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Comparison of energy consumption in residential buildings: case of Eco-Viikki

Helsinki Metropolia University of Applied Sciences

Bachelor of Engineering

Environmental Engineering

Thesis

04.05.2018

Author Title Number of Pages Date	Angelina Bani Arial Comparison of energy consumption on residential buildings: case of Eco-Viikki 29 pages + 3 appendices 5 May 2018
Degree	Bachelor of Engineering
Degree Programme	Environmental Engineering
Specialisation option	Water and wastewater Engineering
Instructor	Kaj Lindedahl, Principal Lecturer

The goal of this Bachelor's thesis was to present comparison between residential energy consumption of two building models in the city of Helsinki: Eco-Viikki buildings and *control* buildings in Herttoniemenranta area. Eco-Viikki is Finland's first pilot project to realized ecological residential area, and was constructed with the highest criteria present at that time. The *control* area is built in the same interval time as Eco-Viikki; however, its building criteria were standard, based on regulations set by the city.

Data analysed in this thesis project was obtained through KAMUT project. A project set to view and measure the urban sustainability transformation in the city.

The results obtained from the statistical *t test* carried out between the electricity consumption data of Eco-Viikki and the control area Herttoniemenranta has shown that there is a significant difference in the mean electric energy consumption of the two areas. The analysed electricity data was normalized with respect to the total area showing that Eco-Viikki consumes an average of 13% more electricity than the control area. However, on other hand, Eco-Viikki consumed less energy on heating than the control area. Eco-Viikki's monthly heating energy consumption and electric consumptions shows to be linearly correlated, regardless of their independences. In other words, increase in heating demand shows as increase in electricity demand. The statistical test result indicates that there is a statistical significant changes in the values of the heating energy consumption in years 2002-2003 and 2015-2016.

There is an observed deviation in water consumption between rental and owner-occupied houses in Eco-Viikki. Rental buildings' consumptions are relatively higher in comparison to owner-occupied buildings which has shown rather stable consumptions within the period of 13 years.

Keywords	residential energy consumption, heating energy, electricity consumption, water consumption, ecological, eco-Viikki

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Abbreviations

FNBC	Finnish National Building Code
DH	District heating
Hert.	Herttoniemenranta
HDD	Heating degree-day

PIMWAG The eco-criteria created by Helsinki City Planning department for Eco-Viikki building project. PIWAG is simply a word made of the authors' first names (Pennanen, Inkinen, Majurinen, Wartiainen, Aaltonen and Gabrielsson).

Eco-criteria	Ecological criteria
R	Is a software environment for statistical computing and graphics

EV	Eco-Viikki
EV1	Versokuja 9
EV2	Versokuja 10
EV3	Versokuja 6
EV4	Norkkokuja 10
EV5	Tilanhoitajankaari 19
EV6	Tilanhoitajankaari 30
EV7	Tilanhoitajankaari 20
EV8	Tilanhoitajankaari 18
EV9	Tilanhoitajankaari 22
EV10	Norkkokuja 3, 4
EV11	Tilanhoitajankaari 28
EV12	Nuppukuja 9

1. Introduction

Nordic countries are known to be energy intensive countries due to factors such as cold climate conditions, highly energy demanding industrial activities, scattered living areas, and high life quality. Generally, residential buildings count the largest share of energy consumption, over one-third of the total energy consumptions [1].
In the last thirty years a global movement toward energy efficiency has started to take place, and for realizing these sustainable approaches, new buildings regulations and instruments were proposed. Some of these goals have yielded concrete and remarkable results while others are still, more or less, on a theoretical and development level.

Highly energy intensive Finland has as well one the biggest energy consumption per capita among its fellow Nordic countries. Several variables influence energy consumption, particularly heating energy consumption; such variables are, for instance climatic variation, the implemented building regulations, and criteria designs. Generally, energy consumption in Finnish residential buildings consist of district heating and electric energy.
A number of studies about correlation between the building design and climatic effects have been conducted; thus, nowadays there is better understanding on design criteria for advanced thermal insulation and better energy performances in building stock.
In Finland energy efficiency requirements for new buildings have become strict in the last decades, which has along enabled a pathway toward sustainability transformation in energy consumption. Eco-Viikki as the country's first pilot project to perform ecological residential area is now being reviewed from sustainability transformation perspective.

1.1 Research aim, scope and objectives

This Bachelor's thesis aims to observe possible patterns of sustainability transformation in energy consumption of Eco-Viikki, by analysing a relatively small dataset of heating energy consumption and electricity consumption from the time interval of 2002-2003 and 2015-2016.

The research hypothesis was whether or not Eco-Viikki building project resulted in ecological energy consumption outcomes in comparison to the energy consumption of conventionally constructed residential building. In other words, this paper focuses on identifying possible trends and development in energy consumption of the chosen buildings in Eco-Viikki and comparing them to the chosen *control area* buildings that are in Herttoniemenranta (Hert.), using data analysis methods. The keywords of this thesis work include residential energy consumption such as electricity, district heat energy, and water consumption.

The research objectives are listed below:
Objective 1**:** to generally review about residential energy consumption in Finland.
Objective 2**:** to analyse heating energy consumption in the chosen Eco-Viikki buildings within comparison intervals of 2002-2003 and 2015-2016 and to conclude whether there is statistically significant difference between the average consumption of the proposed years.
Objective 3**:** to compare the electricity and heating energy consumption data of the Eco-Viikki to the the *control area* (Hert.). Conducting statistical Student's *t* test between the two case-studied areas' electricity data from 2015 and 2016.
Objective 4**:** to observe whether there is a correlation between heating energy consumption and electric energy consumption of the chosen Eco-Viikki buildings' data.

2 General overview of energy consumption in residential housing

2.1 Overview of housing sector in Helsinki

The correlation between the growth of economy and the growth in construction in Finland has been lately witnessed in 2016, whereby construction investments increased by approximately 6.5%. Helsinki has enjoyed its share of this development, particularly in residential construction as the demand for housing highly increased. The national increase in residential construction that happened in 2016 has resulted in some 36,000 dwellings of which Helsinki region alone has a lion share of 45% [2]. Table 1 contains types of the residential buildings and their percentage share in 2016[3].

Table 1 Residential buildings types in 2016 given in percentage.

Types of dwelling in Helsinki, 2016	
Dwelling types	%
Detached houses	25.2
Row -/terraced houses	13.4
Block buildings	60.6
Other buildings	0.7

2.2 Building code and energy audits

Climate affects the amount of end-use energy consumption by buildings. In cold climate countries like Finland heating energy consumption is 68% of the total household energy consumption [4]. Due to the above mentioned aspects, the building code and energy audits are essential, particularly in terms of energy efficiency and environmental sustainability. Consequently, energy efficiency improvements, in terms of ventilation and thermal insulation, are considered but depending on the climatic conditions of area. The Finnish Minister of Environment has set regulations and guidelines on energy efficiency in the National Building Code (FNBC). [4] The focus of FNBC guidelines is to ensure and set minimum requirements for the thermal insulation of the new construction projects which aims for the betterment of building energy performances. [4]

FNBC set requirements whereby the total energy consumption of buildings should align with values given in Table 2

Table 2 Building energy efficiency requirements. The listed categories are only related to residential buildings.

Category		**Heated net surface A_{net}**	**kWh/m^2 per year**
1	Single-family house, terraced house		
	Single-family house	$A_{net} < 120\ m^2$	204
		$120\ m^2 \leq A_{net} \leq 150\ m^2$	$372 - 1.4 \cdot A_{net}$
		$150\ m^2 \leq A_{net} \leq 600\ m^2$	$173 - 0.07 \cdot A_{net}$
		$A_{net} > 600\ m^2$	130
	Log house	$A_{net} < 120\ m^2$	229
		$120\ m^2 \leq A_{net} \leq 150\ m^2$	$397 - 1.4 \cdot A_{net}$
		$150\ m^2 \leq A_{net} \leq 600\ m^2$	$198 - 0.07 \cdot A_{net}$
		$A_{net} > 600\ m^2$	155
	Terraced house		150
2	Block of flats		130

2.3 Residential energy consumption

Heating energy consumption in residential buildings is estimated to be 68% of the total energy consumptions, heating of saunas 5% and energy consumed on heating of domestic water amounted 15%. Energy consumption of dwelling appliances is divided into consumption of household electric equipment, lighting and cooking with an overall average amounting 20% of the end-use energy consumption. [5]

The energy consumption of Finnish households is illustrated in Figure 1.

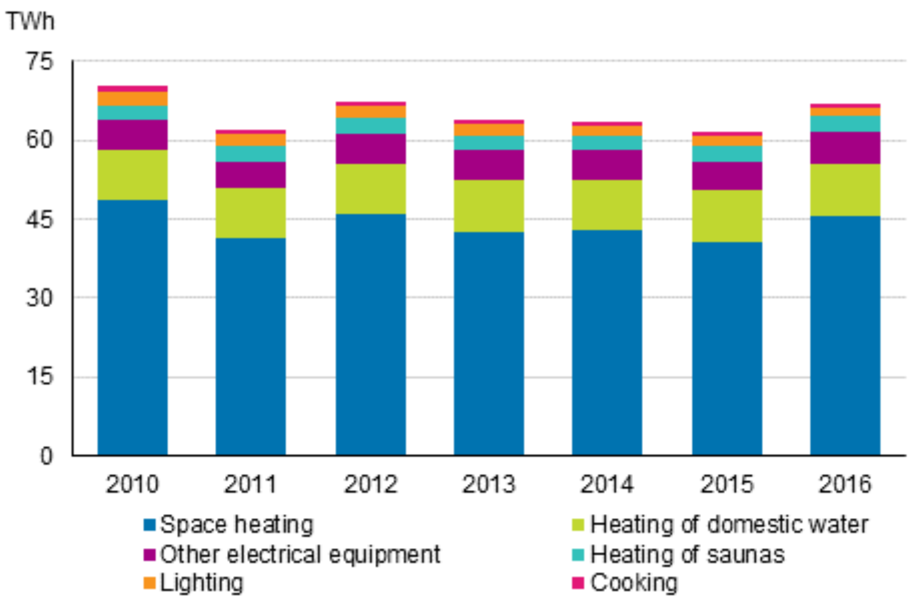

Figure 1 Energy consumption in Finnish households in 2016, Statistics Finland. [5]

Buildings that utilized electric heating systems for space heating tend to have higher electricity consumption, while in the case of building utilizing district heating (DH) system the consumption tend to be lower. Electric heating systems are classified into three different types: heat pump, direct electric heating system, and storage electric heating system. [6]

2.4 District heating

Considering the climatic condition and geographical location of Finland, heating and thermal comfort are essential elements in maintaining comfortable life quality, industrial and other development aspects. The substantial utilization of the potential CHP and district heating in Finland naturally justifies the large share of heated residential stock, particularly in densely populated cities, towns and municipalities that are connected to district heating network. It is estimated that 90% of block buildings, 30% of industrial buildings and 60% of other types of buildings, such as institutional buildings, 10% of detached buildings, are heated by district heating. An approximation of 8% - 9% of heat losses occur because of district heating network [6]. In addition to utilization of DH in space heating, also domestic water is provided through the network.

According to energy report by EU [6], Finland's market share for district heating consumption is 45% of the total heating energy. In 2016 the energy consumption of district heat was 46 TWh, which has increased with 22% compared to the consumption in 2010 [5, 6].

Nonetheless, the future projection on district heating predicts reduction of the consumption to 40 TWh in 2025 [6]. An extensive research conducted by Technical Research Centre of Finland (VTT) [7] discussed the relevant issues and challenges that are facing Finnish DH and the need for a smooth transformation toward new generation of DH in the face of new regulations and the emergence of sustainable energy sources.

2.5 The net energy consumption of a building

The total energy consumption of the building is calculated by taking into consideration the climatic data of the area. This weather data is represented in the regulations and guidelines of energy efficiency of the buildings as well as in the preliminary values set for utilization and operation of the building systems. The internal thermal loads of the system are taken into account when calculating the initial energy consumption data. In other cases, design documents are used for extracting other variables that are important for conducting energy data analysis. [8]

To determine the E-value of the building, the annual purchased net energy consumption of the building, highlighted with the energy coefficients (*see Table 3*) is divided by the total area heated, with respect to the standard consumption of the particular type building that is being audited. The E-Value is basically a content of codes that are utilized to determine energy classification of the building which is in of kWh/m^2. The E -Values are from A to G, where A is the least energy consuming code and G is the most energy consuming code [8]. Residential building such as detached and attached buildings has energy audit value not more than 150 kWh/m^2, while building types such as block apartment building is set to have energy efficiency of 151-170 kWh/m^2. [8] Table 3 contains the older coefficients of energy forms that were outdated by the end of 2017 [8]. The new regulated coefficients of different energy forms were implemented by the beginning of 2018 and change occurred on all of the forms, excluding fossil fuels and renewable fuels [9].

Table *3* Coefficients of different energy form are as in the blow table

Electricity	2
District heating	0.7
District cooling	0.4

Fossil fuels	1
Renewable fuels used in the building	0.5

Building energy consumption consists of all the different types of energy uses in the building, such as space heating and domestic water, cooking and electricity. The data is mostly given, either collected or disaggregated based on the end-use classification or per housing as heating demand of the building in kWh/m^2. Due to the annual climate variation, for instance, Helsinki's average temperature in 2016 was higher than in 2015 Finland [5], the consumption data has to be corrected so that it projects similar weather state. There is section in this paper about weather correction and its calculation methods.

3 Comparison cases

3.1 Ecological model: Eco-Viikki in Helsinki

Paloheimo L. described ecological society in the building criteria for Eco-Viikki in 1994[10] as follows: *in an ecological society the material cycle is made as enclosed and nature-preserving as possible. Energy can be obtained, for instance, from solar or wind energy and other renewable sources. The need for vehicles is minimized and new forms of transport are developed. The optimal size for a functioning community is about 15000 inhabitants. Widely-placed buildings are located near cultivated land and nature corridors. Modern technology is used in energy production as well as in moving information and materials [10,4*].

Eco-Viikki is located in the southern part of Latokartano in Helsinki, and it is the first Finnish experimental ecological community housing and internationally well-known housing project by the turn of the last century. Eco-Viikki has been carried out to set, as well to encourage, an ecological building trend in the country. By the start of 1990s, public awareness of environmental problems and sustainability has increased. Prior to that, in 1987 the Brundtland Commission put definition for *sustainable development* which can open the door for ecological sustainability to become one of the key aspects also in land-use design and building. In Finland this has led positive change in building legislations in 1990 whereby the goals of sustainable development were first introduced and the theory was then put into practice by realizing Eco-Viikki in the mid of the same decade. [10]

Eco-Viikki was built based on strict eco-criteria for the intention to preserve the location's high ecological profile. The performed ecological criteria by multidisciplinary, PIMWAG, were higher and unique. Eco-Viikki's building criteria consist of five parameters which targets the evaluation of the level of ecology of the proposed plans. These plans included pollution, the availability of natural resources, health, the biodiversity of nature, and nutrition. Overall, these parameters cover 16 criteria to be evaluated in the project and are given 0-2 scores, which are determined based on the level 'ecologicalness'. Zero as the minimum point, 2 as the maximum and Table 4 illustrates the criteria for pollution and natural resources. [10]

PIMWAG CRITERIA

Table 4 PIMWAG co-criteria for natural resources.

NATURAL RESOURCES	minimum level	1 point	2 points
Primary energy	30 GJ/gross m^2/50y	25 GJ/gross m^2/50y	20GJ/gross m^2/50y
Heating energy	105 kWh/gross m^2/y	85 kWh/gross m2/y	65 kWh/gross m^2/y
Electrical energy	45 kWh/gross m^2/y	40 kWh/gross m2/y	35 kWh/gross m^2/y
Adaptability and multi-use of space	Standard solution	15% adaptability in flats OR housing functions concentrated in communal spaces	15% adaptability in flats OR housing functions concentrated in communal spaces + versatile spaces in the building

Table 5 contains information of all the buildings of Eco-Viikki case study:

Table 5 The building included Eco-Viikki case study

Eco-Viikki Building	Case-study code	Year of constructi n	Number of dwellings	Gross area m2	Type of the building	Type of housing
Versokuja 9	EV1	Oct-02	4	521.5		owner-occupied
Versokuja 10	EV2	Aug-04	2	477		owner-occupied
Versokuja 6	EV3	Nov-03	4	590		owner-occupied
Norkkokuja 10	EV4	May-01	9	974	T	owner-occupied
Tilanhoitajankaari 19	EV5	Mar-02	23	2182	B	owner-occupied
Tilanhoitajankaari 30	EV6	Sep-00	38	3889	B+T	right-of-occupancy
Tilanhoitajankaari 20	EV7	Apr-00	44	4505	B+T	rental
Tilanhoitajankaari 18	EV8	Aug-01	55	5384	B	owner-occupied
Tilanhoitajankaari 22	EV9	Oct-00	63	6209	B	owner-occupied
Norkkokuja 3, 4	EV10	Jan-01	61	6364	B	rental
Tilanhoitajankaari 28	EV11	Sep-00	87	8265	B+T	rental
Nuppukuja 9	EV12	Mar-03	21	2996	ST	owner-occupied

T - terraced house
B - Block building
BB - Block and terraced building
ST- Semi detached building

3.2 Conventional model: *control buildings* in Helsinki

The *control buildings* are situated in Herttoniemenranta (Hert.) in Helsinki, only about 6km distance south-west of Eco-Viikki. The *control area* Hert. residential buildings were built in 2000-2004 and that fact enable the target to be feasible for comparison to Eco-Viikki. Table 6 represents physical details of the Hert. buildings.

Table 6 Control buildings and their physical characteristics.

Building code	Dwellings	Net area [m²]	Volume [m³]
H1	20	1882	6085
H2	21	5003	16972
H3	27	2950	9200
H4	37	4765	15170
H5	46	3460	489
H6	49	6037	19970
H7	51	5096	17325
H8	52	3687	11500
H9	54	6835	16692
H10	60	5983	18800
H11	71	6989	16350
H12	86	9390	30018

4 Energy data analysis of the both case-studies

The aim of this section was to make a relevant and a good comparison, and to gain a better understanding of the differences in energy performance of the compared buildings. For achieving that goal, several aspects need to be taken into consideration. The bottom line for selecting the buildings is in their comparable physical characteristics, such as total surface area of the building and the number of floors. In terms of the consumption data, the data has to be from the same period of time and with similar intervals and utilizing similar energy sources, for instance district heating for space heating. However, the selection did not proceed as the planned due to the fact that buildings in Eco-Viikki are relatively small in their total area compared to *control* buildings. Consequently, some buildings were left out of the comparison and that resulted in reduction of the amount of the case-studied buildings -8 buildings for each area. The selection was based on the most matching pairs in terms of physical characteristics as it is shown in Table 7.

Table 7 Comparison between buildings in Eco-Viikki and Herttoniemenranta.

Case-study building -Hert.	Case-study building -Eco-Viikki	Hert. -gross area (m²)	EV -gross area (m²)	Difference
H1	EV4	1882	974	-48 %
H3	EV5	3460	2182	-37 %
H4	EV6	3687	3889	5 %
H7	EV7	5096	4505	-12 %
H9	EV8	6037	5384	-11 %
H10	EV9	6835	6209	-9 %
H11	EV10	6989	6364	-9 %
H12	EV11	9390	8265	-12 %
Total differences in area		43376	37772	-13 %

4.1 Weather correction analysis

Heating degree-days

Residential energy consumptions are proven to be dependent on climatic conditions. Furthermore, to conduct reliable conclusions, we ought to take into account the degree-days, whether it is heating or cooling degree days. In the case of this report, the question is most related to heating degree days (HDD). The degree-day parameter is very fundamental and simplified method to estimate heating and cooling energy demand. Heating degree days are calculated by basic subtractions of the outdoor temperature values from the temperature values of indoor, but taking into consideration only the values above zero. Commonly, the most utilized degree-day temperature is S17, +17 °C which is calculated based on the daily average temperature differences of the indoor and outdoor temperatures. The degree-days for a month is the sum of the days' degree-days, respectively a year's is based on the sums of the months'. [11]

Equation 1 below used to calculate heating degree-days

$$HDD = \frac{\sum_{i=1}^{k} T_{Hb} - T_i}{24}, \quad if\ (T_{Hb} - T_i) > 0, \ 0 \leq k \leq 24 \tag{1}$$

Normalization of energy data

Correcting heating energy consumption data is very essential because the consumption data is depending on the weather conditions. Motiva [11], developed different equations for correcting the for different uses; whether for normalizing consumption data for a purpose of comparing buildings in different geographical locations, or comparing the same buildings' energy consumptions of different periods and located in the same area. For the analyses of these case-studies buildings, the latter option is chosen.

$$Q_{norm} = \frac{HDD_{average}}{HDD_{current}} * Q_{consu}. + Q_{HotWater} , \tag{2}$$

$$Q_{concu}. = Q_{total} - Q_{HotWater} , \tag{3}$$

$$Q_{hotwater} = 58 \frac{kWh}{m^3} * V_{hot\_water\_consumed} \tag{4}$$

Where,

Q_{norm} is the normalized heating energy consumption (kWh), $Q_{concu.}$ is the heating consumption on space heating of building (kWh), $Q_{\_HotWater}$ is the heating energy utilized on hot water supply (kWh/m^3), $Q_{\_total}$ is the total measured heating energy consumption (kWh), $HDD_{average}$ is the reference average heating degree-days from years 1981-2010, and $HDD_{current}$ is the heating degree-days of the month/year in which consumption has occurred.

There is no measured data for hot water consumption of Eco-Viikki buildings or of the *control* area, therefore a standard estimation [11], 0.6 m^3/m^2, is used in this the present analysis.

4.2 Eco-Viikki buildings' energy consumption

Eco-Viikki electric consumption in 2015 and 2016:

Annual electricity consumption data in year 2015 and 2016 in the 12 case study buildings of Eco-Viikki is illustrated below in Figure 2 and Figure 3.

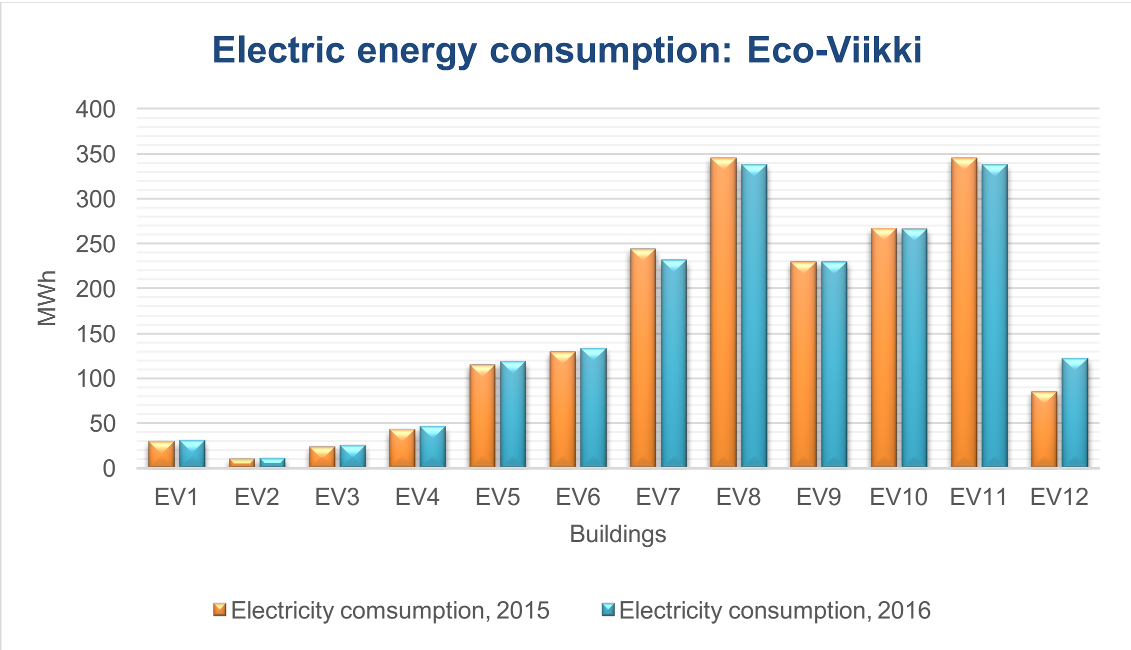

Figure 2 Electricity consumption in the Eco-Viikki case study buildings.

Figure 3 shows a comparison of electricity consumption in the twelve buildings by dividing the total consumption by the total area of the building.

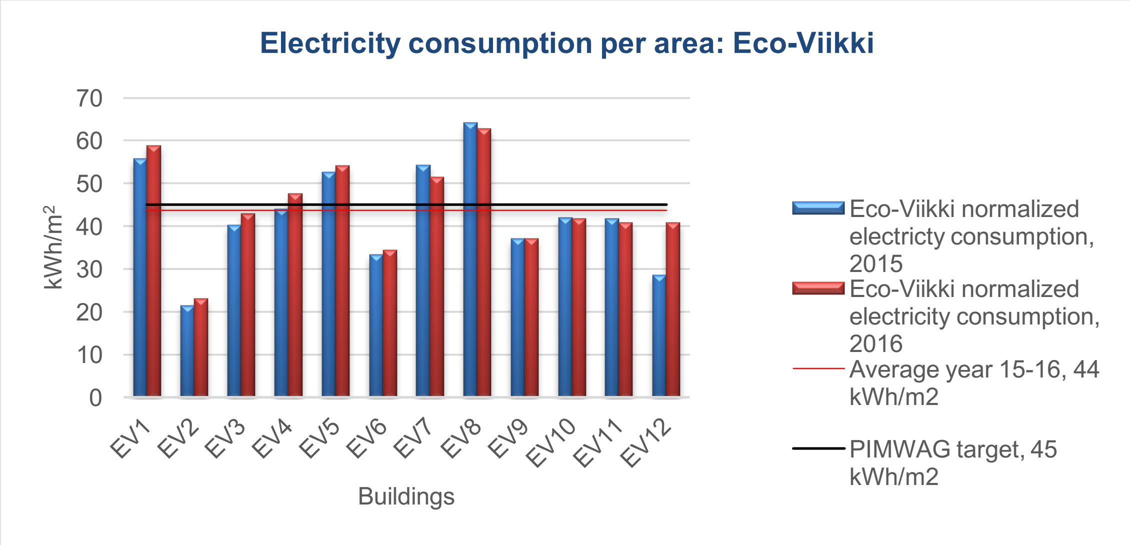

Figure 3 Electricity consumption per area in Eco-Viikki case study buildings.

4.2.1 Heating energy consumption 2002-2003 and 2015-2016

Energy consumption data from years 2002 and 2003 has to be re-normalized again based on recent normalization calculation whereby climatic factor is the ratio of average degree days from 1981-2010 and the degree days of the year whose data is being calculated. Table 8 represents the normalized heating demand data of Eco-Viikki buildings during 2002-2003 and 2015-2016.

Table 8 Annual normalized heating demand values from years 2002-2003 and 2015-2015.

Buildings	Normalized heating demand (kWh/m2), 2002	Normalized heating demand (kWh/m2), 2003	Normalized heating demand (kWh/m2), 2015	Normalized heating demand (kWh/m2), 2016
EV4	115	93	107	106
EV10	138	125	132	121
EV6	136	141	131	140
EV7	101	99	91	94
EV8	102	73	85	87
EV9	102	107	102	99
EV11	120	132	154	150

Figure 4 is a graph illustrating the values that are represented in Table 8, in terms of the demand in 2002-2003.

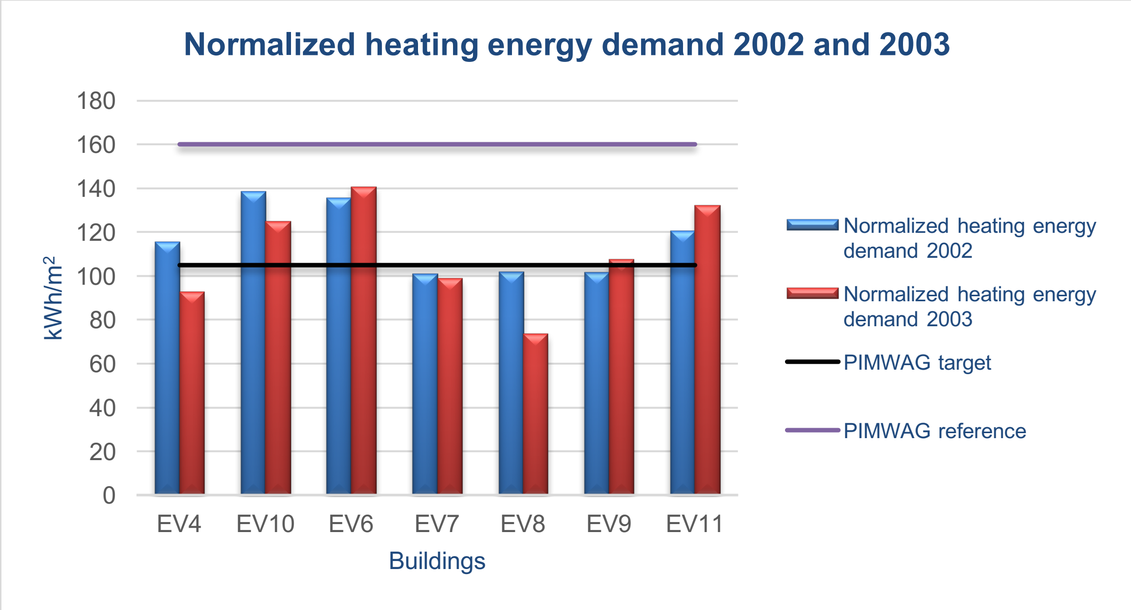

Figure 4 Normalized annual heating consumption in the specified Eco-Viikki in 2002-2003.

Figure 5 is a graph illustrating the values that are represented in Table 8

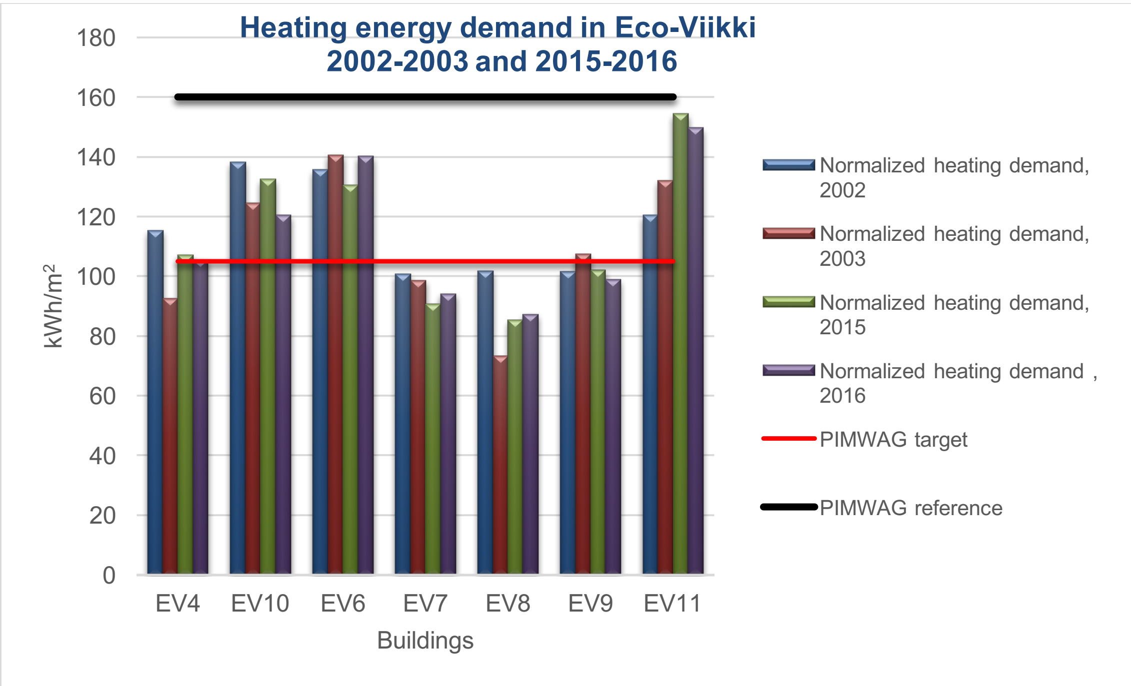

Figure 5 Relationship between normalized heating energy of 2002-2003, and 2015-2016 in Eco-Viikki

Figure 6 illustrates the comparison between the normalized heating energy demand 2015 and 2016. The figure shows only the selected buildings in Eco-Viikki.

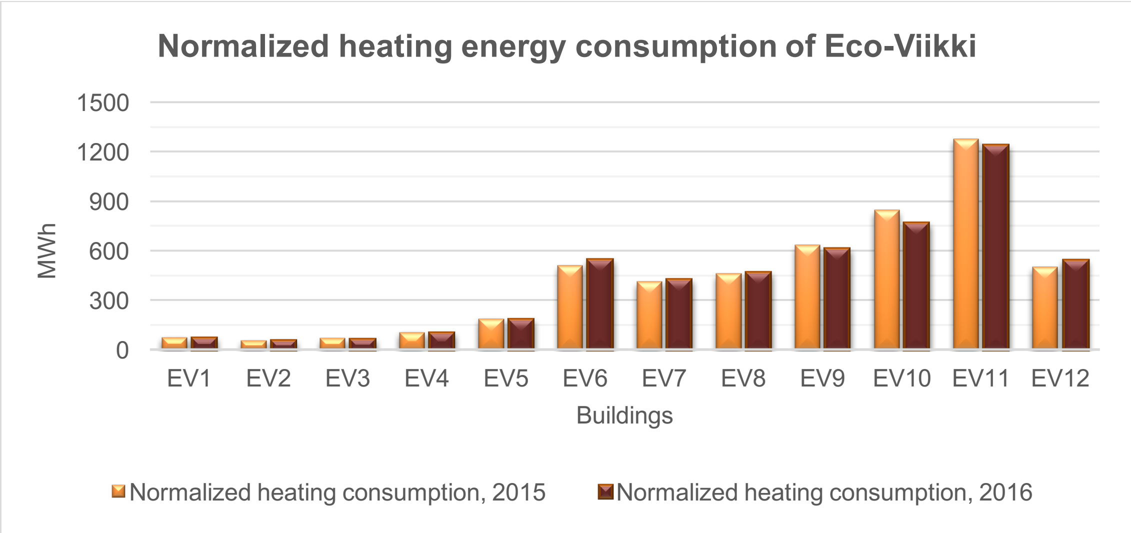

Figure 6 Normalized heating energy consumption of the case-study buildings of Eco-Viikki

According to a report conducted by the city of Helsinki in 2008 [12] the consumption in half of Eco-Viikki buildings have over the top the initial targets set by the city, however *Figure 7* shows that only one-third of the buildings' energy demand is below the initial PIMWAG target, which is 105 kWh/m^2, see Figure 7. Building EV5 (Tilanhoitajankaari 19) has the least consumption in both year 2015 and 2016, 86 kWh/m^2 and 85 kWh/m^2 respectively. Building EV1 appears to have high heating energy consumptions due to its physical characteristics of having large window areas and the smallest area and volume compared to the area's other buildings.

The heating demand of all the buildings are clearly below the reference heating demand, which is 160 kWh/m^2, expect for Building EV12 (Nuppukuja 9). See Graph 5.

The graph below illustrates normalized heating energy demand in 2015 and 2016 in the chosen buildings in Eco-Viikki.

Figure 7 illustrates the normalized heating demands of all the twelve buildings that are included in Eco-Viikki case study. The graph contains the normalized heating energy demand from 2015 and 2016.

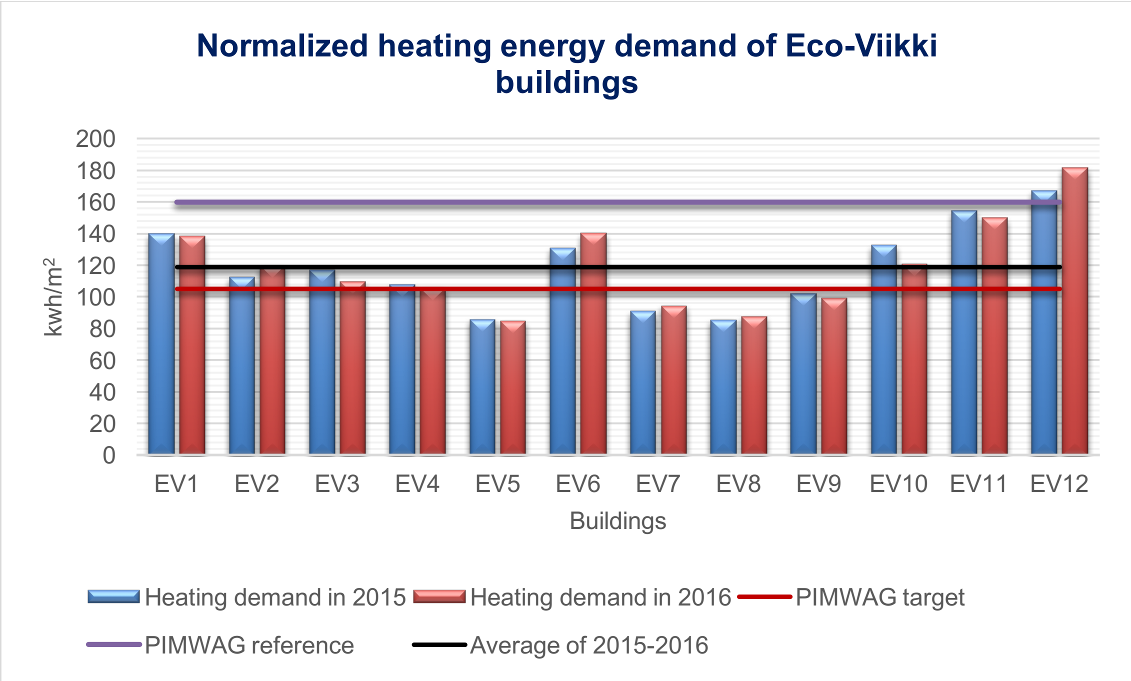

Figure 7 Weather corrected heating demand of all the 12 case-study Eco-Viikki buildings in 2015 and 2016.

4.3 *Control* buildings' heating energy consumption

In this section Hert. buildings' energy consumption is analysed. Figure 8 illustrates the normalized heating demands of all the twelve buildings that are included in *Control* area case study. Figure 8 contains the normalized heating energy consumption from year 2015 and 2016.

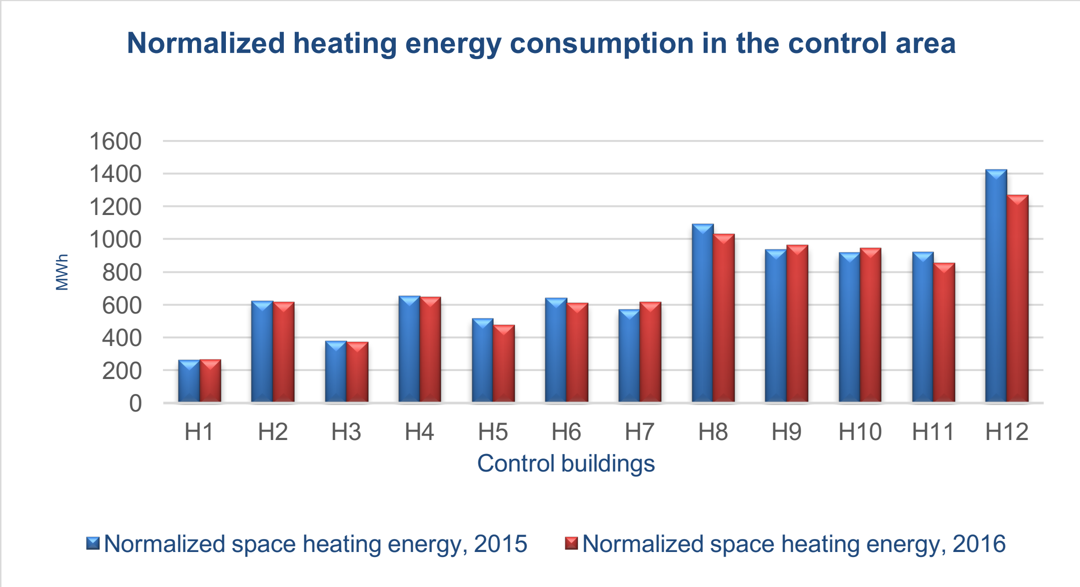

Figure 8 Normalized heating energy consumption of the control building in year 2015 and 2016.

Figure 9 contains the normalized heating energy data of the *control* buildings from year 2015 and 2016.

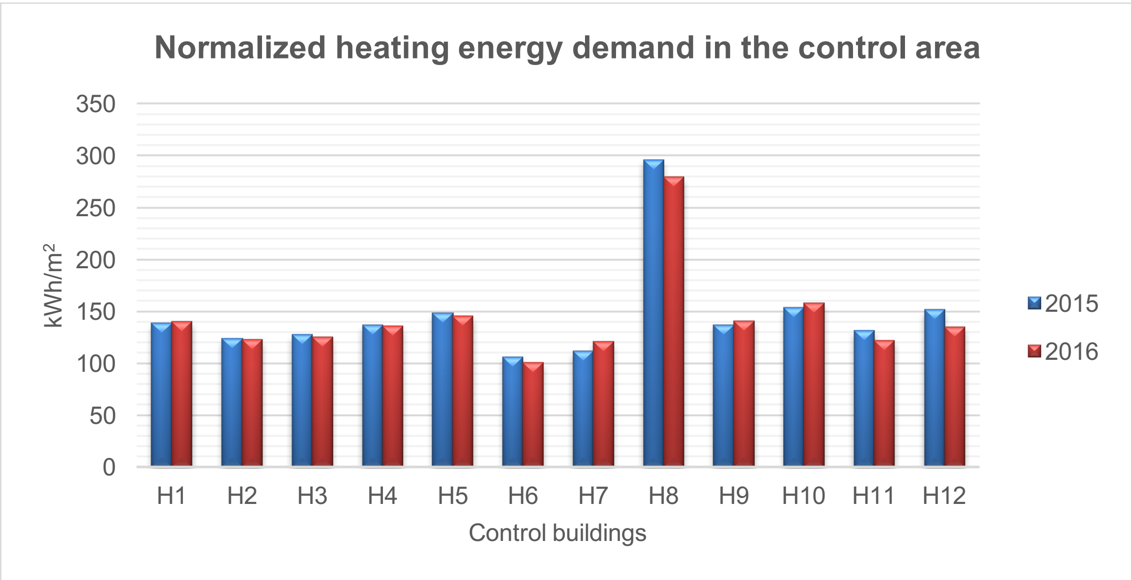

Figure 9 Normalized heating demand of the buildings in the control area.

The normalized values in Figures 4,5, and 6 are found in Appendix 2.

4.4 Comparing heating energy demand

In this section, the comparison between the control Hert. buildings' and Eco-Viikki's buildings' energy consumptions are carried out. Table 9 contains the normalized heating demands of the chosen comparison buildings.

Table 9 Normalized heating energy demand of the comparable buildings of Eco-Viikki and the control area.

Comparison buildings		consumption Herttoniemenranta 2015-2016		consumption Eco-Viikki 2015-2016	
Herttonie-menranta	Eco-Viikki	Heating demand [kWh/m²]	Heating demand [kWh/m²]	Heating demand [kWh/m²]	Heating demand [kWh/m²]
H1	EV4	138	140	107	106
H3	EV5	127	125	86	85
H4	EV6	137	135	131	140
H7	EV7	112	121	91	94
H9	EV8	137	141	85	87
H10	EV9	153	158	102	99
H11	EV10	131	122	132	121
H12	EV11	151	135	154	150

Figure 10 illustrates the annual heating demand in 2015 and 2016 in Eco-Viikki buildings and the Herttoniemenranta *control* buildings (cf. Table 9). The graph shows clearly the energy performance of Eco-Viikki and the *control* area. Although Eco-Viikki performed better the comparison, more than half of its buildings did not achieved the initial Eco-criteria target which is 105 kWh/m

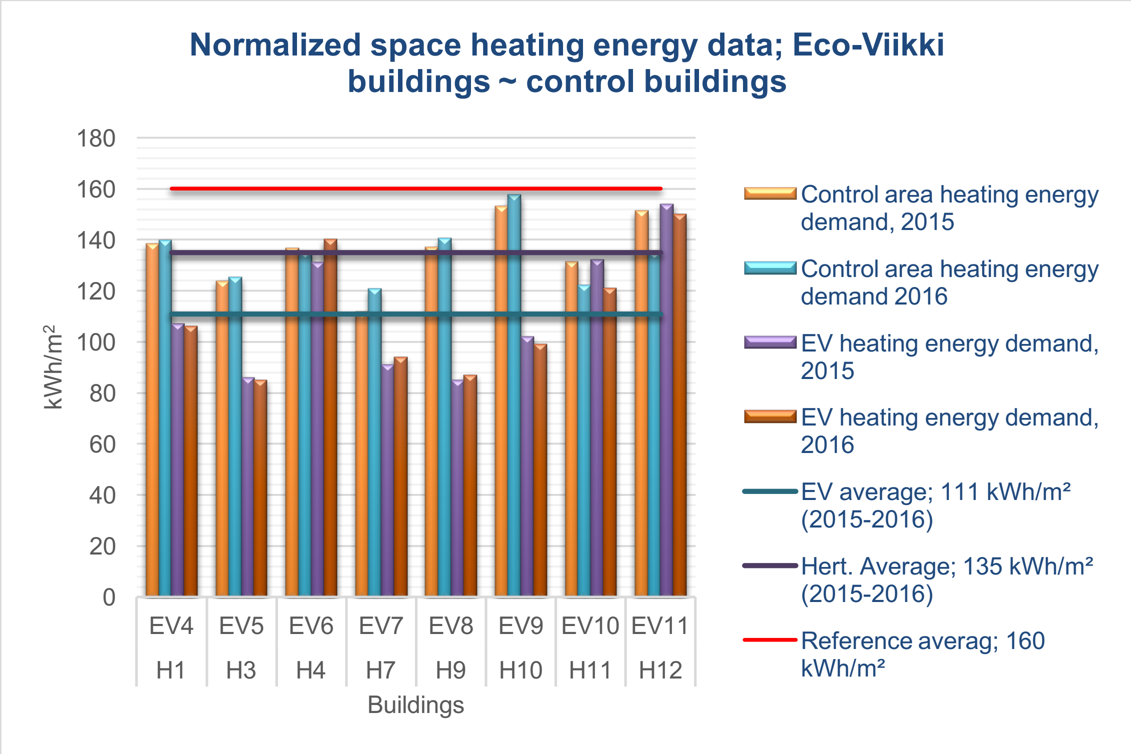

Figure 10 The comparison buildings shown in respect to reference and criteria target values.

4.5 Comparing electricity consumption

Electricity consumption is normalized by dividing the total net consumption by the gross surface area of each of the compared buildings so that energy consumption intensity is obtained and is suitable for comparison.

The initial assumption is that the electricity consumed in all the case-study buildings is utilized on similar purposes such as cooking and electric appliances. Space heating and domestic hot water in all the cases is provided by district heating. Another generally used method for analysing electricity consumption is dividing the consumption value by the volume of the building to obtain a value with kWh/m^3. That parameter can give a poor description of the electric efficiency of the building because it closes out other influences on electric energy consumption. These influences are, for instance the activity of the residents and the numbers of electric appliances in the building. These limitations are as well relevant when using the intensity parameter (kWh/m^2); however, in this report they are negligible since the focus is not on rating the electric efficiency of the building, but rather comparing energy performance of the two comparable buildings.

Table 10 contains the values of electricity intensity of the chosen comparison buildings in a two-year time interval, 2015 and 2016.

Table 10 Electricity intensity of the comparable buildings of Eco-Viikki and the control area

		control area		Eco-Viikki			
Herttoniemenranta	Eco-Viikki	Electricity intensity, 2015 [kWh/m²]	Electricity intensity, 2015 [kWh/m²]	Electricity intensity, 2015 [kWh/m²]	Electricity intensity, 2015 [kWh/m²]	Hert. average (2015-2016)	EV average (2015-2016)
H1	EV4	31	34	44	47	44	46
H3	EV5	95	86	53	54		
H4	EV6	47	47	33	34		
H7	EV7	35	34	54	51		
H9	EV8	34	35	64	63		
H10	EV9	33	32	37	37		
H11	EV10	38	37	42	42		
H12	EV11	39	40	42	41		

It is noticeable, in Figure 11, that there is no dramatic change in consumption values within the same building consumptions in the specified years. As it shows in Table 10 the electric energy savings occurred the most in year 2015, in the both case study residential areas. The interesting fact is that Herttoniemenranta *control* buildings' average electric energy consumption is significantly efficient compared to Eco-Viikki in both of the year, 2015 and 2016. Average electricity consumption in Eco-Viikki is 48 kWh/m^2 and 49 kWh/m^2 in 2015 and 2016, respectively. While Herttoniemenranta control building's average consumption was 44 kWh/m^2 and 43 kWh/ m^2 in year 2015 and 2016, respectively.

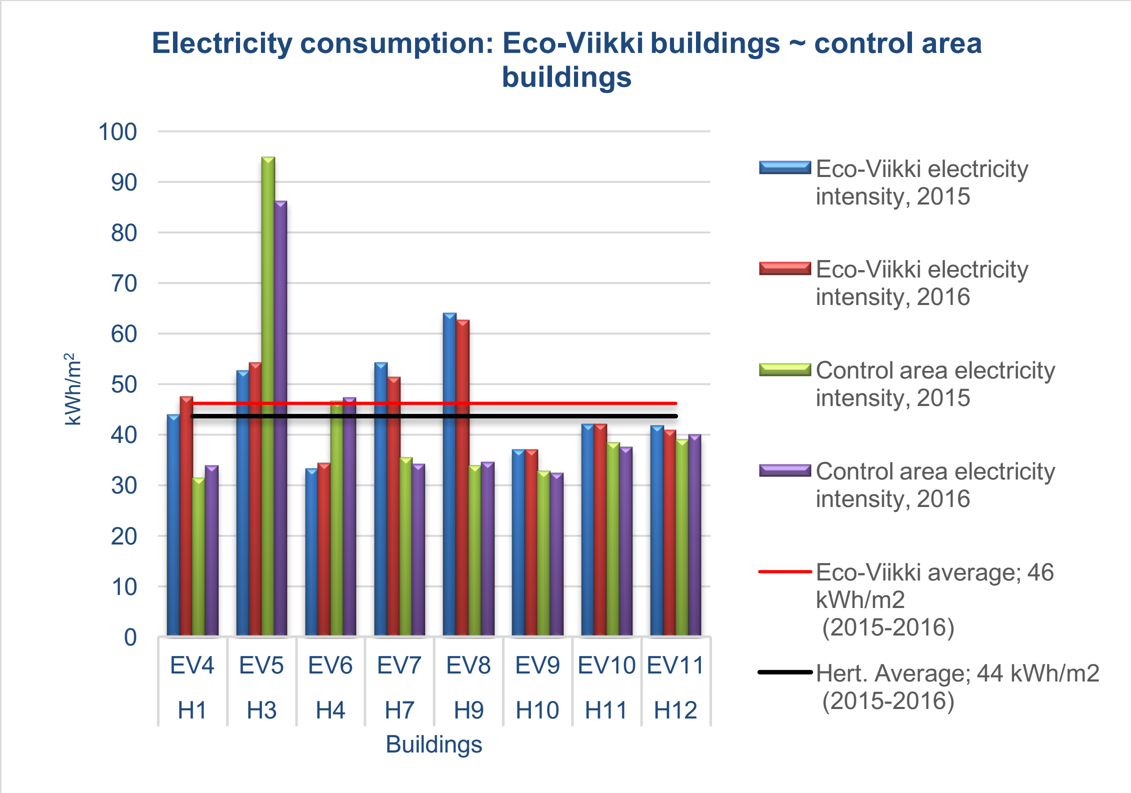

Figure 11 Electric energy consumptions in the both, Eco-Viikki and Herttoniemenranta buildings.

The electricity consumption is influenced by several parameters, such as the design criteria and the level of activity of the occupants themselves. Usually the most relevant parameter affecting the consumption is identified to be the latter one. Therefore, the aforementioned factors are constraints for drawing an accurate conclusion since they are not taken into considerations in this analysis due to the lack of the required data.

Also, it is essential to mention that larger floor areas are generally associated with a higher electricity consumption [13].

5 Statistical analysis of the consumption data

5.1 Results of statistical analysis of consumption data of 2002-2003, 2015-2016 in Eco-Viikki

In this section, the results obtained from the statistical analysis method used to identify whether there is no statistically significant difference between heating energy consumptions from years 2002-2003 and the data from years 2015-2016, is represented.
The size of the dataset is very small, which means non-parametric method is suitable as testing method. For this purpose, the two-sample Mann-Whitney U test was used. The test is run with null hypothesis that there is not difference in the normalized heating energy consumption values of year 2002-2003 and 2015-2016. The test yielded a p-value as 0.4688 which is great (i.e. >0.05), and that indicates that there is a statistical significant evidence that heating demands of years 2002 and 2003 deviate from heating demands of years 2015 and 2016. Arithmetic means of values from 2002-2003 were used as one set of observations, similarly to the case of consumption values of 2015 and 2016.

5.2 Correlations between electricity and heating energy consumption in Eco-Viikki

The aim of this section was to graphically illustrate possible correlations between the two energy consumption parameters: electricity consumption and district heating energy consumption. The left-hand side graph in Figure 12 shows a linear regression line between the two parameters and a positive correlation. The plotted data points are of 192 different observations from the 8 Eco-Viikki buildings are presented in *Table 8.* Simply, the data are measurements of 2015 and 2016 on monthly basis. All the measurements are independent and of different buildings, but are plotted in Figure 13 to show the correlation degree between the total district heating energy consumption and electricity in the area. Figure 13 gives explicit graphical presentations of each of the Eco-Viikki building of consumption is being studied.

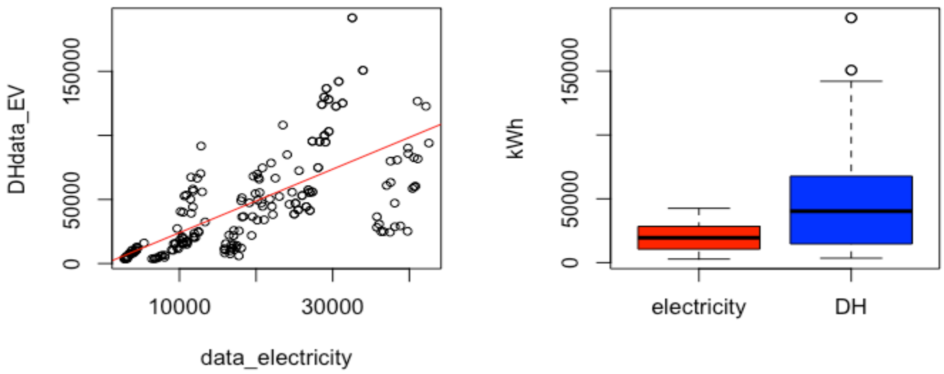

Figure 12 Linearity of the consumption data of Eco-Viikki in 2015-2016.

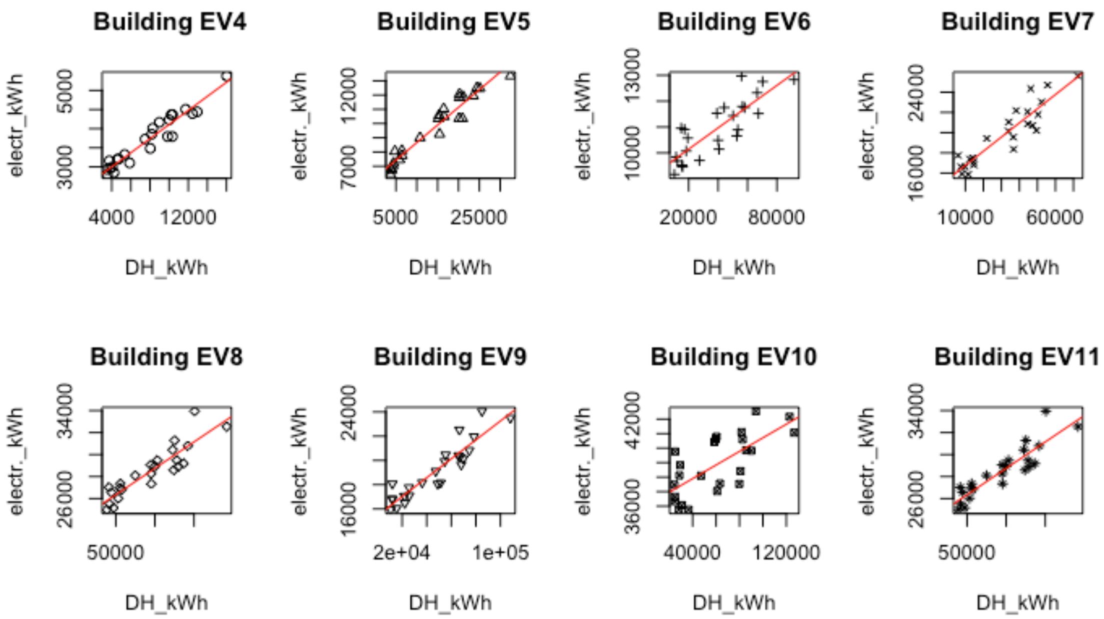

Figure 13 Linear regressions of the 8 Eco-Viikki buildings. There is a strong correlation between energy consumptions in the buildings regardless of independencies of the two variables.

In fact, the correlation seen in the above figures could be simply because the building's characteristics did not change over the data collections period of time. These characteristics could be, for instance, physical dwellings and occupants' characteristics, similarities of efficiency of energy solution.

Figure 14 shows the behaviour in energy consumption of building EV6 throughout the year. The two upper curves (blue and black) are representations of heating energy consumption in 2015 and 2016, and the two lower lines (red and black) are representations of electricity consumption of 2015 and 2016. The monthly basis data is not normalized because of the lacking in an estimation of the heating energy consumed on heating domestic hot water.

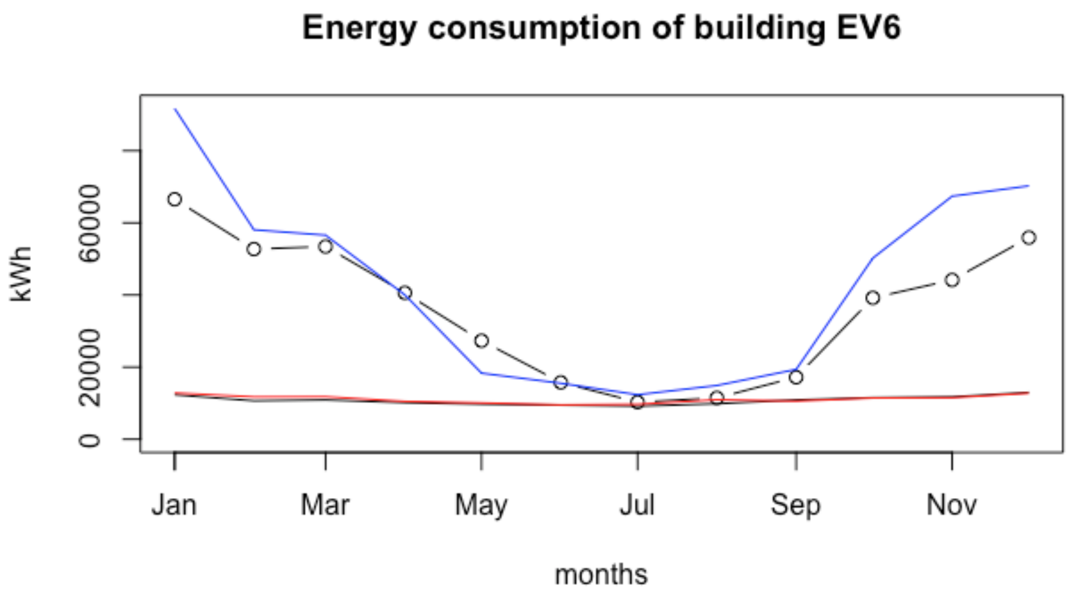

Figure 14 Annualized energy consumption of building EV6 illustrated in scatter lines. The two upper curves show heating energy consumption in year 2015 and 2016. The lower lines, red and black are illustrating data electrical energy consumption from the mentioned period of time.

5.3 Statistical analysis of electricity consumption between Eco-Viikki and the *control* area

The Student's *t* test was chosen for the specified data. The *t* test is rather the best option for the dataset since it determines whether the two independent variables vary significantly from each other or not, as of the *p* value. The p-value indicates how probably the "data-extremes" are observed.

The dependent variables are monthly electricity consumption measurements of Eco-Viikki within an interval of two years, 2015 and 2016. The values are normalized with respect to total area, meaning kWh/m^2. Similar approach was done to the consumption values of the *control* area, Herttoniemenranta buildings.

Details of the data:

Observations	Variables
192	2

Statistical test was run on R and by obtaining a p-value of 0.0003428, confidently the null hypothesis is rejected. The null hypothesis claims that the mean electricity consumption data of Eco-Viikki buildings is equal to the mean electric consumption data of the values from Hert. buildings. Thus, concluding that there is statistically significant difference in the data consumption obtained from the both areas.

In fact, similar conclusion is observed when viewing the results in Figure 9 where the average electricity consumption in Eco-Viikki is 48 kWh/m^2 and 49 kWh/m^2 in years 2015 and 2016, respectively. While Herttoniemenranta buildings have average consumption as 44 kWh/m^2 and 43 kWh/m^2 in years 2015 and 2016, respectively. Although the *t* test analysis was carried out on monthly basis data measurements and not on yearly basis as in Figure 12, still the normalized mean from Herttoniemenranta buildings is 13% lower. The means are 3.63 kWh/m^2 and 4.17 kWh/m^2 for the *control* area and Eco-Viikki, respectively, for monthly consumptions.

6 Water consumption data

In this section, water consumption of seven Eco-Viikki buildings are analysed. Water consumption data is analysed based on annualized consumption of each building within 13 years of consumption. The normalization per capita method is cut out due to the lack data regarding the number of residents.

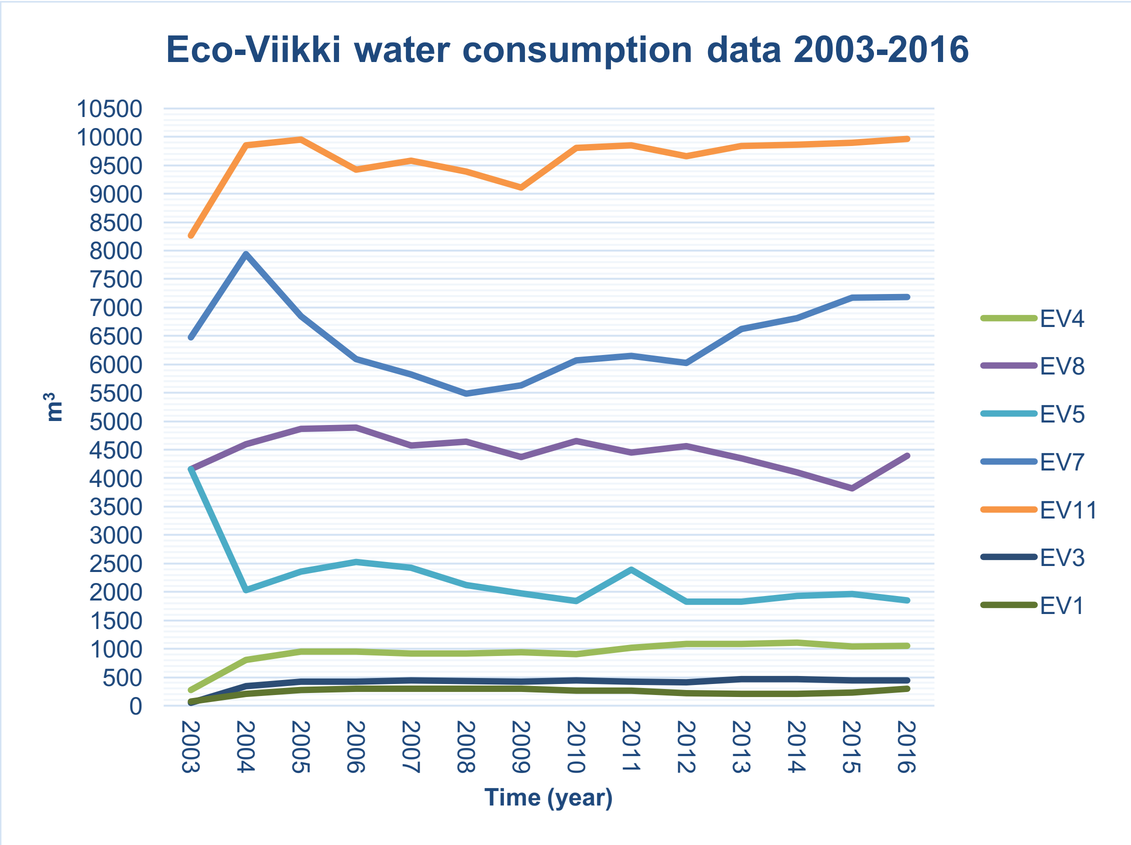

Figure 15 Water consumption measurements from 7 Eco-Viikki buildings within an interval of 13 years.

The above graph (*Figure 13*) illustrates annualized water consumption of the seven buildings in cubic meters. Here, there is substantial deviations between buildings water consumptions is noticeable and that could be explained with facts like the differences in buildings' sizes, thus difference amounts of residents occupying them. Also, there is a decreasing trend in consumption between year 2006 to 2008. This could be explained either by the decrease in the number of residents or/and introduction of new efficient water saving solutions and systems in the buildings. Considering building EV4, the largest building, naturally it will have a higher water consumption.

The comparison between consumption quantity in Building EV7 (Tilanhoitajankaari 20) and Building EV8 (Tilanhoitajankaari 18) is worth noticing. Building EV7 has 11 less dwellings and is 16% smaller in area compared to Building EV8, yet 45% more water consumption.

The variation of consumptions of smaller-sized and owner-occupied buildings are observed to be rather stable in comparison to buildings of rental dwellings, see Table 5.

7 Discussion and conclusion

Consumption data was relatively small in size to draw accurately strong statistical conclusion on heating energy consumption. However, the test results from comparing consumption data of Eco-Viikki seven buildings' from two periods' (2002-2003 and 2015-2016), indicate that there is statistical change in the values. On the other hand, Eco-Viikki heating energy performances in 2015 and 2016 shows to be better than those of the *control* area. However, more than half of the Eco-Viikki buildings which are represented in this analysis did not achieve the initial PIMWAG Eco-criteria for heating demand target (105 kWh/m^2). Interestingly, the correlation between the two energy consumption variables: heating consumption and electricity consumption of Eco-Viikki. The data was shown to be linearly dependant yielding an adjusted R-squared between 0.7 - 0.96 for the studied buildings' consumptions. The regression shows that the both variable values increase and decrease at the same time. This behaviour could be explained considering the changes in climatic seasons; in winter households use more heating and electricity, while less energy in summer and brighter seasons in Finland. There is no observation of possible effect of electricity consumption on heating energy consumption. For instance, no decrease in heating consumption when an increase in electric consumption occur –i.e. due to possible heat gain from household electric appliances.

For future analysis, the influences of internal heat gain parameters, such as electric appliances, solar radiation and occupants, on heating consumption of the building could be studied. For that analysis a compile data containing aforementioned parameters is required, in case of statistical analysis.

The statistical *t* test carried out between the consumption data of Eco-Viikki and the *control* area Herttoniemenranta shows that there is significant difference in the mean electric energy consumption of the two area. The analysed data was normalized with respect to the total area showing that Eco-Viikki consumes an average of 13% more electricity than the *control* area. Important to mention that parameters affecting electricity consumption were not counted while conducting this test. Future studies could be analysis on possible parameters which are influencing Eco-Viikki electricity consumption.

Regardless of dwellings numbers, rental buildings are showing a higher annual water consumption compared to owner-occupied buildings, as in the case of Building EV7 (Tilanhoitajankaari 20).

The aim of this thesis analysis was to provide an insight of energy performance of Eco-Viikki in regard to urban sustainability transformation. The comparison of Eco-Viikki and the *control* area shows that substantial adjustment and efficiency improvement are required for Eco-Viikki to achieve its initial ecological criteria targets and to notably deviate from energy performances of nowadays "conventionally" constructed buildings.

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Appendix 1: Eco-Viikki energy consumption data 2015-2016

*Monthly electricity consumption of Building EV10 is the total consumption by the households and the grocery store in the building.

	Consumption data kWh/month									
Addresses ->	Norkkokuja 3	Norkkokuja 4	Norkkokuja 3 ja 4	Norkkokuja 10			Tilanhoitajankaari 19		Versokuja 6	
2015	Electricity	Electricity	District Heating	Electricity	District Heating	Lighting	Electricity	District Heating	Electricity	District Heating
Jan-15	31639	10909	94010	4440	12940	73	12467	25120	2660	10087
Feb-15	28002	9530	79900	3795	9840	57	10360	20130	2275	7725
Mar-15	30469	10635	81700	3794	10340	61	10355	20940	2517	7287
Apr-15	27924	9639	63300	3483	8030	51	9257	15460	2291	5026
May-15	28690	9404	47150	3102	5870	49	9002	10770	2042	3350
Jun-15	27589	8479	30800	2850	4230	48	7461	5830	1454	2126
Jul-15	27497	8833	24900	2803	3530	49	7004	4210	1201	1404
Aug-15	27842	8801	24920	2967	3810	50	7212	4430	1348	1409
Sep-15	29433	9395	29360	3324	5350	49	8103	6440	1479	2329
Oct-15	30164	10258	58540	3854	8180	54	10574	15340	1903	4980
Nov-15	30058	10576	59800	4009	8290	54	11032	16440	2104	5977
Dec-15	29949	11116	126680	4365	10220	60	12070	20250	2415	7749
2016										
Jan-16	31528	10637	122723	5378	16020	78	13342	32440	3248	12995
Feb-16	28337	10081	80830	4365	10360	66	11877	21160	2856	7116
Mar-16	29697	10903	82670	4231	10010	63	11824	20230	2696	6680
Apr-16	26992	10045	60910	3727	7490	49	10353	15200	2135	4563
May-16	26543	9222	36530	3198	4600	49	7748	6450	1515	1807
Jun-16	27056	8700	28230	2995	4040	47	6733	3940	1393	1634
Jul-16	28514	8967	24430	2932	3490	49	6424	3730	1196	1160
Aug-16	30210	9556	25160	3162	3750	49	6822	3880	1461	1513
Sep-16	28500	9617	28700	3209	4710	47	8053	4750	1528	2137
Oct-16	30035	10761	60400	4165	8980	50	10491	16560	1880	5516
Nov-16	29397	10453	85770	4506	11730	66	11939	23540	2561	8091
Dec-16	28695	11126	90210	4395	12450	70	12503	24420	2844	8172

	Consumption data kWh/month							
Addresses ->	Versokuja 9		Versokuja 10		Tilanhoitajankaari 18		Tilanhoitajankaari 20	
2015	Electricity	District Heating	Electricity	District Heating	Electricity	District Heating	Electricity	District Heating
Jan-15	2861	9087	1178	6643	30653	64375	24702	55684
Feb-15	2430	7345	964	5121	24925	50034	20858	44653
Mar-15	2618	7278	719	4593	26277	49600	22062	44525
Apr-15	2946	5313	794	3955	22752	37776	20157	33890
May-15	1938	3957	761	3023	21382	25314	19423	21900
Jun-15	1534	2560	716	2367	17107	14621	17382	12493
Jul-15	1965	1506	680	2076	15208	10943	16627	7522
Aug-15	2123	1769	782	2319	17637	12440	17743	5981
Sep-15	2177	3099	800	2390	20727	15812	17503	14115
Oct-15	2494	6147	864	3672	25092	35874	21049	34096
Nov-15	2686	6421	929	4378	26783	40058	22183	38185
Dec-15	3278	7668	1022	5853	29246	48755	24348	46251
2016								
Jan-16	3660	11651	1108	9739	33962	82418	25608	72471
Feb-16	2956	7766	842	6091	26539	52259	20212	49465
Mar-16	2933	7424	786	5461	27090	49942	20712	47281
Apr-16	2496	5670	788	3842	24599	36608	18358	36765
May-16	2153	2645	723	2386	20552	17583	17099	14642
Jun-16	2091	2041	731	2301	17711	11339	15864	11612
Jul-16	1152	1371	773	2172	15466	10245	15915	8168
Aug-16	2168	1918	886	2401	18224	11707	16614	9900
Sep-16	2222	3087	897	2507	19430	17748	16791	14660
Oct-16	2643	6525	991	4429	25048	41488	19547	36604
Nov-16	3032	8807	1220	6308	28120	58266	21783	50369
Dec-16	3137	9092	1199	6336	29286	59325	23034	52326

	Consumption data kWh/month							
Addresses ->	Tilanhoitajankaari 22		Tilanhoitajankaari 28		Tilanhoitajankaari 30		Nuppukuja 9	
2015	Electricity	District Heating	Electricity	District Heating	Electricity	District Heating	Electricity	District Heating
Jan-15	24059	84977	33945	150788	12324	66537	1334	60220
Feb-15	19651	68105	28590	124096	10657	52729	10663	49660
Mar-15	20401	65791	30429	122706	10894	53436	1159	50170
Apr-15	18158	51328	28268	95107	10143	40602	9523	41040
May-15	18177	36298	28096	74826	9707	27312	9193	32150
Jun-15	16478	22194	26014	53068	9458	15758	7987	14970
Jul-15	16055	15535	25497	41859	9166	10284	823	14250
Aug-15	16806	12073	27020	41352	9843	11463	8577	14410
Sep-15	17772	25535	27346	55877	10907	17187	9725	15140
Oct-15	19113	47369	29059	94797	11533	39201	1121	37010
Nov-15	20465	55383	29481	103091	11752	44159	11582	43790
Dec-15	22518	66617	31286	125218	12974	55919	13559	49470
2016								
Jan-16	23500	108094	32544	191744	12830	91699	14897	79130
Feb-16	20153	69770	28906	129911	11752	58081	11580	51100
Mar-16	20294	67103	29477	128095	11794	56586	11784	50110
Apr-16	18056	48973	27342	95424	10486	40038	10468	37510
May-16	17058	21756	26814	57507	10071	18322	8769	20940
Jun-16	16830	11934	25144	47090	9521	15516	8266	16350
Jul-16	15936	10656	24987	38593	9685	12341	865	13480
Aug-16	18073	12092	26555	44348	10953	14901	8902	15627
Sep-16	17100	25843	26975	55563	10572	19360	9336	20044
Oct-16	19921	54589	28931	99994	11435	50230	11249	40113
Nov-16	20834	74669	29186	136659	11521	67388	12426	55479
Dec-16	21961	78445	30788	142093	12755	70253	13508	57417

Appendix 2: Normalized heating demand of both Eco-Viikki and the control area in 2015-2016.

Year	Eco-Viikki Building	Case-study code	Year of construction	Number of dwellings	Gross area m2	Heating energy consumption kWh	Normalized heating energy kWh	heating demand kWh/m2	Electricity kWh	Intensity electricity kWh/m2
2015	Versokuja 9	EV1	Oct-02	4	521.5	62150	72875	140	29049	56
	Versokuja 10	EV2	Aug-04	2	477	46390	52701	110	10209	21
	Versokuja 6	EV3	Nov-03	4	590	59449	68740	117	23688	40
	Norkkokuja 10	EV4	May-01	9	974	90630	104459	107	42786	44
	Tilanhoitajankaari 19	EV5	Mar-02	23	2182	165360	187157	86	114898	53
	Tilanhoitajankaari 30	EV6	Sep-00	38	3889	434587	507528	131	129357	33
	Tilanhoitajankaari 20	EV7	Apr-00	44	4505	359295	408659	91	244036	54
	Tilanhoitajankaari 18	EV8	Aug-01	55	5384	405602	458797	85	345031	64
	Tilanhoitajankaari 22	EV9	Oct-00	63	6209	551205	632892	102	229654	37
	Norkkokuja 3, 4	EV10	Jan-01	61	6364	721060	842834	132	266832	42
	Tilanhoitajankaari 28	EV11	Sep-00	87	8265	1082785	1276603	154	345031	42
	Nuppukuja 9	EV12		21	2996	422280	499796	167	85246	28
2016	Versokuja 9	EV1	Oct-02	4	521.5	67997	72011	138	30643	59
	Versokuja 10	EV2	Aug-04	2	477	53973	56669	119	10945	23
	Versokuja 6	EV3	Nov-03	4	590	61384	64609	110	25311	43
	Norkkokuja 10	EV4	May-01	9	974	97630	102762	106	46264	47
	Tilanhoitajankaari 19	EV5	Mar-02	23	2182	176300	184382	85	118110	54
	Tilanhoitajankaari 30	EV6	Sep-00	38	3889	514715	545264	140	133377	34
	Tilanhoitajankaari 20	EV7	Apr-00	44	4505	404263	424192	94	231538	51
	Tilanhoitajankaari 18	EV8	Aug-01	55	5384	448928	469990	87	337649	63
	Tilanhoitajankaari 22	EV9	Oct-00	63	6209	583924	613545	99	229718	37
	Norkkokuja 3, 4	EV10	Jan-01	61	6364	726563	767235	121	265571	42
	Tilanhoitajankaari 28	EV11	Sep-00	87	8265	1167021	1237834	150	337649	41
	Nuppukuja 9	EV12		21	2996	457300	543352	181	122050	41

Year	Case-study code	Heating energy consumption, kWh	Normalized heating energy, MWh	heating demand, kWh/m2	Electricity, kWh	Intensity of electricity kWh/m2
2015	H1	222233	260	138	59	31
	H2	532434	620	124	194	39
	H3	321980	375	127	280	95
	H4	555599	651	137	222	47
	H5	436649	514	148	124	36
	H6	555430	640	106	208	34
	H7	492249	569	112	180	35
	H8	901990	1091	296	276	75
	H9	799370	936	137	231	34
	H10	777760	917	153	196	33
	H11	786100	918	131	268	38
	H12	1206700	1421	151	366	39
2016						
	H1	248643	263	140	63	34
	H2	580971	614	123	184	37
	H3	349710	370	125	255	86
	H4	609510	645	135	225	47
	H5	447543	474	146	121	37
	H6	577820	607	101	203	34
	H7	582854	616	121	174	34
	H8	963070	1030	279	275	75
	H9	906500	960	141	**236**	35
	H10	887968	943	158	194	32
	H11	807580	853	122	262	37
	H12	1197900	1268	135	375	40

Appendix 3: The summary of the conducted t test between electricity data of Eco-Viikki and control ar

```
data:  Hert_electricity_norm and EV_electricity_norm
t = -3.617, df = 342.44, p-value = 0.0003428
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.8307021 -0.2454813
sample estimates:
mean of x mean of y
 3.634988  4.173079
```

Appendix 2