhebungen/statent.html

Quantitative estimation

Both Peta and Hotmap provide maps of cooling demand density at hectare level. However, it is important to note that these approaches are based on continental mapping (top down) and do not take into account site-specific or local conditions (bottom-up).

To determine the sector's cooling demand density for 2015, residential and service space per hectar was first calculated. Other factors considered included a local national cooling index, a market share of cooled space, and the specific cooling needs of the residential and service sector at the national level (Persson, 2017).

According to the authors (Pezzutto et al., 2018), cooling demand is derived based on the average cooling demand for buildings at the country level per floor area and assumed to be based on the ratio between national cooling degree-days and calculated local cooling degree-days. [18]

Solution approaches for supply cooling demand

The first step is to prevent or minimize cooling demand. This can be done by means of various climate adaptation strategies, as mentioned in the beginning of this chapter.

The remaining cooling demand needs to be solved on a technical basis. The cooling demand can be met either by heat pumps, direct cooling/free cooling or absorption chillers.

For direct cooling, for example, heat from groundwater, shallow geothermal energy or ambient heat can be used. If this is not sufficient, cooling can also be generated with a heat pump using electricity. Absorption chillers use waste heat on high temperature level to produce cooling. This can be worthwhile if surplus waste heat cannot be used in any other way in summer.

To reduce the load on the power grid, a high cooling efficiency should be aimed for. If, for example, process waste heat is coupled with heat demand of residential buildings in a low thermal network, efficiency of the overall system is very high. Cooling residential buildings in an interconnected system using environmental heat and a heat pump is also much more efficient than individual air conditioners. Possible distribution systems for coupling cooling and heating in a singular network are explained in chapter “energy map”.[19]

[18] The cooling needs significantly deviate from the observed electricity consumption for air conditioning. Besides, a deviation is driven by the efficiency of AC systems (with a typical COP in the range of 2-4) and the fact, that for most regions the share of building floor area, which is fully air-conditioned is well below 1 (Pezzutto et al., 2018).

[19] Section “Heat/cold distribution systems”

Infrastructure

Infrastructure facilities, such as existing heat supply pipelines, represent investments already made and should continue to be used if possible. Other facilities, such as waste incineration plants, may have waste heat potentials.

To create an energy plan, it is advisable to make an inventory of the existing infrastructure and display it on a map. This ensures that local conditions are taken into account during planning and optimally combined with existing energy potentials. Table 5 gives an overview of buildings and facilities that can be included in the infrastructure map.

TABLE 5: OVERVIEW OF BUILDINGS AND FACILITIES THAT ARE RECORDED TO CREATE AN INFRASTRUCTURE PLAN (SOURCE: PLANAR 2022).

Infrastructure	Purpose	Source
District heating pipelines	Expansion of networks	utility
Heating centre	Expansion of networks	utility
Existing geothermal probes	Correction of heat demand density for district heating (existing individual solutions); possible storage	authority (responsible for approval)
Existing groundwater use	Possibility to integrate individual solution into a network	authority (responsible for approval)
Tunnels	Local waste heat potential, restriction on geothermal energy use	urban planning / Google Maps or local maps
Large settlement infrastructures such as waste incineration plants, sewage treatment plants, …	Local waste heat potential	urban planning / Google Maps or local maps
Data centres / industries and business parks	Local waste heat potential	site development, licensing authority / Google Maps or local maps
Power generation plants	Local waste heat potential	Electricity supplier
Capacity of converters/heat exchangers (heat)	Technical restriction for network expansion	Energy Services Company
Capacity of substations and converters (electricity)	Technical restriction for network expansion	Electricity supplier, grid operator

The H/C map, which should be geared towards the goal of decarbonization, must also take into account and include intersections with gas supply and electricity supply, in order to be able to determine how to deal with existing infrastructure facilities, possible expansions etc.

Potential map

If possible, the surveyed potential energy sources (see then also D2.4) are spatially mapped in the potential map. Locating energy potentials is an important part for the spatial coordination of heat supply and, in addition, for the infrastructure map, and serves as a further important basis for the H/C-map (Figure 8).

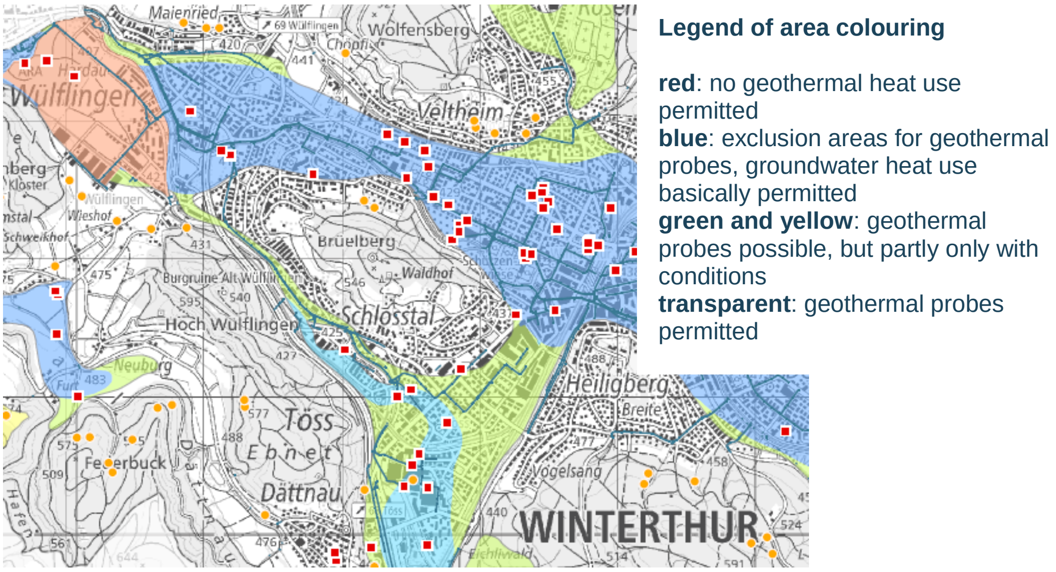

FIGURE 8 : EXTRACT FROM THE POTENTIAL MAP OF THE CITY OF WINTERTHUR (SOURCE: PLANAR 2021).

Some countries provide quantitative data on potential supply per plot. If the data basis is not quantitative, it is recommended to include the following energy sources and information in the potential map:

- Protection zones of groundwater as exclusion zones for groundwater use[20].
- Deep and shallow ground heat (if permitted and usable).
- Surface water (sea, lake, river).
- Tunnels (air or drain).
- Existing groundwater and spring catchments.
- Sewage water system (diameter > 800 mm).
- Big waste heat sources (incineration plant, waste water treatment plant, data centres, industrial waste heat, fermentation/biogas plants)

In addition, there are site-independent or at least less site-specific energy sources that should also be included in planning:

- Wood (sustainable use)[21]
- Biomass (organic waste from households or pruning)
- Solar potential (electric and thermal)

[20] If groundwater heat is used, contamination of the drinking water must be avoided at all costs.

[21] The wood used should come from sustainable forestry, i.e., only as much tree cutting is allowed as will regrow in the same time period. In some countries it is regulated by law (e.g., Switzerland by the Forest Act).

Economic aspects

The energy prices of a heating network must be affordable for the end customers. To be competitive, they must be lower than an individual solution with renewable energy. Since pipeline construction is rather cost-intensive, the connected power per route meter (linear heat density) plays a decisive role (> 2 MWh/m e.g. applied in Munich). Since this is unknown for non-existing grids, the heat demand density is used as an auxiliary parameter.
Another approach to considering costs in the transformation process is to look at the cost per ton of CO_2 emission reduced. There are certainly other approaches that are possible. In this chapter, however, we will focus on two of the approaches mentioned.
In cost calculations, it is enormously important that costs are calculated over the lifetime of equipment and installations in order to obtain comparable values. For example, a gas heating system has a lifetime of 20 years, a gas pipeline of 80 years, a geothermal probe of 50 years and district heating pipes of 50-80 years.

Limit value heat demand density

In this section, physical suitability (heat demand density) is discussed first, followed by economic suitability. According to Persson U. et al. (2019) there are three main cost components for district heating (Figure 9):

- Primary energy cost (heat);
- Ability to pay for (excess) heat;
- Heat distribution costs (dependent on heat demand density, the local heat generation alternative and spatial context).

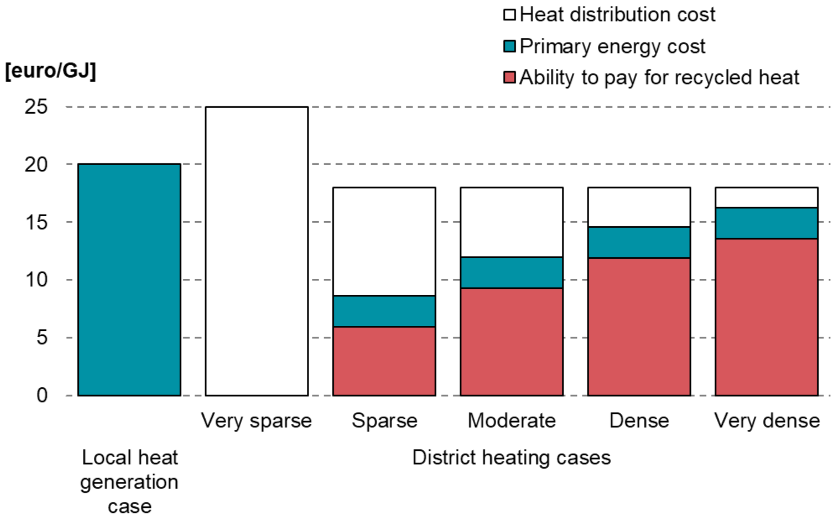

FIGURE 9: EXAMPLE OF COST STRUCTURE COMPARISON BETWEEN ONE LOCAL HEAT GENERATION CASE AND FIVE DISTRICT HEATING CASES WITH RESPECT TO HEAT DISTRIBUTION COSTS, PRIMARY ENERGY COSTS (HEAT GENERATION), AND THE ABILITIES TO PAY FOR RECYCLED HEAT (EXCESS HEAT RECOVERY). THESE FIVE DISTRICT HEATING CASES CONSIDER DIFFERENT CONCENTRATIONS OF HEAT DEMANDS (PERSSON ET AL., 2019).

Persson U. et al. (2019) also emphasize that “the proportion of the heat distribution cost in the total cost for district heat is under direct influence of the heat demand density of the supplied land area”. In denser areas these costs constitute lower proportions of the total cost than in areas of moderate or sparse densities, since shorter distribution pipes can be used per unit of heat delivered.

However, high connection rates are likely to exploit heat distribution infrastructures fully for best economic performance. A high connection rate may even counteract a de-creasing heat demand. It is therefore due to spatial concentration of heat demands, and not primarily due to their volumetric magnitudes, that beneficial conditions for viable district heat distribution are formed (Persson et al., 2019).[22]

The limits used for the density classes varies from case to case. Experience has shown that the limit density for an economic operation of district heating in urban western europe is between 300 - 500 MWh/ha/a (Table 6).

TABLE 6: PHYSICAL SUITABILITY FOR DISTRICT HEATING BY CLASSIFICATION OF FIVE HEAT DEMAND DENSITY CLASSES ACCORDING TO PERSSON ET A. (2019). MODERATE, DENSE AND VERY DENSE CONDITIONS ARE CONSIDERED ES APPROPRIATE PHYSICAL SUITABILITY LEVELS FOR DISTRICT HEATING.

Heat density class	Heat density intervals [MJ/m^2]	Concentration of heat demands
0	0	No modelled heat demand
1	$0 < qL$[23] < 20	Very sparse
2	$20 \leq qL < 50$	Sparse
3	$50 \leq qL < 120$	Moderate
4	$120 \leq qL < 300$	Dense
5	$qL \geq 300$	Very dense

Areas with moderate, dense and very dense heat demands are suitable for district heating. Thus, areas to be supplied with a thermal network can be identified. In order to determine the limit value more exactly, national average values or empirical values of local district heatings can be consulted. It is important to consider whether the limit value is applied to the current heat demand or to the modeled future heat demand. Which areas are actually suitable for district heating or the concrete routing needs to be clarified in a detailed feasibility study following the H/C-map.

Connecting new construction areas can be worthwhile even with a low heat demand density due to low-cost pipeline laying.

[22] See also chapter “heat demand density”

[23] q_L= heat demand density

Cost-effect analysis

Another approach is based on a cost-effect analysis, as carried out in Dublin. Here, the costs per kilogram of CO_2 emissions reduced are analysed and a threshold value is set. All emissions are taken into account. For example, in the case of natural gas, methane losses due to gas leaks are taken into account in addition to direct emissions of CO_2 and NO_X.
For the heat pump and district heatings, the CO_2 equivalents of the refrigerants are considered in addition to the emissions from electricity production. This results in GHG emissions per kWh of delivered heat.
The costs for building different solutions can thus be calculated per kilogram of CO_2 emission reduced and spatially linked to the heat demand. Thus, the most cost-efficient solution can be determined for each area.

Investment-cost-analysis

In its analyses, the City of Vienna weighed the costs of district heating lines against the costs of the necessary expansion of the power line infrastructure. If the installed electricity capacity is not sufficient due to a large number of additional heat pumps, investments must be made in the electricity grid. Ideally, the heat grid is then the better solution in the overall assessment. This approach is, however, only successful if both the electricity company and the heat supply company are owned by the city.
It should also be noted that initial analyses in the city of Winterthur showed that electromobility and the installation of charging stations in all buildings influence the required power capacity more than heat pumps. Therefore, in addition to the heat pumps, the charging stations must also be considered.

Sector coupling
Another impact on the cost-efficiency of the H/C-Map may result from sector coupling. As this topic is too extensive for this guideline, only a brief overview is provided in the appendix.

Energy map

The energy plan defines spatial measures for achieving a sustainable energy supply in accordance with the respective urban goals. For this purpose, the supply areas can be divided into different types of areas.[24]

- Areas of district heating.
- Areas for the expansion of the district heating.
- Individual heating areas (individual solutions).
- Areas for small district heating.

At the very least, areas of individual and district heating should be defined. Depending on local conditions, further differentiation according to the above mentioned categories may be useful. The individual categories are described below.

Areas of district heating

In dense areas, heating and - depending on demand - cooling should be provided in a thermal network. Based on the potential map, a suitable energy source is considered for interconnected areas and it is examined whether the required flow temperatures can be achieved with it or whether the potential heat source can be raised to the required flow temperature (Figure 11).

Areas for the expansion of the district heating

Suitably dense areas next to an existing district heating with free capacity of heat potential and power or space to enlargen the power, should be connected to it. Its feasibility is to be examined in a next step.

Individual heating area

In sparse areas, heat density is most often too low to operate a district heating network cost-efficiently. In these areas individual heating systems are advantageous. For each area, the primary energy source that can be raised to the useful temperature with appropriate heat pumps should be recommended for each system (e.g. geothermal, groundwater, ambient air, wood). In exceptional cases, pellet heating systems can be used instead of heat pumps.

Areas for small district heating

Small areas within individual heating areas, but with a high heat density, can also be defined as areas for small thermal networks. A thermal network can then be established, for example, on the basis of a private initiative (the city can then take a supporting but not responsible role) or be supplied individually.

[24] The classification should consist of at least two types of areas: District and Individual heating areas. The other division is optional.

H/C-map

The areas designated in the H/C-map indicate the desired target state. Feasibility (feasibility studies, assessments by engineers) needs to be examined in detail in a further step after the H/C-map has been defined.
The municipal H/C-map is designed for 15 to 30 years. Based on experience, an H/C-map needs to be updated after about 5-10 years. With the implementation, new knowledge about potentials and feasibility is usually gained, which then needs to be included in an update. Furthermore, in a functioning heat market (tenders of heat networks, private suppliers and initiatives), divergent but equally effective solutions may arise, which then also require an update of the heat cadastre (especially if a connection obligation that is based on the map is implemented).

Zoning and energy source selection

The **spatial coordination** of settlement developement and heat supply is done by combining the compiled information such as infrastructure, future heat demand density, spatial-structural development as well as locally or regionally available energy potentials.
The area classification is based on existing basic maps, described at the beginning of the guideline. In a first step, areas with a high heat demand or cooling density are identified (Figure 10).

If the dense areas are larger areas, they can be designated as areas for district heating. If the areas are adjacent to an existing district heating network, it is necessary to assess whether there is sufficient spare capacity to extend the existing network or whether the area needs a central heating plant of its own. If the capacity is high enough, the area may be designated as an area for expansion of the district heating. If the area is small and isolated from other dense areas, the area is to be designated as a suitable area for small-scale interconnections.

An example of a process of how to classify areas, is depicted in the following flow chart:

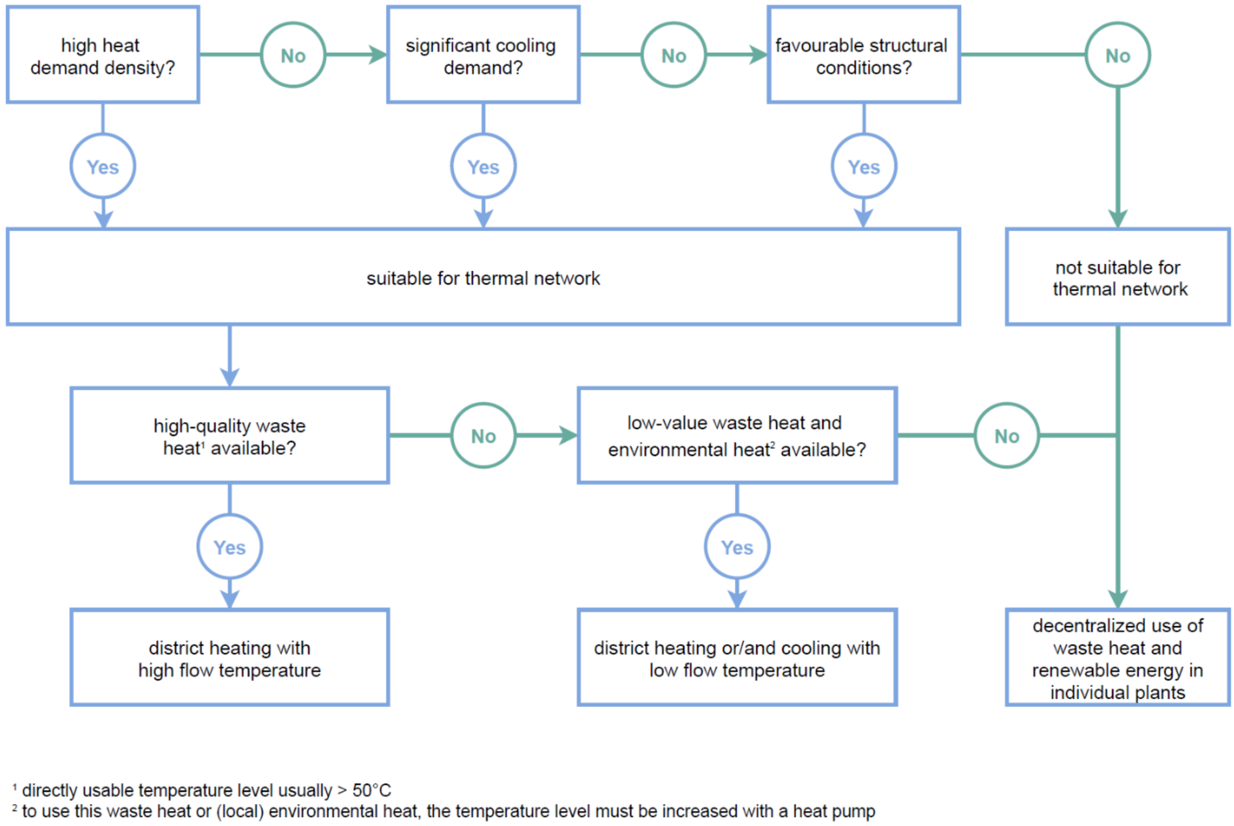

FIGURE 10: DECISION SCHEME FOR DEFINING A SUPPLY TYPE REGARDING HEAT DEMAND DENSITY, DEPENDING ON ENERGY DEMAND AND ENERGY SUPPLY.

After defining the areas for district heating and individual heating, the **most suitable energy source** should be found. If possible, the energy sources should be used in the following order from the point of view of climate policy:

- Infrastructural and commercial waste/recovered heat that can be used directly (high temperature).
- Infrastructural and commercial waste/recovered heat that can be used with heat pump (low temperature).
- Environmental heat.
- Wood.
- Green gas.

Possible energy sources, the corresponding COP of heat pumps as well as the flow temperature demand of heating systems is depicted in Figure 11. These help in finding a suitable heat source if more than one is available. It needs to be taken into account, that temperatures of up to 80°C are possible with heat pumps. In existing buildings, a source with low temperature may thus also be possible.

Green gas (from biomass or power-to-gas) should be reserved for industrial processes and peak capacity in district heating systems due to its limited potential (if not competing with food crop) and should not be used for space heating. Hydrogen may also be used for the uses mentioned above. Since the production of hydrogen today is still energy intensive, it should be used only in case alternatives are difficult to be found (e.g. for truck transports). In the most favorable case, fossil-free gas and hydrogen are produced using electricity (cogeneration) to support power generation in winter.

Figure 11 shows temperature levels of heating systems and heat sources as well as the ranges of heat pumps.

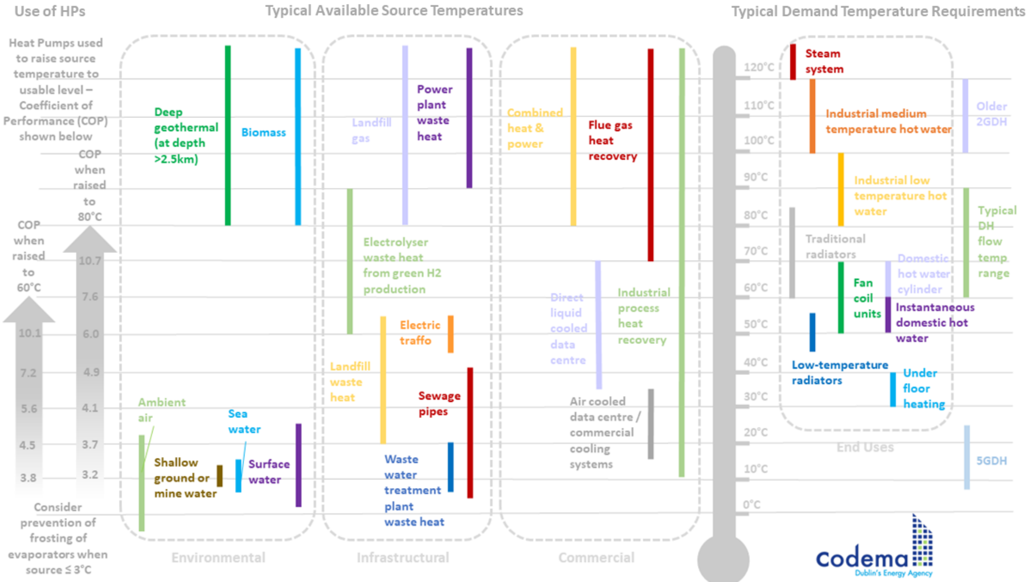

FIGURE 11: TYPICAL AVAILABLE SOURCE TEMPERATURE AND DEMAND TEMPERATURE REQUIREMENTS (SOURCE: CODEMA 2022).

In areas with individual heat production, wood should only be used in case no other option is available. Since wood is a finite resource it should be utilized in the best possible way, i.e. for heat in combination of electricity production. Ideally, this is even done as a pyrolysis process, so that the remaining part of the CO_2 in the coal can be used as a sink on agricultural land, making it more fertile and less susceptible to drought.

The different district heating generations are described in the appendix.

Structural framework conditions

In addition to the basic principles described above, there are other structural conditions that can be taken into account in the zoning process which may point to a district heating solution or not.

Ownership structure of buildings

In the case of condominiums, it is often difficult to convince all parties involved to connect to a thermal network. This is usually easier with cooperatives and investors.

Neighborhood structure

Neighborhoods with single-family homes or loose, smaller multi-family housing estates usually have too low a heat demand density to make connection to a grid worthwhile. However, in areas with dense multifamily development and industrial and commercial areas, an interconnected solution is a viable option. More information is discussed in paper D2.4 (to be published).

Topographical conditions

In cities where topography varies widely, the difference in elevation can be an obstacle. Height differences of more than 30 to 50 meters lead to increased pressure and additional costs. Below that, the height difference can easily be overcome.

Conclusion and next steps

Taking into account the above points, the heat supply can be mapped with the energy sources available per area. On the level of a H/C map, it is not mandatory to plan in all details. With feasibility studies per area, the implementation can be sharpened. In a next step, such H/C maps need to be brought into implementation.

Cities within the Decarb City Pipes 2050 consortium are therefore required to develop concrete transition roadmaps that identify the necessary framework conditions, governance structures, measures, and steps in order to implement these plans. It is recommended for the purpose of enabling implementation that both the H/C map and the transition roadmap be adopted by the City Council.

Glossary and abbreviations

Building and housing register	A building and housing register is used for statistical, research and planning purposes and for the execution of statutory tasks at the national or municipal level. It contains information on construction projects, buildings, apartments, building entrances and streets.
CO_2-equivalents (CO_2-eq.)	Sum of the different greenhouse gases (e.g. CO_2, CH_4, N_2O, etc.) weighted with the respective global warming potential.
District heating	District heating refer to piped (district) heat or cooling distribution systems.
Specific heat demand (ASHD)	This characteristic value indicates the energy demand for space heating and domestic hot water in kWh per year and m² of heated floor area.
Energy demand area	The energy demand area is the sum of all floor areas above and below ground that are located within the thermal building envelope and require heating or air conditioning for their use.
Full load hours	The full load hours indicate how many hours the plant would run to achieve the annual energy production if it only ran at full load and was otherwise idle.
Green gas	In the "power to gas" production process, surplus electricity (from renewable sources) is converted into green gas using electrolysis and CO_2. Gas from biomass fermentation is also considered green gas.
Heat demand density	This quantity tells how high the heat demand per unit of settlement area is (e.g., in MWh/a per hectare).
Low-Thermal-Network	A Low-Thermal-Network is a pipeline network that transports heat at a low temperature level. The useful heat/cold is created decentrally. Via this network, the waste heat (e.g., cooling equipment) from one building can be absorbed and used as heat in another building.
Retrofitting rate	The retrofitting rate indicates how many buildings are retrofitted in terms of energy per year. If the rate is 1%, 1% of all buildings are refurbished in one year.
Seasonal performance factor (SPF)	The seasonal performance factor is the measure of the efficiency of a heat pump system. It indicates how much heat is generated in relation to the electricity used in a year.
Supply temperature	In heating technology, the supply temperature is the temperature of the heat-transferring medium (e.g., water) after it has been heated by a heat source (e.g., solar collector, gas heating) and fed into the distribution system (e.g., pipe).

Bibliography

Arbeitsgemeinschaft QM-Fernwärme. (2018). Planungshandbuch Fernwärme. Bern: EnergieSchweiz.

AWEL. (2018). Energie in Wohnbauten 2018 . Zürich: AWEL.

Bundesamt für Statistik . (2021). Gebäude- und Wohnungsregister .

Heat Roadmap Europe. (2021). online. Retrieved from https://heatroadmap.eu/project/

Heat Roadmap Europe 4 (HRE4). (2017). Heating and Cooling. Facts and figures.

Hemis, H., & Lichtenwöhrer, P. (to be published). Deliverable D2.4, Report on data availability, data sovereignty, quality and exchange in the participating cities and policy recommendations. City of Vienna.

Hemis, H., & Lichtenwöhrer, P. (to be published). Deliverable D2.5, Report on design-approaches for H/C-landscape typologies.

Hotmaps Toolbox. (2021). online. Retrieved from https://www.hotmaps-project.eu

Madsen, A. (2022). Deliverable D3.3, Cross-city summary of H/C-maps.

O'Shea, J. (to be published). Deliverable D4.4, Report on developing transition roadmaps.

Persson, Urban et al. . (2019). Heat roadmap Europe: Heat distribution costs. . Energy, 176. Jg., S. 604 - 622.

PETA. (2022). Pan European Thermal Atlas Version 5.2. Retrieved from https:heatroadmap.eu/peta4/

R Mutschler, M. R. (2021). Benchmarking cooling and heating energy demands considering climate change, population growth and cooling device uptake. EMPA Applie Energy.

S. Pezzutto et al. (2018). Hotmaps Proeject, D2.3 WP2 Report - Open Data Set for the EU28. Retrieved 01 13, 2022, from www.hotmaps-project.eu

Stadtentwicklung Winterthur, Amt für Städtebau . (2019). Winterthur 2040 Synthesebericht Testplanung . Winterthur.

Stadtentwicklung Winterthur, Amt für Städtebau . (2021). Winterthur 2040 Räumliche Entwicklungsperspektive . Winterthur.

Urban, P. (2017). Methodologies and assumptions used in the mapping. Heat Roadmap EU.

Appendix

A1 Heat/cold distribution systems

There are several types of heating and cooling distribution systems. Depending on the buildings they serve in a given area, it is necessary to choose the system that fits best. For example, the supply temperature must match the internal distribution system of the building.

One of the most important factor is the temperature level needed in the building. The required supply temperature of a building is related to the construction method and thus often to the age of the building. The newer a building is, the more likely low flow temperatures can be used[25]. Therefore, if the required flow temperatures are not known in detail, buildings constructed after the year 2000 may indicate the suitability of low-temperature networks. The required flow temperature can also be reduced with an energetic retrofitting.

For heat networks, it is true that as network temperature increases, heat losses also increase (Arbeitsgemeinschaft QM Fernwärme, 2018). In addition, when certain temperatures are exceeded, the technical requirements for the infrastructure increase. Further advantages of lower system temperatures are higher conversion efficiencies and more available heat sources (Persson, Urban et al. , 2019).

The district heatings with high flow temperature (1st and 2nd generation DH) will not be mentioned furthermore because they are sufficiently well known and widely used. The following sections concentrate on systems which (may) include also cooling supply (3rd - 5th generation DH).

Four-pipe system (3rd & 4th generation DH).

In a four-pipe system, there is one heat and one cold distribution. Heating and cooling are produced in an energy center by means of a combined heat pump. A big advantage of this system is that the waste heat of the cold production can be fed directly into the heat distribution (useful temperature). The system is therefore very efficient and profitable (Figure 12).

[25] For well-insulated new buildings with underfloor heating, space heat can be used directly from around 30-40°C. Older buildings, on the other hand, require flow temperatures of 70 -80 °C. For domestic hot water, flow temperatures of around 70°C are usually required in the district heating network to ensure safety due to legionella (Arbeitsgemeinschaft QM Fernwärme, 2018).

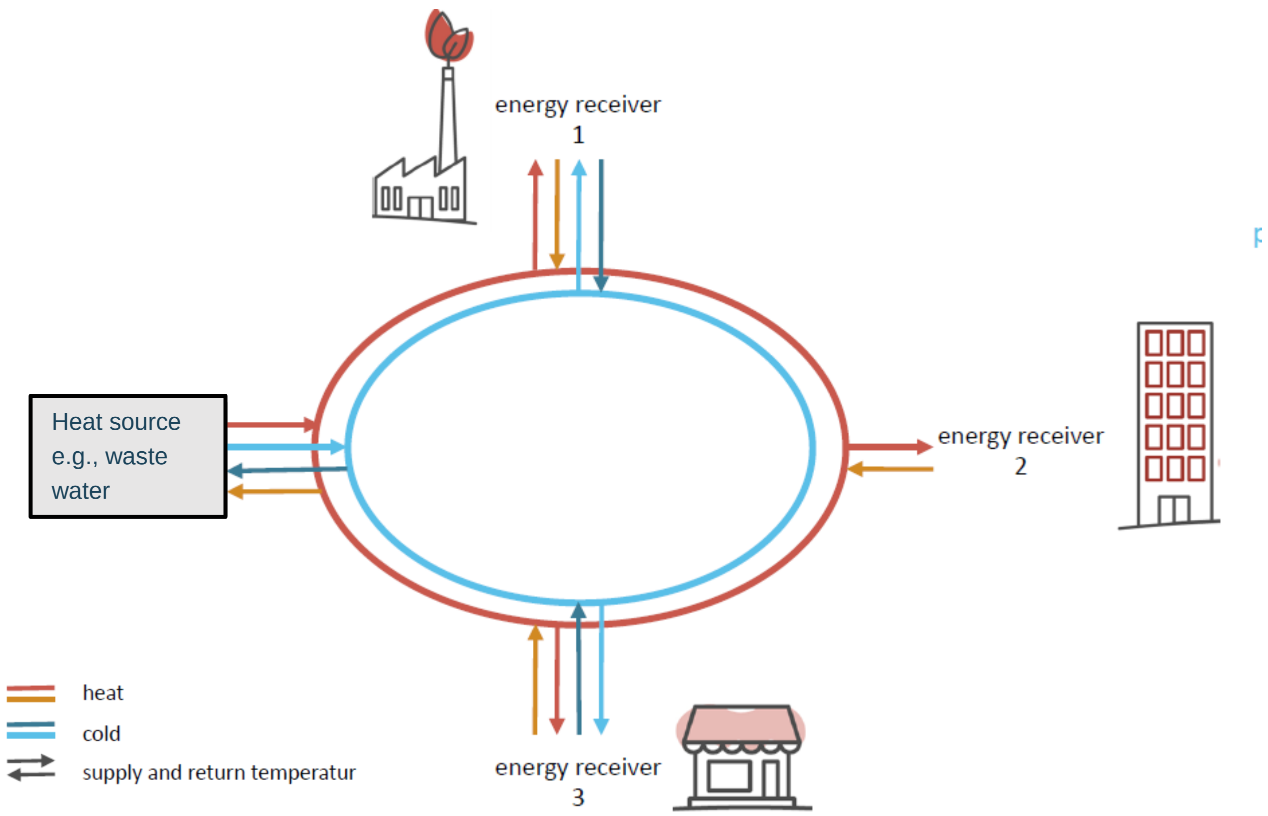

FIGURE 12: SKETCH OF A FOUR-PIPE SYSTEM (3RD & 4TH GENERATION DH). THE ENERGY RECEIVER DECIDES WHETHER IT NEEDS HEATING AND COOLING OR ONLY HEATING. SOURCE: PLANAR 2021.

Low-thermal network (5th generation DH)

A low-thermal network is an interconnected system that is designed for low temperatures. Everyone who is connected to the network can take their heating or cooling requirements from the low-temperature network and raise them to the individual useful temperature by means of a heat pump. Rarely, however, do the cooling and heating requirements of all customers match exactly. Therefore, an external energy source and a (seasonal) storage are often needed to balance the system (Figure 13). A geothermal probe field can serve as a seasonal storage. This absorbs the excess heat in summer and stores it until winter.

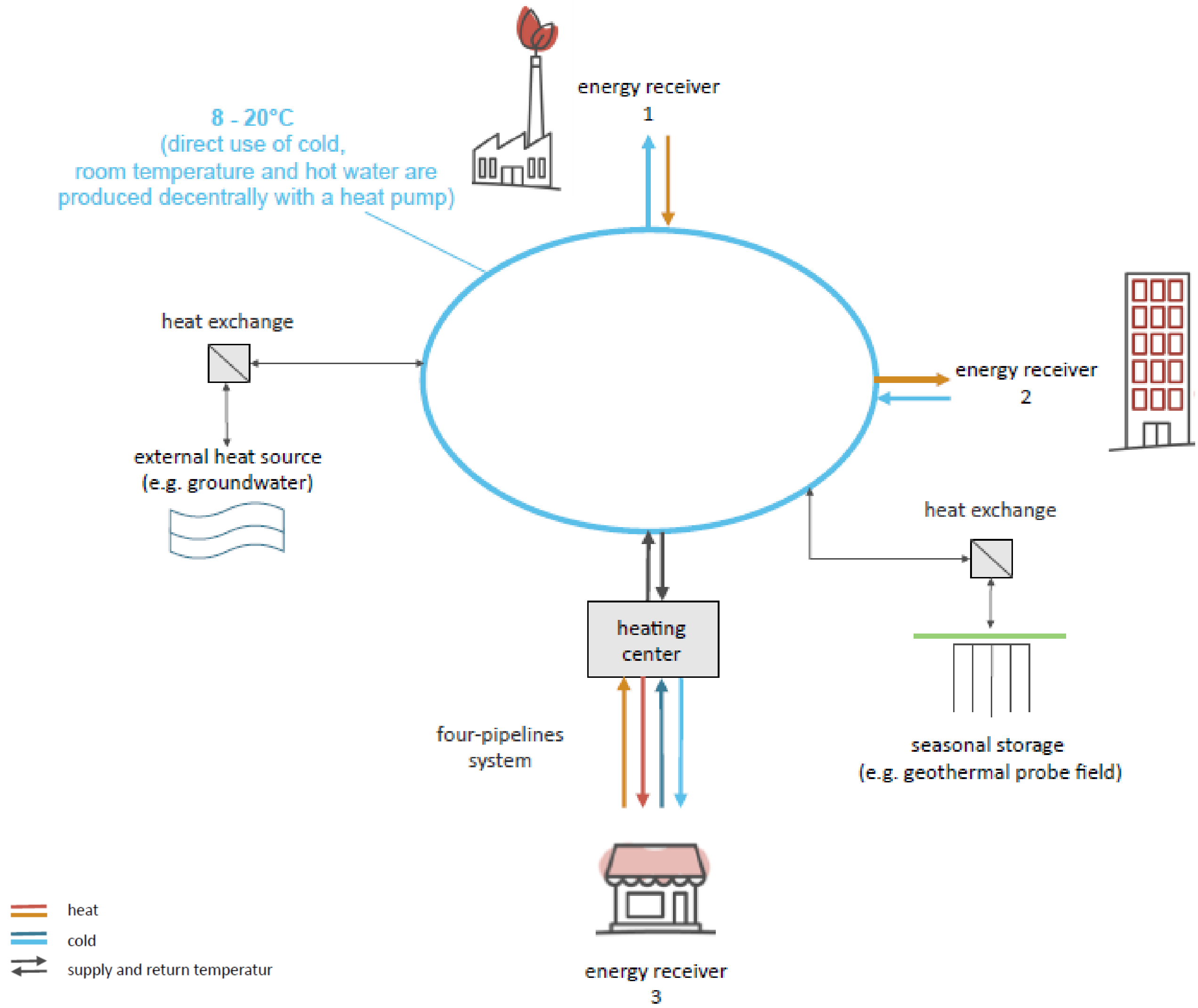

FIGURE 13. SKETCH OF A LOW-THERMAL-NETWORK (SOURCE: PLANAR 2022).

Changeover system (two-wire system)

In a changeover system, the system alternates between a heating and cooling mode (Figure 14). In winter (heating mode), the flow temperature runs at > 70°C, so that customers can heat directly from district heating. In summer (cooling mode), the network temperature changes to about 20°C. The hot water is then supplied decentrally with individual heat pump boilers. The cold can be drawn directly from the grid, so no decentralized chillers are needed. The system therefore pays for itself because less heat pump power is required for hot water use than for individual chillers.
A changeover system is thus only suitable for areas, in which cooling demand is higher than heating demand in summer, and in which heating demand dominates and no cooling is needed in winter. Thus, it is a profitable solution e.g. for residential areas where a four-pipe system is not worthwhile because cooling is needed only in summer.

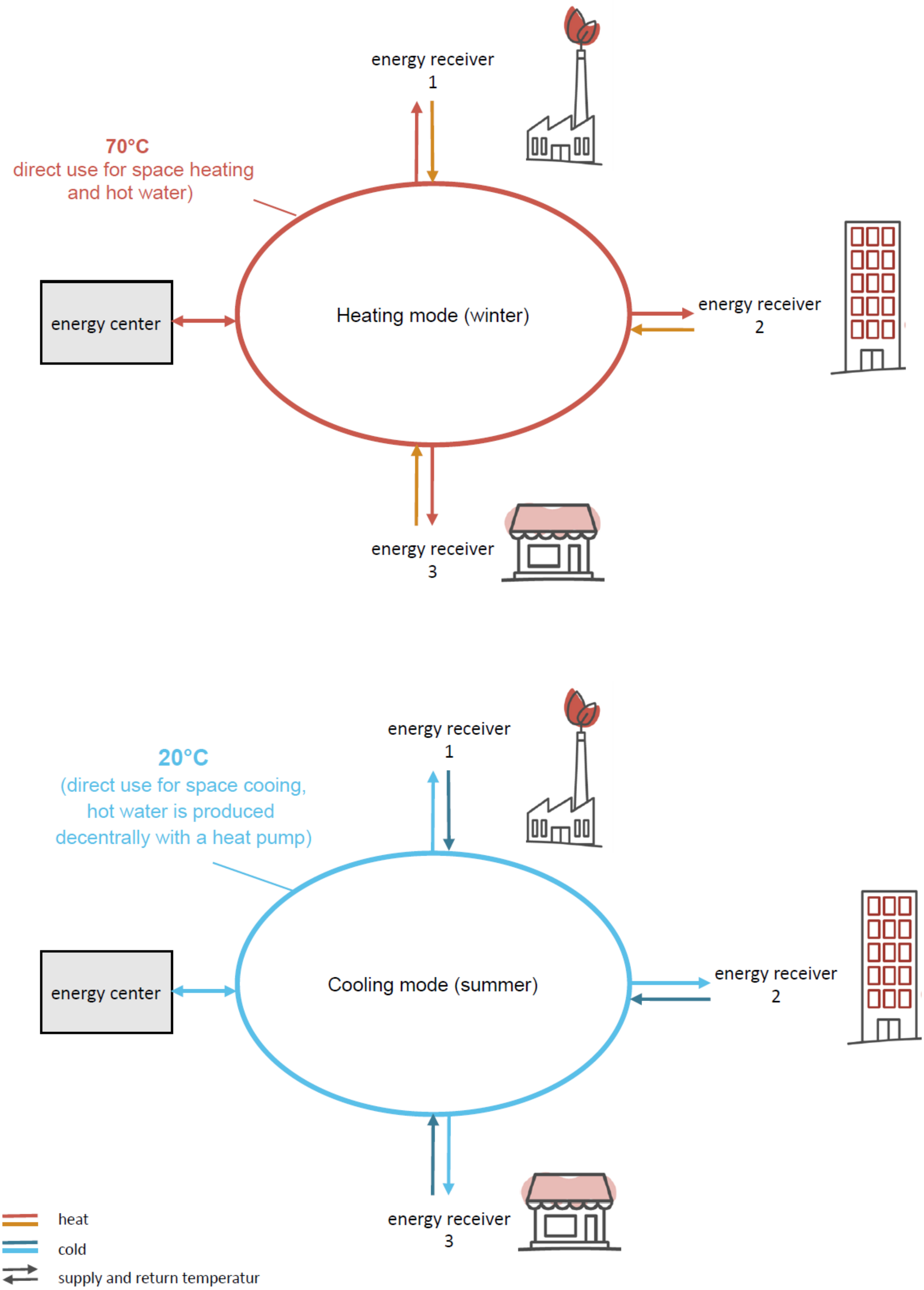

Figure 14: Sketch of a two-pipe-changeover system (source: concept by Tend AG, figure by PLANAR 2021).

A2 Sector coupling

The decarbonization of the entire energy sector will primarily lead to electrification. The power grid is therefore an essential component of the decarbonization strategy. Therefore, all energy sectors are interconnected (Figure 15).

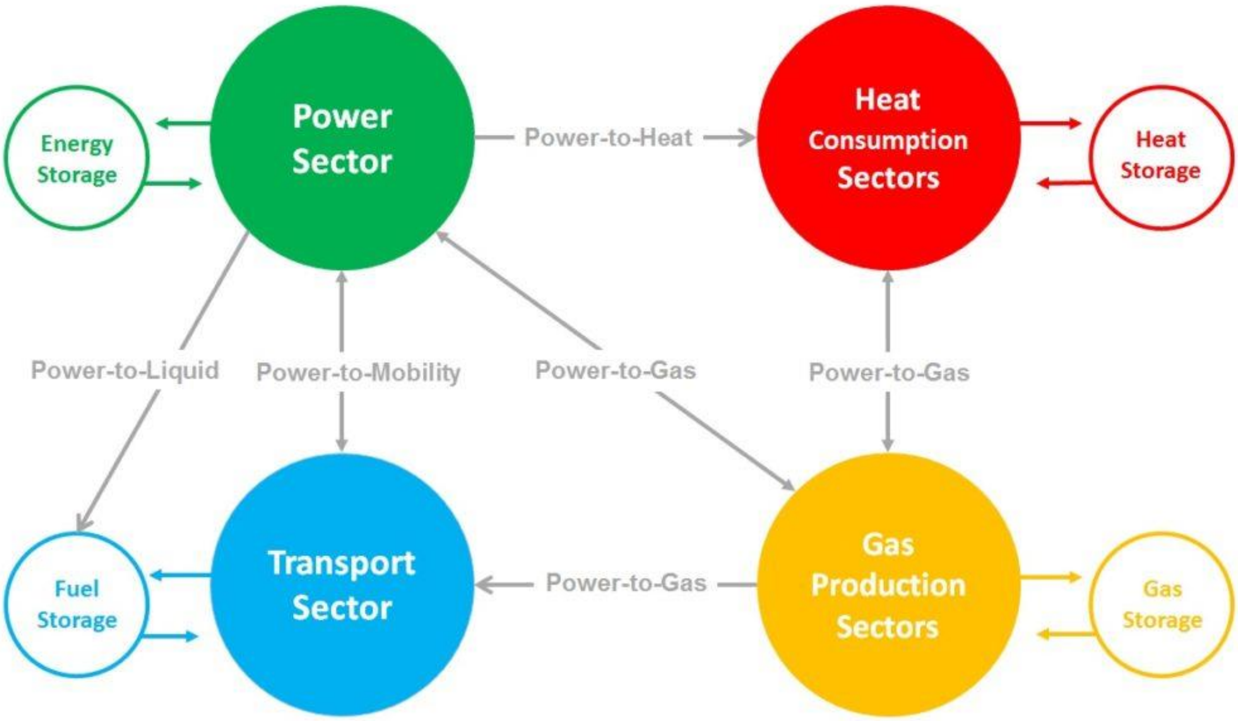

FIGURE 15: SECTOR COUPLING (SOURCE: INGENUITY - SIEMENS)

In most energy plans, the use of heat pumps in decentralized locations will result in an electrification of the heat demand. E-mobility and cooling may also increase the electrical energy demand and pressure on the power grid. On the other hand, more local, decentralised production and diverse energy sources may increase the resiliency of the power grid.
For the overall coupled system to function, storage that is matched to demand is likely to be needed. Thus, zoning and target network planning for gas supply is only the first step in H/C mapping. This zoning and the resulting future electricity demand per area must be determined and coordinated with the power supply. If necessary, the overall system can be optimized by improving the zoning.

First, the overall efficiency should be increased, followed by cost optimization including thermal storage.

Barriers

Sector coupling is also associated with some challenges. During a workshop, the following difficulties were mentioned, among others (see Table 7).

TABLE 7: CHALLENGES AND APPROACHES TO SOLUTIONS WITH REGARD TO SECTOR COUPLING.

Topic	Challenge	Possible Solution
Legal framework	– Lack of legal basis for the need of reusing waste heat	
Energy sources	– Business flexibility: contract for certain quantity of heat: what if data centres produce less waste heat as provided – excess heat used on-site reduced the potential for the DHC grid?	– schedule fluctuating waste heat only as a medium load. – On-site use of heat recovery is the best and cheapest way to use waste heat, which should be the priority before the external use in DH.
Stakeholder	– Companies with different logics, different regulatory frameworks, different heat temperatures production – The different companies do not talk to each other, they do not exchange data (lack of transparency), they would need to see the added value of this overall system integration	– municipality may act as initiator and coordinates the exchange and information between stakeholders. – Preparation of guidelines and directives for waste heat utilization
Data	– lack of knowledge when there is energy surplus and where (matching time and location) – lack of data on waste heat providers (e.g., data centres - locations, potential)	– Possible initiators which can communicate independently are the municipality (executing the H/C-map) or an engineering company doing a feasibility study (non-binding clarification).
Spatial allocation	– huge increase of solar PV production: where to install transformers? – thermal storage locations?	– Spatial planning site protection based on the H/C plan (thermal storage), combined with analyses of the electricity, and charging infrastructure for electromobility

Conclusion

H/C mapping has an impact on both the electricity and gas grids, given the increased use of heat pumps and the decreased use of natural gas. In turn, e-mobility also has an impact on the electricity grid due to the installation of many charging stations in buildings. Electricity grid operators and gas providers, therefore, should be involved in the designation of areas for individual heat pump supply.
In critical areas, where an increase in grid power is necessary for the transition of the H/C-map (and future charging stations), a higher-level view is needed to optimize the overall system. In addition, heat, gas and electricity storage systems need to be considered.

When implementing the resulting overall concept, a connection obligation for the heating networks would be helpful, as the remaining individual solutions would otherwise destroy the planned dimensioning of the power grid. This requires legal foundations and regulations, which may first have to be created.

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