REAP2 - NEW CONCEPTS FOR THE EXCHANGE OF HEAT IN CITIES

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Summary

Cities need to become independent from finite resources, among which fossil fuels. There is great potential to save energy is many cities, however the generation of power is insufficient due to the limited space as a result of urban densities. An energy source less commonly explored is reuse of waste heat from various urban functions. In that matter, central heat grids, powered by industrial waste heat at high temperatures, are well-known, but the lower-caloric heat from buildings as offices, supermarkets, swimming pools and also dwellings is abundant and seldom utilised. This has a two-sided negative effect: energy is lost and the city is heated up, which in summer can aggravate the urban heat island effect, which statistically leads to higher mortality rates.

The Rotterdam Energy Approach & Planning (REAP) was developed to support energy-neutral urban planning in a structured, incremental way. The approach was used in several studies and has received worldwide acclaim. Especially the second step of the REAP method, regarding tuning, exchanging, cascading of energy at various scales, is relatively new, offering new opportunities for cities. Nevertheless, REAP needed to be elaborated further, for practical application in actual urban redevelopment. This was done for the transformation of the Rotterdam city harbours, in a study called REAP2.

The research project, culminated in the proposition of five principles for a heat system in the urban district, including the introduction of novel techniques for the exchange of different temperature levels of heat and involving the spatial plan based on the energy system chosen.

The paper will discuss REAP, the REAP2 research project, the methodology involved, proposition of energy system principles, novel concepts for heat exchange, and spatial consequences.

Keywords: REAP, energy-neutral cities, urban energy system, heat exchange, heat cascading, heat grid

1. Introduction

Cities across the world need to become independent from finite resources, among which fossil fuels. There is great potential to save energy is many cities. An urban energy source less commonly explored is the potential reuse of waste heat from various urban functions.

1.1 The significance of heat exchange in cities

Depending on the source, buildings use approximately 30-40% of all energy in our society. In a city, with heavy industries lacking, this contribution is even 50% or more. In most developed regions the heat demand is still predominant; in the Netherlands this is approximately 70-80% of all energy use in buildings [SenterNovem 2008; Broersma et al. 2012]. The predominant part of this heat is produced by natural gas (producing hot water of 60-90^{o}C), often by means of boilers that are energy-efficient but have an exergetic efficiency of less than 10%. In some cases urban heat grids provide hot water (at 90-130^{o}C), powered by a power plant or industrial processes fired by fossil fuel, not seldom transported over distances exceeding 10 km. So the reuse of waste heat that otherwise would have gone lost may essentially be good, however the current system is not very efficient.

Studies indicate that by approximation 40-50% of the heat demand in cities can be reduced through an optimal use of residual heat inside the city [Tillie et al. 2009a; Kürschner et al. 2011].

1.2 Exergetic inefficiency

Cities receive energy of a higher quality than needed: temperatures around 90^{o}C are used to create an indoor temperature of around 20^{o}C. This may remain necessary for old, poorly insulated buildings with traditional radiators, which cannot be energetically renovated, however with modern well-insulated houses floor heating systems based on 30-40^{o}C suffice, whereas passive houses can even function with radiative heating of 25-30^{o}C. This means that the initial figure for heat demand (based on natural gas consumption) will already be reduced if lower temperatures are provided.

Cities now relying on gas or waste heat from power plants will have a serious problem in the near future. If waste heat is not better seized, cities' hot water supply will have to come from geothermal sources or biomass-fired power plants, both of which are not abundant enough for all of the world's urban areas.

If the lower temperatures could be served by waste heat from other buildings, the same quantity of primary energy would be used multiple times, instead of multiple quantities of energy being used only once. This is the essence of exchanging or cascading heat within neighbourhoods or buildings. Depending on the number of connections or cascading steps and system's efficiency, the intelligent tuning and exchanging of heat of different qualities could reduce the demand for primary energy for heat (at the start of the chain) by a factor of 2 at least.

1.3 The REAP2 project

As described, centralised high-temperature heat grids are well-known, but the lower-caloric heat from buildings as offices, supermarkets, swimming pools and also dwellings is abundant and seldom utilised. This has a two-sided negative effect: the demand for energy is still higher than necessary and energy is lost and the city heated up, which in summer can aggravate the urban heat island effect, which statistically leads to higher mortality rates [Huynen et al. 2001].

The REAP2 study [Dobbelsteen et al. 2011a] discussed in this paper elaborated the method of Rotterdam Energy Approach & Planning (REAP) and applied it to the Rotterdam harbour area of Merwe-Vierhavens. The study led to new technical concepts for energy exchange, which can mean a break-through in energy-neutral city redevelopment.

2. Methods and approaches supporting energy-effective design

2.1 Energy potential mapping

Many cities across the world strive to become energy-neutral, i.e. to use not more energy than they produce themselves The energy still to be used needs to come from renewable energy sources. This challenges city councils, planners and designers with an assignment different form the past, when the provision of energy could be arranged through (cheap) supply from elsewhere. The knowledge of harvesting energy on-site is limited, but there are several methods that can support this endeavour. One of these is energy potential mapping e.g. [Dobbelsteen et al. 2011b], charting the local availability and quantity of renewable energy sources (see figure 1, left).

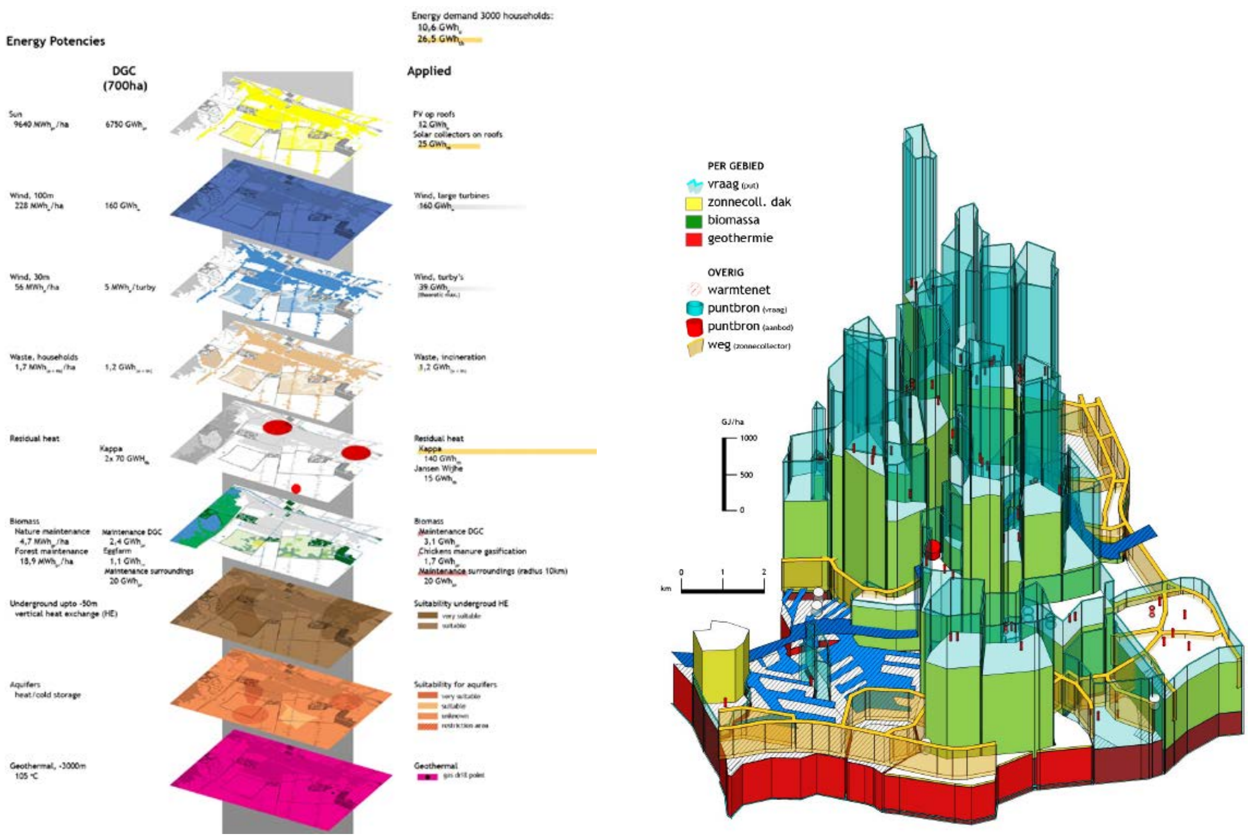

Figure 1 Left: energy potential stack for a new district in Hoogezand-Sappemeer [Broersma et al. 2009], top to bottom: solar potentials, wind at 100 m, wind at 30 m, wastes, residual heat from industries, biomass, shallow underground for heat exchange (down to 50 m deep), aquifer layers for heat and cold storage (50-250 m deep) and deep geothermal heat (3000 m deep) (left). Right: the heat map of the centre of Rotterdam [Broersma et al. 2010]: hollow cores depict the demand for heat in urban areas whereas full cores indicate heat potentials from the sun, biomass and geothermal sources, plus harvestable (waste) heat from roads and industries.

The challenge to make cities energy neutral is complicated: as a result of the (energy-inefficient) existing urban building stock the demand for energy is high and the potential to generate electricity from local energy sources is small due to the limited space per person. Nevertheless, heat potentials seem abundant. A recent study leading to heat maps of the Netherlands [Broersma et al. 2010] indicated that cities have many technical and anthropogenic sources for heat and cold (see figure 1, right), especially if one includes the low-exergetic waste heat from urban functions. These sources are often considered irrelevant and rarely seized. Their presence nevertheless is abundant and as discussed below, they can have a significant effect on the energy consumption.

2.2 The New Stepped Strategy

In line with earlier ideas by climate and energy consultants DWA Dobbelsteen [2008] developed the New Stepped Strategy (NSS) to improve an already existing approach to energy-efficient building called Trias Energtica [Lysen 1996, based on early work by professor Kees Duijvestein]: 1. reduce the demand, 2. reuse residual streams, 3. generate from sustainable sources and let waste be food (see figure 2). The NSS can also be used for the management of other essential streams in the built environment (water, materials, food and even mobility).

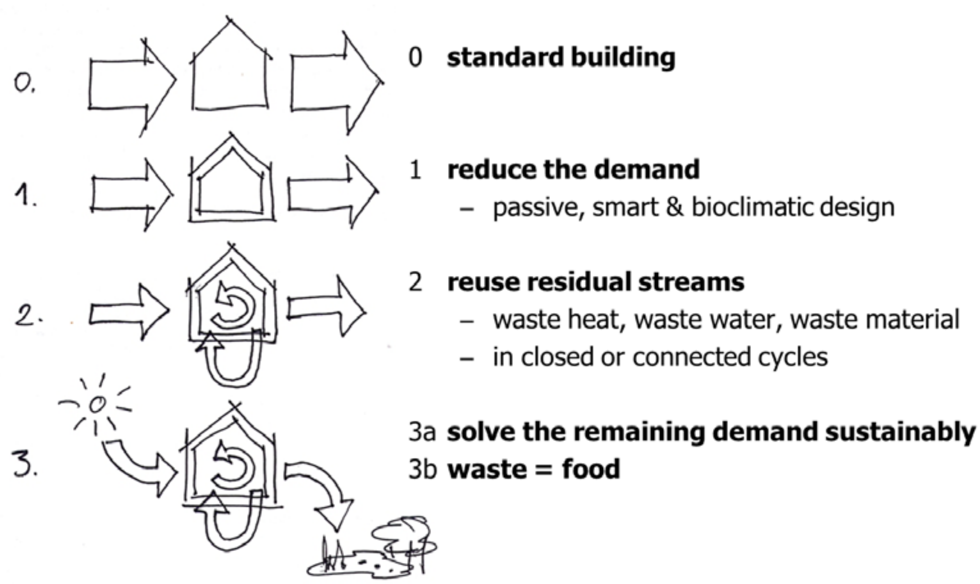

Figure 2 The New Stepped Strategy [Dobbelsteen 2008]

2.3 REAP

In their ambitions Dutch cities as Rotterdam and Amsterdam embraced new methods that can help guide towards energy-neutrality, based on the New Stepped Strategy: the Rotterdam Energy Approach and Planning (REAP) [e.g. Tillie et al. 2009a; Tillie et al. 2009b] respectively the Amsterdam Guide to Energetic Urbanism (LES) [Kürschner et al. 2011].

REAP was developed to support energy-neutral urban planning in a structured, incremental way (see figure 3). The approach has received worldwide acclaim. Especially the second step of the REAP method, regarding tuning, exchanging, cascading of energy at various scales, is relatively new, offering new opportunities for cities.

Theoretical studies reveal that these approaches can transform neighbourhoods to energy-neutrality [Dobbelsteen et al. 2011c; Dobbelsteen & Tillie 2011]. Depending on the type of neighbourhood, approximately 40% of this achievement comes from the exchange of heat and cold, which therefore is a crucial step.

Nevertheless, REAP needed to be elaborated further, for practical application in actual urban redevelopment. This was done for the transformation of the Rotterdam city harbours, in a study called REAP2.

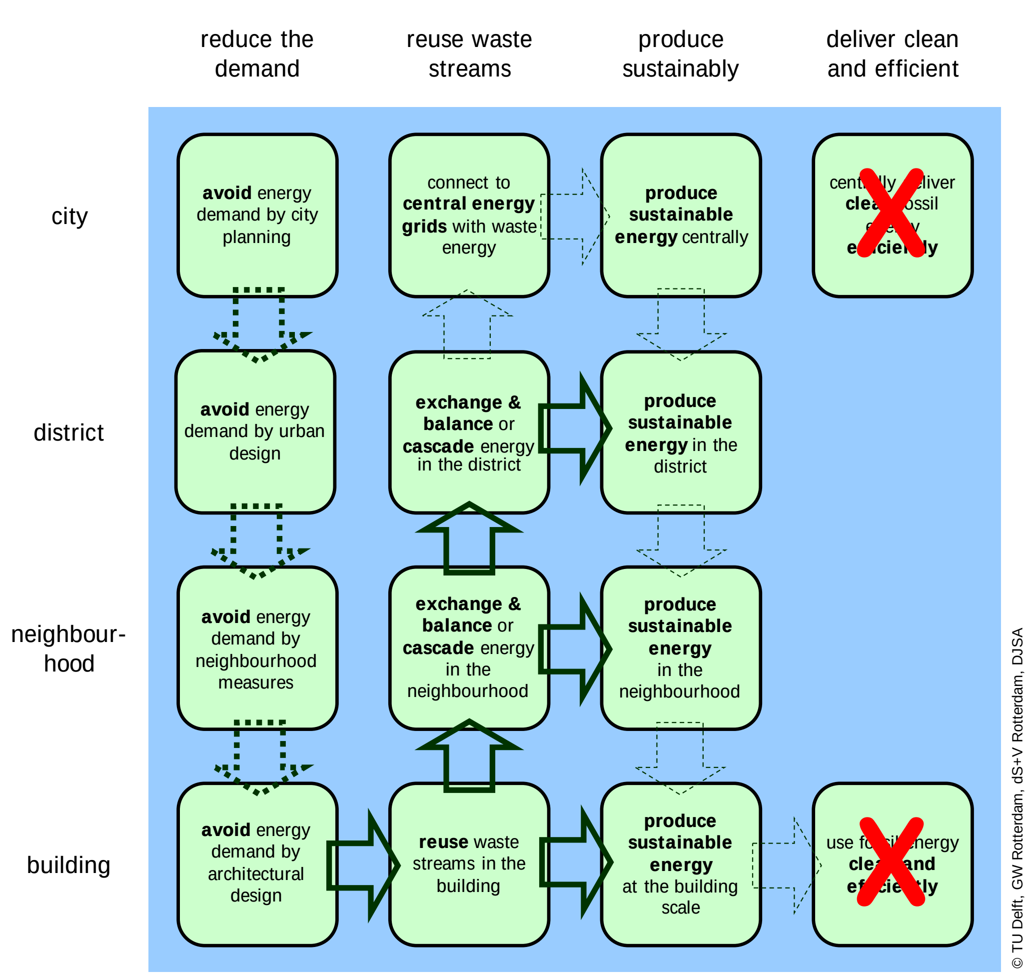

Figure 3 The Rotterdam Energy Approach & Planning (REAP) [Tillie et al. 2009a]

3. The approach to REAP2

3.1 Preconditions for the project

The REAP method evolved from the Rotterdam Hart van Zuid study [described in Tillie et al. 2009b] but this was merely an exercise to see whether an existing district could theoretically become carbon neutral. With the REAP2 project the focus was on a former harbour area within the city, the Merwe-Vierhavens, where industrial activities are projected to end within a limited timeframe, creating the opportunity to actually transform this district into something new. And with the city's ambitions the development of course needs to be sustainable.

For the REAP2 project both the commissioner and principal researcher wanted to elaborate the REAP method by looking at other aspects that might influence the approach to energy, applied to the Merwe-Vierhavens. When assigned to do so, we gathered experts in the fields of energy technology, sustainable architecture and urbanism, social sustainability, building law, and institutional strategies joined forces with the original designers of REAP. This paper can only highlight the technical aspects of the study.

3.2 Tackling the supply and demand for heat

As in most other urban areas, the Merwe-Vierhavens are confronted with a gradual transition toward energy-neutral building. At present the area is still filled with warehouses, industrial buildings, offices and a small power plant, of which some will be in operation still several decades, whereas others will be demolished, creating space for new, sustainable premises. This means that the energy demand, heat in particular (and supply, for that matter), will be very diverse and that the technology and infrastructure both present and to be developed need to be multifunctional (serving current variable demands) as well as flexible (serving all kinds of demands in the future).

3.3 Three principles

The core focus of the REAP2 project was on the elaboration of technical concepts for tuning the demand and supply of heat and cold (step 2 of the NSS) and the spatial, social, legal and institutional consequences of these concepts. Basically there are three principles of tuning heat and cold:

- matching supply and demand directly
- (inter-)exchanging and storing residual heat and cold
- cascading waste heat

These principles could be established on the scale of separate buildings, neighbourhoods (quays), the total area of the Merwe-Vierhavens or even in exchange with the city scale of Rotterdam.

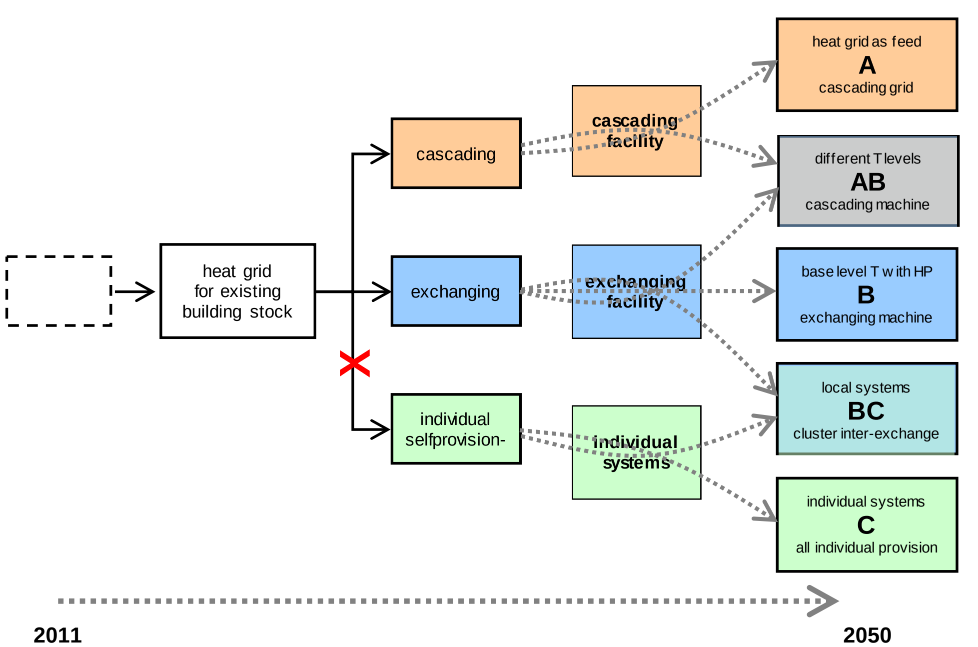

Figure 4 The five strategies from REAP2: two based on connection to the central high-temperature heat grid: A. *heat cascading grid and AB. cascading machine; one introducing a neighbourhood facility: B. exchanging machine; and two disconnected from centralised energy infrastructure: BC. inter-exchange within a cluster and C. individual self-provision.*

4. Technical solutions from REAP2

4.1 Five strategies

The research project culminated in the proposition of five strategies, starting from centralised system using the municipal heat grid as the basis, however cascading different temperatures into the area, down to the individual self-provision of energy (autarkic housing). See figure 4.

4.2 Technical principles

The five strategies can be translated into technical solutions including available utilities but combining and connecting these in a novel way. Figure 5 depicts the principle of a heat-cascading grid, using the return stream of one neighbourhood as main supply for the other.

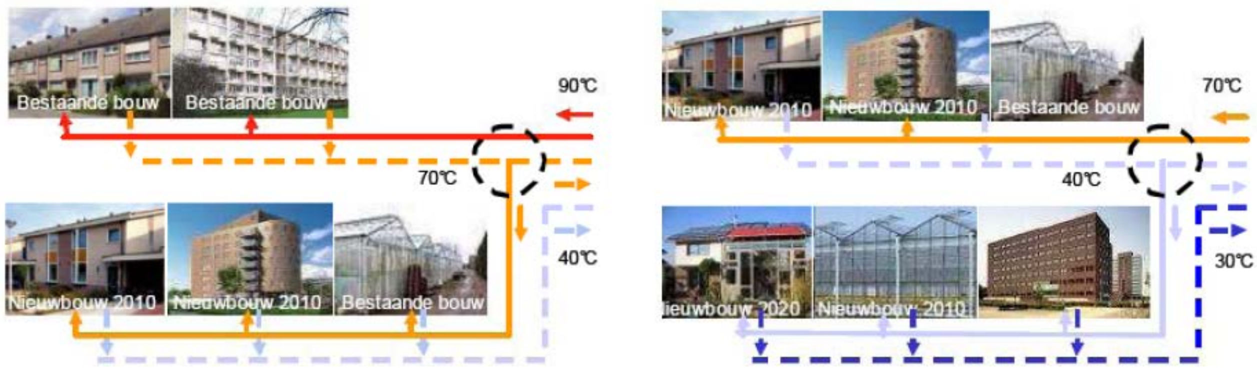

Figure 5 Heat-cascading grid, connecting an old neighbourhood with a newer one (left) and connecting a newer neighbourhood with a very well-insulated one (right); the latter grid can be an extension of the first

Cascading can also be established by an 'in-between machine', connected to the central provision of high-caloric heat but capable to serve different temperatures to different neighbourhoods around. An inter-seasonal heat and cold storage (e.g. underground aquifer storage systems, ATES) can shave off peaks in supplies and demands. See figure 6.

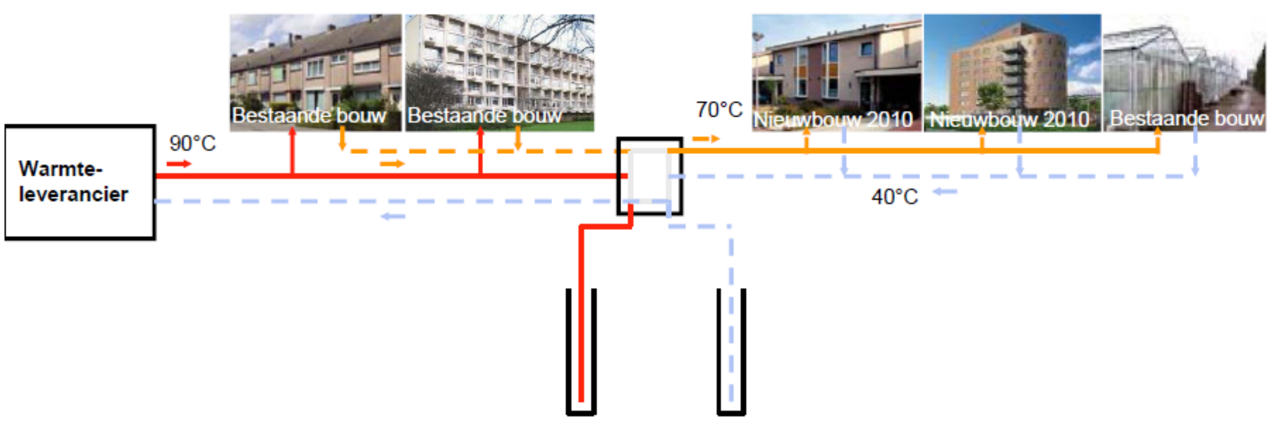

Figure 6 Heat cascading via heat and cold storage facility: excess heat in summer can be stored in the underground for use in winter, when excessive cold can be stored for use in summer

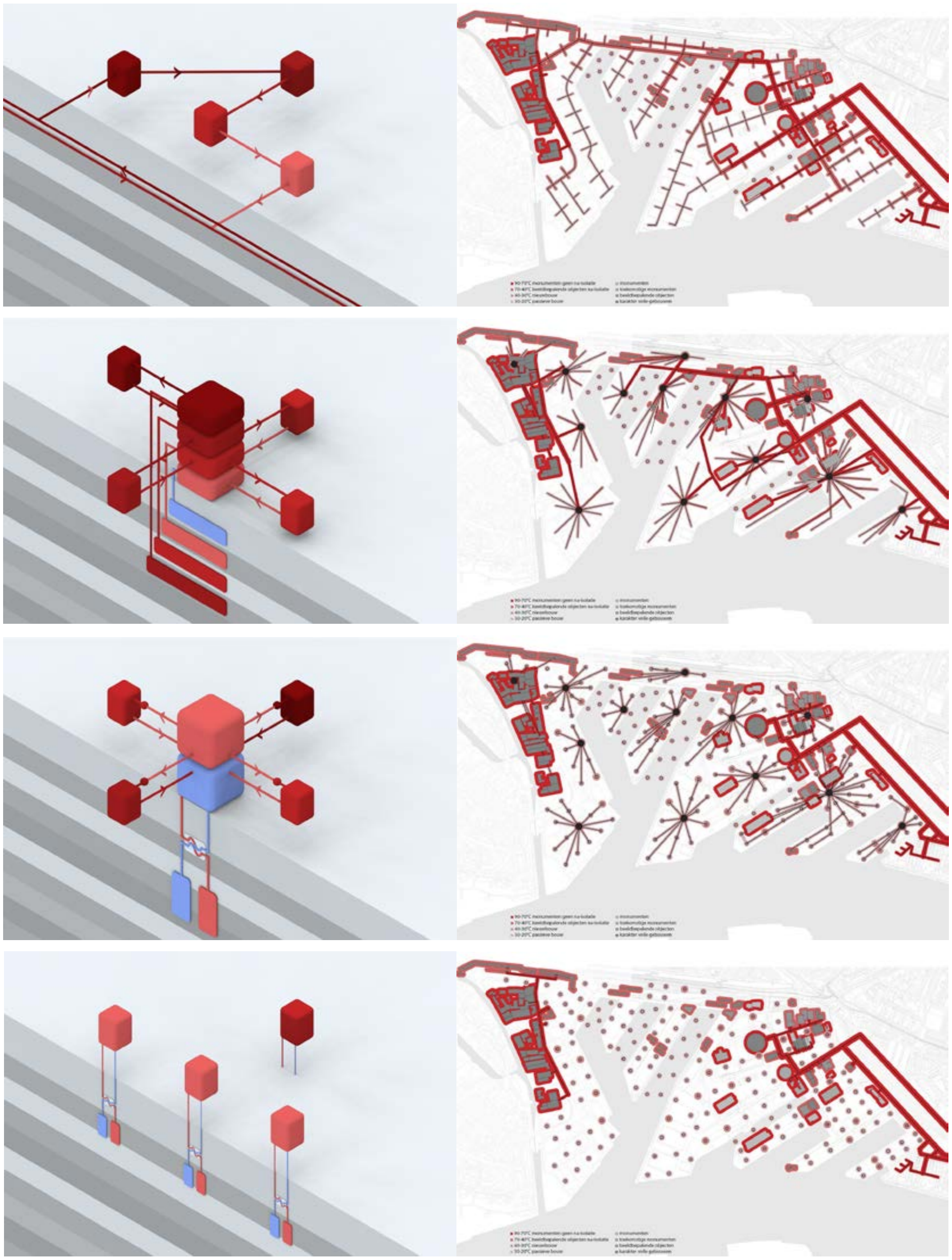

Figure 6 *Technical concepts and spatial implications to the Merwe-Vierhavens of the heat exchange strategies of A (heat-cascading grid), AB (cascading machine), B (exchanging machine) and C (individual self-provision). BC is a smaller combination of C and B [images by Doepel Strijkers Architects]*

4.3 Spatial implications

Each of the five strategies has its specific spatial, social, legal and institutional implications, which were studied and presented by the REAP2 project. Some implications of these become apparent when they are clarified by sketches of the technical principle and their respective spatial influence (figure 7).

5. Conclusion and discussion

5.1 Potential

There are many recent developments in heat and cold grids but these projects focus on the development of heat and cold grids additional to the traditional industry-fed high-caloric heat grid. The local exchange of (low-caloric) heat within buildings and between buildings within an urban neighbourhood or district is not very common. Nevertheless, considering the energy figures of cities, this strategy has great potential.

5.2 Innovation

The heat cascading machine resolving from the REAP2 study is a totally new concept for heat exchange that can be ground-breaking in many countries of the world. As discussed in this paper, the cascading machine can provide water at different temperatures for buildings with different demands – depending on their heat system and thermal insulation – based on the temperature difference between the feed water and the return water.

The heat exchanging machine does neither exist yet but could also be ground-breaking for the exchange of heat and cold in cities. For all buildings in the urban area the exchanging machine provides water at a low-caloric level (e.g. 40^oC), which can be upgraded or downgraded – depending on the demand of a building – by an individual heat pump. The return temperature depends on the heat demand of the building: does it require higher temperatures, then the return temperature is lower than 40^oC; does it require lower temperatures, then it will send back water of higher temperatures. Excess of heat can be stored in hot wells of underground aquifers, excess of cold in cold wells.

Finally, and not least, the question of exchanging heat and cold in cities will bring science on a higher level, integrating thermodynamics into urban planning and taking patterns of energy demand and supply in cities as the basis for novel utilities and infrastructure.

5.3 Discussion

The heat and cold storage proves to be a valuable asset to a sustainable energy system as the availability of renewable energy in the future will be fluctuating and demands change through the seasons. In the case of a cascading machine a multiple, multi-temperature storage system may even be welcomed, delivering the possibility to store different temperatures and hence avoiding great exergy losses. The multi-layered storage system does not exist yet.

The REAP2 study lacked one important aspect that should have been studied: the economical consequences of different energy solutions. The (unrestricted) introduction of new vast infrastructures for this heat exchange in cities may be uneconomical when compared to traditional systems. This is however dependent on the way things are solved and exactly the reason why low-temperature systems should be tackled at scale levels not larger than the neighbourhoods (typically with a radius of not more than 300 m).

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