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Independent Thermal Network Through Thermal Synergy Between Four Architectural Units

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ABSTRACT

The manifestations of climate change are increasing with the days: sudden rains and floods, lakes that evaporate, rivers that experience unprecedentedly low water levels, and successive droughts such as the Tigris, Euphrates, Rhine, and Lape rivers. At the same time, energy consumption is increasing, and there is no way to stop the warming of the Earth's atmosphere despite the many conferences and growing interest in environmental problems. An aspect that has not received sufficient attention is the tremendous heat produced by human activities. This work links four elements in the built environment that are known for their high energy consumption *(houses, supermarkets, greenhouses, and asphalt roads)* according to what is known as the energy synergy to share them within a thermal network independent of the national network. This research concluded that an asphalt road with a length of 6 km is sufficient to heat more than 800 homes, in addition to valuable benefits accrued by hot countries, such as maintaining the quality of the asphalt layer, prolonging its life, and reducing traffic accidents. The supermarket, which needs cooling every day of the year, can meet its energy needs for cooling in the winter by heating the Greenhouse, while the heat flux is stored for each of the greenhouses and the supermarkets for the rest of the year in the thermal tank (TESS).

Keywords: Residual Heating, Smart City, Energetic Programming, Sustainable Building. Energy Circularity.

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إستخدام الحرارة الزائدة لتكوين شبكة حرارية مستقلة بين أربعة عناصر معمارية

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الخلاصة

تتزايد مظاهر تغير المناخ مع الأيام: الأمطار والفيضانات المفاجئة ، وموجات الجفاف المتتالي، والبحيرات التي تتبخر، والأنهار التي تعاني من انخفاض غير مسبوق في منسوب المياه ، مثل دجلة والفرات والراين ولاب. في الوقت نفسه ، يتزايد استهلاك الطاقة، ولا توجد طريقة لوقف ارتفاع درجة حرارة الغلاف الجوي للأرض على الرغم من المؤتمرات العديدة والاهتمام المتزايد بالمشكلات البيئية. أحد الجوانب التي لم تحظ باهتمام كافٍ هي الحرارة الهائلة التي تنتجها الأنشطة البشرية. يربط هذا البحث بين أربعة عناصر في البيئة المبنية معروفة باستهلاكها العالي للطاقة (المنازل والسوبر ماركت والدفيئة والطرق الإسفلتية) وفقًا لما يعرف بتآزر الطاقة لمشاركتها مع بعضها البعض ضمن شبكة حرارية مستقلة تستغل الحرارة الزائدة. وخلص هذا البحث إلى أن طريق إسفلتي بطول 6 كيلومترات يكفي لتدفئة أكثر من 500 منزل بنفس المواصفات المذكورة سابقاً ، بالإضافة إلى الفوائد القيمة التي تعود على الدول الساخنة ، خاصةً مثل الحفاظ على جودة الطبقة الإسفلتية وإطالة أمدها. عمرها الافتراضي وتقليل الحوادث المرورية. يمكن للسوبر ماركت ، الذي يحتاج للتبريد كل يوم من أيام السنة ، تلبية احتياجاته من الطاقة للتبريد في الشتاء عن طريق تسخين الدفيئة ، بينما يتم تخزين التدفق الحراري لكل من الدفيئة والسوبر ماركت لبقية العام في الخزن الحراري (TESS).

الكلمات الرئيسية: التدفئة بالحرارة الزائدة، المدينة الذكية ، برمجة الطاقة ، البناء المستدام. تدوير الطاقة.

1. INTRODUCTION

The percentage of energy spent in buildings for heating purposes ranges from 50 to 75%, while the rest is distributed to electrical appliances and lighting **(Van de Kerckhove, 2019)**. **(Rizwan et al., 2008; Harvey, 2011)** pointed out that urban construction increase temperatures above the surrounding rural and suburban areas. Also, satellites for infrared and thermal activities have shown that pavements are strong heat radiation sources **(Gorsevski et al., 1998).** Though new technologies are continuously developing to accompanist existing current in making green buildings, the common goal is that greener structures are designed to diminish the total effect by: first, efficiently using energy and water, second: protecting inhabitant health and improving worker output, and third: decreasing waste, contamination and ecological dilapidation **(Kamas et al., 2019).** According to Stephen Hawking, if 100 bases are taken for the consumption of electrical energy in 1900, the current consumption is 1300, meaning that the amount of electrical energy consumed has doubled during the one century more than thirteen times. Continuous population increase will turn the globe, due to the heat produced on its surface,

into a red ball **(Hawking, 2001).** The other side of efficient use of energy is not studied enough: that is less heat production. Existing heat networks work with high-calorific heat: Temperatures around 900°C are used to heat buildings to 200°C, while modern facilities, based on low-temperature underfloor heating, succeed with incoming temperatures of 30-40 °C and passive houses can even work at 25°C - 30 °C **(Kristinsson, 2012).** Waste heat remains in the city and results in heat islands. In a small country such as the Netherlands, approximately 100 PJ of residual heat is estimated to be suitable for useful and sustainable reuse. Reusing 100 PJ of excess heat will decrease energy demand from gas plants and hence lead to a reduction of approximately CO_2 emissions by 3.6 M tons **(Kampman, 2019).** From the experience of many known Dutch projects in a supermarket with a central cooling system with a capacity of 200 kW, 30% of the heat can be used with benefits. This means saving 216,000 MJ or about 6,800 m^3 of natural gas annually **(Bovenkamp, 2018).** From projects in Denmark: Super Bruges in Høruphav, Denmark, can provide about 16 standard households of 130 m^2 annually with their heat needs **(Wouter, 2018).**
This research aims to create local networks by reusing residual thermal energy to fulfill human needs, reducing energy production and CO_2 emissions that eliminate environmental pollution.

2. RESEARCH METHODOLOGY

The Design-Builder simulation software is used in this work to simulate the energy flow in the supermarket and the Greenhouse. Also, it is used to control the performance of elements and functions in the selected houses and during upgrading to make them suitable for temperature and heat. The software tool simulates models for heating, cooling, lighting, ventilation, and other energy flows. The computational method is used to analyze the asphalt layer thermally, then to thermally support the supermarket simulation. **Fig. 1** shows the method used in this work.

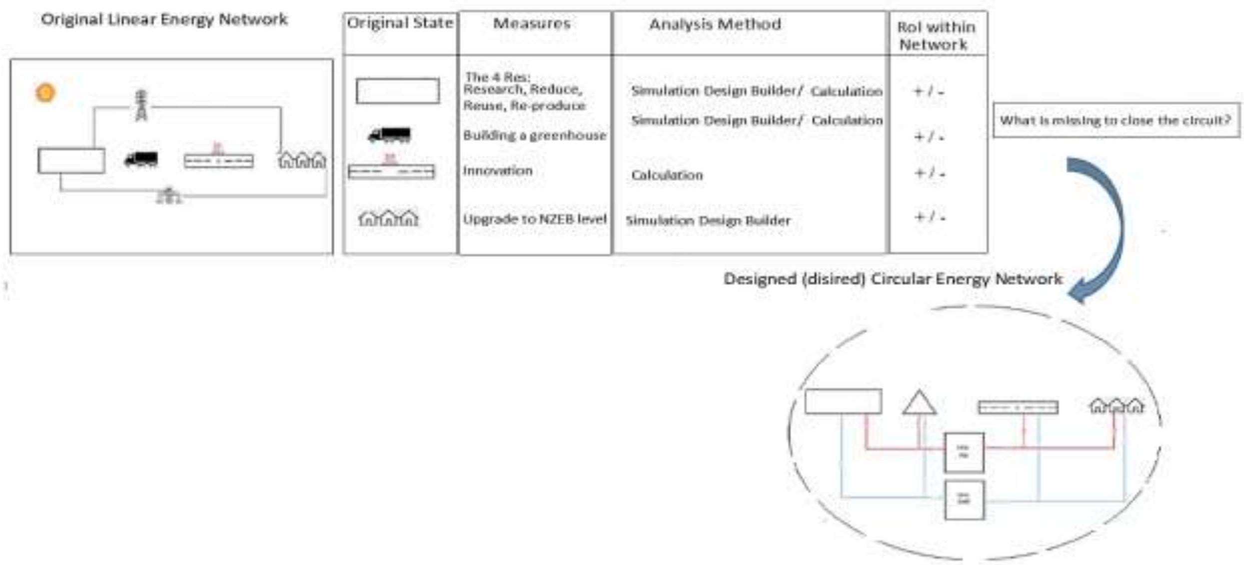

Figure 1. The method used in this work

3. RESIDUAL THERMAL ENERGY SOURCES

3.1 Primary Energy Factors PEF

Approximately 100 PJ of residual heat in the Netherlands is estimated to be suitable for useful and sustainable reuse. Reusing 100 PJ of excess heat will decrease energy demand from gas plants and hence lead to a reduction in CO_2 emission by 3.6 M tons **(Kampman, 2019).** Heat engines can convert thermal energy into mechanical energy with a conversion efficiency of up to 60%. Chemical energy can be directly converted into electricity using a fuel cell. The most common fuel used in fuel cell technology is hydrogen. The typical conversion efficiencies of fuel cells are 60%. The chemical energy stored in fossil fuels is converted to usable energy via heat by burning, with an efficiency of about 90%. Unutilized waste heat remains in the air and results in heat islands. One example of heat loss is shown in **Fig. 2**, a series of heat losses between the energy production and consumption stage. All this heat escapes to the surrounding space.

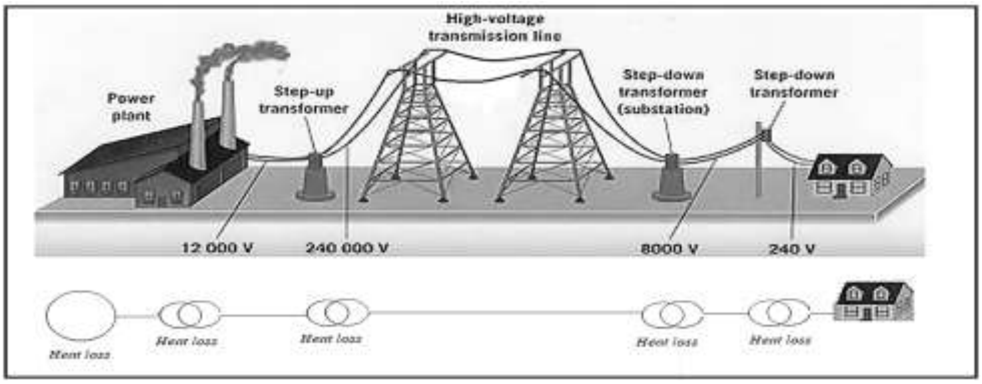

Figure 2. Energy losses

3.2. Flexible Energy Grid

Heat grids waste a lot of energy because they work with high-caloric heat. Based on low-temperature floor heating, modern buildings can be heated with an incoming temperature of 30-40°C, whereas passive houses can even function with a temperature of 25-30°C. Besides, in our way to a world of sustainable energy, there is a need for a flexible energy grid that can tune, exchange, and cascade heat through different scales, as illustrated in **Fig. 3**.

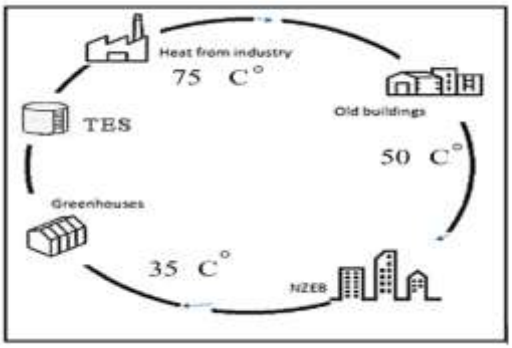

Figure 3. Energy cascade

(Dobbelsteen, 2019) mentioned that the local exchange of (low-caloric) heat within buildings and between buildings within an urban neighborhood or district is not very common. Nevertheless, this strategy has great potential.

3.3. Disadvantage High-Temperature Asphalt Pavement

3.3.1. Urban Heat Island (UHI)

(Rizwan et al., 2008; Li and Harvey, 2011) pointed out that urban construction increases temperatures above the surrounding rural and suburban areas. Also, satellites for infrared and thermal activities have shown that pavements are strong heat radiation sources **(Gorsevski et al., 1998).** Solar radiation is absorbed in heat through the pavement's surface, then through the subsurface, and finally into the lower pavement layers. In the European context, currently, 78% of Europe's population lives in cities, and 85% of the EU's GDP is generated in cities. (European Union, sd)**.** Modern cities are huge, compact masses of heat-absorbing materials such as buildings and roads. Solar radiation increases environmental temperatures, and residual heat passes into surfaces, indirectly impacting the environment **(Rizwan et al., 2008; Filho et al., 2017).**

External surfaces of buildings, like walls and roofs, are always exposed to the atmosphere. During sunrise, buildings and roads absorb a lot of heat energy and store it inside. After sunset, this heat returns in a radiant form to collect in the upper atmosphere of the city. Radiation is the heat transfer from a body under its temperature; it increases as the body's temperature increases. It does not require any material medium for propagation. The amount of absorbed solar energy transferred as heat inside a material's body depends on the material's conductivity. Later, this heat is released to the surrounding area as infrared waves through emission **(Aletba et al., 2020).** UHIs are one of the major challenges currently faced by humans as a result of industrial urban development. It results from artificial and climatic factors **(Maria et al., 2013).**

3.3.2. Deformation of Asphalt Road Pavement

The amount of solar radiation daily absorbed by Asphalt Concrete (AC) road surfaces is up to 40 MJ/m^2 over summer days. The heat absorbed and transmitted by incident sun rays in hot countries distorts and ripples the asphalt layer. The total energy that leaves the body per unit area shown in **Fig. 4** is known as Radiosity J (W/m^2); it is evaluated as:

$$J=\varepsilon E_b+\rho G \quad (1)$$

The various optical body properties are related such as **(Kalogirou, 2014):**

$$\alpha+\rho+\tau=1 \quad (2)$$

The opaque body absorbed energy due to the incident solar radiation such that **(Duffie and Beckman, 2013):**

$$Q=G\,\alpha \quad (3)$$

where
G is the incident solar radiation (W/m^2),
ε is the emissivity of the surface
E_b is the energy from a Black body (perfect absorber),
ρ is the reflectivity of the surface,
α is the absorptivity of the surface,
τ is the transmissivity of the surface,

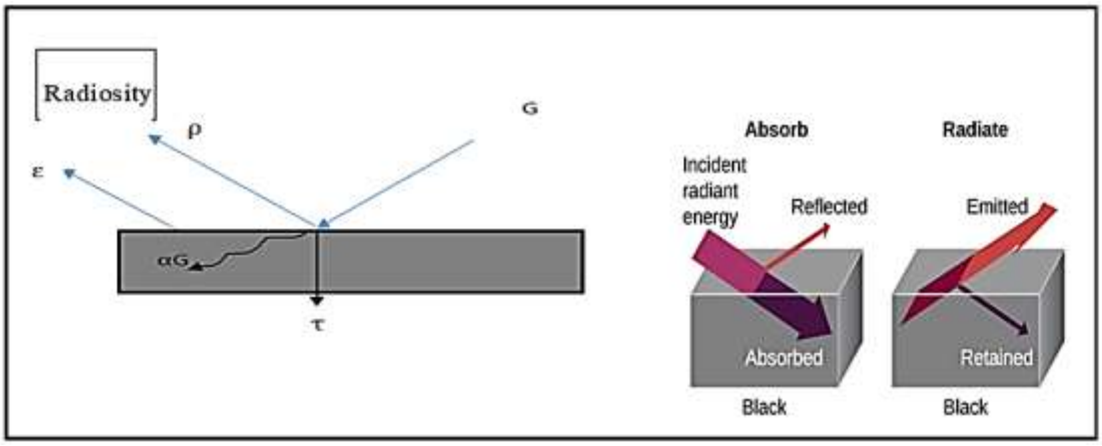

Figure 4. Energy balance asphalt pavement

3.4. Advantages of Harvesting Heat Energy From Asphalt

Harvesting heat from asphalt pavements reduces the pavement's temperature and prevents deformation. This action also reduces the radiated heat from the road surface to the atmosphere (urban heat island). The harvesting process can be accomplished by water flows in a road piping system. The hot water in winter can heat the covered area, thus keeping the road free of snow and frost .This approach leads to a reduction in traffic jams as well as the reduction in traffic accidents due to vehicle skidding.

4. CASE STUDY: LOCAL INDEPENDENT THERMAL ENERGY NETWORK

4.1 Description

The case study for this research is different architectural elements that are part of a residential neighborhood. These components (a supermarket, a 6 km asphalt road, and 400 various types of dwellings) are independently connected to the national electric and thermal power grid. Supermarkets and homes are major consumers of fossil energy, and a large emission of CO_2 accompanies this. A supermarket needs cooling 24/7 to bring the outside temperature to 4-7°C in the cooling displays or storage. A constant hot air flow is on the cooling unit's other side. A fourth component greenhouse is added to reduce the footprint due to the truck, which transports the fruit and vegetables twice a week (total distance of 100 km/week). Traditional greenhouses are also major consumers of fossil energy. Heat absorbed by asphalt contributes to the development of heat islands. The heat deforms asphalt layers and thus reduces the lifespan. The 400 dwellings consume 9.651,74 GJ /year.

4.1.1. Current State of the Neighborhood

It is concerned with the following.

a- The supermarket, with the energy specifications given in **Fig. 5 (Van der Hoeven, 2010)**

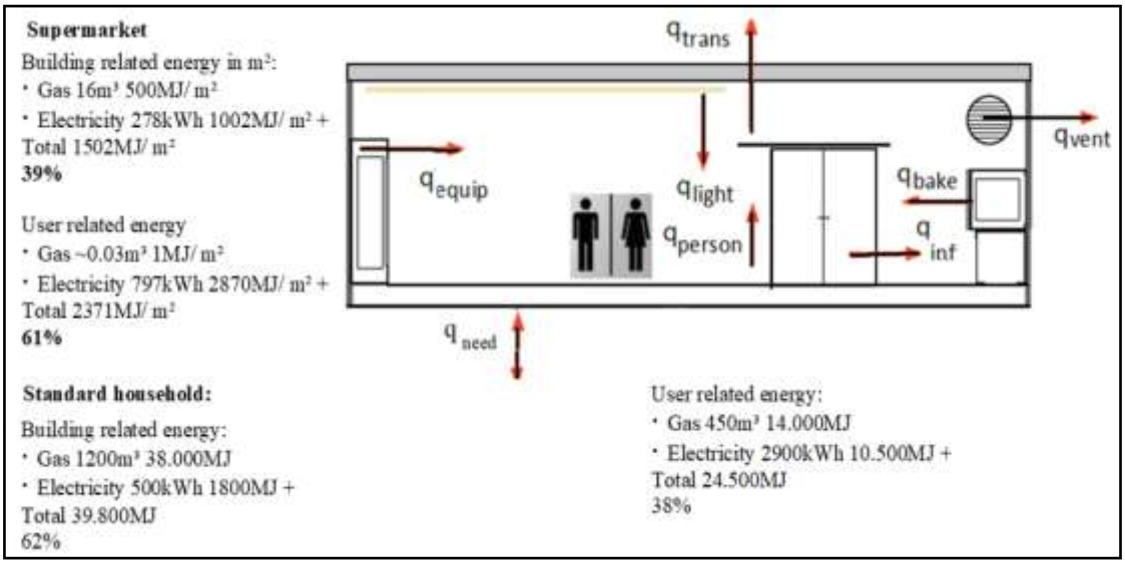

Figure 5. The energy flows in the supermarket

b- Truck
The truck transports fruit and vegetables twice a week, a total distance of 100 km/week, and consumes fuel of 40 Liter of benzene per week or 4 weeks *40 liter/week*12 months = 1920 liter/year. So the annual energy in GJ is:
1920 *33 = 63,360 GJ
in which each liter has 33 MJ

c- Asphalt layer
6 km long, 6 m wide asphalt road, asphalt thickness 0,15 m absorbs 0.75 GJ/year, 600 Watts/m^2 from the incident solar radiation on average. Heat Island's contribution is:
6000*6*0.75 = 21.600 GJ

d- 400 Dwellings

d-1 250 Terraced Houses: Total consumption 250 dwellings = 5.065,74 GJ
d-2 50 Corner house: Total consumption 50 dwellings = 1.142 GJ
d-3 60 Semidetached houses: Total consumption 60 dwellings = 1.808 GJ
d-4 40 Detached houses: Total consumption 40 dwellings = 1.636 GJ
All of the 400 dwellings consume: 5.065,74+1.142 +1.808+1.636 = 9.651,74 GJ

4.2. Dynamic Simulation

The goal of dynamic building simulation here is to balance the expected performance at the building level, i.e., in terms of energy demand and energy production utilization. Energy Plus is a thermal simulation software that allows energy analysis throughout the building and the thermal load.

4.2.1 Analysis of Energy Flows in the Supermarket

The detailed building-related energy in the supermarket is shown in **Fig. 5**. The energy parameters used in the simulation of energy in the supermarket are presented in **Fig. 6**.

The Greenhouse is more times simulated with the parameters:

Dimensions are the same like the supermarket

Interior climate: In accordance with the production requirements, the margin for temperature was set between 15.°C-26.5°C, the indoor Relative Humidity is set on 69%-75%

HVAC: The HVAC system is Fan coil unit - 4pipe - air cooled chiller) is considered to be responsible for heating, cooling and (de)humidifying to unify the results.

Ventilation: Natural ventilation is turned off in the simulation.

Auxiliary energy is set on 0.75 W/m² (On 24/7). This results in a total electricity demand of ~5500kWh/year.

Wall : The outer wall of the greenhouse are represented by 200 mm thick concrete walls. Walls are glazed for 90% (horizontal strip). The remaining 10% resembles the facade structure that would be present in the actual greenhouse.

Roof : The roof is simulated by a 120 mm thick sandwich panel. The roof is then glazed for 100%. However, horizontal and vertical dividers are manually added to the roof surface to resemble actual roof structure.

Floor: in the model is resembled by a 150 mm

Openings: All openings in the greenhouse walls and roof are glazed with:

Simulation 1, I 5,8 W/m².k and 3,8 W/m².K

Simulation 2, II: HR double glazing (Dbl LoE Spec Sel Clr 6mm/13mm Arg U=1,338 W/m².k)

Simulation 3, III triple glass Lo E, clear, U=0,78 W/m².K

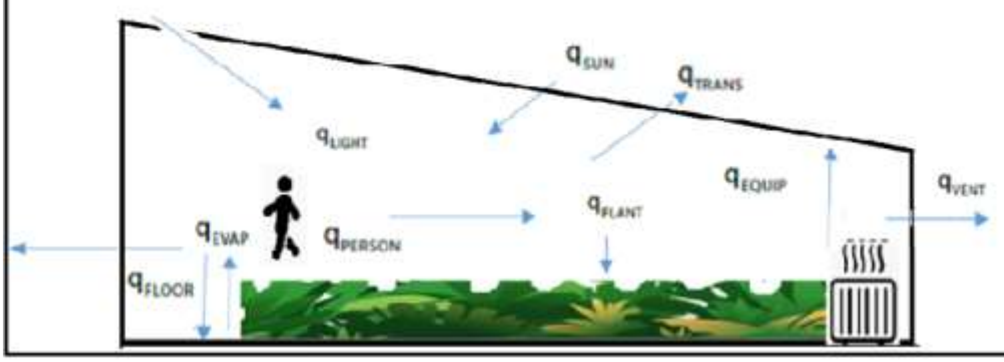

Figure 6. The energy parameters used in the simulation of energy in the supermarket

The simulations run in Design Builder are based on the supermarket with dimensions: 46 m x 15.4 m X 2.9 m. Thermal resistance (R): floor= 4 m^2.K/ W , wall=3,974 m^2.K/ W, roof= 5.88 m^2.K/W; RH 69% - 75%; Equipment: 2-3 ovens; Ventilation: mechanical. The simulation result is shown in **Fig. 7**.

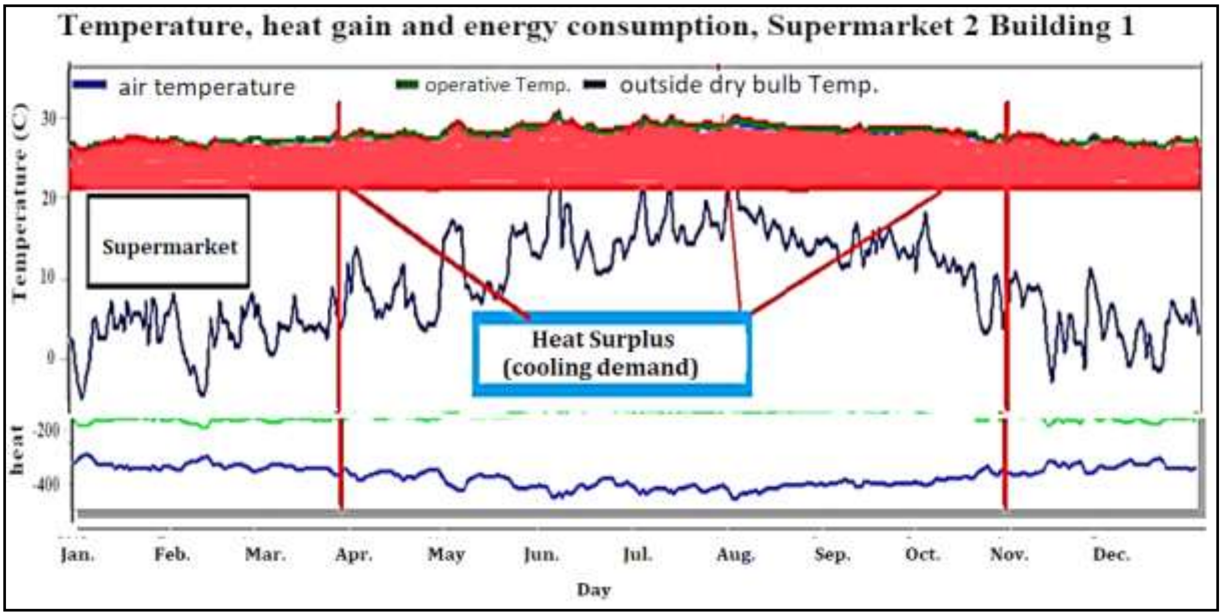

Figure 7. Simulation of monthly temperature in the supermarket, heat surplus over all days of the year

The simulation of energy fluxes in the supermarket shows that the supermarket (at a temperature around 21°C) requires constant cooling due to the large internal heat gains. Even in January, the temperature rises above 26 °C when the outside temperature is 5-10 °C. The season, internal activity, and customer presence affect the cooling or heating demand.

4.2.2. Analysis of Energy Flows in the Greenhouse

A truck transports fruit and vegetables to the supermarket from a greenhouse that is 25 km away from it. The emissions of a product truck are 112 grams of CO_2 per kilometer. It has been assumed that the truck will cover a distance of 25 km 4 times a week. Per special features of Greenhouse, **(Kristinsson, 2012)** confirmed that about 7 times more solar heat enters the Greenhouse than leaves it due to transmission losses through improved heat storage and exchange technology. It is now possible to use the excess heat that greenhouses have in summer records compared to the rest of the year for other functions to make available. The Greenhouse is, therefore, considered as an energy producer. As a result, there is also a diversification in products. The net heat surplus from greenhouses used for external functions is 3,000,000 MJ per hectare greenhouse **(Van Oosten, 2020).** **(Kristinsson, 2012)** designed closed Greenhouse with a double polycarbonate zig-zag glazing developed by General Electric Bergen op Zoom with a heat transfer of 3.5 W/m^2.K. The set point temperature in winter is 19 °C when the temperature outside is -11 ^{o}C (Δ t = 30 °C), and the Greenhouse should be heated with 30 x 3.5 = 105W/m^2. **Fig. 8** shows that the maximum temperature reaches 57 °C when triple glass is used, which is 30 °C above the desired temperature in the Greenhouse.

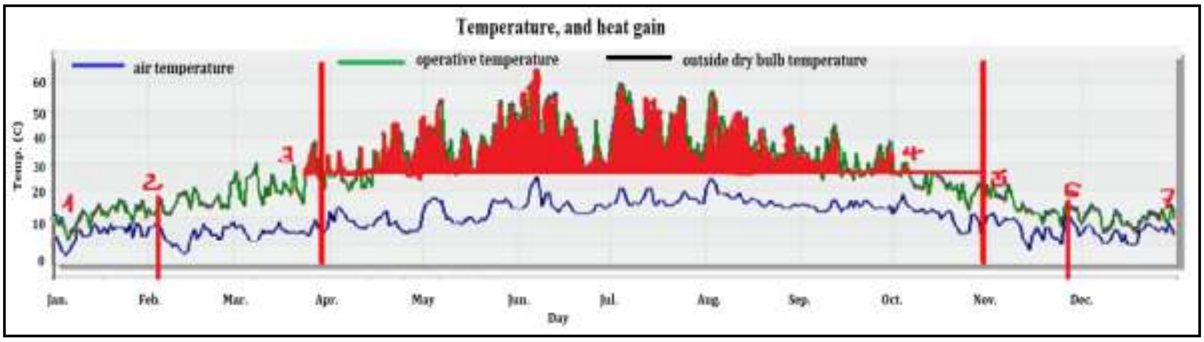

Figure 8. Simulation of heating surplus in the Greenhouse from April until mid-October

4.2.3. Analysis of Energy Flows in the Asphalt Pavement

Dark surfaces absorb heat and do not reflect them much, so they heat up. Much of the thermal energy falling from the sun on a dark surface, such as asphalt, will be absorbed during the day and emitted toward the sky. The dark surfaces of asphalt pavements incessantly absorb the heat from sunrise until late afternoon (before sunset) **(Rizwan et al., 2008).** The amount of energy that can be harvested from pavements depends on the amount of solar radiation, the total area of the pavement, efficiency of the pavement-heat exchanger system in transmitting the heat from the pavement to the fluid inside the system of pipes. The amount of heat energy radiating from the asphalt (shown in **Fig. 9**) to the atmosphere is determined by the difference in the temperature between the pavement surface and the air, according to:

$$q_r = \varepsilon\sigma\,(T_s^4 - T_{air}^4) \qquad (4)$$

where
q_r is the emitted radiation (W/m^2),
σ is Stefan-Boltzmann constant = 5.68x10^{-8} W/(m^2·K^4);
T_s is the surface temperature (K),
T_{air} is air temperature (K),
The emissivity of a body is defined as the ratio of the energy emitted by a real body to the energy emitted by a black body. The emissivity for Asphalt pavements is considered 0.9. The annual thermal gain per square meter of asphalt thickness 0.15 m is 0.75 GJ/ m^2, and 80% is used for heating **(Solaimanian et al., 1990)**

4.2.4 Analysis of Energy Flows in the Dwellings

To reduce energy demand within the summer season, the waste heat can be used to reach the required interior temperature in the houses, as shown in **Fig. 10**. Research; Reduce; Reuse (waste material, waste heat, wastewater); Re-produce (from the kinetic and electromagnetic energy electricity and thermal energy) is used.

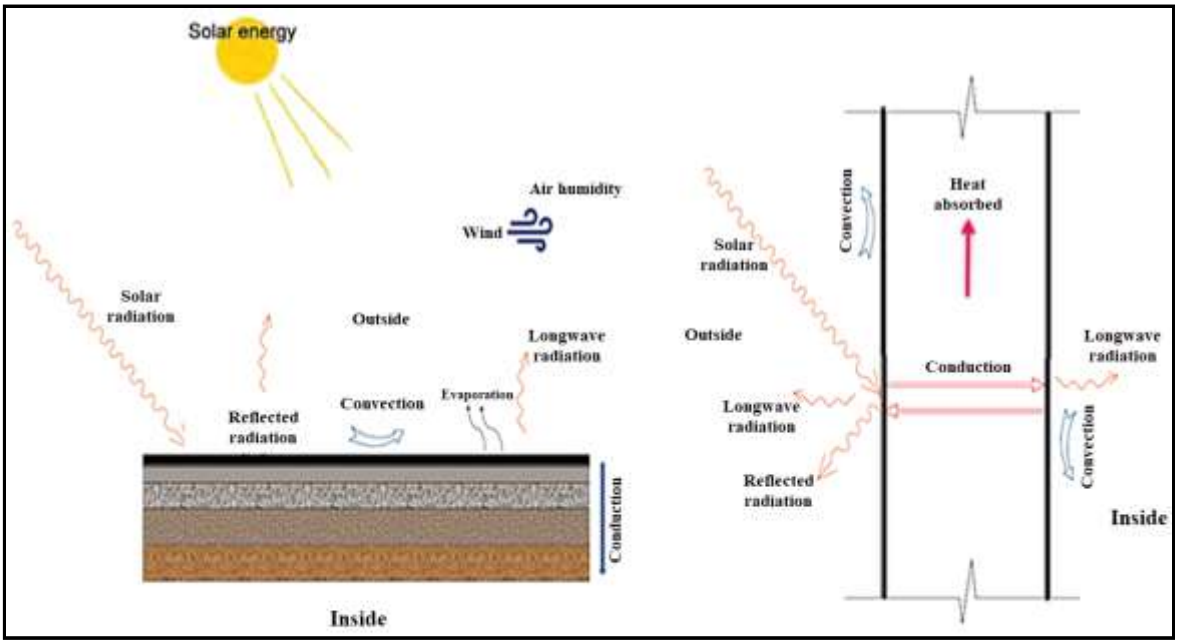

Figure 9. Heat transfer processes in the asphalt pavement and wall

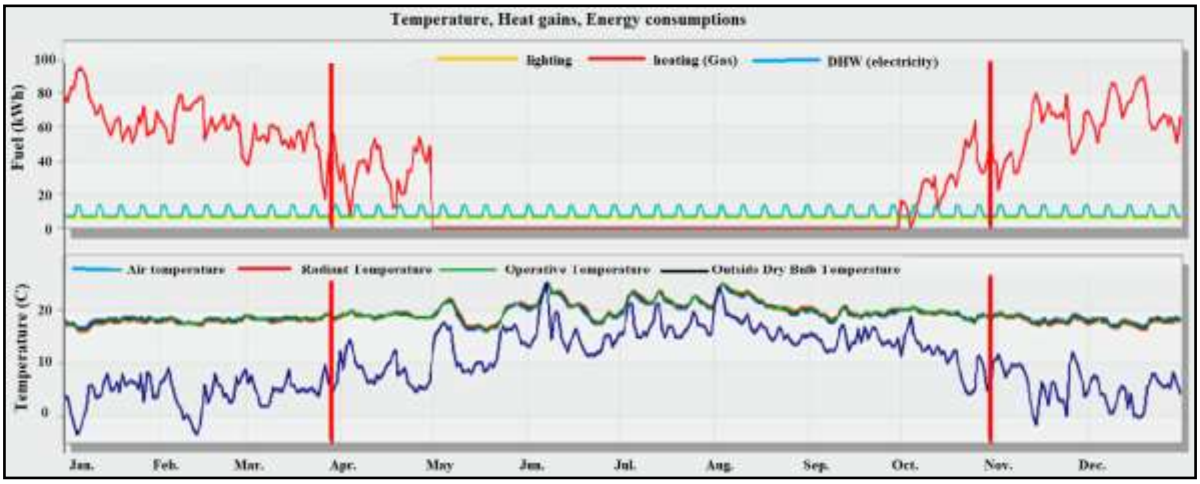

Figure 10. The stable temperature in the houses

5. ROLE OF 4-PARTNERS WITHIN THE THERMAL ENERGY EXCHANGE NETWORK

After the simulation of each of the 3 energy network partners: the supermarket, the Greenhouse, and the 400 dwellings, and the calculation of energy flows in the asphalt pavement, we now look at the position of each of them within the desired network. Which of the 4 is an *energy producer* in winter and summer? We will connect each participant initially to the thermal energy storage TESS.

5.1 The Supermarket

The simulation of energy fluxes in the supermarket shows that the supermarket (at a temperature that revolves around 21°C) requires constant cooling due to the large internal heat gains. Even in January, the temperature rises above 26 °C. Thus there is a cooling demand 24/7, every day of the year. The season, internal activity, and customer presence strongly affect this cooling demand.

5.2 The Greenhouse

The greenhouse indoor temperature is maintained between 18.5 °C and 26.5°C. The Greenhouse requires a lot of heating from 15 October to 15 April to remain above 18.5°C. That depends on the type of glass, insulation, and degree of ventilation. The Greenhouse produces a lot of thermal energy for the rest of the year.

5.3 The Asphalt Layer

The asphalt layer in the summer months and some weeks of the spring and autumn months absorbs huge amounts of the sun's heat, which makes it qualified to be a third source of thermal energy besides the supermarket and the Greenhouse. In this network in the winter, the asphalt is a costumer of energy.

5.4 The 400 Dwellings

The dwellings need heat energy from 15 October to 15 April. They are adapted to reach the level of Nearly Zero Energy Building (according to the Netherlands standard) to reduce their thermal demand. This measure is necessary to benefit these homes from low-temperature energy sources.

5.5 Closing the Circuit with ATES Systems

To close the circuit, we need a central element that combines the 4 units of the thermal network and organizes the processes of supplying it with heat or cold according to the season and need. This element is ATES. In ATES systems, two cold and warm wells are drilled. In summer, groundwater is extracted from the cold well. It passes through a heat exchanger to cool a building. The heat from the building is transferred to the groundwater, which is then injected into the warm well. In winter, the reverse happens: warm water from the warm well is extracted to heat the building. A heat pump is required to increase the temperature of the stored water, usually with a maximum temperature of 25 degrees.

5.6 Energy Exchange between the Supermarket and the Greenhouse

The cooling energy demand of the supermarket is strongly affected by: the season, internal activity, and number of customers. The cooling of the supermarket and heating of the Greenhouse can support each other through energy exchange. It can be achieved by activating the moment the indoor temperature of the greenhouse drops below 21°C. As a result, the greenhouse benefits from the heat surplus of the supermarket, and the supermarket benefits from the heat demand of the Greenhouse. **Fig. 11** shows that the first four months allow the possibility of thermal cooperation between the Greenhouse and the supermarket, where there is a heat surplus compared to a heat shortage in the Greenhouse.

In the following four months, April, May, June, and July, there is a high heat flux in the Greenhouse. Another high heat flux is added in the supermarket for July and August. This amount of heat can be stored for the next season. The thermal behavior of the first four months is repeated in the last three months, where direct heat exchange between the supermarket and Greenhouse is possible. In the coldest month, January, the supermarket has a cooling demand of just 2.4 MWh. All the demand is therefore covered by retrieving the cold energy from the Greenhouse, which has a heating demand of about 12 MWh. The direct heat exchange between the supermarket and the Greenhouse is shown in **Fig. 12.** The pre-processing based on the simulation results shows that 1/2 of the cooling demand of the supermarket can be achieved by direct energy exchange with the Greenhouse.

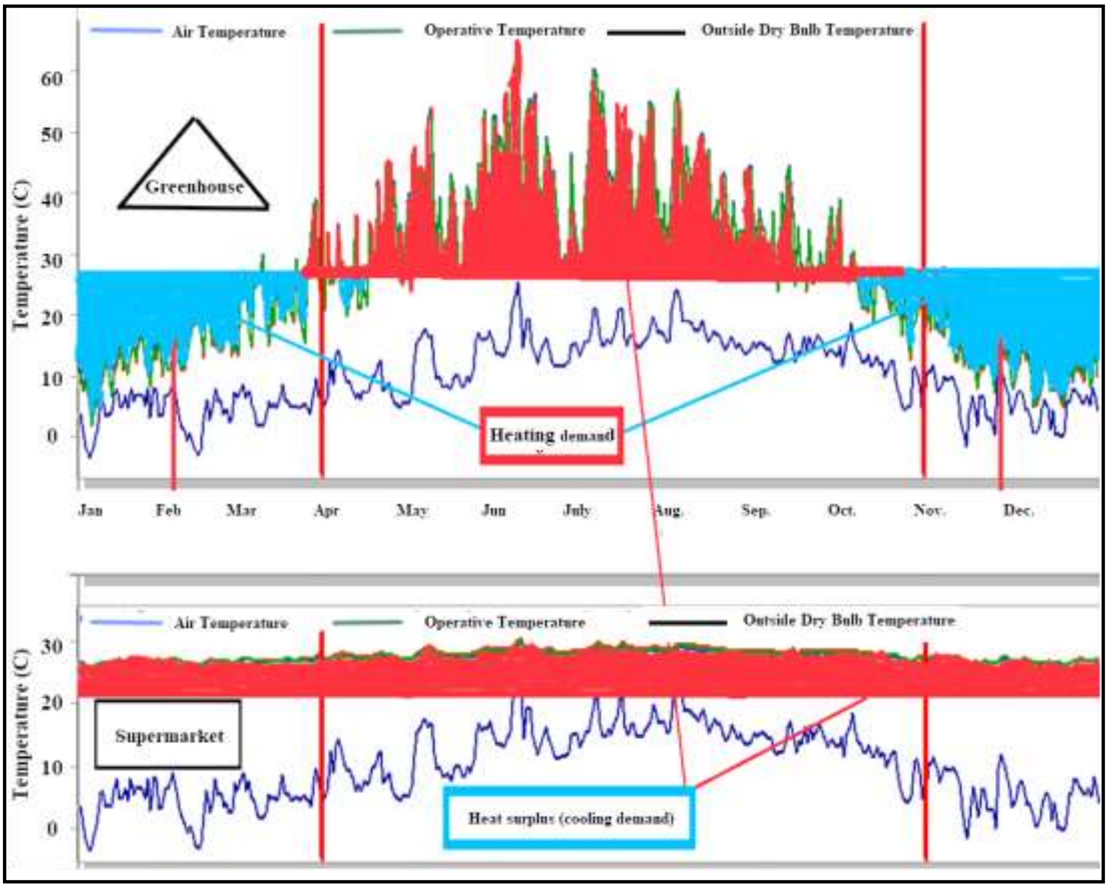

Figure 11. Energy exchange between the Greenhouse and the supermarket

5.7 Energy Exchange between the 6 km Asphalt Road + 400 Dwellings

The number of dwelling units (n) that can be heated by an asphalt road (6 km long x 6 meters wide) can be estimated. The annual thermal gain per square meter of asphalt is 0.75 GJ/ m^2, and 80% of this gain is used for heating.

If a household needs, on average, 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.

The energy required for heating (n) units is the same energy given from the asphalt area

49,23 GJ. x (n) units = 6000m x 6m * 0.8 * 0.75 GJ/ m^2

Number of dwellings n= 438**,** 75 unit

Fig. 13. shows the heat exchange between the 6 km asphalt road and the 400 dwellings in winter and summer.

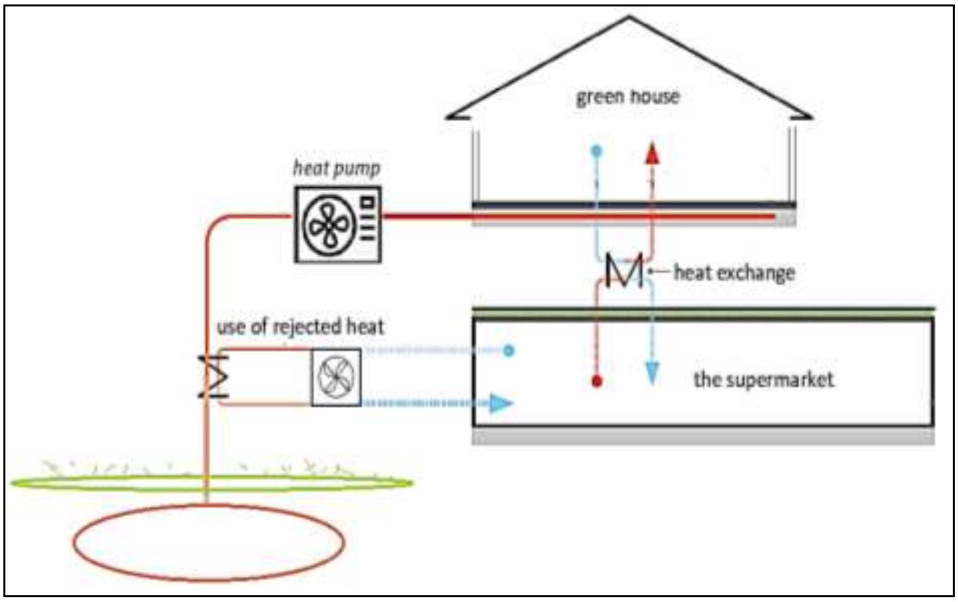

Figure 12. Heat exchange between the supermarket and the Greenhouse

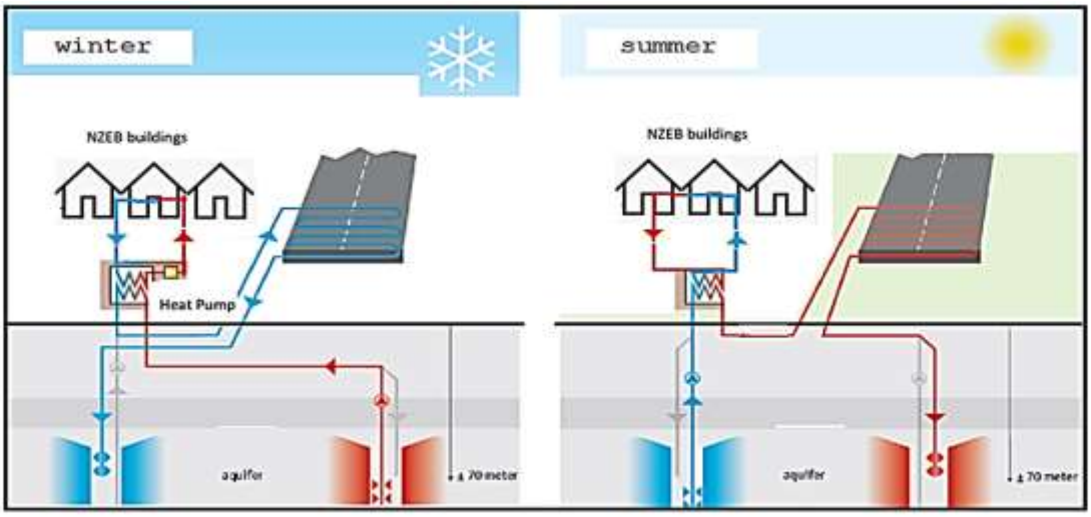

Figure 13. Heat exchange between the 6 km asphalt road and the 400 dwellings

6. THE BENEFITS OF THE ADOPTED SCHEME

The indicated benefit of combined asphalte dwelling is presented in **Table 1.** While the data given in **Table 2** is related to the combination of the supermarket greenhouse.

Table 1. The benefits of the adopted scheme of the combination Asphalt- Dwellings

Measured Profit	**Unit**	**Value**
Saving in thermal energy	GJ	13.903
Saving on natural gas	m^3	394.075
CO_2 saved: Kilo CO_2 per year	kg	701.455
Indirect Profit		
Extend the life of the asphalt layer.		
Reducing the possibility of deformation in the asphalt layer		
Reducing the possibility of traffic accidents on the roads due to freezing on the asphalt layer in winter		
Contribute to reducing the intensity of traffic congestion due to freezing on the asphalt layer in winter.		
Reduce dependence on a centralized power grid.		

Table 2. The benefits of the adopted scheme of the supermarket greenhouse

Measured Profit	**Unit**	**Value**
Thermal energy exchange "cooling."	GJ	6392
Thermal energy exchange "heating."	GJ	6392
CO_2 saved per year	kg	5376
Indirect Profit		
Reduces chances of the existence of heat island effects		
Cancellation of truck necessary for export fruit and vegetables to supermarket		
Reduce dependence on a centralized power grid		

7. CONCLUSIONS

Projects to exploit heat waste from industry, hospitals, and markets for heating have been successfully implemented in many countries inside and outside Europe. These projects remain selective and depend on the existence of special buildings such as a hospital, factory, or data center. Not every neighborhood has a hospital, factory, or data center; in every neighborhood, there are asphalted streets, residential houses, and supermarkets. Four partners are connected in this research: A greenhouse; 400 residential buildings, year-round climatized by low-temperature heating; A supermarket with a year-round cooling demand; 6 km Asphalt pavement. These four functions together form the rectangle representing the independent thermal energy system established in this research.
This solution can be applied in all countries as long as it can be applied in Europe with little solar power. Implementing this approach ensures every neighborhood can take the energy it needs, completely independent of the central grid. An essential element of such a project is the early and long-term coordination of the plans for the reconstruction of the city or part of it because the main point behind it is the idea of building energy synergies. Using waste heat in this small neighborhood results in lower annual gas consumption reduction of CO_2 emissions.

REFERENCES

Aletba, S., Abdul Hassan, N., Jaya, R.P., Aminudin, E., Mahmud, M.Z., Mohamed, A., Hussein, A.A., 2021. Thermal performance of cooling strategies for asphalt pavement: A state-of-the-art review. *Journal of Traffic and Transportation Engineering (English Edition)*, 8(3), pp. 356-373. Doi:10.1016/j.jtte.2021.02.001

Abdul-Wahab, K., and Rezgho, N., 2017. Urban agriculture as one of the ecological applications of the regenerative city. *Journal of Engineering*, 23(9), pp. 64–81. Doi: 10.31026/j.eng.2017.09.11.

Bovenkamp, M.V., 2018. Heat from cooling installations visualized in the heat atlas and potential applications. Amersfoort: KWA bedrijfs adviseurs. (in Dutch)

Dobbelsteen, v.d., 2019. Course materials of Delft University of Technology EDX MOOC courses. Retrieved from Zero-Energy Design: an approach to make your building sustainable

Duffie, J.A., and Beckman, W.A., 2013*. Solar Engineering of Thermal Processes*. 4th Edition, John Wiley & Sons, Inc. European Union. (sd). European Context. Opgeroepen op (May 17, 2020), van eu-smartcities.eu: https://eu-smartcities.eu/about/european_context MOOC TU Delft.

Filho, W.L., Icaza, L.E., Neht, A., Klavins, M., and Morgan, E.A.,, 2018. Coping with the impacts of urban heat islands. A literature based study on understanding urban heat vulnerability and the need for resilience in cities in a global climate change context. *Journal of Cleaner Production*, 171, pp. 1140-1149. Doi:10.1016/j.jclepro.2017.10.086

Gorsevski, V., Taha, H., Quattrochi, D., and Luvall, J., 1998. Air pollution prevention through urban heat island mitigation: an update on the urban heat island pilot project. In: ACEEE Summer Study, Asilomar. 0903.PDF (aceee.org)

Hawking, S.W., 2001. *The universe in a Nutshell*. Bantams Press, London & New York 2001 Stephen Hawking's Universe. New York: Avon Books.

Harvey, H. J, 2011. Numerical simulation and sensitivity analysis of asphalt pavement temperature and near-surface air temperature using integrated local modeling. In: 90th Annual Meeting Transportation Research Board, Washington DC, 2011

Kalogirou S.A., 2014. *Solar energy engineering processes and systems*. 2nd Edition, Elsevier.

Kampman, Bettina, I. N., 2019. *Residual heat, the state of affairs*. Delft: CE Delft. Called on May 17, 2020.

Kamas, W. M., Hassan, A.A., and Fadel, A.H., 2019. Economic benefits for the application of standards of sustainability in construction projects. *Journal of Engineering*, 25(3), pp. 117-1226. Doi:10.31026/j.eng.2019.03.10.

Kristinsson, J, and Dobbelsteen, A., 2012. *Climate Design and Sustainability Structural Design & Mechanics*, Integrated Sustainable design. Chapter 4. https://ocw.tudelft.nl/wp-ontent/uploads/Integrated_Sustainable_Design_Ch4.pdf%20

Maria, V.D., Rahman, M., Collins, P., Dondi, G., and Sangiorgi, C., 2013. Urban heat island effect: thermal response from different types of exposed paved surfaces. *International Journal of Pavement Research and Technology*, 6 (4), pp. 414-422. Doi:10.6135/ijprt.org.tw/2013.6

Rizwan, A, Dennis, L, and Liu, C., 2008. A review on the generation, determination and mitigation of urban heat island. *Journal of Environmental Sciences*, 20 (1), pp. 120-128. Doi:10.1016/S1001-0742(08)60019-4

Solaimanian, M., Holmgreen, R.J. and Kennedy, T.W., 1990. Evaluation of the Troxler Model 4640 Thin Lift Nuclear Density Gauge. The University of Texas in Austin.

UN. Org. World's population increasingly urban with more than half living in urban, 10 July 2014. https://www.un.org/development/desa/en/news/population/world-urbanization-rospects.html%20

Van de kerckhove, Linde B.P., 2019. Statistical Review of World Energy. 2019 London S&B Global Energiezuinig bouwen en verbouwen 2006-2007

Van der Hoeven, F., 2010. Architecture and the Built Environment: Research Portfolio 2010-2015, TU Delft, Architecture and the Built Environment

Van Oosten, H, 2020. *Greenhouse and city in a new alliance, Greenhouse as heat source. The Netherlands*, report Kas Alas warmtebron (in Dutch). https://edepot.wur.nl/116335

Wouter, C., and Wouters, N., 2018. Module Residual heat Basic insights & tools for the identification and qualification of industrial waste heat. Interrg Vlaanderen-Nederlands. (In Dutch)