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Environmental benefits through Storage, Exchange of thermal energy in smart city

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ABSTRACT

The aim of this study is to look at the potential of a local sustainable energy network in a pre-existing context to develop a novel design beneficial to the environment. Nowadays, the concept of smart cities is still in the developmental phase/stage andwe are currently residing in a transitional period, therefore it is very important to discover new solutions that show direct benefits the people may get from transforming their city from a traditional to a smart city. Using experience and knowledge of successful projects in various European and non-European smart cities, this study attempts to demonstrate the practical potential of gradually moving existing cities to the level of smart cities by developing the available environmental resources. Data displays that using residual heat in a small neighborhood results in a lower annual gas consumption of at least 732. 200.00 m³, this incidentally leads to a reduction of CO_2 emission by 1,303,316 kg.

Keywords: Smart city, Residual heating, Smart energy, Energetic programming, Sustainable building.

المكاسب البيئية الناتجة من تخزين وتبادل الطاقة الحرارية في المدينة الذكية

علي بداي
ماجستير هندسة مباني مستدامة
أتريخت – هولندا
مكتب A. Badai لتصميم المباني المستدامة

الخلاصة

تناقش هذه الدراسة، إمكانية تطوير الموارد البيئية المتاحة باتجاه إنشاء شبكة محلية للطاقة المتجددة تنقل المدن القائمة تدريجياً، من مدن تقليدية تعتمد على طاقة المصادر الاحفورية، إلى مستوى المدن الذكية التي تعتمد كلياً على مصادر الطاقة الطبيعية المتجددة، والتي تقلص بذات الوقت كم نفاياتها الحرارية الزائدة الى أقل حد ممكن. نمر الآن في فترة انتقالية حيث مفهوم "المدينة الذكية" مازال غير مكتمل وفي طور التبلور، لذلك لابد من تحشيد أكبر عدد ممكن من المستخدمين للمشاركة الفعلية في هذه العملية الانتقالية. وأسهل الطرق لبلوغ هذا الهدف هو إيجاد حلول تظهر الفوائد المباشرة التي سيحصل عليها السكان من تحويل مدينتهم من مدينة تقليدية إلى مدينة ذكية. توصلت هذه الدراسة الموجزة، بالاستعانة بالخبرة المتراكمة للمشاريع الناجحة في مختلف المدن الذكية الأوروبية وغير الأوروبية، الى إمكانية خفض استهلاك الغاز، بمقدار (732. 200.00) متر مكعب سنوياً وفي في حي صغير ، هذا يعني خفض انبعاثات ثاني أكسيد الكربون بمقدار (1.303,316) كجم في العام.

الكلمات الرئيسية: المدينة الذكية، الحرارة المتبقية، الطاقة الذكية، برمجة الطاقة، البناء المستدام.

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1.INTRODUCTION

Cities and climate change

Today 54% of the world's population lives in urban areas, it is expected that this percentage will increase to 70% by 2050 **(United Nations, 2014)**. This development is related to an increase in population and energy consumption, which is a consequence of increased welfare. The problem is compounded by the fact that most of the energy consumed depends on depletable resources such as oil, coal and natural gas **(Fig 1)**.

It is now known that our way of life has destructive effect on nature. The deterioration in the Earth's environment has reached alarming levels whereby the earth's resources are diminishing due to its severe depletion and pollution. Furthermore, the situation is also worsening due to global warming which threatens with an increase sea level in the coming decades. The Paris Summit in 2015 was the largest summit on earth climate, sustainability and renewable energy **(Al-Bazzaz, 2018)**

In European context, currently, 78% of Europe's population live in cities, and 85% of the EU's GDP is generated in cities. (European Union, sd) Cities therefore, are responsible for the majority of environmental issues. The share of CO_2 emission from consuming fossil fuel in European buildings is between 40-45%. (Science for Environment Policy - European Commission, 2007) The percentage of energy spent in these buildings for heating purposes ranges from 50 to 75%, while the rest is distributed to electrical appliances and lighting. (**Vandekerckhove, 2006-2007**). Meanwhile renewable energy resources comprise only 4% of the world total primary energy consumption in 2018 **(BP Statistical Review of World Energy 2019, 2019).**

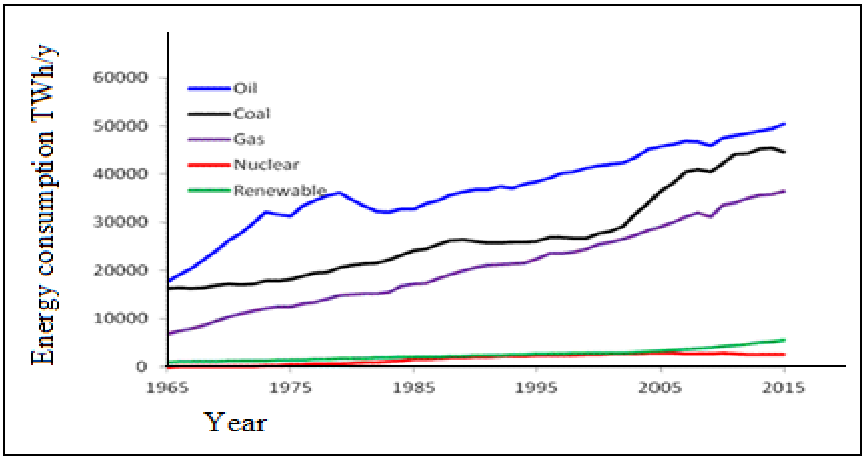

Figure 1. The world's energy consumption.

(BP Statistical Review of World Energy 2019, 2019).

2. SMART CITY AND ENERGY MANAGEMENT

The smart city is a relatively new concept that has been defined by many authors and institutions and used by many more. In a very simple way, The smart city is intended to deal with or mitigate, through the highest efficiency and resource optimization, the problems generated by rapid urbanization and population growth, such as energy supply, waste management, and mobility **(Cavillo, 2016).**

A traditional city has two layers, infrastructure and service layer. The main point that differentiates a smart city is the addition of a third layer in - between the digital or data. **(IGLUS, 2017).**

A smart city is thus a sustainable, safe and efficient city that provides a high quality of life to its inhabitants.

Energy management

Smart management of the city and the building environments reduces the energy consumption of a building. Effective solutions can ensure reliable and efficient operation of buildings **(IoT, 2018).**

Energy management is generating, using and recovering energy. In the future the main energy resources in a smart city will be renewable resources such as wind, solar and biomass. These new systems aren't centrally organized and cannot be managed by traditional methods. There are multi suppliers, multi type of energy, multi production sites. When taking various sources of energy into consideration, it is sometimes not possible to utilize the pre-existing infrastructure **(Cavillo, 2016).** All these factors require the need for technological innovations and flexibility in the energy system significantly.

Reusing residual heat

Thermodynamics tells us that energy is conserved in all its transformations. So the ratio of energy output to energy input is always unity, or 100% but there is always energy loss (unused energy). The efficiency of an energy conversion device is a quantitative expression of this balance between energy input and energy output. It is defined as follows:

$$Device\ efficiency\ = \frac{Useful\ energy\ output}{Energy\ input}$$

If the device is an electric generator, the useful energy output is electricity, and the energy input is the chemical energy of gasoline that is converted into mechanical energy. Not all energy content of the fuel is converted to electricity: most is actually waste heat. So the received kWh s of electricity has cost more kWhs of fuel, which we call the **primary energy**. In the Netherlands for example , the average efficiency of power plants is 45%. So the 3.5 MWh has actually cost 7.8 MWh of primary energy. **(Dobbelsteen, 2019)**. Waste heat which is not being utilized remains in the city and results heat islands. It is estimated that approximately 100 PJ of residual heat in the Netherlands is suitable for useful and sustainable reuse. Reusing 100 PJ of excess heat will result in a decrease in energy demand from gas plants and hence lead to a reduction of approximately CO_2 emission by 3.6 M ton **(Bettina Kampman, 2019).**

IoT and the rol of data centre as a new energy source in a smart city

In major cities, developments surrounding the Internet of Things (IoT) and the growing number of internet users worldwide, have been responsible for an exponential increase in the use of data (Unica Energy Solutions, 2018). Estimates, based on experiences in Stockholm, calculated that the usable residual heat equivalent of approximately 750 MW of data center power. Use of this residual heat in the built environment could reduce around 600 Kilotons of CO_2 from more than one million households due to the possible reduction in fossil heating **(Gauw, Grove, Stuivenwold, & Pegtel, 2018).** In 2017, data center capacity in the Netherlands stands at 1,247 MW. With an average 20 GJ of heating required for a well-insulated home, it is theoretically possible to heat around 2 million households with the excess heat **(Unica Energy Solutions, 2018)**. Alibaba data center in China heats homes. Amazon heats Biosphere project with data center residual heat **(Gauw, Grove, Stuivenwold, & Pegtel, 2018)**. The heat generated by data centers has a relatively constant temperature between 25 C° and 33 C°. This low-caloric heat can be effectively increased to a temperature required by the consumer by means of a heat pump. In order to reuse residual heat successfully for the purposes of energy transition, an all-round solution needs to be drawn up on the basis of four key factors: heat demand; heat supply; heat storage; and the heat grid **(Unica Energy Solutions, 2018).**

2.1 Thermal Energy Storage System TESS techniques

This theoretical potential sun energy striking the earth's surface in one and a half hours (480 EJ) represents more than the worldwide energy consumption in the year 2001 from all sources combined. **(Jeff Tsao, 2005)**. The problem of heat energy from the sun, wind, residual heat from industry, geothermal, is that the heat is released at a time when it cannot be used. There is a mismatch between supply and demand of energy. Therefore, the presence of thermal energy storage system (TESS) in smart city is indispensable. The use of energy storage systems often results in such significant benefits as: reduced energy costs, reduced energy consumption, improved indoor air quality, increased flexibility of operation, and reduced initial and maintenance costs, reduced equipment size, more efficient and effective utilization of equipment, conservation of fossil fuels (by facilitating more efficient energy use and/or fuel substitution), and reduced pollutant emissions (e.g., CO_2) **(Dincer, 2011).**

So far, there are four techniques to store heat: I. sensible heat storage, II. latent thermal energy storage, III. thermochemical heat storage and IV. heat storage through adsorption.

2.1.1. Sensible thermal energy storage

In water

Water is a suitable medium to absorb energy due to high specific heat capacity. The specific heat capacity of water is $4187\ J/kg\text{C}°$. By comparison : steel 500 , wood 1880, concrete 840-920 $J/kg\text{C}°$.

The amount of sensible heat stored, (Q) is calculated by multiplying the related mass m with the specific heat capacity c_p and the temperature difference ΔT before and after the storage is charged or discharged:

$$Q[J] = m[kg]Cp[J/kg\text{C}°].\Delta T[\text{C}°] \quad (1)$$

For seasonal thermal storage we need a very large tank. Therefore, underground layers of sand with ground water can be used to store heat. This is the subsurface aquifers ATESS (Aquifer Thermal Energy Storage systems). In ATES systems two cold and a warm well are drilled. In summer, ground water is extracted from the cold well. It passes through a heat exchanger in order to cool a building. The heat from the building is transferred to the ground water, which is then injected into the warm well. In winter, the reverse happens: warm water from the warm well is extracted to be used for heating the building. A heat pump is required to increase the temperature of the stored water that usually has a maximum temperature of 25 degrees. The cooled ground water is injected in the cold well again. On an annual basis, the heat and cold extracted must be in balance. Ground heat exchangers can also be used to cool and heat buildings, combined with a heat pump. These systems are called BTES systems, 'Borehole Thermal Energy Storage'. Vertical boreholes are the most common, but horizontal ground heat exchangers can also be applied.

Fig 2 shows the three types of heat delivery from data center using thermal storage:
A- direct delivery: no HCS (heat cold system) is used B- indirect coupling: all heat is exchanged via the HCS. C- at a low temperature heat grid: direct heat is delivered from the grid and the HCS only ensures the balancing of the system

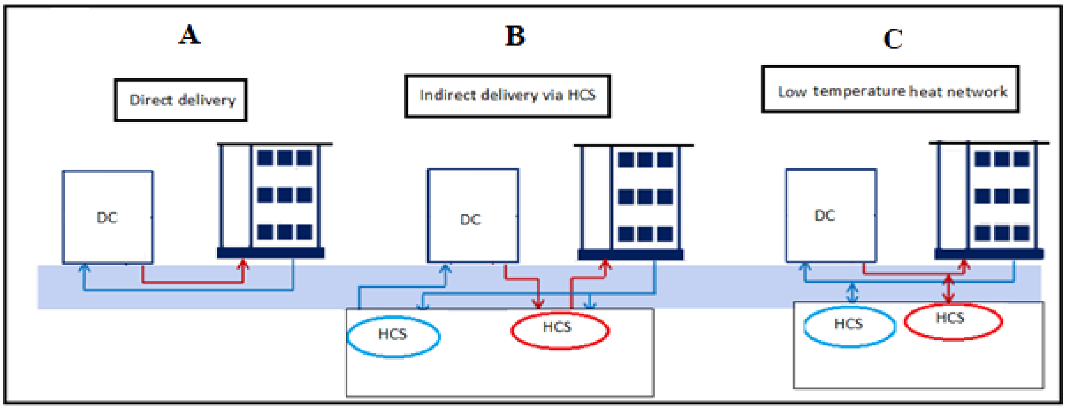

Figure 2. Work of thermal storage, data center and the neighborhood.

In concrete

Concrete is a material with a very dense mass, i.e. a very dense core. In the case of concrete core activation, this mass is 'activated' by having it store and release heat or coolness at strategic moments. With its high density, it acts as a buffer against excessive or too low outdoor temperatures and ensures that the indoor temperature is not affected in any way. It is possible to determine easily whether the system heats or cools your building. **(Glück, 1999)**

Disadvantage of this technique is the slow response time of the system. Large temperature changes due to varying solar heat and internal loads cannot be immediately absorbed.

When T_{wk} is average water core temperature or the average concrete core temperature in C°, Ti is the room temperature in C° and R is the heat resistance between T_{wk} and Ti in m². K/W, then cool – or heating power of a concrete core activation system in W/m²:

$$P = (T_{wk} - Ti)/R \qquad (2)$$

Due to surface condensation, T_{wk} cannot be chosen indefinitely low. Due to a large radiation asymmetry, T_{wk} cannot be chosen indefinitely high. During cooling and heating operation, the heat resistance between Twk and Ti will increase and P will decrease. **(Schmitz, 2006)**
Not only cool and heating power must be supplied, but this should also be delivered for a specific period of time during use. If the heat and cold storage capacity is too small, then in time cooling and heating power that will be to deliver will be limited.

Capacity: $Q = \iint p.dt = \sum p.\triangle t \qquad (3)$

Q:storage capacity Wh /day, P: power in W, t: the running time in h/day **(Olesen, 2005)**

The disadvantages of concrete core activation are limited when concrete surface activation is found. Instead of plastic hoses with distance 100 to 300 mm and diameter 20/2, capillary tubes distance 15 mm and diameter 3.4/0.55 mm are used. **(Schmitz, 2006)**

Concrete core activation was originally developed in Switzerland and is used successfully in the Netherlands, Switzerland and Germany. With an innovative concrete surface activation system in Germany, the efficiency of cooling and heating is significantly improved.

Asphalt as a thermal energy collector

On a summer afternoon, urban areas are generally warmer than surrounding rural as illustrated in figure 1 (EPA, 2003). This urban-rural air temperature difference, known as the urban heat island effect (UHIE). **(Jones, 1990)**

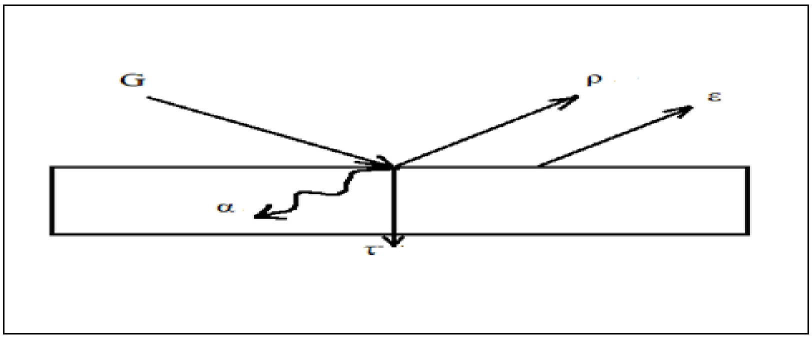

Figure 3. Energy balance on the Surface of an asphalt pavement

Dark surfaces absorb heat and do not reflect them much so they heat up (**Fig 3**).
A large portion of the thermal energy falling from the sun on a dark surface such as asphalt will be absorbed during the day and emitted during the night (ε) towards the sky. This heat contributes to the formation of heat islands.

Besides, the absorbed and transmitted sun rays (α + τ), often in hot countries, distort and ripple the asphalt layer

G= α + ρ + τ + ε (4)

G = solar radiated ; α = absorbed ρ = reflected ; τ = transmitted ; ε = emissive energy

Assuming that one square meter of asphalt, with a thickness of 15 cm , density 1200 kg/m^3 and specific heat capacity $0,92.10^3$ J kg^{-1} K^{-1} is exposed to 600 watts of sun heat on average, and that this temperature is absorbed regularly. Then the increase in temperature per hour (ΔT) of this area of asphalt (without thermal contact with the ocean),can be calculated:

Q = 600W = $6,0.10^2$ x 60 x 60 = $2,16.10^6$ J

m = ρ.A. h = 1200 x 1 x 0,15 = $1,8.10^2$ kg
From equation (1):

$2,15.10^6 = 0,92.10^3 \times 1,8.10^2 \times \Delta T$ ΔT = 13 K

Each object has a temperature above absolute zero, radiates temperature towards the surrounding space. If (T) is the absolute temperature of the surface of the body, Ɛ the emission coefficient, the radiation can be calculated by the Stefan-Boltzmann equation:

$Q = \varepsilon.\sigma.T^4\ w/m^2$ (5)

When σ is a constant Stefan-Boltzmann $= 5{,}67\times10^{-8}$ W $m^{-2}K^{-4}$.

The night sky can be considered as a dome at -25 to -30 C°. When α is heat transfer coefficient for radiation in w/m^2 dark surfaces radiate according to the equation:
$Q = \alpha(T\ surface - T\ night)$ (6) **(Jellema, 1993).**

This un useful heat, which causes heat Islands and deforms the asphalt layer, can be collected and qualified to perform useful purposes in heating houses. The collectors in the asphalt work as a heat exchanger. In summer, the much heat absorbed into the asphalt as a result of solar radiation.This heat is transferred to water via a pipe system that is applied to the asphalt and can be used directly as a source for the heat pump or stored in an aquifer.

By cooling the asphalt, the risk of trace formation, cracking and fraying will decrease. Using the same piping system, the hot water in winter can also be used in cold countries to heat the covered area, thus keeping the road - or other surfaces free of snow and frost. **(Chen, 2008)**

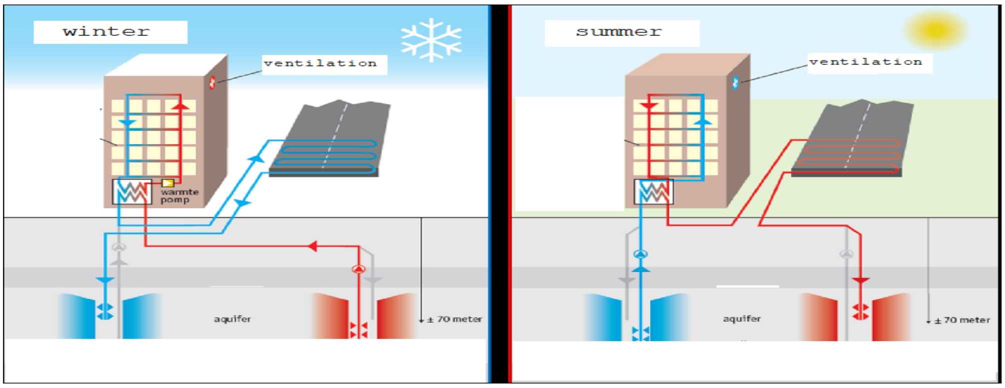

Figure 4. Asphalt as a heat collector.

Fig 4 shows a scheme for using this technology in winter and summer to obtain heat and cooling, respectively.

2.1.2 . latent thermal energy storage.

Other possibility for heat storage is *Phase Change Material* (PCM) (paraffin's, fatty acids, salts). Melting a PCM requires a lot of heat, which is released as soon as the material solidifies. Because the temperature of the material does not change when melting or solidifying, this form of heat storage is called latent or deposits. The most well-known phase change material is obviously water: in the phase change from water to ice, the energy released is 80 times as much energy as cooling down the same amount of water with one degree Celsius. This heat comes back as we reverse the process.. For the built environment various other types of PCM s have been developed and are still being developed. These usually have a higher melting point, which means much energy can be stored at these temperatures. **(Jeff Tsao, 2005)**

2.1.3 . Thermochemical energy storage:

With tthermochemical energy storage, heat is added to a material that is then spattered into two components in an endothermic reaction. The heat can be recovered later by adding these two components together.

$$AB + Heat \rightleftharpoons A + B$$

$$water + Na2\,SO.10H2O \rightleftharpoons Na2\,SO.10H2O + thermal\ energy \quad (7)$$

Thermochemical energy storage reduces the required storage volume from 120 m³ in the case of water and 60 m³ in the case of PCM to only 6 m³. **(Wemmers, 2006)**

2.1.4 . Heat storage through Adsorption

Adsorption is a condition of "adsorption" or gluing of a substance (e.g. water) on the ***surface*** of another substance (e.g. silicate or zeolite), a process that is different from absorption (Absorption, means the penetration of a substance between ***molecules*** of another substance). What makes the process of adsorption particularly important is that the amount of heat produced or preserved depends on the surface area. When water vapor touches the surface of this substance, a large amount of heat is released, i.e. a "dump" of silica is performed and when the hot water vapor passes, silica is heated and recharged with heat. We can estimate the importance of this method if we visualize a cube with a dimension of 1x1x1 square meters with 12 zeolite panels, in which case the water passed from the surfaces of the panels will release a quantity of heat commensurate with the capacity of the touching surface i.e. 24 square meters. **(Bakker, 2006)**

Volume storage

With the requirement for compactness, especially for energy stored in houses and separated buildings, storage of heat in water is impractical. Figure 5. shows that a volume of 120 m³ is required to store heat for a very energy efficient home. A storage system with an energy density of 200M/m³ water or a PCM, gets a storage volume of 75 m³ Heat loss can be reduced when using a vacuum insolation panel (1.4 cm for 3.5 m².k/w) **(Tenpierik, 2005)**. When the heat is stored in a PCM at 65 C° (or water from 40 C ° to 90 C°), and when the annual average outside temperature is 10 C°, heat loss occurs.

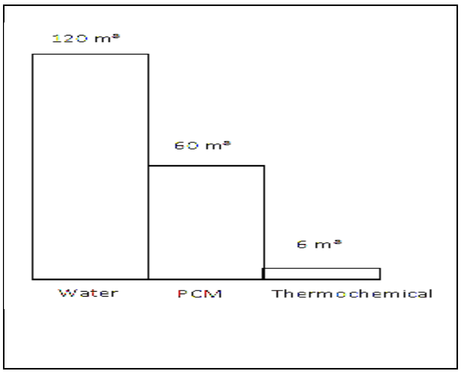

Figure 5. Required volume in m³ for the seasons storage of heat for a very energy-efficient house with three heat storage techniques **(Olesen, 2005).**

The heat loss from storage then becomes 412 W on average. Over the year, the total heat loss is 13 G J, almost as much as the amount of heat stored. This means that the storage must be almost twice as large, but also that the collector surface must be twice as large in order to absorb both the useful and the loss of heat. **(Wemmers, 2006)**

3. EXCHANGE ENERGY WITHIN THE NEIGHBOURHOOD. HEAT REUSE AND HEAT EXCHANGE IN RUSTENBURG AMERSFOORT

Aim, and approach of this study is to test how many units of the 1360 homes in Rustenburg Amersfoort (C) in **Fig 6**, can be heated via exchange thermal energy within the neighbourhood (A, B, E) ..

A: an 10000 m² area 6 m high (distribution center for medical supplies)

B: an asphalt road 6km long, 6 m wide. The annual thermal gain per square meter of asphalt is 0.75 GJ/ m² and 80% of this gain is used for heating.
E: 4 supermarkets with a central system each with a cooling capacity of 200 kW

C:1360 good insulated dwellings-built year 1978-1980. Area of one dwelling 130 m². Annual natural gas consumption for heating and hot water preparation is 1400 m³.

1 m³ gas =1,78 kg CO_2, m³ natural gas = 9.8KWh ,1KWh =3,6 MJ, 1kWh grey current = 0,476 kg CO_2

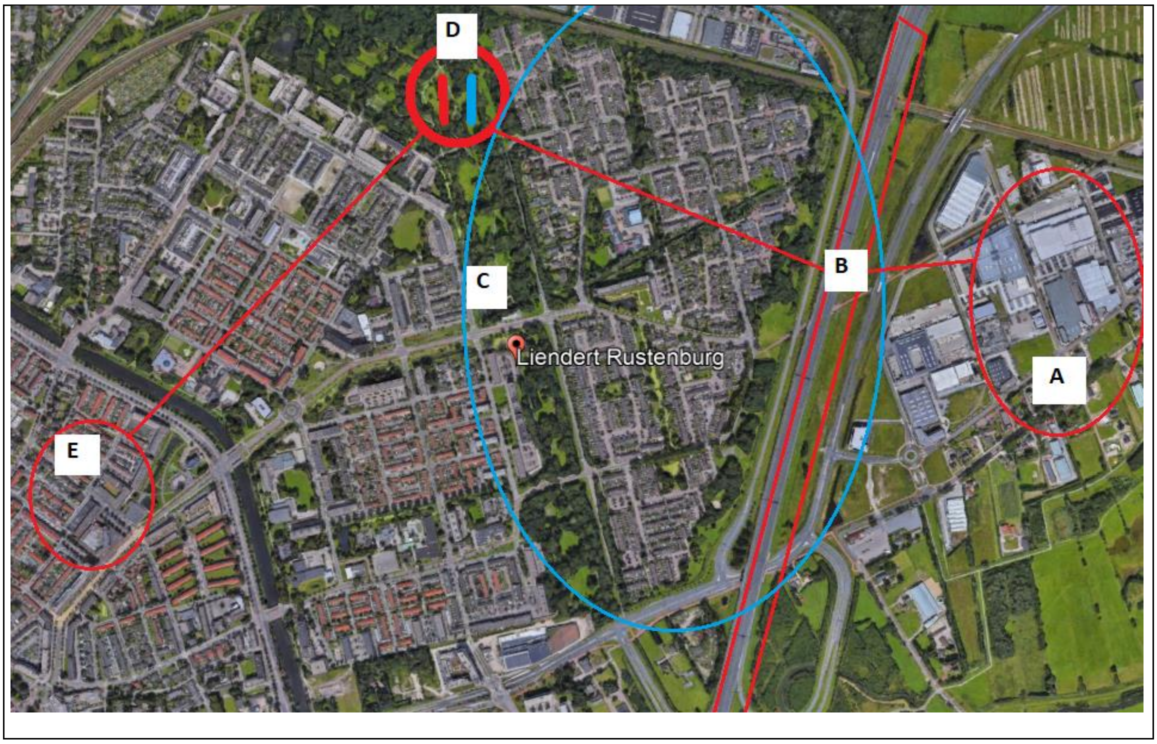

Figure 6. Potentials for a local energy network in an existing environment context Rustenburg Amersfoort.

Heat source A: distribution center for medical supplies, B: an asphalt road, E: 4 supermarkets.

Target C: homes to be heated. D heat storage aquifer

3.1. Store for medicine

A supermarket or a medicine store needs cooling 24/7 to bring the outside temperature down to 4-7°C in the cooling displays or storages. What remains on the other side of the cooling unit is a constant flow of hot air. The following estimates how much heat is released from cooling a medicine storage (A), and how many homes in the area can be heated by this energy:

Rough estimate:

Volume of the space to be cooled:100 x 100 x 6 = 60000 m³. Multiplication factor represents the required number of Watts cooling capacity per m³ content. These are 30,40, or 50 depending on the characteristics of the space. A space which has a very high heat burden or products such as consumables? and medicines, for which a low room temperature is desired have a factor of 50

The required cooling power is then: 60000 m³ x 50 W/ m³ = 3000000 W = 3000 KW = 360x24x3000 = 25.920 MWh.

From the experience of many Dutch projects we know that in a supermarket with a central system with a cooling capacity of 200 kW, 30% of the heat can be used usefully. This means a saving of 216,000 MJ or about 6,800 m^3 natural gas per year **(Bovenkamp, 2017).**

From projects in Denmark: Super Bruges in Høruphav Denmark can provide about 16 standard households of 130 m² annually with their heat needs **(Wouter, 2018).**

Thus: from the 3000 KW power, the gain is 3240 GJ residual thermal energy

Households on average needs 1400 m^3 of gas for heating, hot water and cooking,

That is 49.392 GJ of thermal energy

Number of dwellings = 3240 GJ / 49.392 GJ = 65,59

3.2. Heat from asphalt as a collector of thermal energy

How many estimated numbers of dwellings units (n) that an asphalt road (6 km long x 6 meters width) can heat? The annual thermal gain per square meter of asphalt is 0.75 GJ/ m^2 and 80% of this gain is used for heating:

Dutch household on average needs 1400 $m^3$of natural gas for heating. 1400 m^3 of natural gas is 13.720 kWh = 49,32 GJ thermal energy per unit.

Energy needed for heating (n) units = Energy given from the asphalt area
49,23 GJ . x (n) units = 6000m x 6m x 0,8 x 0.75 GJ/ m^2
Number of dwellings n= 438,75

3.3 The 4 supermarkets

4 supermarkets are situated near each other, each supermarket with a central system with a cooling capacity of 200 kW. This means a saving of 216,000 MJ or about 6,800 m^3 natural gas per year for each one.

Natural gas saved = 6800 m^3 x 4 = 27.200,00 m^3

Number of dwellings = 27.200 m^3 / 1400 m^3 **=19,42**

4. RESULT AND DISCUSSION

Using residual heat in this small neighborhood results in a lower annual gas consumption. This incidentally leads to a reduction of CO_2 emission:

Number of gas-free homes = 523

m^3 natural gas saved = 523 x 1400= 732. 200,00 m^3 per year

CO_2 saved: 523 x 1400 m^3 x 1,78 kg/ m^3 = 1.303,316 kg CO_2 per year

Cost: 0.80 x 732. 200,00 m^3= 585.760,00 euro per year

Comprehensive Energy Network with green houses

Another possibility is to build greenhouses (F in **fig 7**) on the green area. These form a large zone collector and can be connected to and managed by the supermarkets. The advantage of this in addition to the function of an energy source is to shorten transport distance for the green products to the supermarkets.

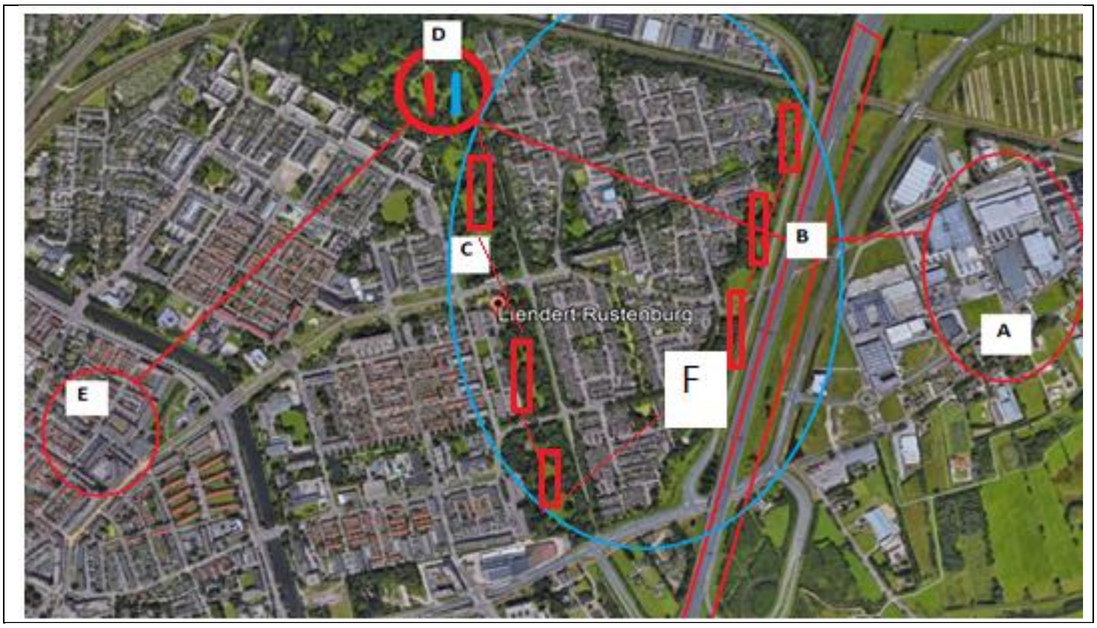

Figure 7. Extensive energy network with greenhouses.

Several papers used in this study provide a standard: 1m² of supermarket heat x m² of dwelling. Waste heat from a supermarket in **(Bovenkamp, 2017)** saves 6800 m^3. If one dwelling utilizes 1400 m^3 gas (Dutch average) this supermarket can heat 5 dwellings, but a good insulated house uses only 900 m^3 then the supermarket can heat more than 7 dwellings. Also, there is a big difference between supermarkets with different areas and different cooling capacity. Let us assume a standard cooled area of 300 m² and a standard dwellings area of 130 m²: If we compare **(Caat, 2017)** with **(Wouter, 2018)** we get the same result (1m² of supermarket can heat 7 m² of dwelling), but from **((Bovenkamp, 2017)** 1m² of supermarket can heat only 2,10 m² of dwelling.

The amount of heat (MJ) extracted from KW cooling capacity can be used instead.

5. CONCLUSIONS

We need more energy, but we destroyed the Earth's ecosystem in order to supply the energy needed for our development. Focusing on the environmental context sustainable design merges the natural, minimum resource conditioning solutions of the built environment and interior design, especially with the innovative technologies of the present **(Hamad, 2020)**

We have the sun that gives us more energy in one day than the need of all humanity for the next 40 years, but that energy is dissipating for nothing. In modern cities, in our industrial age there is heat around us everywhere. In many cases heat is produced as an accidental product in the wrong place and time. This heat causes damage such as the crease of the asphalt layer or create heat island effect.

As cities evolve towards smart cities and the role of the Internet of Things increases, more data centers are needed. For data centers, the continuity of providing a service is essential, this means being a continuous and a stable source of heat. The heat generated by data centers has a relatively constant temperature between 25° C and 33 C°. This low-caloric heat can be effectively increased to a temperature required by the consumer by means of a heat pump. This results in a heating concept which is extremely sustainable and can provide an interesting alternative for existing energy systems, such as gas-powered central heating systems. Smart solutions like use of thermal storage technology and the creation of new thermal networks commensurate with the principle of decentralization of energy centers can transform this untapped and sometimes harmful energy into useful energy that provides many environmental and financial benefits.

REFERENCES

- Al-Bazzaz, R. A. (2018). Similarity and Difference between Sustainable and Green Architecture (a Comparative Study) . *Journal of Engineering*.
- Bakker, v. H. (2006). Warmteopslag onmisbaar voor duurzaam toekomst. 601.
- Bettina Kampman, I. N. (2019). *Restwarmte, de stand van zaken.* Delft: CE Delft. Opgeroepen op May 17, 2020
- Bovenkamp, v. d. (2017). Amersfoort.
- Bovenkamp, v. d. (2017). *Warmte van koelinstallaties in beeld in de warmteatlas en potentiele toepassingen.* Amersfoort: Kiwa.
- Bovenkamp, v. d. (2017). *Warmte van koelinstallaties in beeld in de warmteatlas en potentiele toepassingen.* Amersfoort: KIWA.
- BP Statistical Review of World Energy 2019. (2019). *BP Statistical Review of World Energy 2019.* London: S&B Global Platts. Opgeroepen op May 17, 2020
- Caat, t. (2017). *Towards energetic circularity greenhouse-supermarket-dwelling energy exchange* . Delft .
- Cavillo, S.-M. V. (2016). *Energy management and planning in smart cities.* Madrid: Institute for Research in Technology (IIT) ICAI School of Engineering, Comillas Pontifical University.
- Chen, B. a. (2008). *Harvesting energy from asphalt pavements and reducing the heat island effect.*
- Dincer, R. (2011). INFIRONMENTAL IMPACT OF THERMAL ENERGYSTORAGE. In R. Dinc, *THERMAL ENERGYSTORAGE.* Otawa: A John Wiley and Sons, Ltd., Publication.
- Dobbelsteen, v. d. (2019). *course materials of Delft University of Technology EDX MOOC cours.* Retrieved from Zero-Energy Design: an approach to make your building sustainable MOOC TU Delft.
- European Union. (sd). *European Context*. Opgeroepen op May 17, 2020, van eu-smartcities.eu: https://eu-smartcities.eu/about/european_context
- Gauw, G. S. (2018). *Datacenter Restwarmte& Innovatie.* Netherland.
- Gauw, M., Grove, S., Stuivenwold, E., & Pegtel, W. (2018). *Datacenter Restwarmte & Innovatie 2018.* Amsterdam: Dutch Data Center Association. Opgeroepen op May 17, 2020
- Glück, B. (1999). *Thermische Bauteilaktivierung.* Hamburg: Rud. Otto Meyer-umwelt-stiftung. Opgeroepen op May 17, 2020
- Hamad, M. I. (2020). Developing an Indoor Environment Assessment Tool for Residential Buildings. *Journal of Engineering*.
- IGLUS. (2017, February). *Smart cities MOOC*. Opgeroepen op May 17, 2020, van iglus.org: https://iglus.org/smart-cities-mooc/
- IoT, C. f. (2018). *Driving new modes of IoT CDAIT IoT Thought Leadership Working Group.* USA Georgia: Geogia institute of tecnology Atlanta .

- Jeff Tsao, N. L. (2005). *Solar FAQs.* U.S. Department of Energy, Office of Basic Energy Science, California Institute of Technology, Argonne National Laborator. Opgeroepen op May 17, 2020
- Jellema. (1993). *Bouwkunde 7a.* Leiden: Waltman.
- Jones, P. D. (1990). Assessment of Urbanization Effects in Time Series of Surface Air Temperature Over Land. . *Nature*, Volume 347, No. 6289.
- Mallick, R. B. (2009). *Harvesting energy from asphalt pavements and reducing the heat island effect.*
- Olesen, D. (2005). *Verwarming Ventilate.* Deventer: Uneto VNI. Opgeroepen op May 17, 2020
- Schmitz. (2006). Betonkernactivering versus betonoppervlakte- activering. *verwarming ventilatie*, 147.
- Science for Environment Policy - European Commission. (2007). *Buildings and Climate Change: Current Status, Challenges and Opportunities.* European Commission DG Env.
- Tenpierik. (2005). *Vacuum Insulation Panels Applied in Buildings Component. Delft University of Technology.* Switzerland: Annex 39.
- Unica Energy Solutions. (2018). *Reusing Residual Heat from Data Centers.* Hoevelaken: Unica Energy Solutions. Opgeroepen op May 17, 2020
- United Nations. (2014, July 10). *World's population increasingly urban with more than half living in urban areas*. Opgeroepen op May 17, 2020, van UN.org: https://www.un.org/development/desa/en/news/population/world-urbanization-prospects.html
- Vandekerckhove, L. (2006-2007). *Energiezuinig bouwen en verbouwen.* Opgeroepen op May 17, 2020
- Wemmers. (2006). Thermochemische opslag bij kamrtemperatuur. *verwarming ventilatie*, 882.
- Wouter, N. (2018). *Module Restwarmte Basisinzichten & tools voor de identificatie en kwalificatie van industriële restwarmte Opleidingsmodule Restwarmte* . Nederland.

Figure list