The Mijnwater 5GDHC Grid in Heerlen

Summary

Mijnwater BV [1] in Heerlen deploys and operates what is probably the leading example of a 5th Generation District Heating and Cooling Grid (5GDHC) [2]. While most such systems are still small, Mijnwater provides heating and cooling services to 250000 m^2 of floor space; 40 km of trenches were dug for the main piping; it delivers 20 TJ/a heating, and 20 TJ/a of cooling; peak heat demand is 1.7 MW; it operates 100 high performance heat pumps of 200 kW, and 100 booster heat pumps for domestic hot water; it serves large office buildings, supermarkets, shops, educational buildings, industry, and 400 dwellings. The surrounding region of Parkstad Limburg plans for it to serve 120000 dwellings plus commercial buildings, by 2040. That makes a floorspace of 20 million m^2. An investment of 3G€ for 2040.

What makes it so attractive? It will help make the built environment energy neutral and decarbonize heating and cooling. It does this by recycling waste heat and cold, adding sustainable sources of heat and electricity. The built area in Europe wastes more heat than is required for heating. A small percentage of solar irradiation on the same area is enough for all heating as well. A 5GDHC grid can exploit that opportunity.

How does it this work? A 5GDHC grid has the capability to exchange the energy from heating and cooling between its customers, and store any surplus, to be used at later times. Circular reuse enables a large reduction of energy demand. There will be no more waste heat: it can go into the grid. The current grid started by exploiting the geothermal source of water in the abandoned coal mines under Heerlen. This source is now employed as a thermal energy storage, by recharging it with any excess thermal energy: heat and cold. Cooling buildings in the summer helps to charge the storage with heat for the winter.

In 2015, Mijnwater won the European Geothermal Innovation Award for developing and deploying the method to utilize the extended underground mine water source, with a backbone on the surface that supplies heating and cooling to the town. The expansive underground reservoir became a huge thermal storage that is the basis of this first 5GDHC grid reaching town-scale. Four “cluster grids” are connected to the backbone, and together they cover an area of about 40 km^2. In 2019, Mijnwater is making a jump to the neighboring town of Brunssum. Not by extending the grid, but by starting a separate island 5GDHC, based on borehole- and pit thermal storage. A physical connection may come later. 5GDHC can work without the mine as well [2].

The creative team of Mijnwater, together with the regional cooperation of Parkstad, the Province of Limburg, businesses, social housing and educational institutions, are innovating not just the technology, but the ways to cooperate, the procedures, contracts, the governance, the finance mechanisms, all while figuring out the logic behind this new way to serve heating and cooling to a community. Five EU projects and three national ones recognized the value of having Mijnwater as a member. Investments now sum to 35 M€.

We are confident to apply for the Global District Energy Award of 2019.

Introduction

While comparing the different situations and grids, it became useful to identify the grid of Mijnwater as an example of a new, 5th generation heating and cooling grid (5GDHC) [2]. This was because its design differs substantially from the low temperature, but otherwise more traditional 4th generation DH grids [3]. Both operate at low temperature, which massively reduces the loss of heat during the transport. But in addition, the 5GDHC design enables powerful new capabilities. All customers can simultaneously exchange heat and cold among each other. This is combined with a large capacity of thermal storage and an all-electric distributed generation of heat and coolth using heat pumps. The result is a grid architecture where heat sources are not anymore the central design feature, and the operation can be driven from the demand side. It may seem remarkable, but this grid has no high temperature heat source, not even CHP or biomass.

The Mijnwater grid is pure example of such a 5GDHC grid while being quite unique as it also quickly scaled to a size covering a substantial area in the town. Although many examples of small 5GDHC grids existed for some time, a review of district heating systems from as recent as 2017 did not yet mention this development [3]. In early 2019 a review article was dedicated to 5GDHC systems existing in Europe [2].

System History

Mijnwater is about a decade old, and still has a homogeneous design. It was initiated in 2008 as geothermal pilot by the municipality of Heerlen, as part of the European Interreg IIIB NWE programme and the 6th Framework Programme "EC REMINING lowex". Subsequently, it was upgraded to a full 5GDHC grid design in 2013, and incorporated as 'Mijnwater BV'. The larger region of Parkstad Limburg adopted the grid as an important ingredient of its energy transition vision, with the goal of achieving energy neutrality in 2040 (PALET). This grid can already reduce Urban Energy demand by 50% and reduce CO_2 emissions by 65%. With renewable electricity, the path is open towards zero CO_2.

Because of the region's past in coal mining, the project has a strong social and historical context: Heerlen used to be known as Energy City of the Netherlands. Now, the abandoned coal mines offer a new perspective, as reservoir of sustainable geothermal energy contained in the mine water. The EU potential for using energy from mine reservoirs is huge, as 25 % of urban area is positioned above abandoned mines.

Mijnwater B.V. – a private company now owned by the Limburg Energy Fund – is building a successful business based on this concept and is rapidly expanding connections to the grid. Mijnwater focuses on two main developments: 1. Exploiting the huge mine water reservoir for the extraction and storage of energy; 2. Deploying a hydraulic thermal 5GDHC grid that connects buildings with each other through local cluster grids and connects these geographically dispersed grids and a mix of local sustainable resources with the mine reservoir through the mine water backbone. The size of this system was immediately quite large, due to the extended size of the underground mine system, and the backbone interfacing with it on the surface.

The progress made in the design, deployment, and the operation of a full-scale grid, are unique not only in the Netherlands, but also in the EU. This creates a foundation for knowledge dissemination (expertise center, educational imbedding), that acts as an incubator for the development of 5GDHC hydraulic thermal smart grids, and attracts knowledge-intensive and innovative business to Heerlen.

In 2015, Mijnwater was awarded for its innovative design of the backbone that interfaces with the geothermal water volume in the disused coal mines. In 2019, Mijnwater is as proud of deploying this successful and pure example of a 5GDHC grid, at a scale that makes it a leader in this field.

With this history in mind, our application for this award could be either in the category of 'Modernisation' (the ongoing system growth and optimisation 2016-2018), or otherwise 'Out of the Box' (as leading example of the new 5GDHC grid design).

Configuration of the 5GDHC grid and thermal storage

Mijnwater 1.0 was initiated and built by the municipality of Heerlen [4, 5, 6] as a 4th generation District Heating *or* Cooling network (4DH, 4DHC) [3]. The idea was to make use of warm water in the abandoned and flooded local coal mine as a sustainable source. In the winter, warm water of 28ºC was fed from the mine into the grid to deliver warmth, while in the summer cool water of 16ºC from a shallower cool source was distributed. This was a '4th Generation' grid in the sense that it made use of a low temperature heat source (or high temperature cooling), and also that it distributed the warmth or the cold from a central point to the customers. In this phase, there was no simultaneous exchange between customers. This grid started by serving one large office building (CBS) and a social housing project. However, there were signs that this setup was slowly exhausting the geothermal source, meaning that it could not be scaled up much further. Hence, a new design was made in 2012 by Mijnwater BV.

Mijnwater 2.0
In 2013, the grid was upgraded to 'Mijnwater 2.0', a fully functioning 5th Generation Heating *and* Cooling grid (5GDHC) [7, 8, 2, 9]. The important new feature was that from that time the grid is able to exchange heat and cold between all customers, simultaneously.

Demand driven
In contrast to conventional DHC systems that are based on supply side management, the whole design, operation, and optimisation of the Mijnwater grid is 'demand driven'. Everything starts from the points of demand for warmth or cold and any residual energy is stored for later use. All physical flows of water and energy are initiated at the points of demand for warmth or cold. This saves energy by avoiding any unnecessary pumping around as often done in a more

traditional DHC grid. As a consequence, we will see that the grid needs no central energy plant or source. This is all made possible by a grid optimised for exchanging energy between customers, by thermal storage at each level and time scale, and by a distributed cloud of heat pumps near the end users that guarantee the right temperature, and also generate thermal energy for the grid.

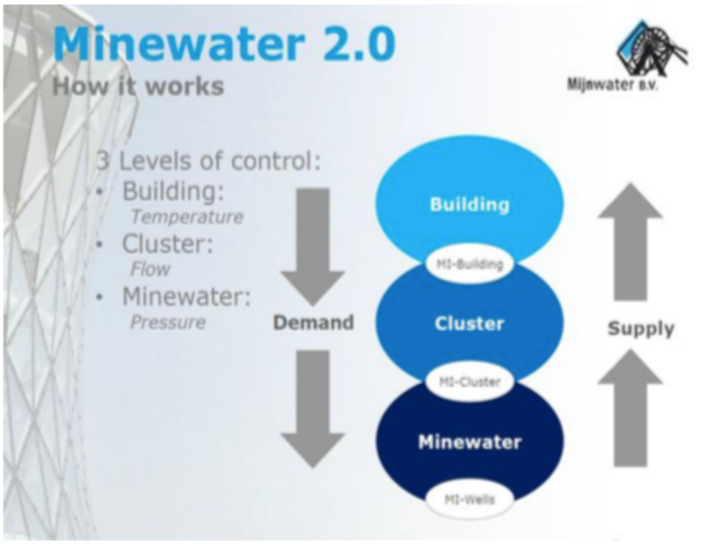

Figure 1: Simple graph to indicate the three levels of energy exchange, and three levels of control, where they connect: the energy station at the buildings (MI-Building), the Cluster Installation (MI-Cluster), and the wells that connect the backbone directly to the mine (MI-Wells).

A two pipe spine: warm and cool

The basic feature is a conventional two pipe spine, one with warm and another with cold water. However, the direction of flow is not fixed. So we cannot speak of a 'distribution line', to the customers, and a 'return line'. Only at the points of demand, a flow between the two pipes is initiated. Heat can be extracted from the warm water using a heat pump, returning cool water at the right temperature, to the cool pipe. Cold is extracted the other way round, by rejecting warmth into the warm pipe. This way, customers in need of cooling will automatically provide waste heat to be used by any neighbour needing warmth.

At one end of this two pipe spine, the pipes are connected via a heat exchanger that ensures either that the residual flow of cold water is turned into warm water, or the other way round. The heat is exchanged with a next level in a hierarchy, which could also be thermal storage.

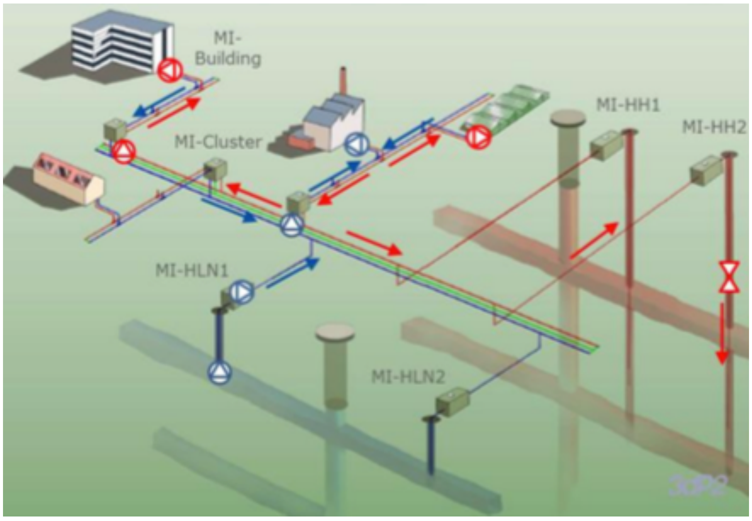

Figure 2: Diagram to demonstrate the three-level design of the Mijnwater grid. The elements indicated are an energy station at a large office building (MI-Building), and an example of industry demand for cooling, a greenhouse demanding warmth. The small grey cubes represent the underground cluster installation (MI-Cluster) connecting a cluster with the backbone. Also indicated are the boreholes to the warm (MI-HH1,2), and the cooler (MI-HLN1,2) parts of coal mine tunnel system.

Exchange of energy between consumers on the grid

If one user needs a certain amount of warmth, and the neighbouring one needs exactly the opposite, this will induce two opposing flows from the warm to the cool and back to the warm pipe. In absence of other users there would just be this local loop, and nothing else. In general, the flows will not cancel exactly, and there will be a residual total demand that needs to be absorbed by a heat exchanger at one end of the two pipe spine.

Thermal Storage

An essential ingredient is the thermal storage. The two-pipe spine enables exchange of heat and cold between nearby locations. The thermal storage enables sharing across time. It separately saves the heat and cold from the past and makes it available in the future. Together, sharing heat/cold over the local area and across different times reduces the total energy consumption significantly. Thermal energy is stored in the buildings and hot water boilers (short term), in the water of the grid, and in the mine water (long term).

A 3-level hierarchy of grids

The Mijnwater grid is designed to function at three separate levels, each with independent controls. The previous Mijnwater 1.0 pipe system which has water from the mine running through it, is now the '**backbone**'. It is connected to the mine at two warm and two cool wells. The wells are bi-directional: this means that water (=energy) can be both extracted and infiltrated. Pressure maintenance and buffer installations at the wells guarantee that the desired flow can always be supplied to the system. The pressure also helps control the dissolved gasses and other substances in the water from the mine. The energy exchange with the clusters takes place through heat exchangers in the cluster installations.

The backbone has two purposes. On the one hand it connects the cluster grids with each other. But its first purpose is to be a large heat-exchanger connecting the warm and cool wells. It is the thermal interface with the long term thermal storage of mine water.

In spring 2019, there are four **'cluster grids'**, each connected to the backbone through a large heat-exchanger in a 'cluster installation'. A cluster grid is a two-pipe spine that enables exchange of thermal energy in the local area, and with the backbone.

The **Building**, or **Local Area Grid**

Each large building(block) is connected via its own 'Energy station', with heat pumps providing the right temperatures for heating and cooling each building. Simultaneously, the water returning to the cluster grid has the correct temperature. This way, the same heat pumps of the 'Energy Stations' also provide the cluster with thermal energy.
To connect a local neighbourhood of individual dwellings, an Energy Station was designed to serve a 'local area grid'. The dwellings are connected to a system of four pipes at low (15ºC/30ºC) and higher temperature (30ºC/45ºC).

Booster heat pumps.

At the end customers, booster heat pumps produce domestic hot water, stored in 120-200 litre buffer tanks. This avoids having long hot water pipes, with resulting heat losses. These are owned, maintained and controlled by Mijnwater.

All electric foundation

Together, the heat pumps of the Energy Stations form an all-electric system that generates the thermal energy for the grid. When new buildings or local area grids are connected to a cluster, the generation power automatically scales along with the size of the grid. The mine water that originally was used as a source of thermal energy is now used mainly as long term storage. The heat used in the winter is replenished in the summer. The thermal mass of the buildings themselves, and the hot water boilers are capable of storing energy on the timescale of a day. The water flowing in the clustergrid, and the backbone also provide some storage during a week, while helping to stabilise the system. The result is a grid that will never run out of energy. It can grow to a much larger size, only limited by the capacity of the grid to transport thermal energy at times of high demand. An example is in the morning, when all offices start work at nearly the same time. This issue is addressed by the next optimisation stage that we call 'Mijnwater 3.0'.

Mijnwater 3.0

The last step in the original design is called 'Mijnwater 3.0', and is still being implemented. Without affecting required comfort levels, it is still possible to optimise the exact timing of demand from buildings. The buildings themselves have a thermal mass, and can store warmth for some time. The water in the grid itself can also be used to store heat for short periods. As an example, large buildings could in principle be heated more slowly by starting slightly earlier in time than requested by the thermostat, to avoid a morning peak from all large office buildings starting the working day at exactly the same time.

The purpose of this optimisation is to reduce maximum peak demand on the grid infrastructure. If a sharp peak is spread over time, the maximum height can come down appreciably. Since the diameter of the existing piping infrastructure always forms a bottleneck in the system, this optimisation of the controlling software will create space to reliably serve a substantially larger number of customers.

At the same time, the (substantial) demand for electricity of the Mijnwater system is shifted and/or spread over time. This can also help stabilise the electricity grid of the network operator, by countering peaks in electricity demand elsewhere, or also variations in electricity generated by wind and solar power.

To conclude: how to define 5GDHC?

It isn't easy yet to define a strict standard, but we could say, based on the Mijnwater experience, that a 5GDHC grid achieves many goals by being 'demand driven'. This property is achieved by an optimized combination of three ingredients, that each seem essential.

1. The basic element in the grid is the spine with a warm and cold waterpipe, on which it is possible to simultaneously exchange warmth and cold between connections. The two-pipe system itself is conventional, but it is optimized for exchanging energy, and the flow of the water is not in one fixed direction.
2. There is sufficiently large thermal storage capacity, so excess energy from the past can be used now, or excess energy from now can be kept for the future. Effectively, thermal storage is like a special 'pipe' that can connect the past with the future.
3. The heat pumps are essential to guarantee the temperature needed by the customers, while also providing the system with a very robust distributed generator of heat and/or cold. This is because the water returned is at the correct temperature for the warm and cool pipe.

Being demand driven helps the system to reach a high energy efficiency. Heat pumps deliver the exact temperature the customers need, while the grid feeds the heat pumps with enough energy to ensure high efficiency of the heat pumps. The exchange of heat and cold helps to reduce the amount of energy needed collectively by the customers on the grid, averaged over longer times. Such a system can grow organically, with new energy stations being added each time a large customer or an area gets connected.

Such an all-electric system provides the option towards complete decarbonization. In 2019, Mijnwater makes use of the Dutch electricity mix, still mainly generated using fossil fuels. But we have a program to put PV panels on buildings to start converting our electricity to sustainable sources.

In addition, it is easy to make use of waste heat at low temperatures, but also high temperature industrial waste heat can be made useful. It is helpful that the system is robust and will not easily become dependent on such high temperature sources.

Finally, we should repeat that a 5GDHC grid does need a sufficient volume of thermal storage, but that this can be provided in ways that do not need a disused coal mine. A 5GDHC grid is possible anywhere. At both small and extended scales.

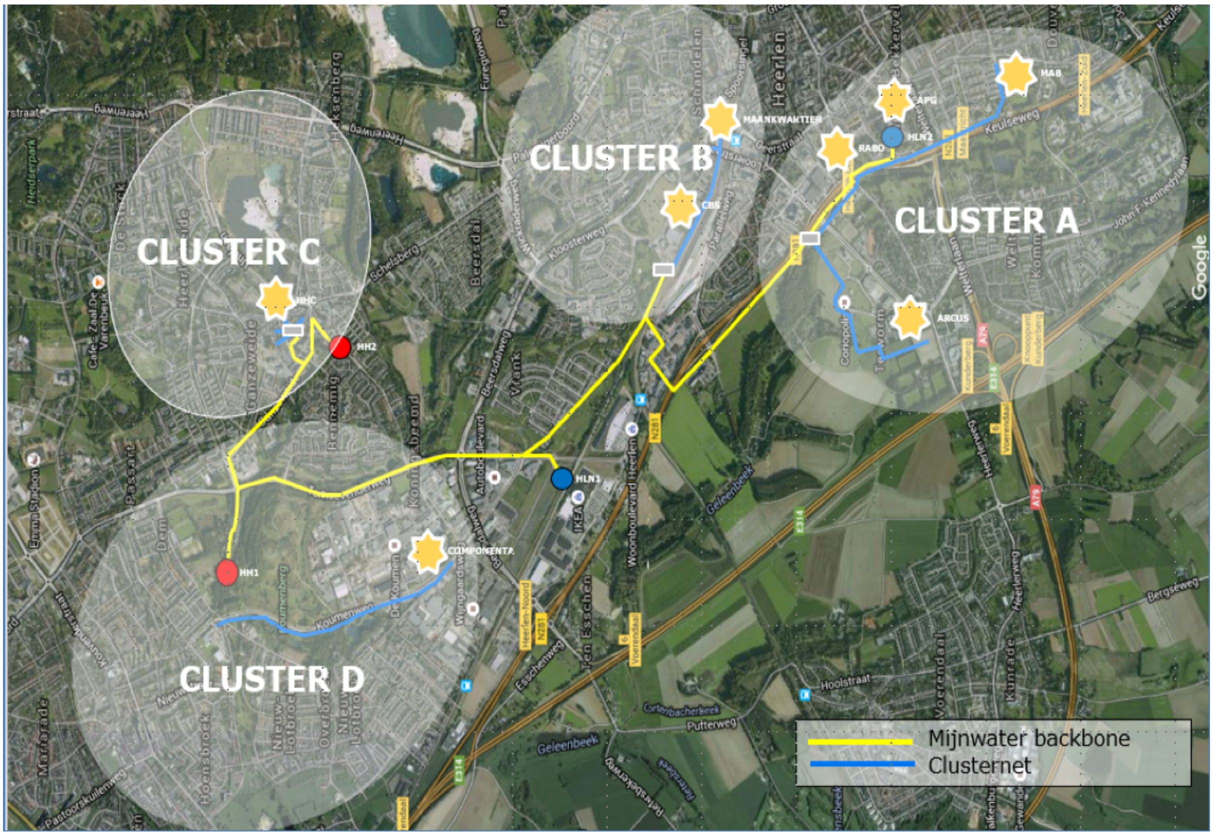

Figure 3: A map of Heerlen showing the backbone (yellow) and the cluster grids (blue). The two red dots are the two wells to the warm part of the mine, blue dots are wells to the cool part.

Performance indicators, calculation details

The Mijnwater 5GDHC grid in Heerlen currently serves 250000 m^2 of floor space in large office buildings, shops, supermarkets, educational institutions, and homes. Total trench length amounts to 40 km, half for the backbone, and half for the 4 cluster grids. In 2017/18, the grid delivered 5139 MWh/a of heating, and 5243 MWh/a of cooling. Our electricity bill was 2283 MWh/a. Peak heat demand was 1.7 MW.

This all-electric system results in a COP of 4.55, which calculates to a primary energy factor $\mathbf{f_{P,F,nren}}$=0.57, a renewable and surplus heat fraction of $\mathbf{R_F}$=82%, and greenhouse gas emissions $\mathbf{K_F}$=92 kg/MWh $CO_{2,eq}$. We are further optimizing the network, which will reduce the electricity bill by 16%, resulting in a COP of 5.44, a (certified) primary energy factor $\mathbf{f_{P,F,nren}}$=0.48, renewable fraction $\mathbf{R_F}$=85%, greenhouse gas emissions of $\mathbf{K_F}$=77 kg/MWh.

These numbers are even more impressive if one realizes that they describe our complete 5GDHC grid in Heerlen, with the best bits, but also the lesser parts needing further growth and development. At least as important as these already achieved numbers is the fact that we are on solid path towards a 100% sustainable system.

We'll soon achieve 67% and 71% CO_2 reductions compared to the Netherlands average gas furnace for heating ($\mathbf{f_{P,F,nren}}$=1.1, $\mathbf{K_F}$=230 kg/MWh, $\mathbf{R_F}$=0) and an average office electric air conditioning system with efficiency of 1.56 [10] ($\mathbf{f_{P,F,nren}}$=1.67, $\mathbf{K_F}$=269 kg/MWh $CO_{2,eq}$, $\mathbf{R_F}$=49%).

Our sources of heat and cold are a mix of geothermal and recycled low temperature heat/cold, enabled by an electric system with heat pumps. We can clearly define total delivered heat and cold. From our geothermal wells, in average over a year, we extract 2623 MWh of heat and 2966 MWh of cooling. This leaves 2517 MWh of recycled heat and 2276 MWh of recycled cooling.

Since we are continuously improving our grid infrastructure, since we are continuously adding new customers to our grid, and since new customers usually need to make improvements to their buildings when they join the Mijnwater grid, it is not easy to define 'before' and 'after' situations for a proper comparison. Due to ownership of part of the heat pump infrastructure in some of the large office buildings, the earliest year with detailed information for proper comparisons is 2016/17, to be compared with 2017/18. Ongoing improvements of our pumping system will be fully operational in 2020/21.

The new paradigm of a 5GDHC grid does not center on sources of energy, but on demand, and the usual performance indicators for sustainable 4^{th} generation grids describe only a part the goals we pursue. In addition to making use of sustainable energy sources, our philosophy is a more integrated one of regional sustainability. We want the owners of buildings to invest in measures at the building level, at least to be ready for low temperature heating, but also to reduce their demand for energy by implementing good insulation, and ventilation with heat recovery.

Our grid is an investment at the level of the neighborhood, collectively, to reduce energy needs beyond what buildings can do on their own, by direct circular reuse of heat from cooling, and by storing excess heat and cold for later use. To be consistent with a future of highly efficient buildings, we must design and optimize our grid to serve many customers with a low demand for energy. A future grid must operate at lower densities of energy demand than in older grids, by eliminating expenditure on fuels, and by using clever buffering to deal with peak demand, so that with the given capacity of our infrastructure, we can serve many more customers. We grow our customer base while exploiting ever more opportunities to exchange energy among them, making our grid ever more efficient.

Project Beneficiaries

The Mijnwater project offers heating and cooling services to building owners and occupants in the city of Heerlen. The building owners get energy at a price approximately 10 % lower than a conventional solution, and independent of increasing fossil fuel prices. In addition, they don't need to invest in gas boilers. The investment needed in the building to be recognized as nearly zero energy (NZEB) is reduced. Mijnwater offers an ESCO construction in which building owners are unburdened for operation and maintenance costs. The Mijnwater project provides a 65% CO_2-reduction in the Urban Area at a relatively low price per ton CO_2, and ultimately 100%. Previous expenditures on fossil fuels are converted towards investments in local green infrastructure, which creates local jobs and strengthens regional independence. Our grid ends the dependence on natural gas. The connection of the thermal building mass in the city through heat pumps to large thermal storage facilities (like the mine water reservoir) will enable services of peak shaving and net balancing for fluctuating green sources on the electric grid.

The necessary investment space is found from the reduced fossil fuel expenditure over the coming 30 years. For a medium sized town of 100.000 dwellings plus commercial buildings, the investment for a geothermal smart grid sums to roughly four billion euros. This can create 5,000 to 6,000 good jobs in the region, dependent on the development of a local clean technology industry. If the savings for a single dwelling are summed over 30 years and recalculated to net present value, the investment space is about €45,000 per dwelling. Half of this amount is needed for a 5GDHC grid, which leaves the other half for energy saving measures in the building. The Mijnwater Company is owned by the local government, so any profits are returned to the community.

Conclusion

There is currently more heat being wasted in Europe than is required to heat all of the buildings. Heating and cooling consume half of the EU's energy and much of it is wasted. A small fraction of the solar irradiation on urban areas is also enough. District heating can capture this excess heat and move it into, or out of buildings. 5GDHC grids are the solution to exploit these opportunities and transform a large part of our urban environment to sustainable energy. It is a great chance to revitalize local economy and business. It is an opportunity for investment. The Mijnwater 5GDHC grid in Heerlen is exploring the way, and leading in this new paradigm.

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