Thematic Research Paper

Potential energetic synergies for the design of a cloud building in IBA-parkstad

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1 Abstract

The use of data in our daily life is growing rapidly and the fundamental node and physical manifestation of this phenomenon is the data center. The architectural impact is not (yet) big, but the environmental impact is. The data center uses a lot of energy and produces residual heat. By looking at conventional heating and the use residual heat, there is still a lot to improve. Potential energetic synergies are explored by looking at several heating demand profiles. The feasibility of utilizing residual heat is mostly dependent on surface area ratio between data center and residual heat user, but also on the way the technical system is organized.

2 Introduction

Background

With the shift towards a digital economy, an increasingly critical role that IT plays for businesses and consumers, the popularity of social media, 'the internet of things' and cloud computing the demand for ICT-capacity is growing fast. The fundamental node of this infrastructure is the data center. Without it, our life stands still. The Netherlands plays an important role in the data center world. It is one of the most favorable places for the accommodation of data centers and has the fastest growing data center market of Europe. The demand for ICT capacity in data centers is directly related to the energy consumption of this sector. In 2012, data centers used 2% of the total electricity consumption in the Netherlands. This is roughly equivalent to the electricity use of 600.000 households (Roossien & Elswijk, 2014). Research by CE Delft in 2014 predicted that the total energy consumption for the next three years, until 2017, would increase by 60%. This corresponds to a growth rate of 17% per year. The surface area of the data centers seems to double in these three years (Afman, 2014). This means data also has a major contribution to CO_2 emissions.

If we look at how our energy system is organized, there is a lot of primary energy with mostly fossil and nuclear sources going into our society. At the same time much residual heat is being lost in the process to air, water or soil. Therefore waste is produced, but not utilized (Broersma, Fremouw, & Dobbelsteen, 2011). Data centers are good examples of buildings that produce a lot of heat. This heat is considered a waste product and is actively dissipated. By utilizing this heat there are opportunities for data centers to contribute to the sustainability of other sectors (Roossien & Elswijk, 2014).

One of the most common indicators used to express the energy efficiency of a data center is the Energy Usage Effectiveness (EUE). The EUE gives the ratio of the energy that is used by the IT equipment itself in relation to the total energy entering the data center. The higher the EUE, the more energy is needed for the support facilities. The average in the Netherlands is around 1,8. Although more and more data centers become greener with a ratio around 1,4 (Sijpheer, Elswijk, & Roossien, 2013). In 2012, the Dutch Green Building Council (DGBC) developed the BREEAM certification specially for sustainable data centers in close cooperation with market participants and governments (Zegers, 2014). This development shows the impact and importance of the data center in terms of energy use.

Relevance

With data growing at an exponential rate and the idea of the ´smart city´ as a future perspective, the question rises how the physical manifestation of the data center as a burgeoning building type should be in the built environment. But, as important, how it could work together in energetic synergy with other functions or buildings. The aim of this research is to explore potential energetic synergies between a data center and residual heat users in IBA - parkstad. The main question is:

- What are the challenges and opportunities for achieving energetic synergy by implementing a data center in IBA-Parkstad and what requirements does this set for the architectural design?

In order to find an answer to this question, the main question is split up in the following sub questions:

- What technical concepts are available for utilizing residual heat from data centers and what requirements do they set for their successful implementation?
- What are feasible applications for residual heat from datacenters?
- Which technical concepts and combination of functions (or of supply and demand profiles) have the greatest potential in IBA-Parkstad?
- How can the architectural design be used to optimize the performance of the synergetic energy concept?

First the main definitions of the research are explained to get a basic understanding of the topic and the research method is briefly described. Secondly conventional heating methods in the Netherlands and IBA-parkstad are discussed. Then the possibilities of residual heat in Parkstad will be introduced together with the heat and cold storage project in the former coal mines. In chapter 6, two fundamental technical concepts that are available for utilizing residual heat from data centers, their requirements and feasibility will be explained. After that the results of the research, an inventory of potential residual heat users and their relation to IBA-parkstad, are presented. Also two energetic models are made as an example how a data center can supply its residual heat. Eventually the goal is to find the challenges and opportunities for implementing a data center in IBA-parkstad and the requirements that they set for the architectural design. The energetic models can function as tools to understand how an energetic synergy works and by this other combinations of functions can be 'tested' during the design process on feasibility.

3 Research Methods

3.1 Definitions

Data center = A data center is a facility used to accommodate computer related systems such as telecommunications and storage systems (cloud). Redundant power supplies, data communication connections, climate control and security are the most important components of concern which makes this type of building highly functional.

Residual heat = Residual heat is defined as the utilization of waste heat. Residual heat can be used for heat supply and cooling of homes, office buildings, greenhouses and industries with low heat demand. The heat is sustainable, only if the residual heat comes from renewable energy sources. Fossil residual heat is not sustainable heat but contributes to energy saving and CO_2 reduction.
(Harmsen & Harmelink, 2007, p.81).

Cloud building = Name for the design proposal in which the data center becomes a regional storage cloud that takes away unwanted necessities such as calculation power, high energy bills, system knowledge and space. At the same time it becomes a place for people in relation to digital services such as an internet shopping pick-up depot, a place for recycling and refurbishment of used devices, a cloud support facility and places where people can do their (digital) work. In this research data center or cloud building have the same meaning.

3.2 Research method

This research starts with a brief background analysis of the current state of heating methods in the Netherlands and it’s technology. Subsequently, literature study and a review of numerical models and engineering data are used to map and understand which technical concepts for energetic synergies between a datacenter and other functions could potentially be successful.
A consideration could be to use energy simulation software in order to calculate specific heat demand profiles and heat supply profiles for several functions. In this research paper the decision is made to review existing data. The reason for this is that specific data obtained from energy simulation software asks for the input of specific parameters and the intention of this paper is to find potential energetic synergies rather than focusing on the calculation of one specific case study.

4 Conventional methods for heating

4.1 The Netherlands

In the Netherlands 3493 PJ of energy is used from oil, coal, gas and renewable sources. This energy is used for the production of electricity and heat, as fuel for transport and as raw material. From this total energy consumption, 38% is used for heat supply. This is the largest consumer of energy in the Netherlands (Agentschap NL, 2013, p.5). Most of this heat is generated with natural gas. Only a small share is generated with wood heaters, heat pumps and geothermal heat. The contribution of these sustainable alternatives to the total heat demand is a slight 3,2%, while in 2020 the Netherlands needs to achieve a total renewable energy share of 16%. Thus sustainable heating is still in it’s infancy.

In utility buildings, such as offices, shops, educational buildings, hospitals and nursing homes, the heat demand varies greatly. Gas consumption per m^2 varies from 14 - 18 m^3 in offices and stores, to 40 m^3 in hospitals. Conventional technique for an office is the high efficiency boiler (92%). In hospitals the use of heat-power coupling (WKK) is common (60%) against almost 0% in offices (Agentschap NL, 2013, p.9).

From the 388 PJ of primary energy needed to heat houses, over 90% is generated by natural gas. In addition, about 1% of oil is used and 6% comes from residual heat sources, such as district heating (estimation 2006). The use of oil, wood and other sources are very limited (Agentschap NL, 2013, p.9). An average household uses around 1500 m^3 of gas. From this, more than 80% was intended for space heating, the rest for tap water and cooking. The heating demand for space heating is on average between 30 and 35 GJ per year, corresponding with 1000 - 1200 m^3 gas per year. Although this is strongly related to the type of house. For example, a building with a low EPC (Energy Performance Coefficient), consumes only around 20 GJ (665 m^3 natural gas) for space heating (Agentschap NL, 2013, p.10). And the gas consumption of houses built today could be even lower since the EPC-requirement in 2015 became 0,4.

4.2 IBA-parkstad

In *Zuid-Limburg* the energy system is for 99% dependent on sources from outside including petroleum and natural gas. Until the 60's the coal mines formed the regions energy source, but after this moment there were no local exploitable energy sources available that could compete with natural gas obtained from Groningen in the north. The rising price of coal could have been a reason to start mining again, but the relative low quality, high wages and pollution that it causes makes it less attractive (Broersma et al., p.151). The share of renewable energy in the region is relatively low compared to the average in the Netherlands with 2,9% against 5,8% in 2015 (Meurink & Segers, 2016, p.15).
Heat demand has a major share in the total energy consumption which is mostly generated by natural gas. In order to reduce CO_2 emissions, the total heat demand needs to be reduced and should be generated with renewable energy. Utilizing residual heat can contribute. For example, heating a house consumes 1200 m^3 gas per year and every m^3 of gas produces around 1,78 kg of CO_2. This means 1200 m^3 x 1,78 kg = 2,14 ton CO_2 can be saved per house every year if the house would use residual heat instead of natural gas.

5 Residual heat and IBA-parkstad

Although in Zuid-Limburg the energy system is not yet optimally organized, there are developments in the area. The ambition of Heerlen is to be a 'climate neutral city' in 2040. That means a city where processes around living and working do not contribute to climate change. This ambition is recorded in the regional document Parkstad Limburg Energy Transition (Gemeente Heerlen, 2015).

In SREX, a research about regional planning and exergy, *sources* (energy supply) and *sinks* (energy demand) were identified within the mix of functions present in IBA-parkstad. This was done because considerable amounts of residual heat with relatively high temperatures disappeared in the atmosphere which is a missed opportunity. The potential of heat cascading was investigated and the main conclusion was that this concept should be applied regionally which contributes to the robustness of the system. Another step could be to connect energy efficiency, biomass use, renewable heat and residual heat. This principle translated into the practice of spatial planning is called energy cascading (Broersma et al., 2011, p.40). Figure 1 shows the principle of energy cascading. A combination of these two concepts is now in development in Heerlen by using mine water.

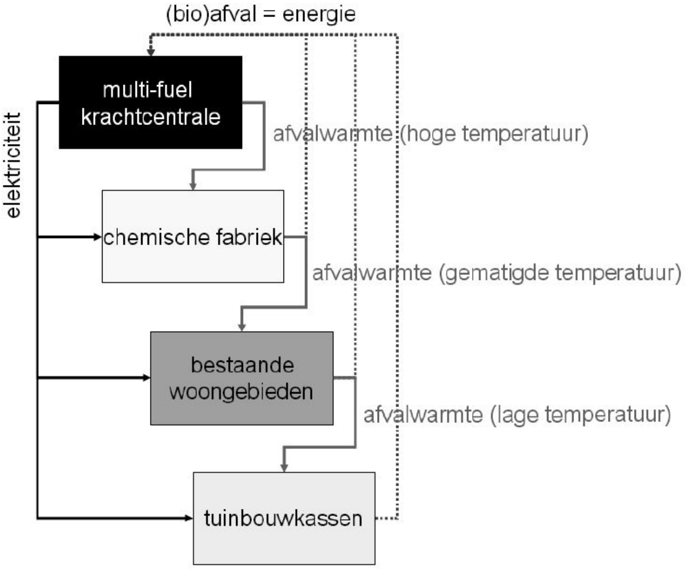


Figure 1: Energy cascade (Broersma et al., 2011, p.40)

Mine water 2.0

The former *Oranje Nassau* coal mines are in use as geothermal sources for durable, low-exergy heating and cooling of buildings. Two heat sources in the north (700 m, 28 °C) and two cold sources in the south (250 m, 16 °C). By using a three-pipe seven-kilometer long water distribution network, called backbone, the mine water from the sources are delivered to the connected buildings. There is a pipeline for the supply of hot water (insulated) from the hot springs HH1 and HH2 and a pipeline for cold water supply (not isolated) from the cold sources HLN1 and HLN2. In the connected buildings are heat exchangers to deliver the heat. Mine water 1.0 used one extra source HLN3, to store the used water (hot and cold). The upgrade of the project, Mine water 2.0, is more complex. It provides energy exchanges (heat and cold) between buildings within a cluster. Different clusters are connected to the mine water backbone. A main advantage is the clean water in a cluster which is not corrosive and thus reduces costs regarding pipeline materials. The backbone still provides heat and cold for every cluster. But this system has the possibility to store energy by injecting heat and cold back into the sources. Energy generation is also added in the system and the system works automatic demand-driven. The municipality of Heerlen wants to realize the objectives of a sustainable energy structure. To realize this, it is important that mine water is combined with other renewable energy sources such as biomass, solar energy and residual heat (Hiddes et al., 2014, p. 5). The mine water structure then is the medium to deliver these energy sources to buildings. This project offers an sustainable heat and cold network where the proposed design for a cloud building could be connected. By using the same location but a different energy source, the fossil energy history of the coal mines is connected to the present renewable energy that it can deliver today.

6 Residual heat from data centers

6.1 Technical concepts for utilizing residual heat from datacenter

The maximum number of residual heat users with a constant heat demand is limited by the amount of heat that the data center can deliver per year (kWh/year). In case of residual heat users with a variable heat demand, caused by seasonal differences, the opening hours and the use of the building, it is crucial to look at the peak demand or the sum of peak demands from a combination of functions and compare these with the maximum amount of residual heat that the datacenter can supply. In both cases the ratio between the surface area of the data center and residual heat users or a combination of residual heat users will decide if the synergy is successful. For example, if a swimming pool of 100 m^2 is linked to a data center of 5.000 m^2, considering that the datacenter has the capacity to deliver 10 times the heat that the swimming pool needs, the supply and demand profiles do not match and potential energy is wasted. This situation could be improved by implementing a form of energy storage or link more residual heat user surface area to the synergy.

Technical concept 1: direct system & heat pump

In case of direct heat supply from a data center to a residual heat user, the data center's cooling demand is dependent on the heating demand of the residual heat user. This means that the heat demand profile and the square meters of the potential residual heat user are directly related to the completion of the cold demand of the data center. In technical concept 1 is chosen to use water to transport the heat. Water can absorb up to 3.500 times more heat than air (Roossien & Elswijk, 2014, p.10). A heat pump is used to increase the water temperature that is useful for low temperature heating on the condenser side. Figure 2 shows this synergy in a simplified way. In section 7.3 an energetic model is made as example.

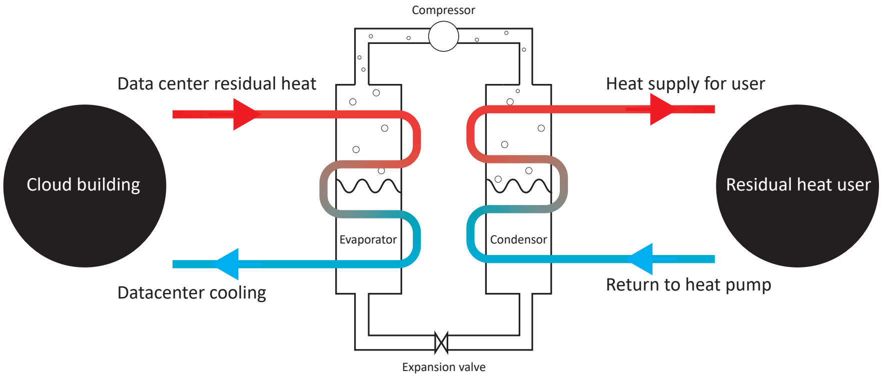


Figure 2: Heat pump between Cloud building and residual heat user (Own illustration, 2017)

Technical concept 2: heat and cold storage & heat pump
Heat and cold storage is a method of storing heat and cold during a season in the ground. It consists of one or more sources between 50 and 300 meters deep, dependent on the ground water layers (aquifers). In winter, warm water is pumped up and usually upgraded by means of a heat pump to heat a building. The cold water returns to the ground. During the summer, cold water is taken from the ground, which cools the building. The water that is then warmed up is pumped back into the ground. The system saves energy if well executed. An important condition is the balance. This means that over a year, on average, as much heat is used as cold. Most buildings don't have a balanced heat and cold demand. But a combination of buildings sharing this system can result in an overall balance. In technical concept 2, the data center shares a heat and cold storage system with one or more residual heat users that use a heat pump. The residual heat of the data center regenerates the hot source. The cold can be used for the data center to cool. In section 7.3 an energetic model is made as example.

6.2 Requirements for implementation

The utilization of residual heat from a data center by another function or building can be successful, but there are a couple of factors that should be taken into account. The next section will discuss these factors briefly.

Temperature - Delivery of heat in practice is not always easy. The heat comes free on a relatively low temperature between 35 °C and 45 °C. So it is important to consider if this temperature fits with the residual heat user and how efficient this is in comparison to another (sustainable) system. The energetic synergy should match on temperature.

Location - Heat loss by transportation is an important issue to take in consideration. As an indication, the heat losses for water transport over a distance of 100 meter, with an outside temperature of 0 degrees are 2 degrees at a maximum (Roossien & Elswijk, 2014, p.11). Also, the more pipes are needed, the more investments have to be made. The distance between the buildings in energetic synergy should be as close as possible.

Annual load duration curve - For every function or building with an heat demand, an annual load duration curve can be made which shows the hours of the year (8760 h) in relation to the specific heat demand (W/m^2). In this curve the peak demand (W/m^2) can also be determined. It is important that this curve 'matches' with the heat that a datacenter can supply. Thus an requirement is that the buildings in energetic synergy are optimized on heat demand and heat supply.

Mutual dependency - If a datacenter is connected to an office building and investments are made in the system which provides heat and cold exchange between those buildings, they are dependent on each other on the long-term. This makes the flexibility and the robustness of the system really important.

Long term flexibility - In the design for a low temperature heat network, it is important to keep up with the current heat demand and the expectations for future demand. Over-dimensioning of pipes leads to additional conduction losses, while insufficient capacity is caused by under-dimensioning. The replacement of pipelines is expensive and often complex in the urban environment (Vliet et al., 2016, p.24).

Adaptation on building level - In addition to a change in the organizational structure, a successful transition to LT heat networks also demands a more integrated approach. Modifications to all components in the heating system are required for successful development. For example, the insulation level of homes must also be included (Vliet et al., 2016, p.24). The buildings in the energetic synergy should be adapted to the system.

There are also 'challenges' that need to be overcome in order to make an energetic synergy a successful. The following section gives an overview of barriers derived from practice.

Costs - Low temperature heat networks are relatively new. Which means it will always be compared by the main heat carrier: natural gas. Since natural gas is relatively cheap in the Netherlands and because there is a very extensive gas infrastructure, the construction of low-temperature heaters is often more expensive at first. Changing an existing heat network to a low-temperature heating system requires adaptations to different network components: generation, distribution and delivery. The costs and benefits of the transition to a low-temperature heating system are unevenly distributed among the parties in the heat chain. This forms a barrier to make the transition. Possible solutions to reduce this investment barrier are for example subsidies for relevant commercial parties or public funding Besides, the ignorance of investors regarding low temperature heat can cause restraint (Vliet et al., 2016, p.26).

Social resistance - Another barrier, especially in the Netherlands, is social resistance to the monopoly position of the heat suppliers (Vliet et al., 2016, p.26). The heat suppliers would have too much power and the heat buyers could no longer choose alternative heating options like gas. Besides, the conversion that some houses need can be expensive and not worth the investment for the owners. But at the other hand there are enough heating network projects in which the citizens together with the municipality play a driving role. Examples are Texel Energy, Thermobello in Culemborg and Hoonhorst in Overrijssel (Vliet et al., 2016, p.26). Although the resistance to the current market model and the monopoly position of suppliers must be taken seriously, there is a trend that citizens in the current market are aware of the opportunities for collective heat. This social acceptance is important for the transition to low temperature systems.

Legionella - Legionella is a bacteria that can cause an acute infection on the respiratory tract. Cell division of the bacterium takes place in water at a temperature between 20 °C and 46 °C. There is a minimum temperature between 55 °C and 60 °C in the Netherlands for hot tap water laid down in legislation and regulations to minimize contamination risk. The Dutch legionella requirement is seen as a barrier in the transition to low temperature systems. To provide hot tap water with a minimum temperature of 60 °C, a high temperature is required in the heat network. This can't be achieved without the use of local re-heating. There are possible measures that can be taken to prevent legionella at tap water below 55 °C , instead of reheating. Technologies are the use of disinfection methods or materials with antibacterial properties. UV radiation and membrane filtration are examples of these technologies. Another solution is the use of small water volumes, which makes legionella unlikely to develop (Vliet et al., 2016, p.26).

7 Feasible applications for the utilization of residual heat

To investigate potential synergies, it is not only important to look at the heat demand profiles, but also to the desirability of the function in the specific area. Thus in section 7.1 and 7.2, where the heat supply and heat demand profiles are presented, the cloud building as heat supplier and every potential residual heat user also contain a brief review which indicate if there are developments around this type of function within IBA-parkstad (Heerlen). Per potential residual heat user, the ratio between the heat supply of the cloud building and the heat demand is calculated in square meters. This indicates how much square meters of the function can be heated with 1 m^2 of data center.

Heerlen is chosen as location to investigate the potential synergies because the city is pointed out as the center of IBA-parkstad which can be a good location for a regional cloud building. The vision of Heerlen is to keep developing its role as ‘central city’ of the region and expand where possible. ‘Central city' is defined as a city where the main regional facilities are housed. Facilities that people from across the region can be proud of and that are well accessible from all over the region (Gemeente Heerlen, 2015). Also *Mine water 2.0* is located here, which makes the place more interesting for the design of the cloud building.

7.1 Supply side: data center

Datacenter	Heat supply	Cold demand
Demand [kWh/year/m2]		21900
$T_{evaporator}$ [°C]	35 °C	
$T_{condensor}$ [°C]	45 °C	

numerical data derived from (Smit,2008)

Temperature - The hot server air entering the heat exchanger has a temperature around 40°C. The efficiency of a heat exchanger is roughly 80%. As a result, the water obtains a temperature which is approximately 5 °C lower than the temperature of the server air. The heat losses of water transport over 100 meters distance at an outdoor temperature of 0 ° C are up to 2 ° C (Roossien & Elswijk, 2014).

Demand type - Constant. A datacenter is a building that needs constant availability. This means that the power supply to the ICT-hardware and primary installations always needs to be running day and night for 8670 hours per year.

Relation IBA - parkstad - One of the most important urban developments in the coming years is the realization of the Smart Services Campus in and around Heerlen center. The proposed cloud building could contribute to these developments. A general trend which is also influencing Heerlen, is that shopping via the internet has taken an enormous flight and the end is not yet in sight. This affects the physical stores, both in quantity and quality. The number of square meters required for retail floor space will decrease. In addition, shops, must provide an impression to remain attractive to the consumer. (Gemeente Heerlen, 2015).

7.2 Demand side: potential residual heat users in IBA-parkstad

Office buildings	Heat demand	Cold demand
Demand [kWh/year/m2]	44 - 127	6,1
Demand hours per year [h]	2618	441
Equivalent peak hours [h]	321	126
Peak demand [W/m2]	137	49
$T_{condensor}$ [°C]	45°C	
Required temperature	18 °C - 23 °C	

numerical data derived from (Smit,2008), (Römer & Jong, 1999)

Temperature - The supply temperature to heat office buildings by low temperature heating is around 45 °C , this suits with the temperature that the cloud building can deliver if a heatpump is implemented.

Demand type - Highly variable. The demand is dependent on the seasons and on the working hours.

Relation IBA - parkstad - Heerlen has a lot of employment in the healthcare sector, SME's, retailers and the financial administration sector. In order to create new employment, there is at least as much attention needed to the preservation of existing employment. Based on current economic growth forecasts, the expectation is that the supply of regular workplaces should not be expanded in quantitative terms (Gemeente Heerlen, 2015). The existing stock offers enough opportunities until 2035. There is also room for small businesses to grow from the mixed areas to a place in a classical business area. There is also room for qualitative improvement, especially in the Avantis, Trilandis and Coriopolis business areas. Here companies are located that are looking for a high quality look. As a result of the rapid development of technology, which makes it possible for people to work time and location independent, future demand for business locations in mixed areas could increase.

Ratio heat supply cloud building / heat demand function - 1 m^2 / 256 m^2

Congress buildings	Heat demand	Cold demand
Demand [kWh/year/m2]	141	4,6
Demand hours per year [h]	4210	445
Equivalent peak hours [h]	833	86
Peak demand [W/m2]	169	53
$T_{condensor}$ [°C]	45°C	
Required temperature	x	

numerical data derived from (Römer & Jong, 1999)

Temperature - The supply temperature to heat congress buildings by low temperature heating is around 45 °C , this suits with the temperature that the cloud building can deliver if a heatpump is implemented.

Demand type - Highly variable. The demand is dependent on the seasons and the spaces that are used.

Relation IBA - parkstad - Coventional facilities in IBA-parkstad are under pressure because of shrinkage and aging of the population. These facilities are in need to function in a broader context and sometimes also need a better location for exploitation. Further clustering and modernizing of these functions the municipality of Heerlen intends to do. One of the features of such facilities is flexibility. This means it can accommodate different types of functions, like a congress building.

Ratio heat supply cloud building / heat demand function - 1 m^2 / 155 m^2

Housing	Heat demand	Cold demand
Demand [kWh/year/m2]	48,5	
Demand hours per year [h]	x	
Equivalent peak hours [h]	1200	
Peak demand [W/m2]	40,4	
$T_{condensor}$ [°C]	45°C	
Required temperature	18 °C - 23 °C	

numerical data derived from (CBS, 2017), (Klimaatmonitor, 2017)

Temperature - The supply temperature to heat houses by low temperature heating is around 45 °C , this suits with the temperature that the cloud building can deliver if a heatpump is implemented.

Demand type - Highly variable. The demand is dependent on the seasons and on the lifestyle and composition of the household.

Relation IBA - parkstad - The housing stock is very outdated. There is a decline in demand for housing and a change in the requested quality within the domain of 'living', also related to more sustainable houses. In addition, the size of the housing stock will have to be better aligned with the population development in Parkstad. There is now a supply surplus on housing which leads to higher vacancy rates (Heerlen 4,5%, 2035 homes, date 31-12-2013, Parkstad 4.3%) than the 2% friction lease required for a smooth functioning housing market (Gemeente Heerlen, 2015). The municipality wants to keep Heerlen attractive and livable, the housing stock will have to be upgraded. The main concerns are: making the existing stock more sustainable, adjust the existing stock for older people and the bonding of promising target groups to the city through the provision of high-quality residential environments. In Heerlen, the center is the only place where new housing can be added.

Ratio heat supply cloud building / heat demand function - 1 m^2 / 452 m^2

Healthcare buildings	Heat demand	Cold demand
Demand [kWh/year/m2]	84	4,9
Demand hours per year [h]	3792	334
Equivalent peak hours [h]	778	128
Peak demand [W/m2]	108	38
$T_{condensor}$ [°C]	45°C	
Required temperature	x	

numerical data derived from (Römer & Jong, 1999)

Temperature - The supply temperature to heat healthcare buildings by low temperature heating is around 45 °C , this suits with the temperature that the cloud building can deliver if a heatpump is implemented.

Demand type - Variable. The demand is dependent on the seasons and on the working hours. Although the heat demand is variable, it has a more constant demand than an office.

Relation IBA - parkstad - In Heerlen the percentage of 65-plus increases (from 20% to 32% in 2035) and the percentage of young people to 20 years decreases (from 18% to 17% in 2035). The departure of high educated young people and young families from the region is enhancing this effect. Also one of the most important social changes in recent decades concerns the transition of the healthcare system. The national policy aims at reducing special care, which combines housing with all-inclusive care packages. The consequence of this policy is that people with care need to live longer independently and are responsible to purchase their own home care. In the short term, this government policy leads to an additional demand for well-suited housing. The majority of this question will have to be filled in by making sure that existing homes are ready. As the population in Heerlen is shrinking and aging, healthcare facilities can become more important.

Ratio heat supply cloud building / heat demand function - 1 m^2 / 261 m^2

Swimming pools	Heat demand	Cold demand
Demand [kWh/year/m2]	459 - 1500	
Demand hours per year [h]	8760	
Equivalent peak hours [h]	3648	
Peak demand [W/m2]	126	
$T_{condensor}$ [°C]	x	
Required temperature	28°C - 32°C	

numerical data derived from (Smit,2008), (Römer & Jong, 1999)

Temperature - The required temperature in the swimming pool is between 28 °C - 32 °C.

Demand type - Swimming pools have a more or less constant heat demand during a year.

Relation IBA - parkstad - Heerlen has a Roman past which is visible through the former thermal complex located in the center. The municipality wants to improve the experience and visibility of this complex, although it is not in use for swimming or bathing anymore. There are a couple of swimming pools in IBA-Parkstad which are being used, Otterveurdt in Hoensbroek, De Joffer in Voerendaal, D’r Pool in Kerkrade and De Bronspot in Brunssum. Parkstad has a history in which swimming pools go bankrupt. This is not only because it is often very expensive to maintain such an accommodation, but also because many municipalities decided to stop subsidizing school swimming. Thus an important source of income was lost. There are plans to stop this trend of recent years and there is a plan to build a new bath for Heerlen and Landgraaf. (Gemeente Heerlen, 2015)

Ratio heat supply cloud building / heat demand function - 1 m^2 / 22 m^2

Sports buildings	Heat demand	Cold demand
Demand [kWh/year/m2]	55	22,6
Demand hours per year [h]	3783	613
Equivalent peak hours [h]	709	205
Peak demand [W/m2]	78	111
$T_{condensor}$ [°C]	45°C	
Required temperature	15°C - 25°C	

numerical data derived from (Römer & Jong, 1999)

Temperature - The required temperature for a sports building is between 15 °C - 28 °C depending on the intensity of the sport. For low temperature heating it is assumed that 45 °C is sufficient as supply temperature.

Demand type - Highly variable. The demand is dependent on the seasons and the hours that the building is used.

Relation IBA - parkstad - The municipality has designated sports clusters in size small and large (Gemeente Heerlen, 2015). These clusters provide space for outdoor and indoor sports, both commercial and non-commercial. In addition there is space for sports related accommodations such as scouting, a skating rink and a playground. There is also space for sports related support functions such as physical therapy or small-scale sales and rental of sporting goods. Sports clusters (L) therefore have a regional function because sports can also be practiced, for which there is no room in other regional centers. There is not specific need for expansion. If program is added, the ambition is to do this within the clusters.

Ratio heat supply cloud building / heat demand function - 1 m^2 / 398 m^2

Schools	Heat demand	Cold demand
Demand [kWh/year/m2]	102	3,45
Demand hours per year [h]	1143	232
Equivalent peak hours [h]	432	276
Peak demand [W/m2]	237	45
$T_{condensor}$ [°C]	45°C	
Required temperature	x	

numerical data derived from (Römer & Jong, 1999)

Temperature - The supply temperature to school buildings by low temperature heating is around 45 °C , this suits with the temperature that the cloud building can deliver if a heatpump is implemented.

Demand type - Highly variable. The demand is dependent on the seasons and the hours that the building is used.

Relation IBA - parkstad - Various school buildings will also become vacant in the future, such as the buildings of Arcus college. Some have been out of use for a long time, for example the former ***Hoge Technische School***. Heerlen wants to focus on the reorganization and reuse of vacant school buildings, which can contribute to the strengthening of neighborhoods. This also applies to other vacant social property.

Ratio heat supply cloud building / heat demand function - 1 m^2 / 215 m^2

Fish farms	Heat demand	Cold demand
Demand [kWh/year/m2]	3305	
Demand hours per year [h]	8760	
Equivalent peak hours	x	
Peak demand [W/m2]	x	
$T_{condensor}$ [°C]	x	
Required temperature	30°C	

numerical data derived from (Smit,2008)

Temperature - For fishfarms it is important to have a constant temperature of 30 °C all year.

Demand type - The heat demand for fishfarms is more or less constant.

Relation IBA - parkstad - There are no local fish farms in the area, but the municipality of Heerlen wants to invest in local food and energy production. In that sense a fish farm could contribute to these plans.

Ratio heat supply cloud building / heat demand function - 1 m^2 / 7 m^2

Greenhouses	Heat demand	Cold demand
Demand [kWh/year/m2]	518	495
Demand hours per year [h]	x	x
Equivalent peak hours [h]	2590	848
Peak demand [W/m2]	200	584
$T_{condensor}$ [°C]	45 °C	
Required temperature	x	

numerical data derived from (Aarssen, 2002), (Zwart, 2013)

Temperature - The supply temperature to heat greenhouses by low temperature heating is around 45 °C , this suits with the temperature that the cloud building can deliver if a heatpump is implemented. The required temperature for growing vegatables is dependent on the species.

Demand type - The greenhouse has a more or less constant heat demand over a year.

Relation IBA - parkstad - Heerlen wants to provide space for and cooperate with various forms and various scale levels of urban agriculture on designated experiment areas but also beyond (Gemeente Heerlen, 2015). By organizing food production in and around the city, the physical and psychological distance between consumer and product can be reduced. Urban agriculture occurs in many forms and at many levels of scale. People can produce food for their own use in their own garden. Neighborhood residents can jointly produce food in vegetable gardens at the edge of the neighborhood and entrepreneurs can produce food in a professional manner and on a larger scale. Local food production can add new value and meaning to transition areas. This stimulates employment and purchasing power improvement in transition areas and thus contributes to economic growth. Through the production of food for a part in its own city also avoids unnecessary transport costs and fossil fuel consumption. Local food production can also be linked to social goals, such as environmental care, a cleaner living environment, educational opportunities and the provision of space for rest and relaxation. This contributes to social cohesion. This creates a certain synergy between functions: local food production goes hand in hand with improving the quality of the living environment. The project area “Gebrookerbos” and the former CBS office are the designated places where local food production is being tested. The municipality is open for other suggestions.

Ratio heat supply cloud building / heat demand function - 1 m^2 / 42 m^2

Algae farms	Heat demand	Cold demand
Demand [kWh/year/m2]	x	
Demand hours per year [h]	8760	
Equivalent peak hours [h]	x	
Peak demand [W/m2]	x	
$T_{condensor}$ [°C]	x	
Required temperature	25°C - 28 °C	

numerical data derived from (Roossien & Elswijk, 2014)

Temperature - The required temperature for growing algae is between 25°C - 28°C.

Demand type - The algae farm has a more or less constant heat demand over a year.

Relation IBA - parkstad - There are no algae farms in the area, but the municipality of Heerlen wants to invest in local food and energy production. In that sense a algae farm could contribute to these plans.

Ratio heat supply cloud building / heat demand function - 1 m^2 /-

Ratio cloud heat supply / function heat demand

The heat supply capacity of the datacenter is 21,9 MWht/year/m2. For every potential residual heat user the heat supply can also be converted to MWht/year/m2. For example the heat demand for a house is 48,5 kWht/year/m2. This is 48,5 kWht/year/m2 -> 0,0485 MWht/year/m2. This means that with 1 m2 datacenter, it is possible to supply heat for 21,9 MWht / 0,0485 MWht = 451,5 m2 of housing. An average terraced house in the Netherlands is 162 m2 (CBS, 2017). This means 1 m2 data center can supply heat for approximately 451,5 m2 / 162 m2 = 2,8 terraced houses in the Netherlands. Figure 3 shows the ratio for heat supply / heat demand in square meters for almost all the potential residual heat users.

Residual heat users built environment	RATIO cloud heat supply / function heat demand	value
Office buildings	1/256	[m2]
Congress buildings	1/155	[m2]
Housing	1/452	[m2]
Healthcare buildings	1/261	[m2]
Swimming pools	1/22	[m2]
Sports buildings	1/398	[m2]
Schools	1/215	[m2]
Fish farms	1/7	[m2]
Greenhouses	1/42	[m2]
Algae farms	x	[m2]

Figure 3: Ratio cloud heat supply / funtion heat demand (Own chart, 2017)

7.3 Energetic models for technical concept 1 & 2

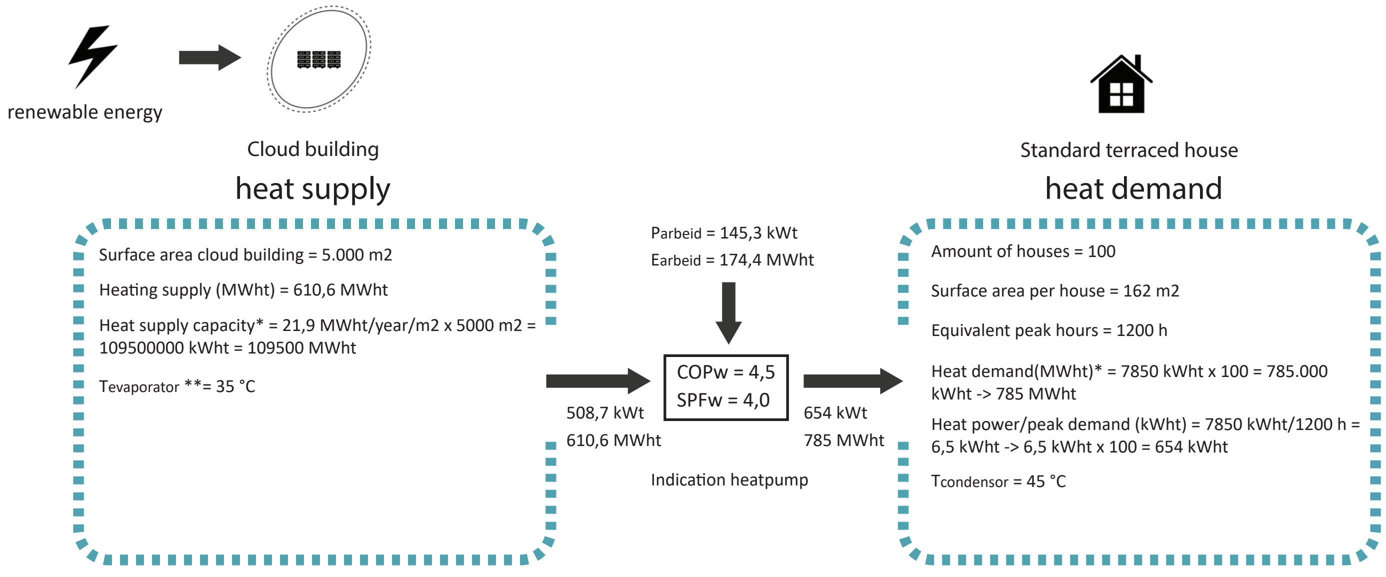
To make an energetic model, the numerical data of the potential residual heat user(s) and the cloud building are combined with technical concept 1 and 2. In this case there is chosen to use 100 standard terraced houses because collective systems are feasible from 50 to 100 houses (Harmsen & Harmelink, 2007, p.31). Theoretically it is possible to select a residual heat user, the square meters and/or a combination of residual heat users and their square meters. Thus during the design process, different kind of function combinations together with the cloud building can be 'tested'.

Energetic model for technical concept 1 - The heating demand from the standard terraced houses is calculated based on numerical data. A standard terraced house in Limburg uses 1190 m^3 gas per year (Klimaatmonitor, 2017). From this gas consumption roughly 75% is used for heating and 25% for tap water. This gives 0,75 x 1190 m^3 = 892,5 m^3 gas for heating. According to Senternovem 1 m^3 of gas is equivalent to 31,65 MJ (see figure 4 with conversion factors). This gives 892,5 m^3 x 31,65 MJ = 28247,6 MJ. Converted to kWh this is 28247,6 MJ / 3,6 MJ = 7846,6 kWht. Because the gas consumption is dependent on different factors, the estimation is rounded off to 7850 kWht. A standard terraced house in the Netherlands has a surface area of 162 m^2 (CBS, 2017). This gives a heat demand for the house of 7850 kWht / 162 m^2 = 48,5 kWht/year/m^2.

Energetic model for technical concept 2 - The natural heat source is indicated with HH1 and HH2. These are the two former underground mine networks, filled with water, where heat can be obtained. HH 2 functions as a buffer to inject residual heat back in the source. HLN1 and HLN 2 are the former underground mines from which cold can be obtained. HLN 2 functions also as buffer to inject cold back in the source. The withdrawal and injection capacity and the temperatures are derived from the actual *Mine water 2.0* project.

Conversion factors	
1 m3 natural gas	31,65 MJ
1 kWh	3,6 MJ

Figure 4: Conversion factors (Meijer & Verweij, 2009)



Surface area cloud building = 5.000 m2

Heating supply (MWht) = 610,6 MWht

Heat supply capacity* = 21,9 MWht/year/m2 x 5000 m2 = 109500000 kWht = 109500 MWht

Tevaporator **= 35 °C

Amount of houses = 100

Surface area per house = 162 m2

Equivalent peak hours = 1200 h

Heat demand(MWht)* = 7850 kWht x 100 = 785.000 kWht -> 785 MWht

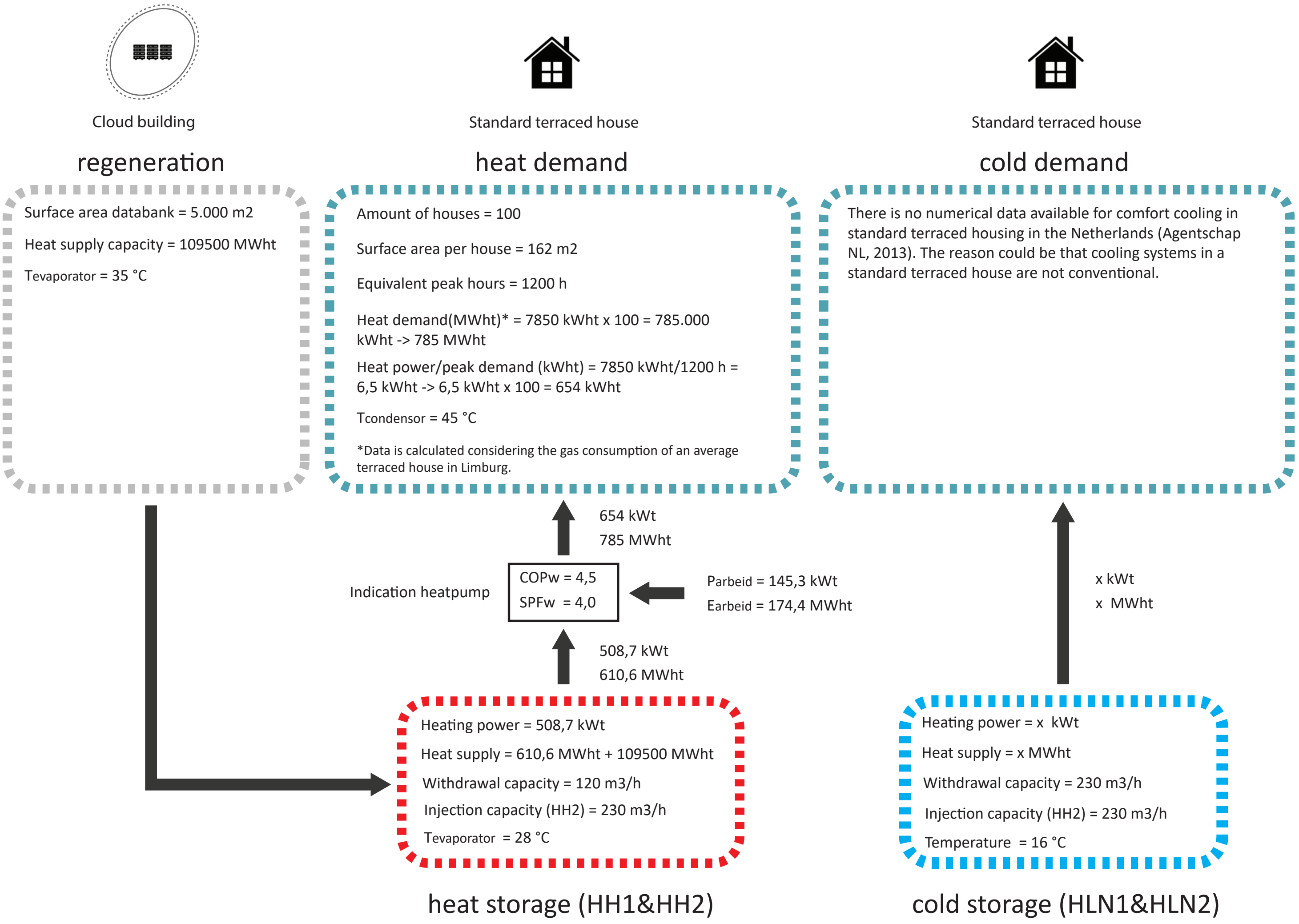
Heat power/peak demand (kWht) = 7850 kWht/1200 h = 6,5 kWht -> 6,5 kWht x 100 = 654 kWht

Tcondensor = 45 °C

*Heat supply of a datacenter per m2 without heatpump is based on a graduation research from TU Eindhoven (Smit, 2008)
**The hot server air entering the heat exchanger has a temperature around 40°C. The efficiency of a heat exchanger is roughly 80%. As a result, the water obtains a temperature which is approximately 5 ° C lower than the temperature of the server air. The heat losses of water transport over 100 meters distance at an outdoor temperature of 0 ° C are up to 2 ° C (Roossien & Elswijk, 2014)

*Heat demand is calculated considering the gas consumption of an average terraced house in Limburg.
*Tapwater is not included in heat demand because high temperatures are needed that are not feasible with residual heat. Tapwater coventionally uses approximately 25% of the gas consumption. 75% is used for space heating. A sustainable solution solution for hot tap water is a heat pump with PVT panels.

Figure 5: Technical concept 1: direct system & heatpump (Own illustration, 2017)



Surface area databank = 5.000 m2

Heat supply capacity = 109500 MWht

Tevaporator = 35 °C

Amount of houses = 100

Surface area per house = 162 m2

Equivalent peak hours = 1200 h

Heat demand(MWht)* = 7850 kWht x 100 = 785.000 kWht -> 785 MWht

Heat power/peak demand (kWht) = 7850 kWht/1200 h = 6,5 kWht -> 6,5 kWht x 100 = 654 kWht

Tcondensor = 45 °C

*Data is calculated considering the gas consumption of an average terraced house in Limburg.

There is no numerical data available for comfort cooling in standard terraced housing in the Netherlands (Agentschap NL, 2013). The reason could be that cooling systems in a standard terraced house are not conventional.

Heating power = 508,7 kWt

Heat supply = 610,6 MWht + 109500 MWht

Withdrawal capacity = 120 m3/h

Injection capacity (HH2) = 230 m3/h

Tevaporator = 28 °C

Heating power = x kWt

Heat supply = x MWht

Withdrawal capacity = 230 m3/h

Injection capacity (HH2) = 230 m3/h

Temperature = 16 °C

Figure 6: Technical concept 2: heat and cold storage & heatpump (Own illustration, 2017)

Conclusion

In technical concept 1 there is a direct relation between heat supply and demand. The cloud building has a surface area of 5.000 m2 and provides residual heat for 100 standard terraced houses. The total heat demand for the houses is 785 MWht and the heat supply capacity of the cloud building is 109.500 MWht. So there is a surplus of residual heat and a cooling demand left for the cloud building. Too optimize the use of residual heat and to prevent that the cooling demand of the cloud building is dependent upon other energy sources, an option could be to optimize the square meters of the houses in relation to the cloud building. Another option is to find a combination of residual heat users that can be connected to the cloud building.

A disadvantage here is that heating tap water with a low temperature heat network is not feasible. Tap water must meet the requirements for legionella prevention in a home installation. This requires that the temperature at the mixing device or at the tap point is at least 55°C or 60°C or should even be a bit higher taking into account heat losses. If the heat pump has to increase the water temperature at the evapo-rator side from 35°C to 65°C at the condenser side, the COP in this condition will be $T_{condenser}$ = ($T_{condenser}$ – $T_{evaporator}$)-> 65 °C / (65°C- 35°C) = 2,2. This maximum theoretical efficiency is low be-cause of the relative high difference in temperature and it also can't compete with a high efficiency boiler in terms of energy costs. There are measures that can bring the tap water to the correct temperature in a more efficient way. In addition to these measures, there are also options that prevent legionella preventively, examples are UV radiation and membrane filtration. However, these options are expensive (Vliet et al.,2016, p.34). In technical concept 1 and 2, tapwater could be provided by:

Booster Heat Pump - This system is designed to create hot tap water in homes connected to a collective heat source. A COP value between 3,8 and 4,6 can be achieved (depending on the supply temperature) (Vliet et al.,2016).

Heat pump & PVT panels - By using a combination of a heat pump and PVT panels, water can be heated up in the sun collector and at the same time electricity can be generated for the heat pump.

In technical concept 2 there is an indirect relation between heat supply from the cloud building and heat demand from the residual heat user. The cloud building does not supply residual heat directly to the houses, but is a regenerator that supplies heat to the heat source. Then the heat source supplies low temperature heat for the houses. In this concept, different types of buildings are sharing a heat and cold storage system in combination with a heatpump that is located close or within the buildings. This means the buildings not only receive there heat or cold demand but also produce a return temperature that goes back in the system. In technical concept 2 the aim is to create a concept which shows how residual heat from the cloud building can be used by another function in the built environment via a shared system. That is why the return flows are left out as well as the cold demand for the cloud building.

8 Conclusion and discussion

Challenges

Technical concept 1: direct system with heat pump - The residual heat temperature of the cloud building should be able to generate the supply temperature for the residual heat user in an energy efficient way. The location of a cloud building should be as close as possible to the location of the residual heat user to prevent high costs and heat losses. The annual load duration heat curve should match with the cloud building. In a direct system with heat pump, ideally the cold demand of the cloud building is equal to the heat demand of the residual heat user. The challenge for the design is to make an energy profile, using the numerical data and energetic model as a tool, which comes close to this ideal situation. The fact that utilizing residual heat creates mutual dependency is important to know. Functions with an unpredictable future are less likely to form an energetic synergy. Bankruptcy, program expansion or shrinkage or other threats have a major influence on the success of this concept. This forms a challenge in the program for the design. Long term flexibility of the system itself is in this concept relatively less important, because heat demand and supply are existing within a closed system that is made for the situation as it is. Adaptation on building level is also a challenge. For example, if the residual heat user is an existing building it might need an update to be able to heat with low temperature and extra insulation could also be necessary for optimal use of the heat.

Technical concept 2: heat and cold storage with heat pump - In a system with heat and cold storage and heat pump the residual heat is stored in a underground hot source. The supply temperature that a residual heat user demands, is depending on the temperature of the hot source. The location is also important, the cloud buildings needs to be as close as possible to the heat and cold aquifers and the residual heat user. To compare the annual load duration curve of the residual heat user with the heat supply of the cloud building is less important in this concept because hot and cold can be stored. This concept has more ‘robustness’ as more types of buildings can be connected to get an overall year balance in hot and cold use. But the system should be organized well, because it can still be sensitive to change. For example, if a major residual heat source falls out, it can cause imbalance. Thus scale is also important, because heat and cold sources and sinks are not always located in the same area. Long term flexibility of the heat network in this concept is important. The heat network can grow and also needs enough capacity in the future. Adaptation on building level should also be taken into account with this concept.

Costs, social resistance and legislation on legionella are forming a barrier for both concepts.

Opportunities

Next to the challenges there are certainly also opportunities for residual heat of the cloud building. *Zuid-Limburg* has a relatively low share of renewable energy and wants to improve this. Because heat demand is a big energy consumer in the Netherlands (38%) and most of it is generated by natural gas, residual heat can help to reduce CO_2 emissions. Heerlen wants to be a climate neutral city in 2040. In residual heat lies a big opportunity to contribute to the sustainability of other functions and for the area as a whole. Another opportunity is to connect to the project *Mine water 2.0*, an existing heat and cold storage system that has the potential to supply heat and cold for a lot of buildings in the region. As most buildings and functions have a bigger heat demand than cold demand, the addition of a regenerating sink is a positive one.

Feasible applications

All functions in the built environment that can use low temperature residual heat and with this save fossil generated heat are essentially suitable. The residual heat users can be split in functions with a constant demand and with a variable demand. For technical concept 1, a residual heat user with a constant demand profile is preferred in which the square meters are optimized resulting in minimum left-over cooling demand. For technical concept 2 the demand type is less important.

The ten potential residual heat users presented in this research are from the type utility, housing, leisure and food/energy production. In the utility and housing sector, the main question in IBA-parkstad is to sustainably renovate the current stock. Because of shrinkage there is no need for expansion. In the leisure and food/energy production sector, there are opportunities to expand. There are plans for a new swimming pool for Heerlen and Landgraaf and experimenting with local food production is encouraged by the municipality to stimulate the local economy and create social cohesion. If the design of the cloud building will have a surface area of approximately 5.000 m^2, it means the following for potential energetic synergies:

- In case of the swimming pool, the congress building, the healthcare building, the school and the sports building it is not feasible to form an direct energetic synergy with heat pump using technical concept 1. These buildings have a small heat demand footprint in comparison to what the cloud building will be able to deliver.
- Providing residual heat for a combination of housing and offices in the region is a possibility since these functions have relative large surface areas.
- Providing residual heat for local food production such as greenhouses, fish farms or algae farms is a feasible possibility since these functions have a high heat demand per square meter and are able to vary in size. For example, growing vegetables can be interesting on a small scale, but also on a very large scale. With a swimming pool this is not possible.

Heating tap water is not feasible with low temperature residual heat and a heat pump. This is because the water needs to be at least 60 °C by legionella legislation. It doesn’t mean that natural gas has to be used. A smart option is the combination of a heat pump with PVT panels for hot tap water and also reduce CO_2 emissions with this.

The architectural design can theoretically be optimized in favor of the energetic synergy by the ratio of square meters. If local food production is combined with the cloud building, the maximum surface area of greenhouse is dependent on the surface area from the cloud building. It is also important to generate as much as renewable energy as possible with the cloud building itself to provide electricity for the ICT and in that way produce sustainable residual heat.

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