A FEASIBLE SOLUTION FOR MAKING THE MIXED USED BUILDING ENERGY NEUTRAL

Hua Fan

Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft
Research tutor: Regina Bokel
Design tutor: Emiel Lamers

Abstract

This paper demonstrates a set of solutions for an energy neutral, mixed used building in Marineterrein Area, Amsterdam. There are basically three steps, reduce energy demand, reuse waste energy streams, which will be discuss in detail and producing renewable energy including human energy. Space heating, cooling, domestic hot water and electricity for lighting are four categories for examining energy neutral. The building consists of 100 student housings, a gym which can produce human energy, and a supermarket with constant cooling demand for balancing heating and cooling scheme in the building. By adding heat recovery system for refrigeration in supermarket, domestic hot water and mechanical ventilation system, heating load of the building decreases and part of waste heat streams is reused. Together with electricity producing by human activities in gym and solar power, the mixed used building could reach energy neutral.

Key word: *energy neural, mixed used, heat recovery, human energy*

1. Introduction

In the past few centuries, the world population experienced continues growth, which was estimated to have reached 7.6 billion as of October 2017, and will further increase to 11.2 billion by the year 2100. (World Bank, 2017) Increasing urbanization is accompanied by population growth. The United Nations prognosticated that about 86% of the developed world and 64% of the developing world will be urbanized by 2050 and about 1.1 billion new people live in urban over the next 13 years. (United Nations, 2014) Netherlands is a highly urbanized country, which also undergoes population growth, from 10 million in 1950 to 17 million now. About three quarters of population work and live in urban area. (PBL, 2016) Urbanization is always associated with consumption-related environmental problems. In wealthy cities, the resource intensive problem is more serious because of rising of resource consumption, demands of urban transportation and infrastructure. Consumption related problems are dominant in affluent city. (Poumanyvong&Kaneko, 2010) As the most populous municipality and the capital of Netherlands, Amsterdam is changing with influx of people and increasing urban density. In order to remain competitive, Dutch economy is able to be more efficient with energy and natural resources to seek for smart and green technologies. (PBL, 2016) Hence, human activities might have great potential in generating clean energy that hasn't attached great attention yet. Large population in Amsterdam is a great source for energy production. Furthermore, growing urban density causes housing shortage and high housing price. Particularly, shortage of student housing needs urgent attention as many students studying in Amsterdam are forced to move outside. In 2012, residential buildings account for 45% of heating and cooling final energy consumption, while industry is 37% and tertiary is 18% in Europe. (European Commission, 2016) It indicates that many things could change in residential buildings to reach better energy performance.

Marineterrein Area has been a restricted military base at the center of Amsterdam and began to transit towards a more public program in 2015. The Bureau Marineterrein Amsterdam and the Dutch government are looking for created and untraditional projects with economic value and societal values, as well as having connection with urban fabric. Hence, a mixed function, energy neutral building with student housing, fitness center and supermarket is suggested to be designed in Marineterrein Area.

The thematic research question is to find a feasible solution for a mixed used building being energy neutral. This paper will mainly focus on utilising energy waste flow and using renewable energy such as human energy, to realizing energy neutral. In the mixed function building, student apartments are necessary to solving shortage problem and fitness center for generating power from human activities. Moreover, a supermarket is added to balance the heating and cooling consumption of the building in order to achieve energy neutral.

Methodology

Tillie et al (2009) illustrated a new three stepped strategy towards energy neutral based on the sustainable approaches since 1980's. The first step is to reduce energy consumption in building scale, minimizing energy demand by smart design. The second step is reusing residual energy stream, that the waste energy from one chain could be collected and reused in different chain. The last step is generating energy sustainably, for instance, generating energy through human activities. Noorman (2014) distinguished three forms of energy used directly by household: motor fuel for transportation, heat for cooking, hot water and space heating; electricity for lighting, washing, cooling etc. However, referring to the reference research and considered this mixed function building with commercial and residential uses, energy forms are simplified into four categories: space heating, cooling, Domestic hot water and lighting. Hence, the paper will map the energy demand in terms of these four categories first, and try to find the energy neutral solution through three stepped strategy demonstrated above.

2. Reduce energy demand

In building scale, reduce energy consumption is the first strategy for an energy neutral building. There are multiple ways to reduce consumptions, for instance, bioclimatic and smart design, orientation, conservatory, insulation, building mass for reducing heating and cooling, and daylight access with less electrical equipment for reducing power. (Tillie et al, 2009) Vartholomaios (2015) searched the relationship between orientation and thermal heat gain, and turns out that compared with other orientations, southern orientation has more evident impact on heating load. While width/height ratio (W/H ratio) is larger than 1.5, the heating load in winter has no considerable change for all orientations. Moreover, the southern, southeastern, southwestern orientation could have efficient solar gain in heating season. At the same time, building could access more daylight and reduce power consumption. Then, Harvey (2009) illustrated that insulation levels in the ceilings, walls, windows and doors thermal properties, air tightness of the envelop could all effect the effectiveness of thermal envelope. A well-insulated building could reduce heat/ cooling lost. Kim&Moon (2009) revealed that using energy efficient appliances not only reduce electricity consumption, but also internal heat. Hence, using effective appliances and smart home appliance control are recommended for reducing consumption.

Table 1. Energy consumption of each function in a typical building

<table>
<tr><th>Mixed Function</th><th>Each Functions</th><th>Space heating (kWh/m^2)</th><th>Cooling (kWh/m^2)</th><th>Domestic hot water</th><th>Lighting (kWh/m^2)</th></tr>
<tr><td rowspan="5">Fitness Center</td><td>Training court</td><td>190.5</td><td>0</td><td rowspan="5">32400 kWh</td><td>60</td></tr>
<tr><td>Fitness suit</td><td>465.4</td><td>0</td><td>61.3</td></tr>
<tr><td>Reception/ Common Area</td><td>354.8</td><td>0</td><td>61.3</td></tr>
<tr><td>Changing room</td><td>676</td><td>0</td><td>46</td></tr>
<tr><td>Refreshment and bar areas</td><td>185.3</td><td>0</td><td>61.3</td></tr>
<tr><td colspan="2">Student Housing</td><td>192</td><td>0</td><td>48 kWh/m^2</td><td>7.93</td></tr>
<tr><td colspan="2">Supermarket</td><td>146.2</td><td>615.6</td><td>57.4 kWh/m^2</td><td>184.68</td></tr>
</table>

In this fitness center, domestic hot water is required for faucets and shower rooms. Maintains temperature of shower facility is 40 to 100 degree Celsius and the baseline at the fitness facility is 6 to 8 user shower available from 6 to 22 o'clock. (Illeperuma, 2014) Hence, the annual energy consumption of domestic hot water is 32400kWh and with efficient retrofit appliance, the annual consumption could be about 10800 kWh. For typical residential, self-catering flat for educational use, the fossil fuel is 240kWh/m2, and the electricity is 54kwh/m2. While for good practice one, the fossil fuel is 200kWh/m2, and the electricity is 45kwh/m2. (Moss, 2006) Majcen (2016) explained that lighting accounts for 14.7% electricity use in Dutch housing and Gerdes et al (2016) illustrated that 20% of gas energy consumption is for hot water supply and 80% for space heating. For good practice supermarket, the fossil fuel is 200kWh/m2, and the electricity is 915kwh/m2. While for a typical supermarket, the fossil fuel is 261kWh/m2, and the electricity is 1026kwh/m2. (Moss, 2006) 56 percentage of fossil fuels consumption is for space heating while 22% for hot water. In terms of electricity use, 60% for refrigeration, in this case is space cooling, and 18% for lighting. (CBECS, 2003)

In conclusion, energy consumptions of good practice functions are shown below.

Table 2. Energy consumption of each functions in a good practice building

Mixed Function	Each Functions	Space heating (kWh/m^2)	Cooling (kWh/m^2)	Domestic hot water	Lighting (kWh/m^2)	Area (m^2)
Fitness Center	Training court	86.3	0	10800 kWh	39	255
	Fitness suit	201.2	0		41.4	150
	Reception/ Common Area	168.4	0		41.4	120
	Changing room	299.4	0		29.6	220
	Refreshment and bar areas	109.5	0		41.4	70
Student Housing		160	0	40 kWh/m2	6.61	2000
Supermarket		112	549	44 kWh/m2	164.7	1420
		Space heating (kWh)	**Cooling (kWh)**	**Domestic hot water (kWh)**	**Lighting (kWh)**	**Area (m^2)**
Total		624967.5	779580	153280	277627	4235

3. Reuse residual energy streams

Energy exchange between different functions could lower total energy consumption in the building. “Heat recovery in the context of buildings and their services can be defined as the collection and re-use of heat arising from a process that would otherwise be lost.” Most industrial process, for instance, heating, cooling and ventilation are able to save energy from heat recovery systems and devices. (Carbon Trust, 2011)

All urban areas and buildings produce waste streams, which could be utilized but rarely are. Reusing these waste energy streams, for instance, waste heat, water, would reduce the primary demand. (Tillie et al, 2009) Some functions need constant cooling demand all the year round and produce waste heating, which could be collected and reuse for heating other functions and vice versa. After mapping the energy demand of different users function, arranging the size and location of different functions would be able to reach the energy scheme. For example, the area of supermarket is determined by student housing and fitness center. Supermarket needs large amount of energy for cooling all the year for refrigeration. Theoretically, if the supermarket is more than 1416m2, the heating produced by cooling in the supermarket could satisfy the heating demand of other functions.

3.1 Heat recovery from Supermarket

Supermarket operates refrigeration systems to maintain food quality within storage area. 60 percentage of total electrical energy consumption is used for refrigeration system. Fricke (2011) illustrated that a significant number of waste heat is emitted by condensers of refrigeration.

Only 10% of rejected energy is high grade, most of which is low grade. The low temperature of waste heat results in low quality, which means it typically be recovered and used for water heating and space heating. The basic process is that a heat recovery exchanger is installed to transfer heat from the discharge gas producing by compressor to process water or other spaces. From high temperature, high pressure gas, which consists of condensing heat and superheat, heat exchange extracts waste heat, and emit excess heat to outdoor. Arias & Lundqvist (2002) explained about 40-70 percentage of the necessary heat is recovered because of regulation, low cooling load in cold days and unsmart system design in practical experiences. Hence, in this case, assume that 70% rejected heat is recovered, 545706kWh energy is added to heating load.

3.2 Directly energy exchange

The first solution is to transfer heat between two functions directly. The influence of users and the function property result in temperature fluctuation within one space. In general, the space with high temperature in the middle would be helpful to heat other functions. For instance, as appendix 1 shows, in the gym, changing room has the highest temperature, and the heating could only transfer from changing room to other spaces. According to the second law of thermodynamics by Clausius statement, heat spontaneously transfers from higher temperature region to lower temperature region. Direct energy exchange between two spaces depends on temperature difference, surface area and heat transfer coefficient without other media.

3.3 Ventilation with heat recovery

In commercial and residential building, installing trigeneration or cogeneration technologies system, or recovering waste heat from air- conditioning systems and ventilation system are two main methods for recovering low temperature heat waste. Using recirculated air for recovering energy from air- conditioning systems and ventilation system is the most efficient way. Recovering heat from extracted air, different types of heat exchanges would prevent heat to lose into the atmosphere, as well as pre heating or cooling the incoming fresh air. (EEX) With fans and control systems, mechanical ventilation systems are able to provide fresh air regardless of the suitability and availability of natural forces, as well as participating in heating and cooling of air-conditioning system of the building, assisting in naturally cooling and distributing thermally conditioned air. (CIBSE, 2016) Mechanical ventilation system with heat recovery (MVHR) extracts the air from the polluted sources, for instance, kitchen, gym, training court, bathroom and supplies air to living rooms. The systems could produce better indoor air quality and comfort.

Meanwhile, the extracted exhausted hot air goes through a central heat exchanger and transfer heat to the cool fresh air. Hence, before the air is supplied by boiler to the space, less heat is needed. It provides a balanced low energy solution for ventilation system in the building. However, this system requires power to run associated equipment. Monahan & Powell (2011) illustrated the importance of air tightness to the efficiency of this heat recovery system. A well-designed MVHR system could theoretically offset this energy demand in a relatively air tight building through heat recovery. According to Carbon Trust (2011), the efficiency of this system is generally between 55% and 65%. In some circumstance, nature and temperature of waste heat could increase the efficiency of some heat recovery devices. Harvey (2013) illustrated that the extra primary energy required for operating fans is much less than the energy saving by the system in cold climates. Although MVHR adds about 8 kWh/m^2 annual energy use, it could reduce the heating load by $30kWh/m^2$ annually in Sweden. The data has value for reference through the Dutch climate is less cold than Sweden. Hence, the annual heating recovered by MVHR system would be: $30kWh/m^2*4235m^2=127050kWh$

3.4 Domestic hot water heat recovery

Bertrand at el (2016) illustrated that in 2013, residential domestic hot water energy consumption accounts for about 16% of heating demand of European household, and the number is presumed to increase significantly in the future. Hot water carries away a large amount of energy through drain to the environment. This energy could be recovered with waste water heat recovery system. By extracting the heat from waste hot water from drain, a domestic hot water heat recovery system uses this waste heat to warm the incoming water. Therefore, energy for heating water up to the temperature requirement and strain on the boiler are both reduced. The device of this system is simple, without any controllers, nor electrical components. The maintenance requirement is little and lifespan is long. However, although it could save the heating money and meet the sustainable code standard but have a long payback period.

In this mixed function building, showers in student housing and changing room of fitness center could install the recovery system. According to Sports England (2008), six changing rooms should have one shower, and the number of changing room should to be able to satisfy the need of participants at peak periods so the capacities should established on the demand for large group of people using the changing rooms simultaneously. Hence, 10 showers are estimated to be installed for maximum 60 changing rooms. Student housing has independent bathroom, so there are 100 showers totally. Based on the research data of Deng et al (2016), assuming each shower lasts for 10 minutes and the flow rate is 5L/min. With a heat exchange, 0.4kWh in summer and 1.1 kWh in winter could be recovered each shower. In Netherland, with an average drinking water temperature above 20 Celsius degree, 122 days are counted as summer, while 243 days as winter. Hence, 100 student housings could recover heat from hot water of: (1.1kWh*243+0.4kWh*122)*100=31610kWh

Assuming showers in fitness center are used 60 times each day, the annual recovery heat would be: (1.1kWh*243+0.4kWh*122)*60=18966kWh
Hence, the domestic hot water heat recovery in the building could save 50576kWh annually.

3.5 Heat pump and energy storage

Refrigeration system makes cold air for supermarket from electricity and air. Ventilation system and domestic hot water system uses electricity to make hot air and water. All the heat recovery techniques has a large demand of electricity, which though is not account into the energy neutral scheme like lighting consumption, but still need to be noticed. Aquifer thermal energy storage (ATES) store is suggested to be used for recovery thermal heat seasonally. The system uses underground water operating in seasonal mode. In summer, heat exchanges extract heat from building and transfer into aquifer, creating storage of heated ground water and energy flow reverses in winter. Hence, the system could store energy underground and use for the building throughout the year. In this case, the supermarket has continuous cooling demand for refrigeration system and space cooling demand in summer time, the ATES system release the burden for cooling demand.

Table 1. Energy consumption after reuse waste energy streams

	Heating Demand (kWh)	**Cooling Demand (kWh)**	**Lighting (kWh)**
Total demand	778247.5	779580	277627
Refrigeration system	-545706	-	-
Ventilation system	-127050	-	-
Domestic hot water	-50576	-	-
Energy demand after heat recovery	54915.5	-	277627

4. Produce clean energy

4.1 Human Energy

Human energy is clean and sustainable, although it is inefficient way for electricity generating while considering the income amount of fuel (food) and outcome energy that human produce. However, harvesting energy which would be otherwise, lost to environment producing by human activities is sustainable. Jansen (2011) illustrated several forms of human energy that could generate power: body heat, upper limb motion, finger motion, walking (heel drop). There into, muscular work has relatively high potential for generating power compared to other possibilities.

Firstly, for collecting energy from human steps, a modular floor tile from Pavegen Company could convert kinetic energy into storable electricity. The waterproof tiles could feed the power into a grid directly, and endure ice, snow and rainfall. The 600 mm length and 450mm width textile made by steel, recycle aluminum and rubber, could generate 7 watt per step. On average, each step pushes the title down about five millimeters for generating electricity. (Grose, 2012) It is a new trend to combing aerobics with another activity for instance, dance, boxing or martial arts and fitness is viewed as a fun leisure. (Sports England, 2008) Hence, Pavegen tiles are installed in training court for harvesting kinetic energy. Assume that there are total 3 hours aerobics training classes with 30 people training together every day. The average speed is 150 steps per minute in the training court so each step is about 0.4 second. This produces 2.8 joules per step of energy. The yearly running hour of gym ranges from 2754 to 5355 hours. (CIBSE, 2008) Supposing the average opening hours of the gym is 4000 hours annually, the totally the training court could produce:

2.8 J/step*150step/minute*180miute*30people*365day=827820000joules=229.95kwh/year

However, the current limitation of this technique is the high cost and comparatively low energy production. However, in the past year, the price of the system has dropped 70 percent the founder of the company is convinced that they will continue to improve the technology and expenditure.

Then, cardio studio is another place with potential for harvesting energy from human activities. Fitness equipment such as treadmill, rowing machine has great potential for generating electricity. The equipment could be retrofitted by ReRev system to make alternative energy, so kinetic motion is captured to contribute to the electrical system of the building. According to ReRev Company (2011), kinetic energy is converted to direct current and sent to the system, and then the system converts the direct current to alternating current, which can be used to power the building. Each unit of ReRev produces 50Wh per thirty minutes, which is equal to 0.1 kWh per hour. Although the initial cost is large, more units are installed, less price the single unit has. According to the benchmark provided by Sports England (2008), the minimum requirement of fitness gym area is 25m^2, and in order to guarantee a range of options for users, the majority of fitness rooms occupy 100-200m2 areas and for cardio vascular area, the machine footprint ranges from 1.5-2 m^2/machine. Hence, considered of the circulation area and properties of different fitness machines, 40 ReRev units were estimated to be installed. However, it is impossible that all equipment runs at the same time all the year round. Assuming each equipment runs for 30 hours per week (the data based on the survey of Wake Forest Gym [1]), the annual electricity generating by fitness room would be:

0.1kWh/hour *40units *30hours/week*52 week=6240kWh/year

In conclusion, human power contributes 6470 kWh electricity annually to the building.

4.2 PV Panel

Solar energy is the most common renewable energy for energy neutral building because of its high efficiency and capacity. According to CBS, gross renewable electricity production in the Netherlands by solar power increases every year, which produces 1555 million kWh in 2016. (CBS, 2017) Photovoltaic (PV) technologies could realize generating power by solar energy. The process of photovoltaic is quite, clean and highly reliable with low maintains cost. A PV module has many interconnected solar cells, which generate DC electricity. Then, an inverter converts the DC to AC for most applications. The National Renewable Energy Laboratory (NREL) (http://www.nrel.gov/rredc/pvwatts) provides an online tool for calculating energy producing by PV system. In Amsterdam, suppose the solar panels faces south, with a tilt angle to 20 degrees for a fixed system, approximately 25m^2 standard PV system could generate 3605kWh electricity every year. Hence, roughly 1880m2 PV panels are required, generating 271157kWh electricity annual to reach energy neutral in lighting.

4.3 PV-T Panels

Since a large amount of PV panels are needed for electricity, adding solar collectors for heating might not be suitable for design purpose. Hence, PV-T could be installed instead of PV panels and solar collectors. Photovoltaic thermal hybrid solar collectors, known as PV-T, combines solar cells and thermal collector and are able to transfer solar energy into electrical and thermal energy. Hence, PV-T panels and PV panels could be installed together for producing sustainable energy. According to UK Gov (2016), the electrical energy accounts for 37% of total output energy while thermal is 63% in PV-T system. A 15m^2 system (7800KWth thermal and 2.25kWp electric) will produce about 2250kWh electricity and 3830 kWh thermal annually in the climate condition similar to Netherlands and the installation of the panel is south facing without shading. The building will reach the goal of energy neutral if it generates 54915.5kWh thermal energy and 277627kWh electrical energy sustainably. Combined PV-T panel and PV panel together, 216m^2 PV-T panel and 1700m^2 PV panels could produce this amount of energy.

5. Conclusion

The paper provide a guidance for designing an energy neutral, mix function building in Amsterdam. Following the three steps approach raised by Tillie et al, which is reduce demand, reuse waste energy and produce clean energy, the building realizes energy neutral. The paper mainly research the approach of reuse waste energy streams and sustainable production and calculates the performance of several heat recovery systems and clean energy production systems. In order to reuse waste energy streams, heat recovery for mechanical ventilation, refrigeration and domestic hot water are added. As fitness center is one of the function in the building, energy produced by human activities, though is a small amount of electricity compared with other technologies, also take into account combining with PV and PV-T panels for electricity generation. Many of these systems for energy neutral are still in development stage, which might have better performance and low price in the future. Many technologies are expensive at present with long financial payback period. In real practice, there are more difficulties for a building, especially the middle to large size building with relatively high energy consumption to realize energy neutral because of high budget. Furthermore, conflicts between architecture and technologies also exist. For instance, a large amount of PV and PV-T panels, about 1900m^2 are needed, which might affect the artistic design of the building. However, all approaches discussed in the paper could be a guideline for building a low energy consumption building for future city and finally reach energy neutral.

6. References

1. https://energyefficientgyms.weebly.com/rerev-at-wake.html

Arias, J., & Lundqvist, P. (2002). Heat recovery in recent refrigeration systems in supermarkets. In 7th International Energy Agency Conference on Heat Pumping Technologies.

Bertrand, A., Aggoune, R., & Maréchal, F. (2017). In-building waste water heat recovery: An urban-scale method for the characterisation of water streams and the assessment of energy savings and costs. Applied Energy, 192, 110-125.

Carbon Trust UK HQ, 2011, Heat Recovery: A Guide to Key Systems and Applications. Carbon Trust UK HQ, London, UK. https://www.carbontrust.com/media/31715/ctg057_heat_recovery.pdf

CBS (2017), Hernieuwbare Energie in Nederland 2016, https://www.cbs.nl/nl-nl/publicatie/2017/39/hernieuwbare-energie-in-nederland-2016

CIBSE (2008), Energy benchmarks TM46: 2008, The Chartered Institution of Building Services Engineers,http://www.quidos.co.uk/wp-content/uploads/2015/08/CIBSE-TM46-Energy-Benchmarks.compressed.pdf

CIBSE (2016). Ventilation and Ductwork : Cibse Guide B2 : 2016. 7. ed. 3.2.3.3 Displacement Systems. (pp. 2-19).London: Chartered Institution of Building Services Engineers: http://app.knovel.com/hotlink/toc/id:kt0114Q9D1/ventilation-ductwork/displacement-systems

Commercial Buildings Energy Consumption Survey (2003), U.S Energy Information Administration

Deng, Z., Mol, S., & Van der Hoek, J. P. (2016). Shower heat exchanger: reuse of energy from heated drinking water for CO2 reduction. Drinking Water Engineering and Science, 9(1), 1.

El Asmar, M., & Tilton, C. (2015). Student Housing Energy Consumption: A Comparison of Chilled Water, Heating, and Electricity Use. Procedia Engineering, 118, 1038-1043.

European Communities. (2016). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategy for Heating and Cooling, Communication from the Commission to the European Parliament

Fricke, B. A. (2011). Waste Heat Recapture from Supermarket Refrigeration Systems (No. ORNL/TM-2011/239). Oak Ridge National Laboratory (ORNL); Building Technologies Research and Integration Center.

Gerdes, J., Marbus, S., & Boelhouwer, M. (2016). Energietrends 2016. https://www.ecn.nl/publicaties/PdfFetch.aspx?nr=ECN-O--16-031

Grose .T.K (2012) Tiles May Help Shrink Carbon Footprint by Harnessing Pedestrian Power, National Geographic News, May 20, 2012, https://news.nationalgeographic.com/news/energy/2012/05/120518-floor-tiles-turn-footfalls-to-electricity

Harvey, L. D. (2013). Recent advances in sustainable buildings: review of the energy and cost performance of the state-of-the-art best practices from around the world. Annual review of environment and resources, 38, 281-309.

Harvey, L. D. (2009). Reducing energy use in the buildings sector: measures, costs, and examples. Energy Efficiency, 2(2), 139-163.

Jansen, A. J. (2011). Human Power empirically explored.

Majcen, D. (2016). Predicting energy consumption and savings in the housing stock: A performance gap analysis in the Netherlands.

Monahan, J., & Powell, J. C. (2011). A comparison of the energy and carbon implications of new systems of energy provision in new build housing in the UK. Energy Policy, 39(1), 290-298.

Moss, K. J. (2006). Energy management in Buildings. Appendix4 Benchmarking, Taylor & Francis.

Noorman, K. J. (2014). Green households: domestic consumers, the environment and sustainability. Analysis of Household Metabolic Flows, Routledge.pp39

Illeperuma, I. A. (2014). A Cost Benefit Analysis of Improving Energy Efficiency of a Fitness Facilty. Journal of Environmental and Resource Economics at Colby, 1(01), 89.

Kim, J. J., & Moon, J. W. (2009, July). Impact of insulation on building energy consumption. In Building Simulation (Vol. 2009, pp. 674-680).

PBL (2016), Cities in the Netherlands, Facts and figures on cities and urban areas, Netherlands Environmental Assessment Agency The Hague, https://www.rijksoverheid.nl/...netherlands/cities-in-the-netherlands.pdf

Poumanyvong, P., & Kaneko, S. (2010). Does urbanization lead to less energy use and lower CO 2 emissions? A cross-country analysis. Ecological Economics, 70(2), 434-444.

Recover waste heat in commercial buildings (low temperature waste heat recovery), Australian Government Department of the Environment and Energy (EEX), https://www.eex.gov.au/opportunity/recover-waste-heat-in-commercial-buildings-low-temperature-waste-heat-recovery

ReRev company (2011), how it works, 2011, http://rerev.com/howitworks.html

Sports England (2008), updated 2008 guidance-fitness and exercise space, 2008, https://www.sportengland.org/media/4203/fitness-and-exercise-spaces.pdf

Tillie, N., van den Dobbelsteen, A., Doepel, D., de Jager, W., Joubert, M., & Mayenburg, D. (2009). REAP Rotterdam Energy Approach and Planning: Towards CO2-Neutral Urban Development. Pieter Kers: Rotterdam, The Netherlands.

UbEg (2007), Energy Need for a Standardized supermarket: heating cooling refrigeration, Intelligent energy Europe, http://ubeg.de/IGEIA/IGEIA-D8---energy-study-supermarket-Germany.pdf

United Nations (2014) World Urbanization Prospects, 2014 revisions https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.pdf

UK Gov(2016) Low Carbon Heating Technologies - Hybrid Solar Photovoltaic Thermal Panels, Department for Business, Energy and Industrial Strategy, London https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/545246/Solar_PVT_FINAL__1_.pdf

Vartholomaios, A. (2015). The residential solar block envelope: A method for enabling the development of compact urban blocks with high passive solar potential. Energy and Buildings, 99, 303-312.

Voss, K., & Musall, E. (2013). Net zero energy buildings: international projects of carbon neutrality in buildings. Chapter 8 Renewable Energy, Walter de Gruyter.272-284

World Bank Data (2017), https://data.worldbank.org/indicator/SP.POP.TOTL

7. Appendix

7.1 Temperature in different functions

	Space Type	Temp(ºC)
Fitness Center	Space Type	Temp(ºC)
	Training Court	16-18
	Fitness Suit	16-18
	Reception office	16-20
	Changing Room	20-25
	Refreshment and bar areas	18
Student Housing	Student Housing	21
Supermarket	Market Area	19-25
	Cashier Area	21-25
	Storage Area	17
	Office and Social Rooms	21-24

Fitness center temperature:

Carbon Trust UK, Carbon Trust UK HQ, GPG390, Good Practice Guide, Saving energy at leisure, Carbon Trust,

https://www.worcester.gov.uk/documents/10499/27253/Carbon_Trust_Good_Practice_Guide_Saving_Enegy_at_Leisure.pdf/5ca3b78d-a828-4e26-bfc8-b08bc5161450

Supermarket temperature (uBeG, 2007)

Apartment temperature:

http://www.theiet.org/sectors/built-environment/topics/future-power/articles/mvhr.cfm

7.2 Energy Scheme