Project Acronym: cRRescendo
REF EC: FP6-513563
Deliverable number: A4.1 and 4.2
Deliverable name: Monitoring and Research Report
Lead participant: Ecofys

Report
Public
Participant: Ecofys

Deliverable 4.1 and 4.2 Monitoring and Research Report Demonstration Almere

CONCERTO INITIATIVE
cRRescendo

Combined Rational and Renewable Energy Strategies in Cities, for Existing and New Dwellings and Optimal quality of life

Instrument: Integrated Project
Thematic Priority: Integrating and Strengthening the European Research Area (2002-2006), Sustainable Energy Systems

Date: July 2012
Authors: Antonin G. van de Bree, Lou Ramaekers, A. Nesen Surmeli

CONCERTO is co-funded by the European Commission

(BACKSIDE FRONTPAGE)

A4.1/2 Monitoring and Research Report Demonstration Project Almere

ECOFYS Netherlands B.V. | Kanaalweg 15G | NL-3526 KL Utrecht| T +31 (0)30 662 33 00 | F +31 (0)30 662 33 01 | E info@ecofys.nl | I www.ecofys.com

A4.1/2 Monitoring and Research Report Demonstration Project Almere

- Confidential –

By: A.G. van de Bree, L. Ramaekers, A. N. Surmeli
Date: 31 July 2012

Project number: BENNL10043

Summary

The demonstration of two sustainable communities in Almere as part of the cRRescendo-project within the European Concerto-program was followed by a mandatory monitoring of the energy performance of both communities. The development process of the two areas was quite different. This is also reflected in the results of the monitoring. The differences can be found in various reports related to the project and are only briefly addressed in this report. The mandatory monitoring is combined with research activities on the characteristics and behaviour of elements related to energy use. Synergy was found in monitoring and research activities: monitoring data is the basis for research and research improved the accuracy and reliability of the monitoring results.

The project-proposal stated minimum requirements to monitor all buildings and all energy flows. This turned out to be unrealistic for over 2000 dwellings. A different approach focused more on establishing a good image of the energy-use "to produce well monitored field experience of energy supply and demand patterns to be communicated for the benefit of other CONCERTO projects and serve as a basis for future actions" as stated in the CONCERTO-program. The monitoring plan for Almere uses multiple data sources sometimes even for the same energy flow and looks at various levels (community area, sub-station area, building, equipment) with various frequencies of data collection. All data is stored in a single database with a common framework for corrections, intra- or extrapolation and timestamp. The data sources range from manual recording (for large numbers of dwellings) to automated reading (for high frequencies of data collection). Frequencies vary from yearly (for most dwellings) to each 5 minutes (for the Solar Island). Weather data required for normalisation was obtained from nearby official weather stations. Also characteristics of the buildings and the number of occupants is collected in order to relate energy use to them.

The monitoring concerns the communities "Noorderplassen-west" (NPW) in the north and "Columbuskwartier" (CK) in the west. Both communities differ in size. NPW is the largest community with about 1500 dwellings while CK has about 700 dwellings. CK has a higher ambition on energy saving compared to NPW. Three qualities of energy performance in dwellings are distinguished in each community: Eco Houses, Solar Houses and Passive Houses in order of increasing ambition. Solar Houses are mainly found in CK. Passive Houses are exclusively found in CK. CK contains also one Energy Zero House. Solar Houses and Passive Houses are equipped with PV systems. The PV systems on dwellings are standardised to 14 modules of 75 W_P CIS-technology with some exceptions. The total amount of installed PV-systems is 518 KW_P. NPW contains a Solar Island, a large field of 520 coupled solar collectors with a total aperture area of 7135 m^2 who supply renewable heat to the primary grid of the district heating of Almere.

Table 1 - Characteristics of Eco Houses (only single family dwellings) according to the cRRescendo-proposal and the actual commissioned values.

Average values	Unit	Columbuskwartier		Noorderplassen-west	
		Proposal*	Commissioned	Proposal*	Commissioned
EPC	--	0.80	0.80	0.90	0.90
Floor area	m^2	130	183	117	182
Façade insulation	m^2K/W	3.85	3.74	3.85	3.16
Window transmittance	W/m^2K	1.71	1.64	1.71	1.58
Roof insulation	m^2K/W	3.85	3.94	3.85	3.41
Floor insulation	m^2K/W	3.25	3.96	3.25	3.20
Ventilation	dm^3/sm^2	1.00	0.83	1.00	1.03

Note:
(1)*Proposal values reflect all data set and not only values for monitored buildings.

Table 2 - Characteristics of Solar Houses (only single family dwellings) according to the cRRescendo-proposal and the actual commissioned values.

Average values	Unit	Columbuskwartier		Noorderplassen-west	
		Proposal*	Commissioned	Proposal*	Commissioned
EPC	--	0.75	0.60	0.75	0.71
Floor area	m^2	111	140	116	171
Façade insulation	m^2K/W	3.85	4.07	3.85	3.17
Window transmittance	W/m^2K	1.71	1.62	1.71	1.67
Roof insulation	m^2K/W	3.85	4.96	3.85	4.79
Floor insulation	m^2K/W	3.25	4.98	3.25	3.22
Ventilation	dm^3/sm^2	1.00	0.95	1.00	0.92

Note:
(1) * Proposal values reflect all data set and not only values for monitored buildings.
(2) In NPW, solar houses are the ECO-houses satisfying energy performance of SH (EPC<0,75). However, they do not comply with the other requirements of SH certification.

Table 3 - Characteristics of Passive Houses (only single family dwellings) according to the cRRescendo-proposal and the actual commissioned values.

Average Values for Passive Houses	Unit	Columbuskwartier		Noorderplassen-West	
		Proposal*	Commissioned	Proposal	Commissioned
EPC	--	0.30	0.35	--	--
Floor area	m^2	112	107	--	--
Façade Insulation	m^2K/W	3.85	7.58	--	--
Window transmittance	W/m^2K	1.71	0.85	--	--
Roof Insulation	m^2K/W	3.85	9.50	--	--
Floor Insulation	m^2K/W	3.25	5.09	--	--
Ventilation	dm^3/sm^2	1	0.18	--	--

Note:
(1) * Proposal values reflect all data set and not only values for monitored buildings.

Domestic hot water (DHW) use is important for accurate analysis but is hardly measured due to the lack of separate meters. So, DHW had to be estimated in most cases. To this end the method described in the Dutch standard NEN 7120 was adopted. This method estimates the DHW use based on the number of occupants which is based on the amount of (usable) floor area. The exact relation between the number of occupants and the (usable) floor area of the dwellings is determined for both communities. For CK this relation differs significantly from the standard. Although all occupants had the opportunity to relay their monthly energy-use through the internet, most did not. Therefore a more active approach was planned. Once a year households were visited by trained people to gather their meter readings. This was done for three consecutive years and resulted in the collection of the energy-use of almost 600 households or about 30% of all households. Interpolation to monthly energy use for heating and normalization depends on actual heating degree days and, in particular, on related weight factors that take into account the contribution of passive solar. The hypothesis was that contribution of passive solar in energy efficient dwellings is significant in assessment of heating demand for the purpose of this study and existing weight factors would not reflect this relation due to the fact that historically they are based on total energy use including the ones for DHW and cooking. Heat is only delivered for heating and DHW and in Almere in cases of a CTW-system only for heating. A study on this subject resulted in a new set of weight factors for heating degree days in energy efficient dwellings as well as a small shift in time. A slightly different set of four (instead of three) weight factors for the heating part only was used to even analyse the specific situation more accurately.

Table 4 – Comparison of the traditional weight factors (for total heat consumption) and reassessed weight factors (for space heating only) for heating degree days.

Month	Traditional weight factors	Month	Reassessed weight factors (for heating only)
April to September	0.80	April to October	0.70
October and March	1.00	November and March	1.00
December to February	1.10	December to February	1.30

In order to strengthen the basis of the analysis, an extensive set of formulas was composed for processing, correcting and normalizing the collected data prior to the aggregation of data and the calculation of the various ratios. This work also included a description of the method to take into account the growth of the number of dwellings and occupants in both areas. This is especially of interest for assessing the distribution losses in the secondary grid of the district heating. The heat supplied by the sub-stations had to be corrected not only for normal heat demand (depending on weighted heating degree days) but also for the increasing heat demand each time a new dwelling is connected to the grid. The results are presented according to the categorisation of the community data sheet of the CONCERTO-program.

<u>Renewable Energy Supply</u>

The Solar Island was monitored in two ways: detailed based on sensors to control the system and monthly based on the measured heat delivered to the primary grid. Both monitoring systems provided somewhat different results due to non-calibrated sensors. The annual normalized yield amounts to 8400-8900 GJ. The Solar Island produces 1.18-1.25 GJ/m^2 which is comparable with individual collectors. The virtual unlimited storage capabilities of the district heating network, allowing more transfer of solar energy, is countered by the necessity to raise the temperature first to 70 °C before it can contribute to the heat demand. It takes more time to create a higher temperature in the collectors.

A large number of small PV-systems are installed, most of them of CIS-technology and a size of 1050 W_P. The PV-systems are integrated in the roof (with various tilt and orientation) or in the façade. About 80 systems are monitored. The annual, monitored yield is 60-65 kWh/m^2 PV. Most electricity was used by the occupants themselves (>95%). The monitoring revealed various structural and non-structural defects causing loss of renewable electricity production. According to a detailed calculation based on applied PV- and inverter-technology, the actual yield is only 70% of the theoretical yield.

ECOFYS
sustainable energy for everyone

ECO buildings

The ECO buildings consist mainly of energy efficient dwellings in various categories (Eco Houses, Solar Houses and Passive Houses). The results for space heating, DHW and electricity use are presented by category. The number of multifamily buildings in both communities is low and so is the number of monitored multifamily dwellings. Therefore the analysis of the energy-use focuses on single family dwellings. As can be seen by the first three tables, the actual constructed floor area is significantly bigger for Eco Houses and Solar Houses compared to the cRRescendo-proposal. A similar observation can be done with respect to geographical location. Monitored houses in NPW have an average floor area of 178 m^2 while houses in CK have a floor area of 137 m^2. The size of the dwelling determines strongly the heat demand and the electricity use. This can be seen in the next graphs and table. While Eco Houses demand less space heating per m^2 floor area then expected, the total demand for space heating is the same as expected. The same is true for Solar Houses and Passive Houses with the additional remark that Passive Houses are constructed *smaller* then expected. Another observation is that Solar Houses use more space heating then expected per m^2 as well as in total. This would also be the case if Passive Houses were constructed bigger. The higher the ambition, the harder it is to reach it. More attention is required for the construction process and for the use of the building by the occupants in order to benefit from the potential energy efficiency. Data collected through the internet which requires a bigger effort from the occupants, is lower for Eco Houses as well as for Solar Houses. Occupants who participated (also) through the internet have higher motivations regarding energy. The differences in heat demand per m^2 reflect quite nicely the energy performance (coefficients) for the different categories.

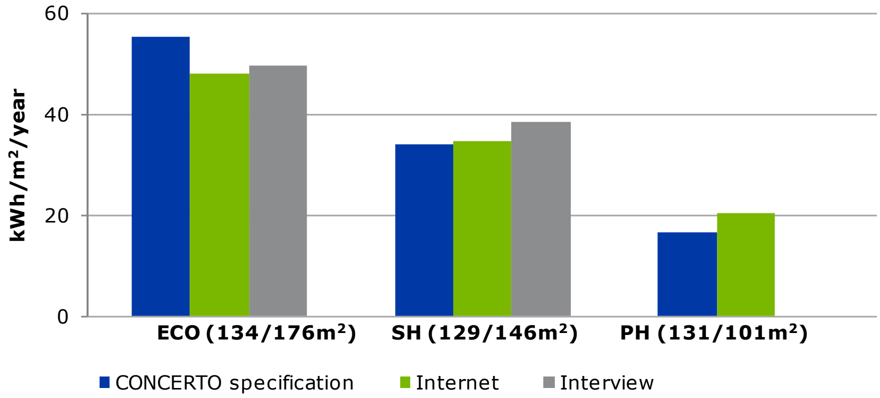


Figure 1 - Average annual energy demand for space heating per square meter of floor area for all building types. The mentioned areas are proposed and commissioned values.

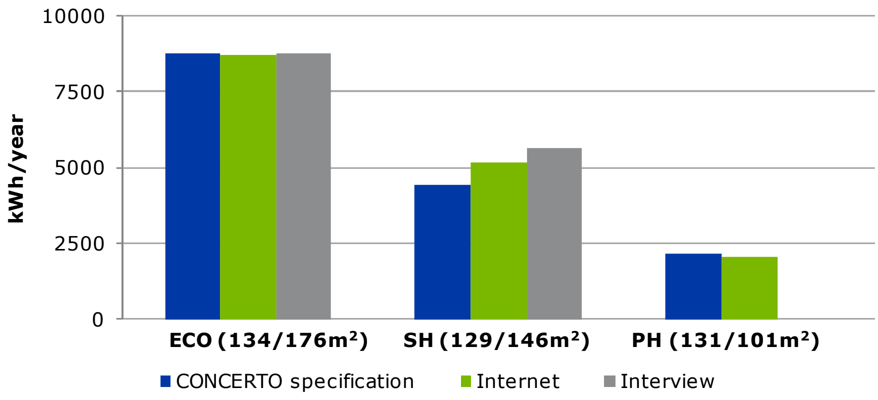


Figure 2 - Average annual energy demand for space heating per dwelling for all building types. The mentioned areas are proposed and commissioned values.

Electricity consumption is measured by three different monitoring methods; monthly (with internet), yearly (with interview) and detailed (with data-loggers) data collection. There is a strong correlation between area and electricity demand for all types of energy efficient buildings. Thus, the variation in proposed and monitored consumption can be explained by the difference of proposed and actual average floor area. Moreover, the hourly data collection in 20 dwellings is used to examine electricity consumption patterns. Three distinct groups of consumers are created according to electricity consumption levels; low, mid and high electricity consumption. The results are also compared with the average electricity consumption of Netherlands according to the data from EDSN. No extra precautions were adopted for reduction of electricity consumption in Almere. Thus in all three groups in Almere and the average demand in Netherlands similar weekly consumption pattern is observed, with peaks in the morning and afternoon, and a base load of approximately 50% of the average power consumption.

Table 5 – Average energy demand for electricity in single family dwellings (kWh/year/building).

Building type	CRR [1]	Interview	Internet
Columbuskwartier	**3138**	**3184**	**2893**
Passive House (BEST 17) [2]	3246		2845
Solar House (BEST 4)	3138	3184	2941
ECO House (BEST 3)	--	--	--
Noorderplassen-West	**3129**	**4409**	**4965**
ECO House (BEST 7)	3106	4790	4537
Solar House (BEST 8)	3151	4029	5393

Note:
(1) CRR represent the average proposal values for the dwellings that were monitored with interview. Therefore proposed values shall be evaluated in comparison to interview data not to internet data with the exception of PH.
(2) The proposal values of Passive Houses are presented for the dwellings included in the internet monitoring. The proposal shall be compared to internet monitoring result.

Rational Use of Energy

The rational supply of heat by the Combined Heat and Power station of Diemen was not operative until the mid of 2012. Therefore, the monitoring is limited to the assessment of the distribution losses in the secondary grid of the district heating system, e.g. the piping network between sub-stations and the buildings themselves. This last part of the district heating system causes the largest distribution losses due to increasing branching. Supplied heat from several sub-stations was compared with (extrapolated) heat demand from the connected buildings. Only some sub-stations with almost only dwellings connected were analysed.

Table 6 – Monthly average heat demand and distribution loss per m^2 floor area related to various sub-stations.

Sub-station code	Gross Floor Area [m^2]	Avg. EPC [-]	Demand 2010-2011[1] [kWh/m^2]	Demand 2011-2012[1] [kWh/m^2]	Distr. Loss 2010-2011[2] [kWh/m^2]	Distr. Loss 2011-2012[2] [kWh/m^2]
ABX3WR1 (CTW)	59948	0.91	5.97	5.57	2.07	1.64
ABX3WR2 (CTW)	36795	0.91	4.36	4.23	3.62	2.23
ABX6WR2 (CTW)	46867	0.88	5.56	5.56	2.51	1.21
ABX6WR3 (CTW)	32026	0.74	4.02	3.24	2.11	2.04
ADH1WR2 (ITW)	43522	0.64	4.54	4.08	4.01	4.20

Note:
(1) Demand for total energy use: including space heating and DHW.
(2) Loss for total energy use: including space heating and DHW.

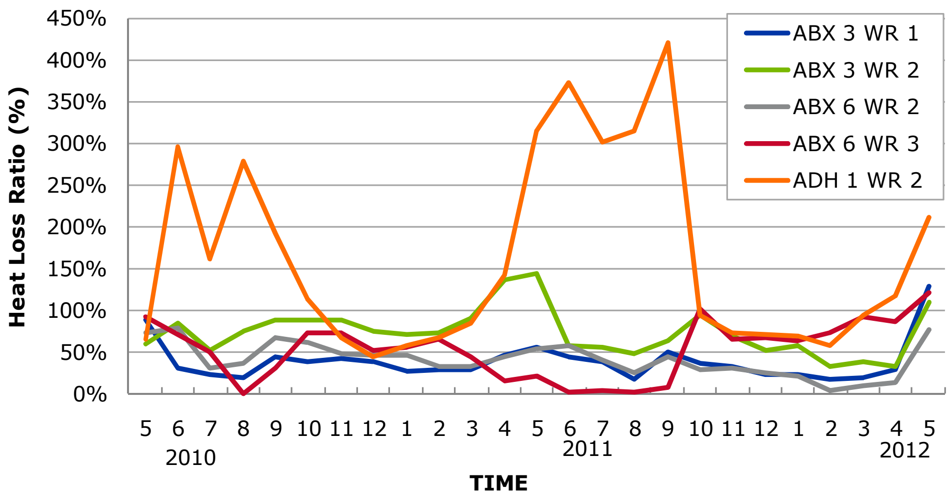


Figure 3 – Monthly rate of energy loss on distribution networks, total for DHW and space heating.

The distribution losses vary from 30% to 100% of the actual total heat demand (space heating, DHW) depending on the sub-station and the period. It can be seen that with the exception of ABX 3 WR 2 the ratio of heat loss is inversely proportional with the energy performance of the buildings. The newly developed areas tend to have higher distribution loss ratios as a result of higher energy efficiency of dwellings, so less heat demand. The excessive distribution loss is primarily related to space heating.

The monitored distribution losses are also compared with the theoretical distribution loss based on the Dutch standard NEN 7125. On the average the difference of the total annual distribution loss between the two methods is 16.5 kWh/m^2 floor area or 20% of the total heat demand for sub-station ABX 3 WR 1. Possible causes as: higher operating set-points, missing heat losses (e.g. transmission loss of the sub-station-building), actual average heat demand is higher then the monitored heat demand at 25% of the dwellings and heat leakage could not explain the difference or were found to be unlikely. Some further investigation revealed a correlation with precipitation, evaporation and drainage in the area. Although the real cause could not be determined, the monthly effective insulation value of the piping system that would cause the extra distribution loss can be explained for 50% (R^2-value) by the accumulated precipitation in the ground.

The owner of the district heating system also looked into the issue. Unfortunately the results of this additional investigation were not available at the due date of this report.

Table of contents

List of Illustrations

List of Tables

List of Abbreviations

Q_H (t)	Measured energy demand for space heating in period t
$Q_{H;a}$	Average annual energy demand for space heating
$Q^*_{H;a}$	Extrapolated annual energy demand for space heating
Q'_H	(Normal) energy demand for space heating
$Q_{H;i}$	Average energy demand of dwelling type (i) for space heating
Q'_{Solar}	(Normal) energy yield of a solar system
$Q_{sup;j}$	Measured heat energy supply from sub-station (j) for a certain period in J
Q	Measured energy use for space heating and domestic hot water combined for a certain period in J
Q^*	Total heat energy demand for space heating and DHW extrapolated
$Q^*_{loss;j}$	Heat energy loss through transmission network of sub-station (j) for a certain period in J
Q^*_j	Extrapolated total energy demand for the dwellings that are connected to sub-station *j* in certain period in J
$Q_{j;i}$	Measured energy demand from dwelling *i* connected to sub-station *j* for a certain period in J
Q^*_{DHW}	Calculated energy use for domestic hot water based for a certain period in J in case it is not directly measured
Q_{Solar}	The amount of solar energy produced by the collectors in solar island
Q_{EU}	The net renewable energy supply provided to the system after heat exchange unit
$Q_{sup\text{-}RES;NPW}$	The amount of renewable energy (heat) provided to the distribution network of NPW
$Q_{sup\text{-}RES;Almere}$	The amount of renewable energy (heat) provided to the distribution network city of Almere

$Q_{sup\text{-}RE;i}$	Energy balance at a supply system (i) in a certain period in J
$DD(t)$	Measured degree-days for period t
DD_a	Measured annual degree-days
DD_w	Weighted degree-days
$DD_{w;a}$	Annual weighted degree-days
$DD_w(t)$	Weighted degree-days in period t
$DD_{w;Almere}$	(Normal) weighted degree-days in Almere
w	Weighting factor for the passive solar contribution:
w^*_i	Calculated weighting factor for building type i
Y_i	Heating energy demand of dwelling (i) per degree day for a period t
Z	Average annual energy demand of dwellings per degree day
I	Irradiation
A_i	Gross floor area of dwelling (i) in m^2
A_g	Usable floor area according to NEN 2580
T_{amb}	Ambient temperature
$\Delta T_{amb;max}$	Maximum monthly average temperature difference in °C
T_{Mains}	Water temperature supplied by the mains in °C
T_{DHW}	Average domestic hot water temperature associated with the amount of domestic hot water in °C.
$T_{sup;i}$	Supply water temperature measured at the outlet of system (i) in °C.
$T_{return;i}$	Water temperature after it is distributed and recollected from the use in dwellings measured at the return of system (i) in °C
t	Time period

N	Number of occupants
$L_{Day;60°C}$	Average amount of domestic hot water per person per day in L (=40,3 for NL)
ρ_w	Density of water in kg/m^3 (1,0)
c_w	Specific heat of water in J/kgK (4180)
V_i	Amount of water flow measured at (i) in a certain period in m^3
KNMI	Royal Netherlands Meteorological Institute

1 Introduction

This report provides the results of monitoring study conducted in Almere from the demonstration part of the cRRescendo project. Almere has two districts, so-called sustainable communities that are part of the cRRescendo project: Noorderplassen-west (NPW) and Columbuskwartier (CK). In both communities Solar House (SH), Passive Houses (PH) and ECO houses (ECO) are constructed. Each category has different energy performance targets. The monitoring includes collection of data on the parameters effecting demand and supply of both heat and electricity of these houses as well as other related objects.

Chapter 2 provides an overview of the aims of cRRescendo project and the scope of monitoring with regards to project goals.

The objects of monitoring are mainly the energy efficient dwellings, renewable energy supply systems such as district heating and the Solar Island. In chapter 3 the properties of objects of monitoring are described in detail. The parameters that affect energy supply and demand are defined to provide a clear framework for the monitoring results.

The monitoring in Almere aims at accurate and reliable image of the energy use of over 2000 buildings in two areas. The approach on how to do this without measuring every single building is described in chapter 4. The monitoring plan of Almere uses multiple sources to obtain a reliable insight in the energy performance of the communities. Sometimes even for the same energy flow. The data sources are first analyzed in terms of their suitability to represent a specific data set and hence their usability for the analysis.

The approach for evaluating energy efficiency of buildings possibly differ for low-energy buildings as conventional methods may fail to reflect influential factors that are intrinsic to building design. Thus in chapter 5 the assumptions underlying two basic factors of energy analysis are investigated and alternative methods are proposed for a more rational and realistic assessment of building performance.

Next to the collection of data also *correction* of data is crucial for the analysis. Thus, a plan that provides track of time of use and demand pattern of each monitored dwelling is applied in this project. Also more common corrections, e.g. normal heating degree days, etc. were taken into account. The method of corrections are addressed in chapter 6.

The results from monitoring through internet and by interview are discussed in detail in chapter 7. The data is presented for each building type (Passive House, Solar House and ECO House) for space heating, domestic hot water and electricity consumption separately. The results of different monitoring sources are in agreement with each other. The performance of the district heating system in the area and analysis of heat losses are given based on the monitoring data from sub-stations and energy demand in dwellings. Moreover, the results of the monitoring of the Renewable energy supply systems, namely the Solar Island in Noorderplassesn-west and PV-systems in Columbuskwartier are included in this chapter.

Finally chapter 8 includes major conclusions and provides recommendations for design, development and analysis of parameters effecting demand, energy generation and the energy transmission systems are analyzed in this research.

2 Goal and result

2.1 CONCERTO-Program

The cRRescendo-project is part of the CONCERTO-program of the European Commission. The focus of CONCERTO projects are primarily on demonstrating the environmental, economic and social benefits of integrating renewable energy sources (RES) together with energy efficiency (EE) techniques through a sustainable energy-management system operated on a community level.

CONCERTO projects are expected to produce well monitored field experience of energy supply and demand patterns to be communicated for the benefit of other CONCERTO projects and serve as a basis for future actions.

In parallel to research conducted on technical aspects of RES, the socio-economic research component will analyse the local trends in energy costs, prices and savings, as well as social impact, quality, and added value of the energy services provided. The promotion of the use of renewable energy sources brings best results when combined and linked with activities towards energy efficiency.

Therefore, the CONCERTO initiative stresses the significant increase of the share of RES supply (green electricity, heating /cooling etc) simultaneously with the reduction of energy demand and overall management of energy.

2.2 cRRescendo Results

This section provides information over what is delivered in terms of number of buildings, area of PV, etc within cRREscendo project.

Table 7 - Overview of applied measures in Almere according to Community Data Sheets (CDS).

CDS-category	Description
Large Scale RES	Solar-Island (6700 m^2 thermal solar collectors)
Large Scale RES	PV-systems on Solar Houses, Passive Houses and public buildings
ECO-buildings	Buildings with 10%, 25%, 50% or 100% primary energy saving
Polygeneration	Flue gas heat recovery CHP Diemen + greening of electricity

Table 8 gives the number of buildings that are commissioned, which means they have complied with the cRRescendo criteria. There are additional buildings which were constructed in the area but remained out of the commissioning.

Table 8 - Eco-buildings: commissioned BEST-categories in Almere.

BEST-Category	Area	Category	#
01. Apartment	CK	Houses	140
02. Apartment EPC<0,75	CK	Houses	83
02. Apartment SH	CK	Houses	
03. Single-family dwelling	CK	Houses	63
04. Single-family dwelling EPC<0,75	CK	Houses	343
04. Single-family dwelling SH	CK	Houses	
05. Apartment	NPW	Houses	68
06. Apartment SH	NPW	Houses	40
07. Single-family dwelling	NPW	Houses	859
08. Single-family dwelling PO	NPW	Houses	116
09. Health centre	CK	Non-Houses	3
10. Office	CK/NPW	Non-Houses	1
11. Primary school	CK/NPW	Non-Houses	6
12. Shopping centre	CK	Non-Houses	-
13. Sports accommodation	CK	Non-Houses	1
14. Child-day care centre	CK/NPW	Non-Houses	-
15. Health centre	NPW	Non-Houses	8
16. Shopping centre	NPW	Non-Houses	-
17. Single-family dwelling PH/EZ	CK	Houses	104
18. (International) school	CK/NPW	Non-Houses	2

Note:
SH (Solar House) and EPC<0,75 within the same BEST-category do not differ in respect to the energy-requirements of the cRRescendo-proposal. They differ in respect to the non-energy-requiremenst (e.g. material-use and comfort-levels).

The houses differ in energy performance as indicated by the abbreviations in Table 9.

Table 9 - Eco-buildings: description of main energy performance.

Abbreviation	Description
(None)	Eco-house with 10% (NPW) / 20% (CK) primary energy saving
EPC<0.75	Eco-house with (about) 25% primary energy saving
SH	Eco-house with (about) 25% primary energy saving and complying with the other re-quirements of BRL 5015 (inspection-certificate Solar Houses)
PH	Eco-house complying with the Passive House standard
EZ	Eco-house with a (seasonal) energy-balance (energy-zero)

3 Characteristics of Almere Communities

This section describes the properties of objects that were included in the monitoring of Almere communities. The objects of the monitoring on the demand side are energy efficient dwellings and on the supply renewable energy systems like district heating and the Solar Island, a large complex of solar collectors that supplies renewable heat to the district heating. The performance of each system, parameters effecting demand, energy generation and the energy distribution systems are analyzed in this research. Two sustainable communities, Columbuskwartier (CK) and Noorderplassen-west (NPW), have been part of cRRescendo project in Almere (see Figure 4).

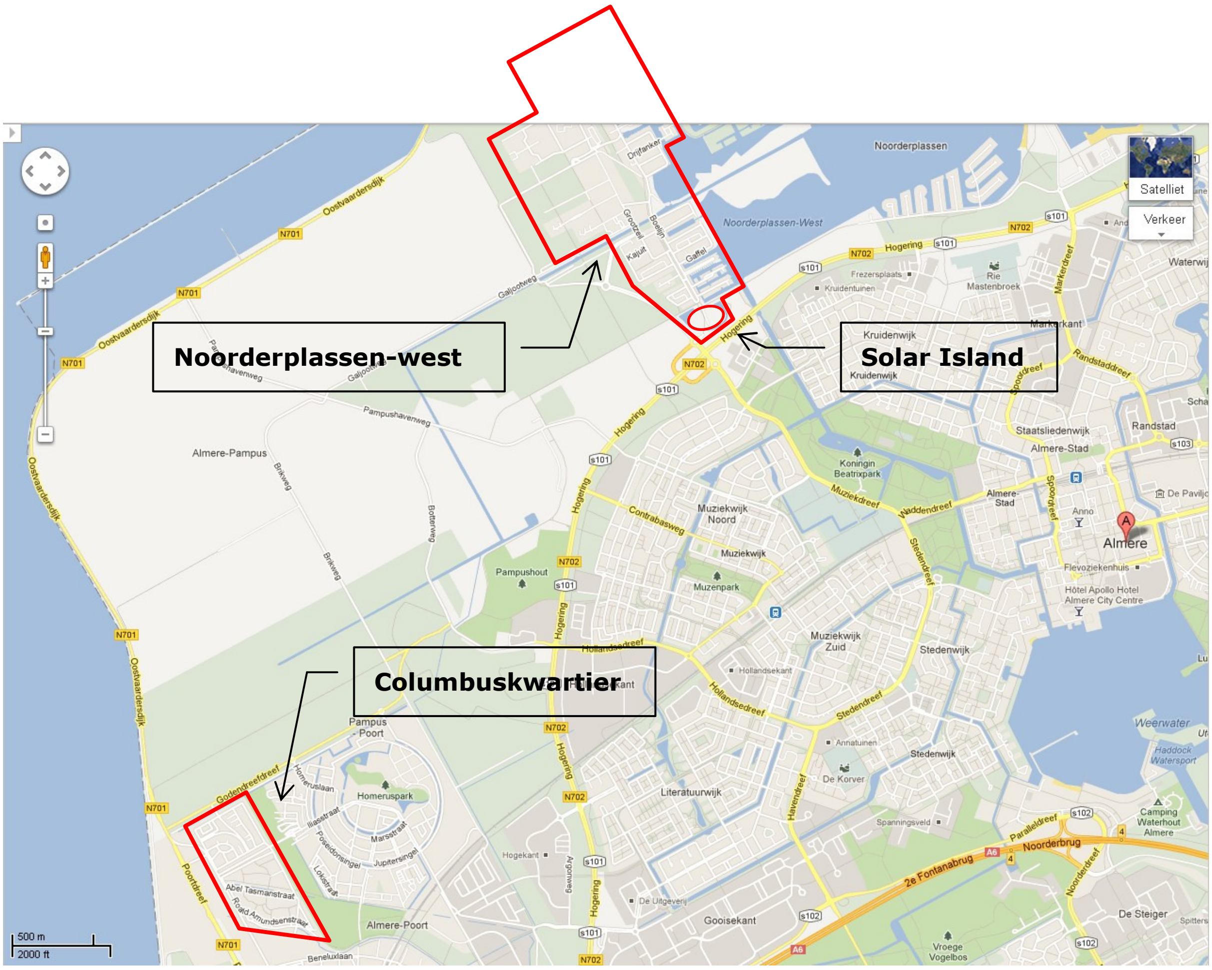


Figure 4 - Location of the two sustainable communities in Almere

For each sustainable community, the energy system is analyzed under three main levels of boundary conditions. Each level has components of energy supply and energy demand on various levels of detail. On first level the sustainable community represents all energy efficient dwellings and all supply systems in a specific sustainable community. The second level is the system created by each substation (for distribution of heat) and the set of buildings served by the specific network of each substation. The smallest system in this study concerns energy supply and demand on the scale of a single building. Energy use of a single device, component or appliance can be considered under the final system.

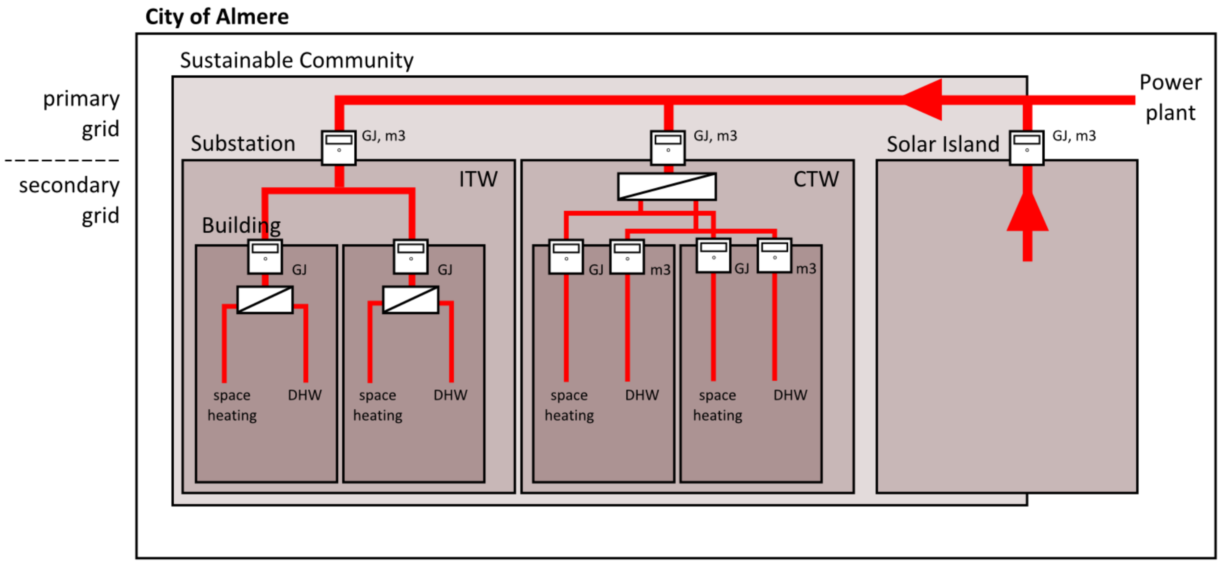


Figure 5 - Representation of energy system boundary levels and ITW and CTW systems

Monitoring includes measurements and collection of data on various levels of the boundary systems to provide a detailed overview. Properties of elements on each energy system level are therefore important in order to analyze the results of monitoring.

3.1 Sustainable Communities

Almere has two districts that are part of the cRRescendo project: Noorderplassen-west and Columbuskwartier. The characteristics of two districts differ from each other in terms of their energy ambition and development process. In Columbuskwartier, almost half of the dwellings follow the energy efficient design principles and construction requirements for so-called "Zonnewoningen" (Solar Houses). These design principles and construction requirements are described in an official Dutch guideline: "Nationale beoordelingsrichtlijn voor het inspectiecertificaat voor Zonnewoning" (BRL 5015). The guideline involves amongst others energy efficiency and application of sustainable energy and materials. Majority of the dwellings in Noorderplassen-west are Eco-houses with only a focus on energy efficiency. The most distinctive property of Noorderplassen-west is the renewable energy contribution of the Solar Island.

Table 10 - District properties based on building commissioning

District	Number of dwelling units	Total area of dwelling units (m^2)
Columbuskwartier	718	99911
NPW	1101	189739

3.2 Renewable Energy Supply

Almere has adopted energy efficiency and large-scale renewable energy into its urban development. The overall aim is reducing conventional energy use with some 30% according to the community data sheet (CDS) of the cRRescendo-proposal. In both communities all heat is provided to the dwellings by means of district heating.

Columbuskwartier is part of the area Poort. In this area dwellings receive heat from an existing combined heat and power plant in Diemen, part of Amsterdam across the Markermeer, the central lake between Almere and Amsterdam. Heat recovered from the hot exhaust gases is transported over about 13 km to Almere. This solution replaced the original idea of a local biomass-plant that would produce both 100% renewable heat as well as 100% renewable electricity. The heat recovery covers the expected renewable heat. The renewable electricity, also produced otherwise by the local biomass-plant, is covered by green certificates that cover the same amount of electricity. The monitoring of renewable electricity by green certificates is not covered in this report.

In the area Noorderplassen-west, dwellings receive heat from the city district heating, a gas-fired CHP. The Solar Island near Noorderplassen-west supplies renewable heat to the city district heating. Partly this heat is transported to this area and, in case of excess heat, partly to the rest of Almere. The renewable heat of the Solar Island covers mainly domestic hot water and also compensates for distribution losses that otherwise would demand fossil energy.

3.2.1 Polygeneration

Dwellings in both Columbuskwartier and Noorderplassen-west receive heat through the district heating infrastructure. Almere is almost completely covered by district heating from the beginning of its existence in the 1970’s. An extended primary distribution network through the whole city delivers heat to a large number of sub-stations that each cover 250-350 dwellings. Sub-stations deliver heat for space heating and/or domestic hot water (DHW) to buildings through a secondary distribution network. The equipment in the sub-stations includes the heat exchangers for heating and service water, pumps, valves, control devices and safety equipment. Sub-stations have their own code and name, often the address at which they are located.

There are two types of distribution systems (also see Figure 5).

a. Separate distribution:
   Distribution of (space) heating and DHW separately. Two separate piping systems (supply/return) are installed, one for (space) heating and one for DHW. The temperature setpoint for (space) heating is set back depending on the ambient temperature (70-40 °C).

b. Combined distribution:
   Distribution of (space) heating and DHW combined. A single piping system (supply/return) is installed. The supply temperature is constant and determined by the DHW-requirements (65-68 °C).

Both systems have their advantages/disadvantages depending on the point of view. The advantage of combined distribution is the lower costs for piping, a disadvantage for separate distribution. In case of separate distribution of heating and domestic hot water, both energy flows are measured separately, while in case of combined distribution, only the *total* heat is measured. In both systems certain part of the heat is lost during distribution. It would be interesting to learn whether there is an advantage for distribution losses. A separate distribution has the advantage of the ability to lower the supply temperature for (space) heating. But at the same time the heat loss area is bigger due to a twin piping system, which is a disadvantage in this respect. The analysis of distribution loss is presented in section 7.3.1.

The strategy in Noorderplassen-west is mainly separate distribution of (space) heating and DHW. Only four stations are constructed for combined distribution. The strategy in the area Poort is predominantly combined distribution of heating and DHW. Columbuskwartier is part of the area Poort.

Table 11 – Sub-stations in Columbuskwartier

Code	Name	Distribution method of Heating and DHW	Total gross area of connected dwellings [m^2]	Total gross area of connected non-dwellings [m^2]
AHD 1 WR 1	Henry Stanleystraat	Combined	22477	6416
AHD 1 WR 2	James Cookeroute	Combined	43245	503
AHD 2 WR 1	Olivier Bruyneelstraat	Combined	16274	--
AHD 2 WR 2	Henry Hudsonstraat	Combined	6436	--

Figure 6 - The approximate location of the sub-stations in the area Poort. Only known sub-stations by the end of 2011 are depicted. The Columbuskwartier is part of the area Poort.

Figure 7 - The approximate location of the sub-stations in Noorderplassen-west. Only known sub-stations by the end of 2011 are depicted.

Table 12 - Sub-stations in Noorderplassen-west

Code	Name	Distribution method of Heating and DHW	Total gross floor area of connected dwellings [m^2]	Total gross floor area of con-nected non-dwellings [m^2]
ABX 3 WR 1	Giek 0	Separate	59659	101
ABX 3 WR 2	Dek 24	Separate	36517	279
ABX 4 WR 1	Spiegel 9	Separate	36356	6302
ABX 4 WR 3	Sprietzeil 1	Separate	7733	12518
ABX 6 WR 1	Jacobstaf 32	Combined	31796	--
ABX 6 WR 2	Boelijn 112	Separate	46356	280
ABX 6 WR 3	Boelijn 176 to	Separate	32026	--
ABX 7 WR 1	Schuifknoop 13	Combined	13682	--
ABX 7 WR 2	Schuifknoop 29	Combined	21570	--
ABX 8 WR 1	Sprietzeil 39	Separate	15429	--

3.2.2 Solar Island

The Solar Island is a unique project for Almere and for The Netherlands (see Figure 8 for image). It is an innovative project combining solar energy and district heating. The question here would be: can the city district heating, which acts as unlimited heat storage, increase the yearly yield of the solar collectors compared to an individual system (with limited heat storage). On the other hand the disadvantage of the Solar Island is the need for higher water temperature in the collector before it can be fed into the district heating which operates at 80-60 °C while individual collectors can use lower supply temperatures as they react directly with cold water.

Table 13 - Properties of single solar collector unit in Solar Island

Length (m)	Width (m)	Effective apperture area (m^2)	Insulation
5.96	2.52	13.72	90 mm mineral wool in Aluminium casing

Figure 8- An aerial photo of the Solar Island during construction. Courtesy of Nuon

In Noorderplassen-west the Solar Island provides locally generated renewable energy. There are 520 installed flat plate collectors with a total collector aperture area of 7135 m^2. Each collector is arranged at a south 37° angle to ensure an optimum yield (see Table 13 for properties). The facility provides energy to buildings in Almere. The heated water is transferred to the sub-station of the Solar Island then it is pumped to the district heating system, thus supplying heating and hot tap water to the area.

3.2.3 Solar PV systems

Renewable energy supply in Columbuskwartier is characterized by stand alone solar PV-systems integrated to the building. Most houses are fitted with solar PV panels, the so-called Solar Houses. As well as dwellings, an international school is equipped with PV systems.

The technology used for PV-system determines the efficiency of the output and the collector size and nominal power has to be calculated accordingly. The PV systems used in the district have different properties. Different materials are used in collectors, which suggest different system efficiencies. The technical characteristics of the PV systems are summarized in Table 14.

Table 14 – Technical properties of PV systems in the area Columbuskwartier.

Building function	Technology/product	Total nominal power [W_P]	Tilt angle, orientation [°]
Residential	CIS WSG0036 E075	441000	10°, 15°, 25° & 90° (various orientations)
	TSF-60 Colored CIS	4620	unknown
	MDZ 240	5760	unknown
	MPE 225/230 PS 04	4140	unknown
Non-residential	CIS WSG0036 E075 Multichrystalline <school, etc>	31800 30250	36° (south) 90° (s
TOTAL		517570	

Certain physical factors affect the efficiency of the PV-system. The PV panel has to be located in a way that it is protected from shade by trees or nearby buildings. In Columbuskwartier 393 of dwellings, have panels on the rooftop and in 29 buildings PV panels are integrated on the façade. The PV panels integrated on the façade are predominantly installed by the same installer. The position with regards to the building envelope and the tilt angle are customized according to the building, hence installations may be built into the roof or walls of a building. The main concern is to ensure maximized exposure of the collector panel to the direct sunlight.

3.3 Energy Efficient Dwellings

Both districts in Almere contain energy efficient buildings designed and constructed according to various energy performance levels. Those include both single family dwellings and apartment buildings. In Columbuskwartier a portion of the ECO-houses are designed as apartment buildings.

The multi family dwellings were still under construction when the monitoring started. Thus in Columbuskwartier the number of ECO houses and the available monitoring data regarding to those buildings remain considerably low and would not provide representative information when handled together with single family dwellings. The fraction of monitoring for apartment buildings remains low in both areas. Therefore, the energy consumption data presented in this report refers only to single family dwellings. This provides a better indication of specific energy use. The distribution of buildings within various energy performance levels in each district is given in Table 15 (for the fraction of monitoring see also Table 27).

Table 15 – Number of single family dwellings

Area / Building type	Completed 2010 (1)	Completed 2012 (1)	Commissioned 2012 (2)
Columbuskwartier	**305**	**515**	**509**
Passive House (BEST 17)	0	104	104
Solar House (BEST 4)	299	342	342
ECO House (BEST 3)	6	69	63
Noorderplassen-west	**1534**	**1578**	**960**
ECO House (BEST 7)	1418	1462	859
Solar House (BEST 8)	116	116	101

Note:
(1) Known to be completed at July 31th, 2010, the start of the monitoring.
(2) Commissioned at July 31th, 2012, the end of the project.

Energy demand in dwellings depends mainly on the design and construction of the buildings in addition to the type of heating systems, appliances and number and behaviour of occupants. Properties that inherit in building's design and construction are depicted by a number of parameters to reflect their relation with regards to energy demand. Heated floor area, insulation of building envelope, number of occupants and Energy Performance Coefficient (EPC) are important parameters that are monitored and related to energy demand.

In the initial stage of the project above mentioned parameters for each dwelling type were assessed within cRRescendo proposal. The assessments were based on the urban planning of the area, number of building for each building type and the reduced energy consumption goal that were mentioned in development plan by City of Almere. However, the final design of dwellings including the floor plans, materials used etc were not available at that stage. During the design and construction, some characteristics of the dwellings units have diverged from the assessed values, due to construction practices, material availability, economics, site boundaries, etc. Following tables also provides a comparison of the characteristics proposed in the cRRescendo project specification and acquired by commissioning.

3.3.1 ECO-Houses

ECO-houses are included in the cRRescendo proposal with an aim of approximately 20% of energy demand reduction. Table 16 presents the average insulation values that are proposed in both districts for this purpose. In Columbuskwartier the realized facade insulation values remained lower than the expected in the project. The actual insulation values for rest of the components were the same or slightly better than the proposed ones. In Noorderplassen-west except the window insulation the insulation values at commissioning phase of all components stayed lower than the proposed ones, specifically a difference is observed for facade insulation.

The EPC levels proposed in the project proposal has remained the same for commissioned values in Noorderplassen-west.

A significant difference between proposed and actual commissioned values lies in the average floor area of dwellings. In both districts the housing units were built larger than the proposed design. An increase of 41% and 55% is observed in Columbuskwartier and Noorderplassen-west, respectively.

Table 16 - Characteristics of single family ECO-houses, comparison of proposed and commissioned values.

Average Values for ECO-house	Unit	Columbuskwartier		Noorderplassen-west	
		Proposal*	Commissioned	Proposal*	Commissioned
EPC	--	0.80	0.80	0.90	0.90
Floor area	m^2	130	183	117	182
Façade insulation	m^2K/W	3.85	3.74	3.85	3.16
Window transmittance	W/m^2K	1.71	1.64	1.71	1.58
Roof insulation	m^2K/W	3.85	3.94	3.85	3.41
Floor insulation	m^2K/W	3.25	3.96	3.25	3.20
Ventilation	dm^3/sm^2	1	0.83	1	1.03

Note:
(1)*Proposal values reflect all data set and not only values for monitored buildings.

The average number of occupants per dwelling in ECO-houses is 1.76 and 3.18 in Columbuskwartier and Noorderplassen-west, respectively. Considerably high ratio of occupants lives in ECO-houses. It is known that occupant behaviour can change energy demand drastically. Therefore, it is plausible to observe a high scatter on energy consumption levels within the data set of monitored ECO-houses.

3.3.2 Solar Houses

Solar Houses (SH) emphasize integration of solar energy, by use of solar panels as well as optimal use of day lighting, next to application of sustainable materials as well as requirements on overheating. On average there are 1.60 and 3.64 occupants per Solar House in Columbuskwartier and Noorderplassen-west, respectively.

In Columbuskwartier the actual commissioned average insulation levels are higher than proposed values, except for the windows. The situation is not the same in Noorderplassen-west. The roof insulation is higher however; the insulation values of the remaining components are slightly lower than the proposed values. This effects the energy performance of the buildings. As a result in Noorderplassen-west the actual average EPC values are 6% lower than the proposed ones. This ratio is higher for Columbuskwartier, 20%.

Similar to the increase in average floor area for Eco-houses the Solar Houses were built larger than the proposed values. An increase of 47% in Noorderplassen-west and 26% in Columbuskwartier is measured.

Table 17 - Characteristics of single family Solar Houses, comparison of proposed and commissioned values.

Average Values for Solar Houses	Unit	Columbuskwartier		Noorderplassen-west	
		Proposal*	Commissioned	Proposal*	Commissioned
EPC	--	0.75	0.60	0.75	0.71
Floor area	m^2	111	140	116	171
Façade insulation	m^2K/W	3.85	4.07	3.85	3.17
Window transmittance	W/m^2K	1.71	1.62	1.71	1.67
Roof insulation	m^2K/W	3.85	4.96	3.85	4.79
Floor insulation	m^2K/W	3.25	4.98	3.25	3.22
Ventilation	dm^3/sm^2	1	0.95	1	0.92

Note:
(1) * Proposal values reflect all data set and not only values for monitored buildings.
(2) In NPW, Solar Houses are the ECO-houses satisfying energy performance of SH (EPC<0,75). However, they do not comply with the other requirements of SH certification.

3.3.3 Passive Houses

Passive Houses (PH) have minimal energy demand due to their very high insulation levels and tight building envelope. Passive Houses are only located in Columbuskwartier. The same insulation levels as Eco-houses and Solar Houses were proposed for Passive Houses in cRRescendo specifications. However a significantly high level of overall insulation is acquired in commissioning, except for windows. The actual insulation levels remained 97%, 146%, 54% higher for façade, roof and floor, respectively. The commissioned EPC level remains slightly above proposed value.

The commissioned average floor area of Passive Houses in Columbuskwartier is 5% lower than proposed area in cRRescendo.

Table 18 - Characteristics of Passive Houses, comparison of proposed and commissioned values

Average Values for Passive Houses	Unit	Columbuskwartier		Noorderplassen-west	
		Proposal*	Commissioned	Proposal	Commissioned
EPC	--	0.30	0.37	--	--
Floor area	m^2	112	107	--	--
Façade Insulation	m^2K/W	3.85	7.58	--	--
Window transmittance	W/m^2K	1.71	0.85	--	--
Roof Insulation	m^2K/W	3.85	9.50	--	--
Floor Insulation	m^2K/W	3.25	5.09	--	--
Ventilation	dm^3/sm^2	1	0.18	--	--

Note:
(1) * Proposal values reflect all data set and not only values for monitored buildings.

An energy-zero house (EZ) is also introduced in Columbuskwartier with a seasonal energy balance.

4 Monitoring Process in Almere

Part of the cRRescendo proposal is technical research. This research involves measurements and monitoring to verify whether technologies and systems installed perform according to expectations and/or the overall targets for energy performance have been reached.

From these research aspects a monitoring guideline was produced which also mentions the minimum requirement for monitoring according to the CONCERTO+ initiative. During the study existing analysis methods are updated to accurately evaluate performance of energy efficient buildings. The minimum requirements are monitoring energy use or energy production per building per month for the following energy flows:

- Space heating demand
- Domestic hot water heating demand
- Electricity-demand
- Cooling demand
- Electricity supply from RES
- Heat supply from RES

The ambition to collect data of all energy flows (when present) for over 2000 buildings for each month soon turned out not to be feasible due to lack of voluntary participation of occupants, even when participation was minimized to opening the front door in order to allow a professional to record the meters. There always remain occupants who decline to co-operate and the ones who did co-operate were not always at home when the "recorder" visited the building. Automatic data-collection by installing monitoring equipment in all buildings was not possible within the monitoring budget.

A different approach focused more on establishing a good image of the energy-use instead of closely following the text of the proposal. The minimum requirements to measure each flow each month for each building was not the only answer "to produce well monitored field experience of energy supply and demand patterns to be communicated for the benefit of other CONCERTO projects and serve as a basis for future actions" as stated in the CONCERTO-program. The monitoring plan for the demonstration project in Almere aimed just at this.

4.1 Sources

The monitoring plan of Almere uses several sources to obtain a reliable insight in the energy performance of the communities. The various sources cover monitoring of different number of buildings.

Various sources have been used to get an impression of the energy use in both sustainable communities. Multiple energy flows are measured, some of them even in different ways to establish a more reliable image of the total energy supply and demand patterns. Table 19 presents a global overview of these sources measured entities and measurement frequency.

Table 19 – Data-sources, measured energy flows and their monitoring interval and/or other energy-related aspects for Eco-buildings.

Energy Flow (monitoring interval)	Source (data-provider)					
	Building characteristics (Dev./Almere)	**Interview (Ecofys)**	**Sub-stations (Nuon)**	**Internet (Ecofys)**	**Data-logger (Ecofys/ External)(4)**	**Solar Island (Nuon)**
# of dwellings covered	Ca. 2000	Ca. 600	Ca. 2000	Ca. 80	20	Ca. 1200
Electricity		Yearly	-	Monthly	10 min.	-
Appliances		-	-	-	Hourly(1)	-
Space Heating		Yearly	Monthly	Monthly	10 min.	-
DHW		-	Monthly(2)	Monthly(3)	-	5 min.
PV-system		Yearly	-	Monthly	10 min.	-
Temperature		-	-	-	Hourly	-
Ambient Temp.		-	-	-	Hourly	5 min.
Irradiation		-	-	-	Hourly	5 min.

Note:
(1) Various household equipment only.
(2) Only when DHW is separately measured (in GJ and m^3).
(3) Only when DHW is separately measured (in m^3).
(4) Hourly data from external source (KNMI) except appliances.

Next to the collection of data also *correction* of data is crucial for the analysis. Especially when it is considered that the project is based in a developing urban area. Throughout its development the number of dwellings considered for energy demand changed over time. It is important to observe and record those parameters in order to analyse energy supply in relation to energy demand. Thus, a plan that provides track of time of use and demand pattern of each monitored dwelling is applied in this project. Also more common corrections, e.g. normal heating degree days, etc. were taken into account. All corrections are addressed in chapter 5.

Comparing the results of the various energy flows in different ways increases the reliability of the results. The different data sources are first analyzed in terms of their suitability to represent a specific data set and hence their usability for the analysis. There are various situations where different properties of the data set related to each source gains importance. For certain questions of the research, the number of available observations are important. In other cases the duration and frequency of the monitoring affects the usability of the data. Therefore, the choice of the use of each source depends on the scope of the analysis and determined by evaluating the following concerns:

a. Representativeness:
   In cases that the aim is extrapolation of monitoring data to a larger number of dwellings it is important to have a large number of observations that can randomly represent the total population. On the average the number of dwellings monitored by the source 'Interview' represents 25% of the total number of dwellings where as the monitoring franction of the source 'Internet' remains to be lower, approximately 4%. Therefore, the monitoring data from 'Interview' is used as the main source for the analysis of demand. Moreover, data collection through 'Internet' is based on people who volunteered for this more time consuming process. It is anticipated that people who volunteered to this kind of data recording are more conscious about their energy consumption. Hence it is possible that the data may not represent the average user behaviour. The data collection through 'Interview' provides more random distribution as it represents a larger share for each building type in both districts.

b. Accuracy:
   Detailed monitoring provides high frequency measurements, specific for each device. However, this process bares high cost, thus is not appropriate for monitoring large numbers of buildings. Measurements in twenty dwellings are conducted within detailed monitoring process with data-loggers. The data set is too small to be used for extrapolation. It is used for assessment of internal temperature differences in energy efficient dwellings, electricity consumption patterns and energy use in specific cases.

c. Frequency:
   Measurement frequency gains importance especially when comparison of two different energy flows is required. When various flows are analyzed with regards to each other, the same level of monitoring frequency, e.g. annual, monthly or hourly, is considered. This strategy is followed for the analysis of heat distribution losses in each sub-station for analysis of district heating. As the amount of heat supplied form each sub-station is measured monthly the demand is also required to be represented monthly. Therefore, the monitoring data based on 'Internet' is preferred over the data from 'Interview'.

Moreover, the data obtained is compared with the proposed values in the cRRescendo proposal. Any dwelling data may be related to one of the four source category as shown in Figure 9. The first section (I) represents the assessments included in the cRRescendo proposal regarding to building characteristics (e.g. area, number of occupants, thermal insulation) as well as energy performance. The cRRescendo values are calculated for a standard, normalized year. Therefore all energy indicators are normalized. Section (II) represents the parameters of performance and building characteristics acquired by commissioning and/or measured during monitoring process. Monitoring is done over all finalized buildings whether they are commissioned or not, which means that monitoring process also includes buildings that either did not match the cRRescendo requirements or were not delivered according to a due date but were finalized at the period of monitoring. The data referring to this part are collected by different methods such as 'Interview', 'Internet' and 'Detail monitoring'. First, all measured data are normalized to enable comparison with the expected or proposed values (as mentioned in the cRRescendo-proposal). As a further step the monitored data are used as a basis to assess energy performance of dwellings by extrapolation that were not included in the monitoring, represented in section (III). This provided a general overview of the energy performance of all buildings in both districts. Those extrapolations are also used where distribution losses for each sub-station are analyzed.

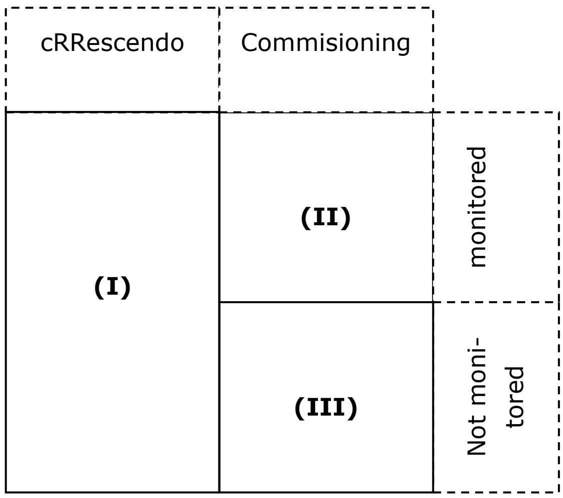


Figure 9 – Illustration of data source category

Additional to building properties, data representing external climatic conditions are also monitored. Ambient temperature and irradiation is obtained from nearby official weather station Lelystad (at 25 km to NE) next to the locally measured ambient temperature and irradiation. Weather data of Amsterdam (at 30 km to W) from IWEC is used for normalization of the results as explained in section 6.3. Solar irradiation in the area of Solar Island is measured by three PV-cells positioned in the same plane as the solar collectors. Three PV-cells are used to prevent reading errors due to incidental shading (e.g. by small objects, birds) or reading errors. Only the two readings that agree most are used.

4.2 Time Coordinates

The monitoring contains various data-flows from different sources. Each source creates a time stamp for each measurement. The time stamps are recorded in different time coordinates (e.g. UTC, CET, etc.). Comparison of data from different sources requires a single time coordinate. Especially for data from the data-loggers who collect hourly or sub-hourly data. In this project, Central European Time (CET) is adopted as the general time coordinate because of the local aspect of the results. Table 20 shows the original time coordinates for each data-flow.

Table 20 - Time coordinates of the different data series.

Data series	Source	Time step	Time coordinate1
Interview	Ecofys	Yearly	N/A2
Sub-stations	NUON	Monthly	N/A2
Internet	Occupants	Monthly	N/A2
Elli-Track	Ecofys	Hourly	CET + DST
Smart meter	NUON	15 minutes	CET + DST
Solar Island3		5 minutes	CET + DST
Plugwise	Ecofys	Hourly	CET (?)
Weather	KNMI	Hourly	UTC
Normal weather	IWEC	Hourly	CET

Note:
1. N/A=not applicable (see note 2), CET=Central European Time, DST=Daylight Saving Time, UTC=Universal Time Coordinate (Greenwich Time).
2. Only dates are recorded. Time is not recorded. The recorded values are assumed to occur at midnight (24:00 CET).
3. Solar Island data also includes (raw, non-calibrated) local weather data.

4.3 Monitoring Building Characteristics

The monitoring plan of Almere focuses on the large scale renewable energy systems and the Eco-dwellings. Data are distinguished in parameters, characteristics of measures and energy-flows. The data are collected by measurements, inspections and/or by questionnaire. The EPC values (according to NEN 5128) is calculated since it cannot be measured. The energy flows are related to parameters or characteristics of the measures.

Monitoring contains gathering and measurement of various parameters that relate to properties of buildings that influence energy use.

Usable floor area is one of the most important parameters as it is strongly related to energy demand. In general larger floor area demands more energy due to a larger number of appliances as well as increased demand for space heating. It is therefore crucial to indicate average floor area of each building type. All (normalized) energy flows are related to the amount of usable floor area in order to provide comparable results among various categories of buildings.

The thermal characteristics of dwellings are factors that have an impact on the energy demand. Especially energy required for heating in the climatic conditions of Almere is prevailed by the buildings' ability to resist heat loss through building envelope. Therefore, thermal insulation values of several components are provided to give a clear overview of the building properties.

Overall energy performance of dwelling units is summarized as the average energy performance coefficient (EPC) calculated according to NEN 5128:2004. Lower EPC values indicate better energy performance. The calculation of the EPC is based on characteristics of the building envelope, the HVAC-equipment and the use of the building. The EPC was already calculated in the cRRescendo-proposal (based on the reference dwellings as defined by the Dutch energy agency AgentschapNL). During commissioning the EPC-values were collected based on the specifications submitted for the application for the building permits.

Another parameter is the number of occupants. This parameter is especially relevant for (the estimation of) the domestic hot water use.

The energy yield of solar systems are related to the amount of collector area of solar systems.

Table 21 - Monitoring-parameters.

Parameter	Units	Question.	Drawing	Inspect.	Remark
Occupants	[-]	X	X		Measured / calculated
Net floor area	[m^2]		X	X	Based on final design
Gross volume	[m^3]		X		Based on final design

5 Performance Analysis Framework

The energy efficiency of a building depends on many factors. The approach for evaluating energy efficiency of buildings may need to be different, depending on the type and design of building. Standard assumptions and analysis methods that are normally applicable to conventional building designs may fail to reflect performance of energy efficient buildings to allow a more accurate assessment of energy performance.

Two factors that affect directly the analysis of performance are evaluated in this section. Firstly the parameters of DHW demand assessment are analyzed. The study has searched whether the basis of estimations for DHW demand in terms of number of occupants and average water volume consumption per person per day provides agreement with the demand in Almere. Secondly, the weight factors for Heating Degree Day (HDD) have been analyzed in order to provide a more accurate distribution of energy use for space heating over a year.

This section provides details of research approach used throughout the rest of this report to promote informative, reliable and accurate study results of building performance based on the dataset of monitoring as presented in Chapter 6.

5.1 Evaluation of DHW in High Performance Dwellings

The number of occupants strongly determines the use of DHW. Section 6.3.2.1 explains the method and parameters of assessment. In case the number of occupants is unknown; the Dutch standard NEN 7120:2011 proposes estimation based on the usable floor area of the dwelling. The estimation is based on a large number of dwellings all over the Netherlands.

However, it is not certain that the standardised relation between floor area and number of occupants suits a particular area such as in Almere. Therefore the relation is reconsidered based on the actual data collected by monitoring. The number of occupants is known for about 30% of the dwellings in Almere. The monitoring data is obtained between 2010 and 2012.

For the analysis the average floor area is grouped into classes with 10 m^2 increments. Then the average number of occupants within each class is plotted and the regression equation is developed. The relation is compared with the results of equation 9 according to NEN 7120:2011 for Columbuskwartier and Noorderplassen-west in Figure 10 and Figure 11, respectively.

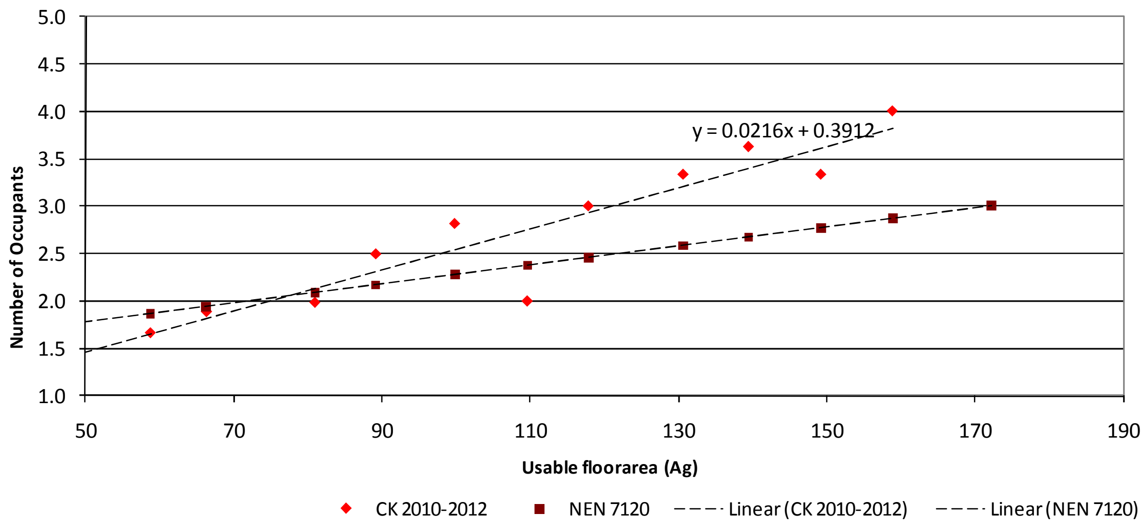


Figure 10 – Relation between floor area and number of occupants in Columbuskwartier

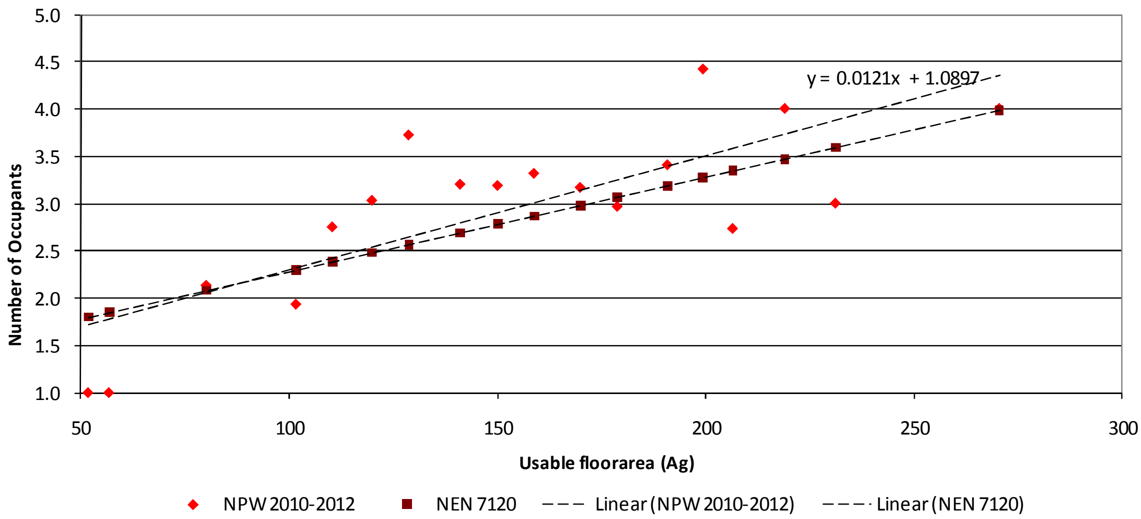


Figure 11 – Relation between floor area and number of occupants in Noorderplassen-west

The results indicate that the relation between floor area and number occupants is different from what is suggested in NEN 7120. The difference is more significant in Columbuskwartier.

Figure 10 shows that for smaller houses, specifically with a floor area less than about 80 m^2, the actual number of occupants is less than suggested by the standard. Hence, the assumption of number of occupants based on NEN 7120 for these small dwellings tends to overestimate the DHW demand. This observation is especially important due to the fact that the majority of houses in Columbuskwartier are smaller than 90 m^2. The difference between monitored and standard based assumption is closer in Noorderplassen-west. Based on these results, in order to estimate number of occupants two equations are used in this study:

$$N_i = 0.39 + 0.021 \cdot A_{g;i} \text{ (if i = Columbuskwartier)} \quad (1)$$

$$N_i = 1.09 + 0.012 \cdot A_{g;i} \text{ (if i = Noorderplassen - West)}$$

Wherein:

$$A_g = 0.85 \cdot A$$

With:

N	Number of occupants
A_g	Usable floor area according to NEN 2580
A	Gross floor area
i	Location (sustainable community)

Note: Ratio between gross floor area and net usable floor area is accepted as 0.85 for Dutch dwellings

Additionally, the average volume of water use per person per day is analyzed. The average monitored demand of water volume per person proved to be in line with the Dutch average. There are no extra corrections made for use of DHW in Almere.

5.2 Evaluation of Weight Factors for Heating Degree Days in High Performance Dwellings

The energy demand of a building for heating is reflected by the concept of Heating Degree Days (HDD). The heating requirement for a building is considered to be directly proportional with the number of HDD at that location. It is derived from measurements of outside air temperature related to a base temperature. For historical reasons HDD are often made available with base temperatures of 16 °C or 18 °C that are approximately appropriate for a good proportion of construction systems. In this study a base temperature of 18 °C is used.

5.2.1 Discussion of conventional weight factors

In addition to the outdoor temperature and time of the year, there are other conditions that affect the thermostat. Thus, not all of the heat loss of a building is replaced by the heating system and some is met from heat gains arising from solar irradiation or heat-generating occupants and equipment (internal gains) within it. The heat gain from occupants and equipment is fairly constant and considered within the assumption for the base temperature. However the amount of solar irradiation changes throughout the year and can cause significant difference in the heat demand of a building. To reflect the influence of the changes in solar irradiation, normally, the degree-days are multiplied by a weighting factor to adjust for seasonal influences. This is called weighted heating degree days. Weighting factors act on the total (heat) consumption for practical reasons.

Weight factors enable to consider the influence of mainly passive solar contribution throughout the periods of the year. Especially for our analysis on energy efficient buildings, which by their design adopt use of solar gains and energy conservation, the correct calculation of the effect of solar gains on heating demand is crucial. There is a good indication that reassessment of weight factors for heating degree days is needed to better express the distribution of heating demand of energy efficient buildings such as Eco-, Solar- and Passive Houses over the year. Therefore in our study the weight factors are calculated for space heating demand as this is sensitive to external temperature fluctuations throughout the year. The results can not be directly compared with traditional weight factors because the traditional weight factors also act on domestic hot water consumption.

5.2.1.1 Calculation of weight factors for energy efficient dwellings

Weighting factors (w) for energy efficient dwellings are re-assessed based on the heat energy demand data collected with monthly data through internet through the period March 2010 and March 2012. The heating demand and degree days are averaged over the mentioned period to calculate the monthly values for a 12 month period. Then, two coefficients are calculated:

$$Y_i(t) = \frac{\overline{Q}_{H;i}(t)}{\overline{\overline{DD}}(t)} \tag{2}$$

$$Z = \frac{\overline{Q}_{H;a}}{DD_a} \tag{3}$$

With:

Y_i	Heating energy demand of dwelling (i) per degree day for month t
$Q_{H;i}$	Average energy demand of dwelling type (i) for space heating in kWh/m^2
DD(t)	Measured degree-days for month t
Z	Average *annual* energy demand of dwellings per degree day
$Q_{H;a}$	Average *annual* energy demand for space heating of dwellings kWh/m^2

DD_a Measured average annual degree-days

The new weight factors (w^*) are calculated for each month as the ratio of heating energy demand per HDD for a certain month, namely Y_i, to annual heating energy demand per HDD, namely Z, as:

$$W_i^*(t) = Y_i(t) / Z \tag{4}$$

With:

W_i* Calculated weighting factor for building type i for month t

The calculated W_i* for energy efficient dwellings are analyzed with respect to weight factors that are currently in use for each month. The conventional weight factors consist of 3 values associated with specific (monthly) periods during the year. A similar and comparable approach for updated weight factors was desired. Moreover, it is believed that use of 12 different values (for each month) may cause complexity and it is prone to errors in performance calculations. Therefore, for practicality, proposed weight factor scores are generated by grouping monthly W_i* values, according to different periods of the year.

5.2.1.2 Proposed weight factors for energy efficient dwellings

The heating degree-day weight factors are calculated for each energy efficient building type in Almere, namely ECO-houses, Solar Houses and Passive Houses. Figure 12 presents the average monthly weight factors for each building type and their average.

The dataset for Passive Houses is not suitable to provide strict conclusions alone, compared to ECO-houses and Solar Houses. It has a limited data set in terms of both number of monitored buildings (approximately 10% of all monitored buildings) and the monitored period (10 months). Thus, the values that solely represent weight factors for Passive Houses are included for indicative purposes. On the other hand, the number of passive buildings within the monitoring represents almost 13% of the total Passive Houses. Hence, includes important data about the effect of passive solar energy contribution on weight factors. Therefore, it is included in the calculation of average weight factors for all energy efficient dwelling types.

The data of ECO-houses and Solar Houses represent comparable monitoring data set in terms of both number of dwellings and the 24-month monitoring period. The weight factors for ECO dwellings and Solar Houses remain very close. The analysis indicates that a single set of weight factors can be suggested for buildings with improved or high energy performance based on average values of all energy efficient dwelling types.

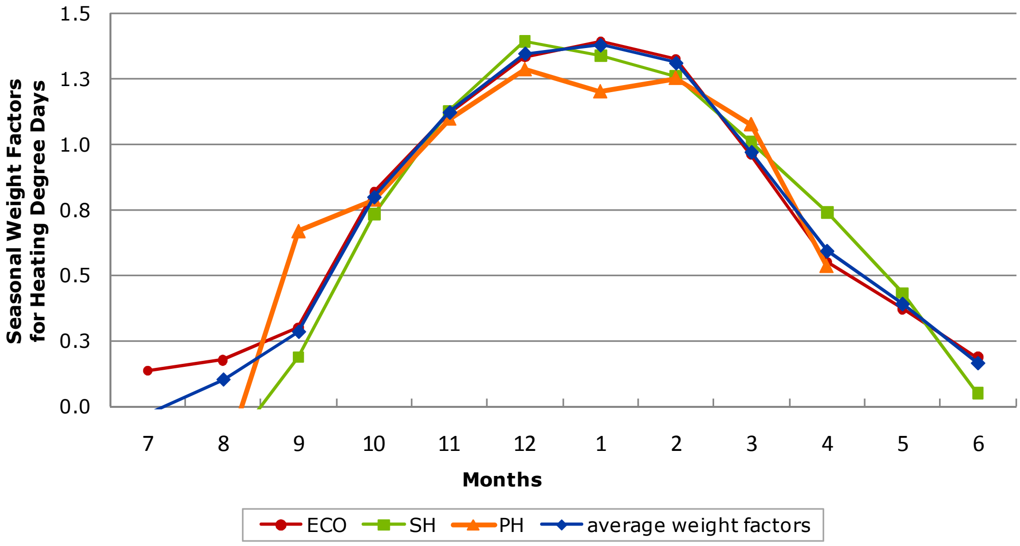


Figure 12 – Calculated Weight factors for Degree days for space heating only throughout the year for energy efficient dwellings.

Figure 12 shows that Passive Houses and Solar Houses also revealed negative values for weight factors in July and August. The most probable cause originates in the assumption on the calculation of heating demand. The energy demand for space heating is calculated by subtracting the DHW use from the total energy demand. The majority of Solar and Passive Houses are located in Columbuskwartier where the sub-stations are combined system (ITW) which does not provide separate measurement of DHW. Thus, DHW demand has to be estimated based on method described in section 6.3.2. In July and August, the heat energy demand is so low that the estimated DHW demand remains higher than measured total energy demand, thus results in energy demand for space heating below zero. The estimated DHW demand does not take into account reduced demand due to prolonged absence of occupants, e.g. due to holidays. Negative heating demand is not plausible in real life conditions. In fact the result points out in July and August that the demand for space heating and the weight factors are very close to zero. The average weight factors maintain the reasonable output.

Updated values of weight factors are proposed by analysing the periods where a significant change in the weights are observed throughout the 12 months. It can be seen in Figure 12 that December, January and February create a natural group on the peak of the curve. This period is significantly different from the two transition months that limit its two ends, namely November and March. The change in the value of the weight factor in those transition months and the slope of the curve can be easily observed. Thus, the three weight factors for December, January and February are averaged to provide weight factor for this heating period. Another uniformity is observed for months May, June, July, August and September bordered by the breaking points in October and April. Therefore, similar to the winter period the weight factors for each period are calculated by averaging the months with identical patterns. Table 22 presents proposed weight factors for energy efficient dwellings. The proposed values suggests a clear differentiation between winter and summer months followed by two transition periods to reflect smooth and continuous distribution 12 months without increasing the total number of factors.

Table 22 – Proposed weight factors for HDD for heating only in energy efficient dwellings

Period	Proposed weight factors for heating degree days in energy efficient dwellings
May to September	0.30
October and April	0.70
November and March	1.00
December to February	1.30

Figure 13 provides the comparison of proposed weight factor groups for specific periods of the year and existing weight factors that are currently in use. It is seen that a significantly different distribution of weight factors are reached based on the data of energy efficient dwellings. The results are discussed under two issues;

Sensitivity to seasonal change:
The proposed weight factors display a more curved shape compared to the shape based on traditional weight factors, as weight factors in our study are calculated based on only space heating and the energy efficient dwellings are sensitive to seasonal changes. The pattern of traditional weight factors does not reflect such high sensitivity to seasonal changes. This is an expected outcome due to the fact that energy efficiency measures (e.g. orientation, insulation) reduce heating demand and increase the relative contribution of the solar heat (which remains the same). In this, we assume that traditional weight factors –although acting on the total (heat) consumption– are also mainly related to space heating since they date from the era before buildings were insulated.

Difference of heating season:
The proposed weight factors indicate a resizing in the heating season. Instead of the four month peak of conventional weight factors the new weight factors have a shorter heating season as November is now indicated within the transition period where the effect of solar radiation is higher and effective on heat energy demand.

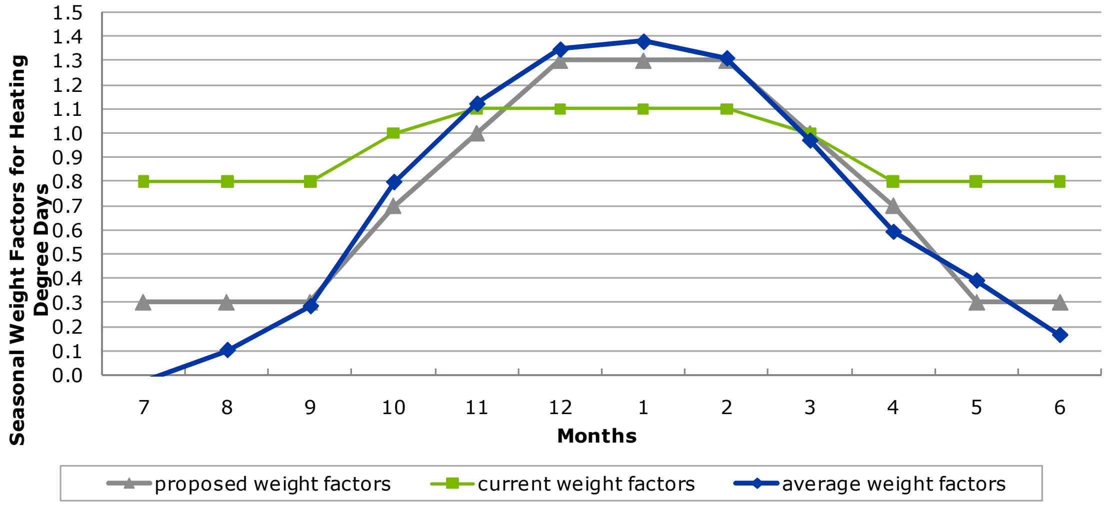


Figure 13 – Proposed weight factors for energy efficient buildings compared to conventional weight factors for heating degree days in the Netherlands, also in comparison with the measured weight factors in Almere.

5.2.2 Analysis of base temperature

The most appropriate base temperature for any particular building depends on the temperature that the building is heated to, and the nature of the building. One way of establishing a base temperature for a building is to use mean internal temperature of the building instead of the pre-set base temperature. This would give a better indication of the realized energy performance as the base temperature is derived from the actual data that is monitored on existing building typology instead of a standard temperature value. The possibility of a revised base temperature for energy efficient dwellings is analysed by using the mean internal temperature of the 20 dwellings where hourly measurements are carried out by detailed monitoring.

Table 23 – Average room temperatures for different dwelling types (°C). The value between brackets is the standard deviation of the room temperatures.

[°C]	Number of monitored dwellings	Average Dwelling	Bedroom	Living room
All types	20	19.3 (1.0)	18.3 (1.3)	20.2 (0.8)
ECO	13	19.0 (1.0)	17.9 (1.4)	20.0 (0.7)
SH	7	19.8 (1.1)	19.1 (1.4)	20.5 (1.0)

During the monitoring devices are positioned in bedroom and living room of 20 dwellings. The mean internal temperature for each dwelling is derived by the average of bedroom and living room temperatures. Table 23 presents the average temperature measurements. Standard deviation is given in the brackets. The results show that there was a significant divergence from the normal base temperature 18 °C. Energy efficient dwellings tend to have 2 °C higher average interior temperature. A base temperature of 20 °C would be more appropriate for energy efficient dwellings. This was not taken into account in the studies on weight factors of heating degree days.

6 Performance Evaluation and Analysis

Parameters of the study are based on calculations, different sources of measurement and theoretical assumptions. For a thorough evaluation and comparison of parameters with each other various methods are used. This section provides a general overview of assumptions and calculations adopted in this study.

6.1 Calculation of cRRescendo Proposal Values for Energy Demand

At the proposal stage the expected energy demand of buildings are assessed based on the calculation method of the Dutch standard for calculating energy use in new buildings (NEN 5128:2004) for the Dutch reference buildings, a collection of typical dwellings with distinct floor plans, constructions and sizes. The typology of the actual planned houses in Almere were matched to a specific reference dwelling. The energy-use of a (reference) dwelling also depends on the applied energy-measures. Various packages of energy-measures were composed to define the energy-quality of a dwelling. The packages match the various ambitions on energy-saving within the cRRescendo-proposal (Eco-buildings, Solar Houses and Passive Houses). This was done for each reference dwelling. The total energy use of an area can now be predicted by the calculated energy-use of a specific reference dwelling with a specific energy-quality and by the number of dwellings represented by those characteristics.

NEN 5128:2004 is replaced with NEN 7120 in July 2012. The new standard NEN 7120 was only used to estimate the number of occupants based on the usable floor area. The number of occupants is important to estimate the use of domestic hot water, which is hardly measured separately. The old standard was less precise in the number of occupants.

6.2 Energy Performance According to NEN 5128

The standard NEN 5128:2004 describes how to calculate the energy performance of a building and expresses the result as the non-dimensional energy performance coefficient (EPC). The standard determines the energy-use related to the building design based on the thermal properties, the efficiency and sustainability of the systems which influence energy demand. Also external (e.g. solar) and internal gains (e.g. occupancy) are taking into account. The energy consumption covers space heating, cooling, domestic hot water, mechanical ventilation and lighting. The EPC is determined by dividing the calculated energy use of a building by an allowed energy use, which is based on the heat transfer surface of the building envelope and the heated floor area of the dwelling.

Energy Performance Coefficient

Features of residential building

- Heat-transfer surface
- Total heated area
- Correction Factor

Characteristics of energy use

- Primary energy consumption for space heating
- Primary energy consumption for hot water
- Primary energy consumption for ventilation
- Primary energy consumption for lighting
- Primary energy consumption for cooling
- Primary energy consumption for humidification
- Reduction in primary energy consumption by photovoltaic solar energy systems

Figure 14 – Main determinants of the energy performance coefficient of new buildings according to the Dutch standard NEN 5128.

6.3 Processing of Monitoring data

The measurement data is processed in order to eliminate yearly variations in climate and to compare results with cRRescendo proposal values. According to available measured data and requirement of analysis several calculation methods are applied. The methods and related assumptions are provided in detail in this section.

6.3.1 Normalization

Normalisation is the process of correction for weather variations so that energy consumption in different years (with different weather) can be compared to a normal year, often the average of a large number of years. The community data sheet (CDS) that is provided in cRRescendo project describes energy savings and use of renewable energy in a normal year. This normal year represents the influence of the exterior climate over a longer period. Occupancy and use influences also energy consumption and can differ from the average occupancy and use (for a specific building category).

The measured data for ambient temperature, occupation and use of the building does not necessarily match with this normal situation. Therefore, monitoring data is normalized to allow comparison of measured data with design data. Design data are, almost by definition, based on a normal situation.

Weighted degree-days are used to normalize for the influence of the exterior climate. Remaining differences between the proposed and measured energy use can have several other causes:

- A different (=non-normal) user behaviour.
- A discrepancy between energy characteristics of buildings in theory and in practice, possibly related to the building method and/or the skills of the contractor.
- An error in the (theoretical) energy model.

These causes are much harder to relate unambiguous to the different energy uses.

6.3.1.1 Heat energy

The heat energy supply and demand is evaluated for two purposes; space heating and domestic hot water. They are monitored individually or combined depending on the type of the heat distribution system and related meters on sub-stations and dwellings. Normalization of heating differs for both situations.

a. In the case of DHW and heating is supplied separately to the dwellings, normalization process of the heat energy can be applied directly to the measured heat for space heating. This is applicable to Collective DHW systems (CTW) where only cubic meters of hot water measured.

b. In the case where heating and DHW measurements are combined, normalization process must be carried out after subtraction of the energy demand for domestic hot water. This is applicable to ITW systems where total energy is measured in kWh.

6.3.1.2 Ambient temperature

Heating degree-days are used to extrapolate energy-use for heating to a specific period (with no measurement of heating) and/or to normalize energy-use for heating to a standard or average climate.

The formula can be used to extrapolate measured heating-data to a whole month or a whole year. The extrapolated annual energy-use for heating based on degree-days is as follows:

$$Q^*_{H;a} = Q_H(t) \cdot \frac{DD_{w;a}}{DD_w(t)} \qquad (5)$$

With:

$DD_w(t)$ Measured weighted degree-days in period t

$DD_{w;a}$ Measured annual weighted degree-days

$Q_H(t)$ Measured energy demand for space heating in period t

$Q^*_{H;a}$ Extrapolated annual energy demand for space heating

The ratio of Q_H and DD_W is (fairly) constant (for a specific building) and represents the amount of heating per weighted heating degree-day. This constant is also applied to the extrapolated period.

The normal energy-use for heating corrected for degree-days is as follows:

$$Q'_{H;Almere} = Q_{H;Almere} \cdot \frac{DD_{w;Normal}}{DD_{w;Almere;a}} \qquad (6)$$

With:

DD_w;Almere (Normal) weighted degree-days in Almere in year a

Q'_H (Normal) energy demand for space heating in Almere in an average year

The period taken for heating and for the corresponding degree-days has to be the same. The measured period and location do not necessarily have to be the same as for the normalized period and location.

Correction of heating demand is based on weighted degree-days. Degree-days are the sum of the differences of the (average) set point (18 °C) of the interior temperature in the building with the ambient temperature for a specific period. With the use of proposed weight factors the weighting takes into account the contribution of (passive) solar to heating.

$$\begin{aligned} DD_{w;i} &= w^* \cdot \sum_{year} \frac{18 - T_{amb}(t)}{24} \cdot when \cdot T_{amb}(t;i) < 18 \\ DD_{w;i} &= 0 \cdot when \cdot T_{amb}(t;i) >= 18 \end{aligned} \qquad (7)$$

With:

DD_w Weighted degree-days

$T_{amb}(t)$ Ambient temperature of hour t

T Hour of a year

W^* Weighting factor for the passive solar contribution (see section 5.2):
w*=1.3 for December to February
w*=1.0 for March and November

w*=0.7 for April and October
w*=0.3 for May to September

I The location: Almere, Lelystad or Amsterdam (Normal)

The weighted degree-days are calculated for two measured locations and for the normal ambient temperature in Amsterdam. The weighted degree-hours are calculated in the same way.

The ambient temperature strongly influences the demand for heating and cooling. A warmer or colder year decrease or increase the energy demand for heating. A warmer or colder year also influences summer comfort (since in general no active cooling is present in both investigated communities). Normalization of summer comfort is almost impossible since summer comfort also depends on many other variables.

6.3.1.3 Irradiation

Measured irradiation compared to normal irradiation is used to correct the yield of a solar system like photovoltaic panels and solar hot water collectors for a normal year, similar to heating.

The normal yield for solar energy is as follows:

$$Q'_{Solar;Almere} = Q_{Solar;Almere} \cdot \frac{I_{Normal}}{I_{Almere}} \qquad (8)$$

With:

I (Normal) irradiation in Almere

Q_{Solar} Neasured energy yield of a solar system

Q'_{Solar} Normal energy yield of a solar system

Again, the period taken for yield and for the corresponding irradiation has to be the same.

6.3.2 Heat Energy Measurements

Both sustainable areas have district heating system to supply heat to the buildings. Heat energy is monitored in terms of domestic hot water (DHW), space heating and combination of both. Measurements are done on each sub-station to monitor the heat energy supply to the districts. Monitoring through 'Interview' and 'Internet' is conducted on the dwellings to monitor the energy demand. Each building has a meter to register the use of heat. In most cases, a single distribution-pipe provides heat for both heating and DHW. Only the total amount of used heat is measured. In some cases, a separate distribution provides collectively produced domestic hot water. In those cases, heating and domestic hot water are measured separately: heating in GJ and domestic hot water in m^3.

6.3.2.1 Combined measurement (ITW)

In the case of combined distribution of DHW and heating, the heat measurement is done for the total amount of energy for both. Since DHW is not measured, the energy demand for DHW and heating can only be calculated indirectly according to the following equation:

$$Q = Q_H + Q^*_{DHW}(n)$$
$$Q^*_{DHW}(n) = t \cdot N \cdot L_{Day;60°C} \cdot \rho_w \cdot c_w \cdot (65 - T_{Mains}) \tag{9}$$

With:

Q_H	Measured energy use for space heating for a certain period in J
Q	Measured energy use for space heating and domestic hot water combined for a certain period in J
Q^*_{DHW} (n)	Calculated energy use for domestic hot water based on the number of occupants (n) for a certain period in J in case it is not directly measured
T	Number of days for a certain period
N	Number of occupants (see Equation (1))
$L_{Day;60°C}$	Average amount of domestic hot water per person per day in L (=40,3 for NL)
ρ_w	Density of water in kg/m^3 (1,0)
c_w	Specific heat of water in J/kgK (4180)
T_{Mains}	Water temperature supplied by the mains in °C see equation (11))

The supply temperature is kept constant at 65 °C for reasons of prevention of Legionella-disease.

6.3.2.2 Separate measurement (CTW)

The use of domestic hot water in Almere is measured separately in m^3 of water in case of separate collective supply of domestic hot water. The associated energy use is:

$$Q^*_{DHW} = \rho_w \cdot c_w \cdot V \cdot \left(\overline{T}_{DHW} - T_{Mains}\right) \tag{10}$$

With:

Q^*_{DHW}	Energy use for domestic hot water in a certain period in J
ρ_W	Density of water in kg/m^3 (1.0)
C_W	Specific heat of water in J/kgK (4180)
V	Amount of domestic hot water used in a certain period in m^3
T_{DHW}	Average domestic hot water temperature associated with the amount of domestic hot water in °C.
T_{Mains}	Water temperature supplied by the mains in °C (see Equation (11))

The calculated energy use for domestic hot water is compared with the theoretical energy use according to NEN 7120. The sub-stations for heat distribution in the area Noordenplassen-west and Poort who deal with collective domestic hot water only, are operated to supply a fixed domestic hot water temperature of about 65 °C ± 3 °C to the buildings.

The temperature rise or the difference of the supply temperature with the mains water temperature is also measured indirectly through the sub-stations in both Noorderplassen-west and Poort who deal exclusively with domestic hot water. These sub-stations measure both the amount of heat in GJ and the amount of water that transports the heat in m^3. From this, the temperature rise of the water can be calculated.

A difference with the theoretical mains water temperature can have several causes like a different average ambient temperature then normal, higher or lower (average) supply temperature, higher or lower (average) mains water temperature (e.g. small water distribution network with limited influence of the ambient climate) and/or even an incorrect theoretical determination.

The energy use is excluding distribution heat losses between the sub-station and the dwellings.

6.3.2.3 Mains Water Temperature

Mains supply domestic water to all buildings. The energy use for domestic hot water depends on the supply temperature of the water, which depends itself on the ambient temperature in case of water supplied by mains buried in the ground. Equation (11) according to (Burch & Christensen, 2007) describes the relation between the mains temperature and the average annual ambient temperature. The resulting mains temperature is an average for the whole network. Mains temperature can vary between buildings and can vary slightly during the day.

$$T_{Mains} = \overline{T}_{amb} + 3.3 - R \cdot \frac{\Delta T_{amb;\max}}{2} \cdot \cos\left(2\pi \cdot \frac{t(i) - 15 - Lag}{365}\right)$$
$$R = 0.4 + 0.01 \cdot \left(\frac{9}{5} \cdot \overline{T}_{amb} - 8\right) \tag{11}$$
$$Lag = 35 - 0.01 \cdot \left(\frac{9}{5} \cdot \overline{T}_{amb} - 8\right)$$

With:

T_{Mains}	Water temperature supplied by the mains in °C
T_{amb}	Average ambient temperature in a year in °C
$\Delta T_{amb;max}$	Maximum monthly average temperature difference in °C
$t(i)$	Day of the year

The normalized mains water temperature varies from 10.2 °C till 16.4 °C with an average of 13.3 °C for the Netherlands. This average matches empirical data. The measured ambient temperature for Lelystad (source: KNMI) between August 1st, 2010 and July 31st, 2011 was 9.6 °C. The maximum monthly average temperature difference for the same period was 18.1 °C. Using these figures, the mains water temperature should have varied between 8.8 °C and 17.0 °C during the monitoring period.

6.3.3 Energy Calculations for Solar Island

The Solar Island converts the energy from sun into heat energy to be used in dwellings. The solar collectors in the Solar Island heat the water to approximately 90 °C. The heated water is transferred to the heat exchange unit. The heat energy is delivered to the heat supply grid and the cooled water is returned back to the solar collectors. The heat energy produced by the Solar Island is supplied to Noorderplassen-west and to the city of Almere. Temperature and flow rate of water are measured at several points through the network as schematically shown in Figure 15. The temperature and the flow of water is measured at 5 seconds interval. Thus, the heat energy is calculated for five-second period to avoid data loss. Consecutively, heat energy calculations are averaged to periods of 5 minutes to maintain sufficient data. Monthly energy production is calculated by aggregating energy yield results over 5 minutes.

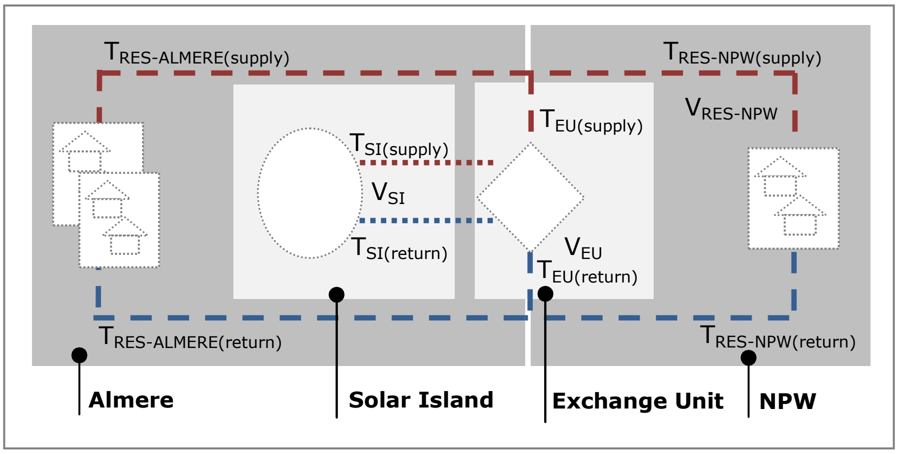


Figure 15 – Flow of solar energy produced in the Solar Island.

Following energy flows are determined according to below equation;

- The amount of solar energy produced by the collectors in Solar Island ($Q_{sup;IR}$),
- The net renewable energy supply provided to the system after heat exchange unit (Q_{EU}),
- The amount of renewable energy (heat) provided to the distribution network of NPW ($Q_{sup;RES;NPW}$)
- The amount of renewable energy (heat) provided to the distribution network city of Almere ($Q_{sup;RES;Almere}$)

Energy is calculated as a function of heat capacity, mass and temperature difference of water that is entering and leaving the system as:

$$Q_{\sup;RE;i} = \rho_w \cdot c_w \cdot V_i \cdot \left(T_{\sup;i} - T_{return;i}\right) \tag{12}$$

With :

$Q_{sup;RE;i}$	Energy balance at a system component (i) in a certain period in J
ρ_w	Density of water in kg/m^3 (1.0)
C_w	Specific heat of water in J/kgK (4180)
V_i	Amount of water flow measured at (i) in a certain period in m^3

$T_{sup;i}$ Supply water temperature measured at the outlet of system component (i) in °C.

$T_{return;i}$ Water temperature after it is distributed and recollected from the use in dwellings measured at the return of system (i) in °C

Once the energy flow is determined as above, it is possible to calculate the share of sustainable heat in the total heat consumption of the area Noorderplassen-west. The energy losses within heat exchange unit and transmission between the collectors and the unit is calculated as:

$$Q_{loss-internal} = Q_{\sup;IR} - Q_{EU} \quad (13)$$

6.3.4 Sub-stations

6.3.4.1 Connected dwelling area

The number of buildings served by a sub-station normally does not vary in time. However, in case of a new urban area which is still under construction, it does. In both districts every week new houses are accepted by their new owners and start demanding heat. Figure 16 shows the development of both districts in time. In Noorderplassen-west construction of dwellings started in 2004. Therefore at the start of monitoring in mid 2010, the district already contained already 85% of the total planned floor area (of which 15% less then 1 year old). Within the following two years new dwellings have been added to the district. Construction in Columbuskwartier started early 2009. Therefore at the start of monitoring in mid 2010, the district contained also 85% of the total planned floor area. But in contrast to Noorderplassen-west 50% were less then 1 year old.

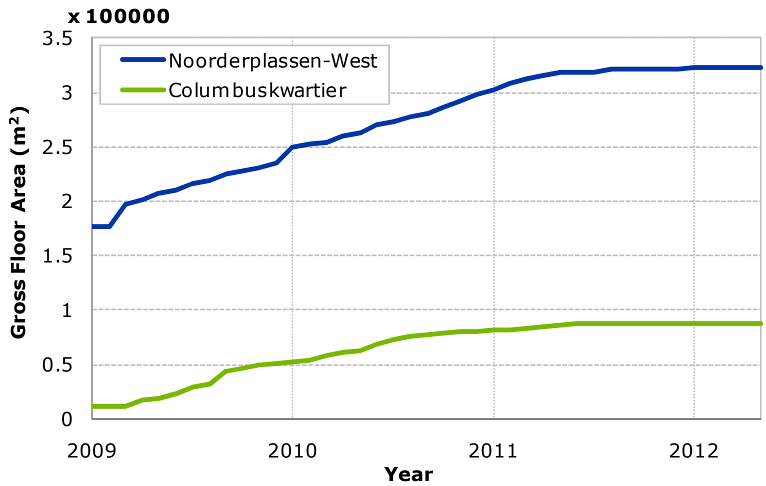


Figure 16 - Progression of connected net floor area to sub-stations for heating

The increase of the number of buildings connected to a specific sub-station is recorded in order to compare the energy use for heating and/or domestic hot water per m^2 and/or per person delivered by the sub-station and used by the occupants.

$$A_j(t_i) = \sum_{ti}^{i \in j} A_i \qquad (14)$$

With:

A_j	Gross floor area (A) of all dwellings connected to a specific sub-station (j) on moment t in m^2
A_i	Gross floor area of dwelling (i) in m^2
t_i	Date of acceptance of dwelling (i)

6.3.4.2 Distribution heat energy losses

District heat is transmitted from each sub-station to buildings as hot water in a closed network consisting of flow and return pipes. District heating pipes are thermally insulated and laid in the ground, usually at a depth of 1 to 0.7 meter. The heat carried by water circulating in the pipes flows partially to the ground. By quantifying the energy loss during distribution of energy, one can estimate the efficiency of a district heating system. It is plausible that high distribution loss indicates a non-rational use of energy. The loss has to be assessed relative to the demand. In Almere the heat demand is expected to be low following the implemented measures in the buildings. The data acquired from sub-stations and dwellings aims to provide insight to following questions:

- What is the share of energy loss through distribution related to energy demand?
- Does the loss ratio changes over the seasons?
- Do the different types of the distribution network (CTW and ITW) have different (mean) loss ratio?
- How does measured distribution loss relates to the theoretical calculated losses?

Two methods are used for the assessment of distribution losses. In order to address to the first three questions, the losses are calculated based on measurement data from sub-stations and dwellings. Then, to provide insight into the effective parameters of the last question, the losses are assessed based on properties of the heat distribution network such as pipe diameter, length, insulation level, etc. by using a theoretical calculation procedure mentioned in NVN 7125:2011.

It should be noted that after each sub-station the distribution pipes pass through two heat exchange units additional to the one inside of the sub-station. The heat losses at this stage are recorded in measurement data. However, it is not exclusively taken into account on the theoretical calculation procedure.

6.3.4.2.1 Measurement method

In this section, heat losses are estimated on the basis of energy system input from sub-stations and heat energy demand at the point of consumption in dwellings. Monitoring data collected through internet and interview is used as the basis of monthly analysis as it represents the monthly consumption.

a) Energy loss

The assessment of the energy loss through distribution network is made with following equations that are valid for DHW, space heating or their combination for each sub-station network where applicable.

$$Q_{\sup;j} = Q_j^* + Q_{loss;j}^* \tag{15}$$

With:

$Q_{sup;j}$	Measured heat energy supply from sub-station (j) for a certain period in kWh/m^2
Q^*_j	Extrapolated energy demand from dwellings connected to sub-station (j) for a certain period in kWh/m^2
$Q^*_{loss;j}$	Heat energy loss through transmission network of sub-station (j) for a certain period kWh/m^2

As presented in section 3.3 monitoring covers certain number of dwellings. However, it is required to estimate the total energy demand from all dwellings connected to a specific sub-station. Since the area was still under development during the monitoring, the floor area connected to a specific sub-station increases over time. The average energy demand that is acquired from the monitoring data are used to extrapolate the total energy demand to all dwellings connected to a specific sub-station. The usable floor area of all monitored and non-monitored buildings for each sub-station is known. Hence the extrapolation is done as follows:

$$Q_j^*(t) = \sum_{i=mon} Q_{j;i}(t) \cdot \frac{\sum_{i=all} A_{j;i}(t)}{\sum_{i=mon} A_{j;i}(t)} \tag{16}$$

With:

Q^*_j	Extrapolated total energy demand for the dwellings that are connected to sub-station j in certain period in J
$Q_{j;i}$	Measured energy demand from dwelling i connected to sub-station j for a certain period in J
$A_{j;i}$	Measured gross floor area of dwelling i connected to sub-station j in m^2
t	Period

Then the average relative share of network energy losses is stated as a ratio of demand and loss which can be calculated as $Q_{loss;j} / Q_j$.

b) Available data set

The heat loss through the distribution system is calculated on monthly basis for some sub-station network for the period between May 2010 and May 2012. In the case of combined distribution networks, the energy losses are calculated by considering the total energy demand from dwellings both for space heating and DHW. When the distribution system is separate the transmission losses for DHW and space heating can be calculated separately as well, if required. In this analysis total energy for space heating and DHW is used to calculate comparative figures between distribution loss expected for ITW and CTW systems.

As mentioned previously the space heating and DHW is distributed by 8 combined systems, 4 in Columbuskwartier, 4 in Noorderplassen-west, and 7 separate systems in Noorderplassen-west. Hence, monitoring included data collection for energy supply on 15 sub-stations. However, a number of constraints over the data necessitated excluding certain sub-stations out of the analysis for the sake of accuracy.

a. Constraints related to connected buildings:
   Four of the sub-station networks (ABX7WR3, ABX4WR1, ABX4WR3 and ADH1WR1) also served energy to significantly to non-residential buildings. The monitoring for energy demand covered only dwellings. Initial analysis has proved that the energy demand of dwellings is not representative for non-dwellings. Thus, accurate comparison of energy supply and energy demand was not possible for those sub-stations. The analysis included only the sub-stations that are connected to none or negligible amount of non-residential floor areas that can be mostly characterized as (very) small office as extensions to dwellings.

   The demand data for the dwellings connected to sub-station ADH2WR1 was only available for only 10 months in 2011. Additionally only few dwellings provided data within this sub-station area. Insufficient amount of data is regarded insufficient for conclusive analysis.

b. Constraints related to monitoring data:
The initial comparison of supplied energy with energy demand in a number of sub-station networks (ABX4WR3, ABX6WR1, ABX8WR1) revealed erratic results. The energy demand plotted seems to be the same and in some cases for some periods even higher than the energy supplied by the sub-stations. This would imply a negative heat loss (or heat gain).

For the area of sub-station ADH1WR1 the energy supplied by the sub-station was approximately 10 times higher than the energy supplied by other sub-stations. It is concluded as an error in the recording of the data.

Possible causes of constraints are determined as follows and analyzed in detail in section 7.3.

- Wrong assumption of total number/area of buildings connected to a specific sub-station:
Highly unlikely as the area of each dwelling is collected from building permit.

- Calculation error on assessment of heat energy demand (e.g. Extrapolations to annual heat demand of monitored dwelling to the whole area):
Highly unlikely as a significantly high monitoring fraction (25%) is acquired by internet monitoring process.

- Error in sub-station readings:
An error that is observed over the general trend of data is highly unlikely as raw data are controlled during pre-process.

- Leakage in the distribution system:
The supply company may be neglecting or is not aware of this due to the low frequency of their monitoring plan which is once a year. This cause is unlikely as the district heating system is equipped with automatic leakage detection.

- Demand from non-residential buildings connected to the sub-station.

More information is asked from NUON for the dataset for this group to provide explanation of possible errors in data recording. They have been exempted from the analysis since this information is not received during the study.

6.3.4.2.2 Theoretical method

NVN 7125:2011, section 7.2 presents methods to estimate the monthly distribution losses as a function of pipe diameter, insulation level, depth of piping installation, temperature of water within pipe system, external temperature and the total length of the network system. Heat distribution network of sub-station ABX 3 WR 1 (CTW) is used as a case study for calculations.

Detailed information regarding to pipe diameters, type of pipe was only available for only 1 of the 6 streets in sub-station network. Based on this data the pipe types for unknown streets is limited to

DN80/160 for all main branches and DN65/140 smaller branches. Length of the pipes is calculated according to partial pipe installation plan provided by NUON and district urban plan.

Single insulated pipes in the same slot are used for supply and return pipes. The theoretical model uses pre-calculated values of pipe size and specific heat resistance per length to calculate heat losses. For calculation of the resistance of pipe, generally used values are as follows:

- heat conductivity values for pipe insulation: 0.03 W/mK (Source: pipe properties)
- heat conductance of ground around pipes: 1.75 W/mK. (Source: NVN 7125:2011)
- installation depth of pipes: 1 m (Source: installation information)

The supply temperature of the water is determined with regards to ambient temperature according to the setpoint-settings provided by NUON. According to this relation the temperature of supply water is adjusted by pre-determined set point temperatures. Set point for winter is used if the external temperature is equal or lower than -7 °C. The set point for summer period is used if the outside temperature is higher than 20 °C. Set point temperatures are reported by NUON as 75 °C and 40 °C for winter and summer, respectively. Between -7 °C and 20 °C the setpoint changes proportional. The supply water temperatures are calculated by equation (17).

The return temperature of water in the return pipes is determined according to the calculated difference between supply and return water temperature based on delivered heat (in GJ) and involved flow of water (in m^3) for transport of heat as provided by Nuon. The supply and return water temperature is then averaged to calculate pipe water temperature.

$$\overline{T}^{*}_{\sup;i}(t) = T'_{set;summer} + \frac{(T'_{set;winter} - T'_{set;summer}) \cdot (20 - \overline{T}_{ext;i}(t))}{27} \tag{17}$$

$$\overline{T}^{*}_{pipe;i}(t) = \frac{\overline{T}^{*}_{\sup;i}(t) + \overline{T}^{*}_{return;i}(t)}{2}$$

With:

$T^*_{sup;i}$	Calculated average supply water temperature of sub-station (i) in month (t) in °C.
$T'_{set;summer}$	Pre-determined set point temperature of supply water when the outside temperature is higher than 20 °C.
$T'_{set;summer}$	Pre-determined set point temperature of supply water when the outside temperature is equal of lower than -7 °C.

$T_{ext;i}$	Average measured outside environment temperature by KNMI in month (t) in °C.
$T_{pipe;i}$	Average calculated pipe water temperature in month (t) in °C.
$T_{return;i}$	Calculated average return water temperature of sub-station (i) in month (t) in °C.

The theoretical model returns results under the assumption that heat losses only occur through the pipes and does not consider factors that can possibly affect the amount of heat losses such as installation errors, damaged or corrupted pipe insulations due to ground water, use of different set point temperatures than the provided. To consider the possible effect of these factors sensitivity of the results of the theoretical model are analyzed with regards to these parameters.

6.3.5 Missing Data

When working with a large number of objects and a large number of data, missing data is inevitable. This paragraph describes how the problem of missing data is solved. The problem concerns missing data of characteristics of buildings and missing data from measured energy use or other entities that varies in time.

6.3.5.1 Building characteristics

Building characteristics are used to calculate various specific energy uses. Typical building characteristics are floor area, number of occupants, insulation value, etc. In case no energy performance could be retrieved, the legally maximum energy performance was accepted as actual to be on the safe side. In reality, energy performance coefficients are often lower than the legal maximum, especially in Almere where the community council actively stimulates improved energy performance of buildings.

There is no certainty about the exact total amount of heated floor area, even on a specific moment. For some dwellings the amount of heated floor area could not be retrieved. Leaving out the unknown amount of heated floor area is not considered as an option because in reality also heat is supplied to existing but unknown floor area by the sub-station. In case the (usable) floor area is unknown, the average floor area of all other dwellings from the same category in the same area (Columbuskwartier, Noorderplassen-west or sub-station network where required) is used.

6.3.5.2 Solar Island

Data of the Solar Islands is recorded in CET+DST. This causes in spring one hour without data and in fall one hour with data overwritten by the next hour. Both hours occur at 2:00 AM, so there are no consequences for the energy data since the sun and by consequence the Solar Island too are not productive during the night. Ambient temperature data are corrected by linear interpolation of the missing sub-hourly values.

The water flow and temperature readings and irradiation measurements are recorded in each 5 seconds. The results are summed to represent monthly irradiation and respective energy yield. In the case of missing data for calculation of energy from exchange unit the missing values are interpolated proportional to solar radiation. In the case of missing data for calculation of energy flow to Noorderplassen-west the missing values are interpolated proportional to heating degree days.

6.3.5.3 Dwellings surrender schedule

The exact moment of start of heat demand for each individual building is not quite clear. The acceptance date that are recorded by the housing developer and the installation date of the meters by the energy service company (NUON) are the indicators of the time of actual start of the demand. According to the energy service company, the meters are mounted a couple of weeks before the acceptance-date. It was found that the average number of days between the recorded date of the installation of the meter and the acceptance of the dwelling was 50. The housing developer supplies information to the authorities about the start but also about the closing of the project. From this it was found that the average number of days between installation of the meter and closing of the projects was 145. The difference of 95 days between the acceptance and the (formal) closing of the project is almost the same as the legal 3 month service period after acceptance of the building. This is likely a co-incident because the range in number of days between different moments for individual buildings is quite large.

For the analysis the acceptance date supplied by the housing developer is used. In case no acceptance date was known, the installation date of the meter was used as a basis and 50 days were added to this date to get the (average) acceptance date.

After acceptance of the dwelling, the occupants spent some time decorating their new houses. In general occupants spent 2 to 8 weeks for decorating. Heat demand during this period does not represent normal use of the dwelling.

7 Results and Discussions on Performance Measurements

7.1 Renewable Energy Supply

The renewable energy systems are installed in CK and NPW for heat and electricity energy supply. The energy yield and efficiency of systems are presented in this section.

7.1.1 Solar Island

The amount of solar radiation available on the Solar Island area is measured by three PV-cells positioned in the same angle as the solar collectors. Among the three measurements the average of the two highest values are accepted as the lowest value is likely to receive a slight shade due to the light posts or other objects in the area. The records from the site measurements are compared with data available from the Royal Dutch Meteorological Institute (KNMI). Both measurements provided a good agreement.

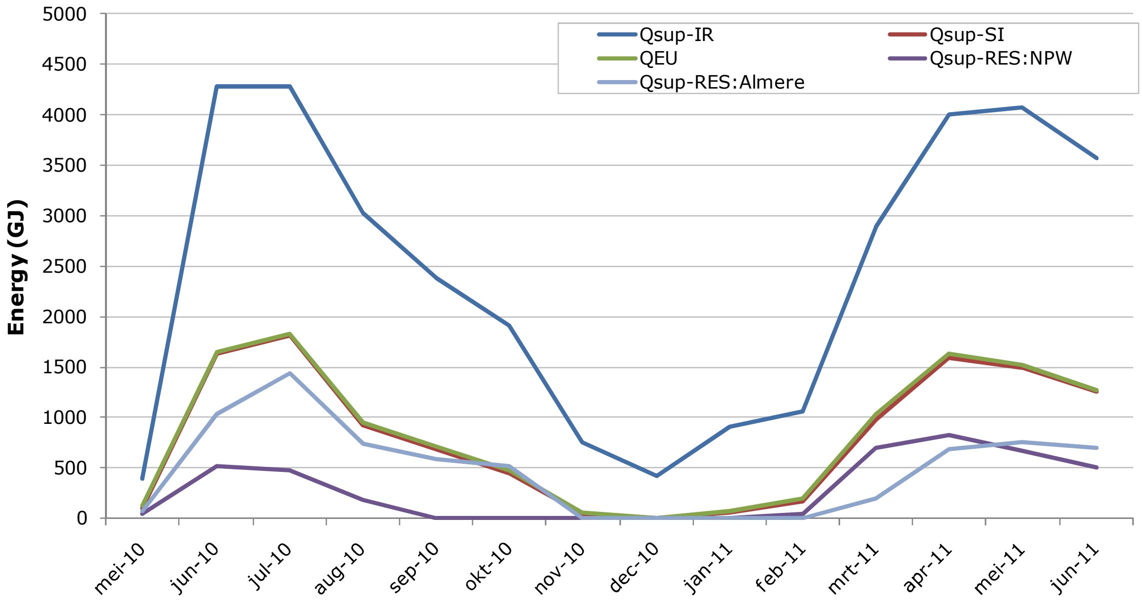


Figure 17 – Solar energy produced in Solar Island and transferred to Almere and Noorderplassen-west. The data is <u>not</u> normalized (for normal irradiation).

Figure 17 provides the flow of energy measured from May 2010 to June 2011. For the analysis of yearly energy yield of Solar Island and renewable energy supplied to dwellings, respective energy flows are calculated for one year period between July 2010 to June 2011.

Table 24 - Flow of energy (corrected data) (GJ) between Solar Island, Noorderplassen-west and city of Almere.

Time	Q_{EU}	$Q_{sup\text{-}RES:NPW}$	$Q_{sup\text{-}RES:Almere}$	$f_{Normalization}$	Q'_{EU}	Q'_{SUB}
mei-10	116.3	49.2	67.2	1.379	172.5	1076.3
jun-10	1530.8	500.8	1030.0	0.847	1394.2	1255.3
jul-10	1704.2	347.7	1356.5	0.881	1614.4	1400.8
aug-10	878.6	151.3	727.2	1.094	1033.5	931.4
sep-10	664.8	22.5	642.3	1.034	739.1	711.9
okt-10	438.3	-61.0	499.4	0.911	429.4	416.9
nov-10	54.0	54.0	0.0	1.232	71.6	64.6
dec-10	3.8	3.9	0.0	0.953	3.9	2.1
jan-11	62.5	62.5	0.0	1.022	68.7	62.8
feb-11	177.6	172.2	5.5	1.291	246.6	231.0
mrt-11	955.5	764.7	190.7	0.882	906.2	876.4
apr-11	1514.6	824.9	689.7	0.741	1206.8	1179.8
mei-11	1411.6	663.0	748.6	0.909	1379.7	1354.5
jun-11	1186.3	494.1	692.1	0.963	1228.4	1211.2

The results presented in this section provide the solar irradiation and respective renewable energy use specifically for the period of monitoring. Table 24 indicates the relation of renewable energy yield with respect to a normalized solar irradiation. $f_{Normalization}$ is the ratio of solar irradiation between the monitoring period and the same period in a normal year. Based on this factor the renewable energy yield of Solar Island is calculated for normalized conditions (Q'_{EU}). It can be seen that for a full year (between July 2010 and June 2011) there is 10% more yield than in a normalized year. Thus, it should be considered that the renewable energy provided to the dwellings within the monitoring period is slightly more than average conditions.

A second data-source (Q_{SUB}) directly provided the yield of the Solar Island. The normalisation factor was also applied to these data, resulting in Q'_{SUB}. Normalized values of both sources do not correspond exactly, probably due to measurements errors. The normalized, yearly yield amounts to 8400-8900 GJ based on the last 12 months in Table 24 of both data-sources.

The amount of energy production and supply is based on the measurements conducted on various points of Solar Island and heat distribution system according to method described in section 6.3.3. The energy flow presented in this section are calculated based on flow and temperature of water within the distribution system and not direct measurements. Moreover the water flow to Almere is not directly measured but derived as a difference between water flow measured at the Heat Exchange

Unit (V_{EU}) and flow measured in distribution system to Noorderplassen-west ($V_{RES;NPW}$). Inaccuracies are possible in temperature and water flow readings and in calculation based on interpolations for missing data. Thus, the initial data analysis indicated that there is room for measurement correction which then enable the data to accurately reflect the renewable energy share in dwelling areas.

The first step of measurement correction is applied on the output of energy from the heat exchange unit. The ratio between energy output of solar collectors ($Q_{sup;SI}$) and heat exchange unit (Q_{EU}) is calculated as 103%. Under normal conditions, rather than an increase, a 1-2% decrease in energy output is expected at the heat exchange unit due to system losses. Therefore, a correction factor of 5% is applied to the energy output from heat exchange unit. Additionally, the results are compared with data recorded by energy supply company (NUON) referring to monthly energy output of Solar Island. It is seen that there are differences between two sources in the first three months of data collection. The results remain in good agreement for the rest of the data collection period. There is no information regarding to the possible causes of discrepancy between data sources or which of the two sources are more reliable. However, the observed inaccuracy in heat exchange unit measurements made it more plausible to introduce a second correction of 2% which enabled a better agreement of results to the measurements provided by Nuon. The total correction factor is 7%.

The second step of correction is required for the energy balance between energy supplied from energy exchange unit and total energy provided to dwellings in Almere and Noorderplassen-west. The balance between supplied and distributed energy showed discrepancies every month. It is assumed that the observed imbalance is distributed proportional between renewable energy supplied to Noorderplassen-west and Almere (in order to obey the law of energy conservation). The results are presented in Table 24, raw measurement data is given in Appendix A.

The annual average ratio of irradiated solar energy ($Q_{sup;IR}$) and produced solar heat ($Q_{sup;SI}$) for the Solar Island amounts to 32%. In each month during the monitoring for certain period abundant renewable energy, e.g. not needed in Noorderplassen-west, was transferred to the rest of the city of Almere. Each month there were also periods when renewable energy was not sufficient to cover heat demand in Noorderplassen-west, thus extra energy was supplied from the larger district heating system of Almere. The annual share of solar energy provided to Almere and Noorderplassen-west can be provided within a range based on the measurement errors. The annual share of solar energy is 61-57% for Almere and 38-34% for Noorderplassen-west. Thus, in the case of uncorrected and unbalanced data 9% of the energy is not recorded for any of the areas. The data processing as explained above provides this amount to be taken into account in the results.

The total yield of the Solar Island is between 8440-8928 GJ for a normal year. The net collector area is 7135 m^2. Accordingly, the energy yield of solar collector in Solar Island is 1.18-1.25 GJ/m^2. Individual collectors typically have a yield of 1.1-1.4 GJ/m^2. From consumers' point of view a complete comparison of the two systems (Solar Island and individual collectors) shall include economical terms as well as energy yield in a situation of housing project development. Individual collectors would cost an individual consumer € 2600,- incl. installation, overhead costs (project developer) & VAT. In return they receive 3.5 GJ (renewable) heat per year for free. Considering the yearly heat tariff inflation (3-4%) it will take consumers 18 to 19 years to spend also € 2600,- on the initial fee of € 508,- for the Solar Island and the same yearly amount of heat (delivered by Nuon). Table 25 gives the break down of costs for both cases. Taking into account a loss of 2% interest (of own money to pay for the individual solar collector minus the initial fee) the payback time even increases to 23-25 years.

Table 25 – Comparison of Solar Island and individual collectors from consumers' perspective.

Costs per dwelling (incl. VAT)	Solar Island	Individual collector
Investment	€ 508,- (financial contribution to Solar Island)	€ 2600,- (cost of collector)
Energy costs	€ 24,- per GJ (2011)	--

7.1.2 PV Systems

Eco-houses are equipped with stand-alone PV-systems in Columbuskwartier. The electricity production of systems is monitored by interviews and internet web site.

Table 26 – Monitoring results for RES-Electricity in CK for each building type.

Building quality	PV Yield per PV area [kWh/m^2_{PV}/year]		Renewable electricity to grid [kWh/m^2/year]	
	Internet	Interview	Internet	Interview
ECO Houses	-	-	7.9*	
Solar Houses	58.1	60.0	1.3	2.0
Passive Houses	66.7	-	3.4	

(*) Few PV systems in Noorderplassen-west is from private commissioning. No PV-yield was recorded from those PV systems

The PV-yield is also estimated based on calculations in which the actual solar irradiation, the size, the orientation and tilt angle of the PV-system, the technology of the PV cells and the inverter type are considered. It is possible to assess the expected electricity production of each PV-system given the specific combination of those parameters. 84 PV-systems, on which the monitoring data is available, are included in the calculation. The monitoring data are then compared with the modelled results of PV-yield and presented in Figure 18.

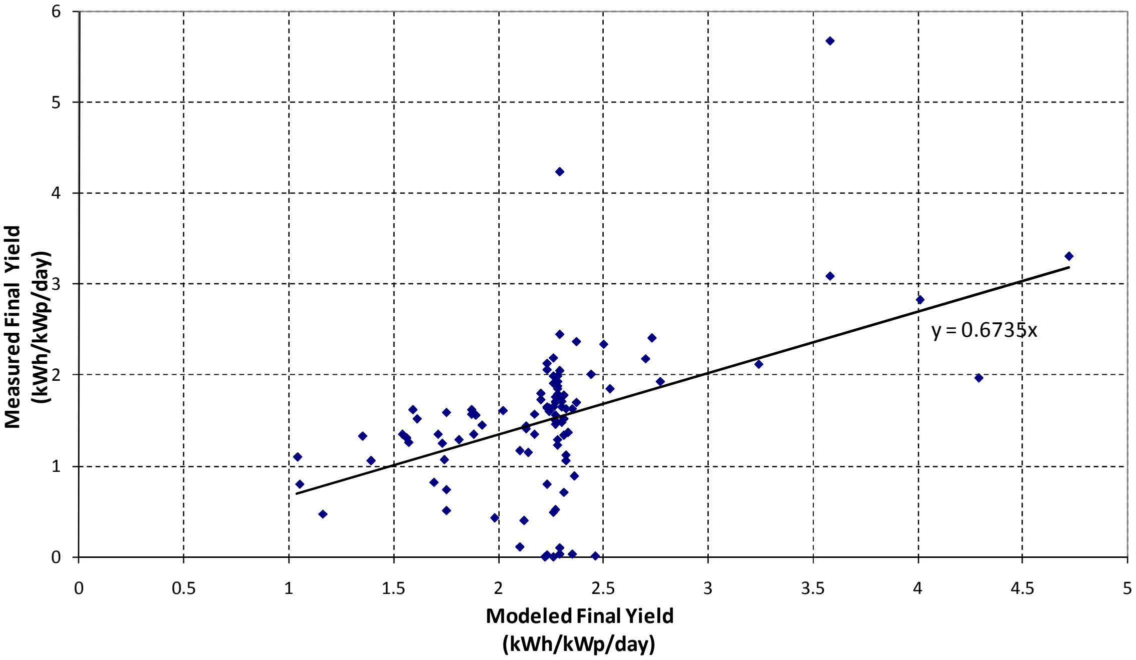


Figure 18 – Modeled PV yield versus measured yield data. The modeling included actual solar irradiation, orientation, tilt, and photovoltaic & inverter technology.

It is observed that the average measured yield is only 67% of the modelled yield. In certain cases the comparisons revealed satisfactory correlation, an example of this is given in Figure 19.

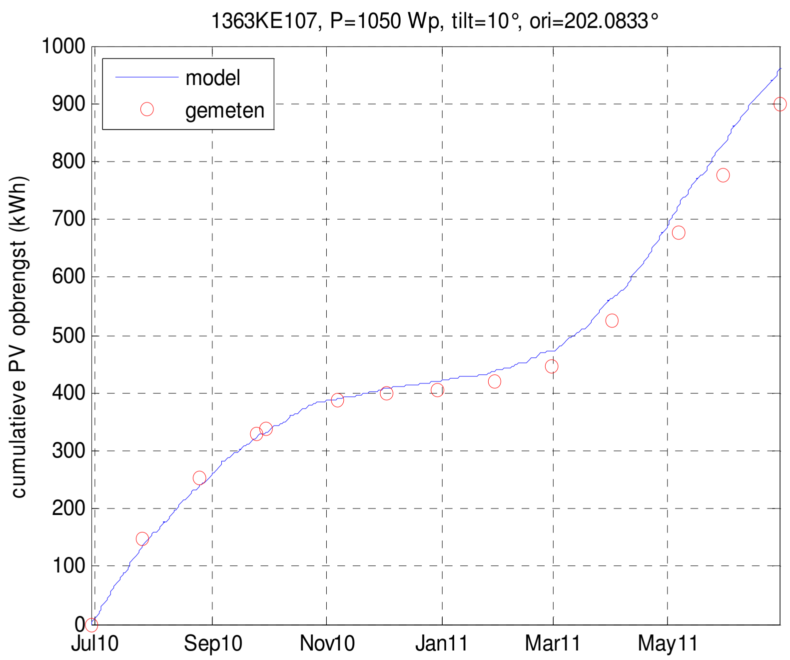


Figure 19 – Cumulative PV yield graph that follows the same trend and values between expected and measured data.

It is known that a full agreement between expected and measured PV yield is not likely. However, the present correlation is considered to be low. Hence a further investigation is recommended. A case-by-case analysis over PV yield measurements shows that approximately 20% of systems are diagnosed with a faulty installation or an incorrect meter reading. Furthermore, the main causes of divergence of monitoring data from model data are elaborated under two main titles.

a) Structural causes

Structural causes are the factors that are experienced due to the location or construction of the PV system and may require refurbishment of the system for improvement of the performance. The monitoring data that is affected by this kind of causes mostly follows the production trend of model results but a difference in the amount of PV yield between model and monitoring values is observed as in Figure 20.

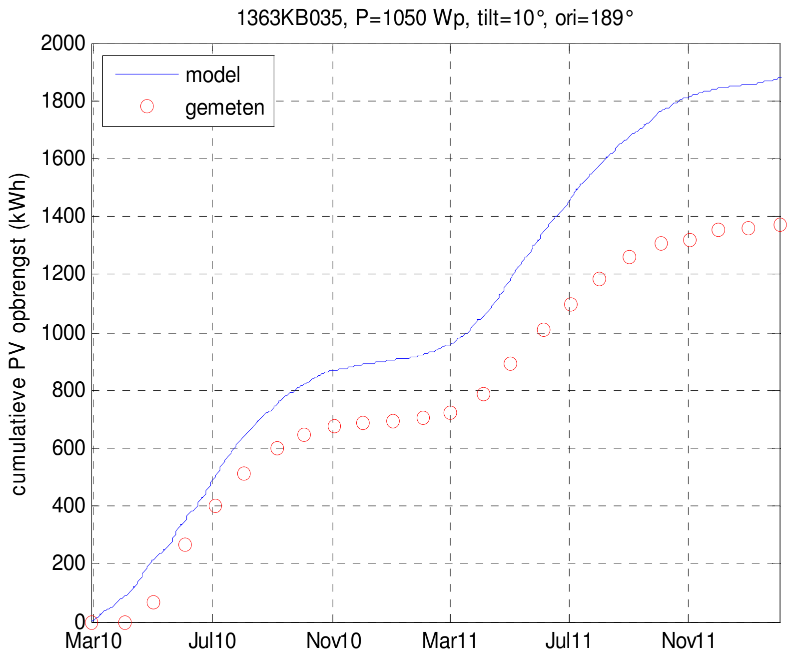


Figure 20 – Cumulative PV yield with agreement of model and measurement in yield trend, but not in yield itself.

Causes are indicated as;

- Pollution and accumulation of dust on the PV panels may occur due to low (10%) tilt angle of some collectors. This decreases PV yield, which is not anticipated in the model.
- The position of the PV-system within the building shell may affect the amount of air circulation around the collectors. In case of limited air circulation the temperature of the PV-cells rises, hence lower PV yield is acquired than expected.
- Shading from nearby trees and buildings may decrease the PV yield lower than expected model results. This is hardly the case in Columbuskwartier.

b) Non-structural causes

Apart from installation problems occasional errors in measurement or model parameters can cause differences in expected and monitored results. An example of divergence in the results is given in Figure 21. Relevant causes are characterized as;

- Incorrect meter readings or reading from only one inverter where there are two inverters mounted.
- Failure or malfunctioning of the PV system after a certain period.

* Incorrect PV power indicated in the database.
* Error in the input data to the model (e.g. inverter type).

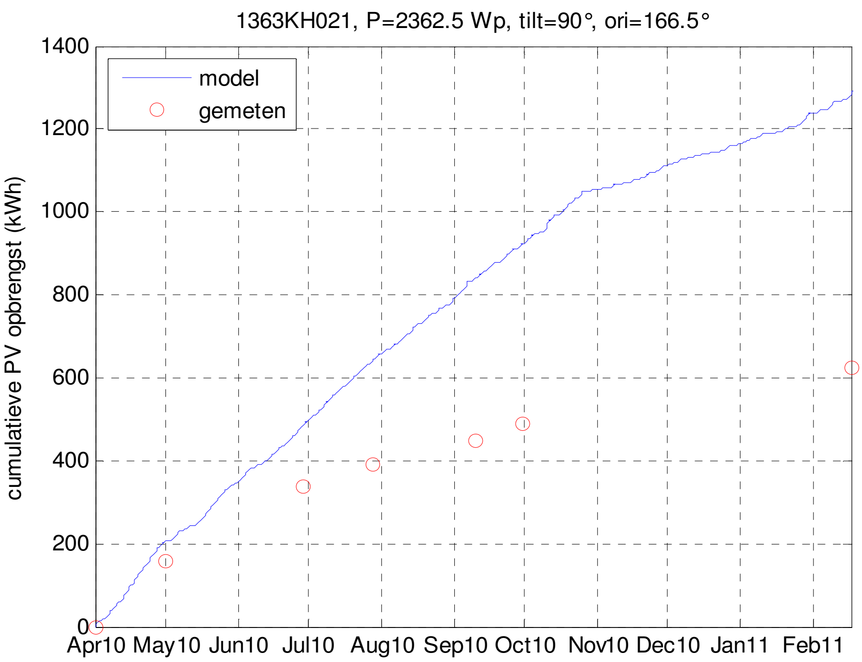


Figure 21 – Example of cumulative PV yield without agreement between model and measurement in both trend and values. The PV-system is mounted vertical (in the façade).

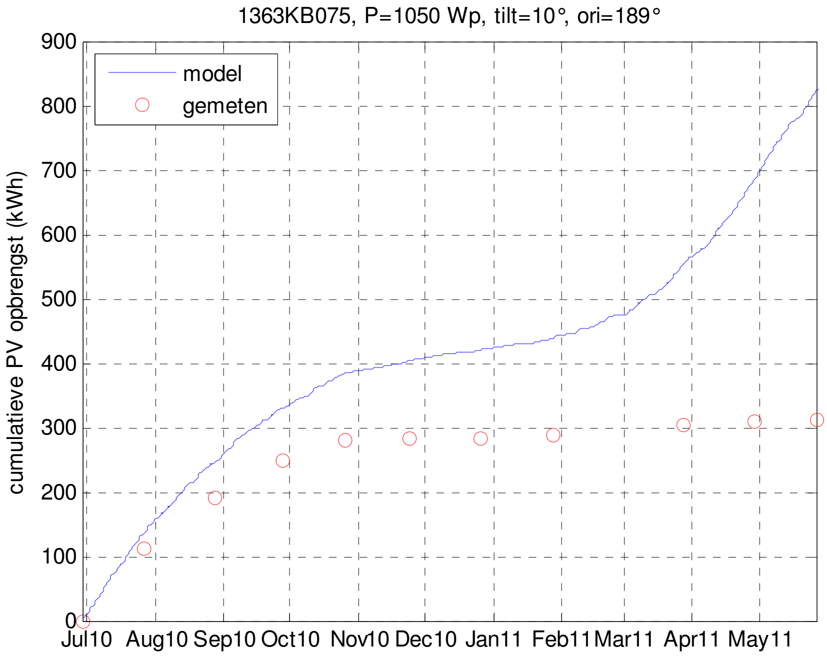


Figure 22 – Another example of cumulative PV yield without agreement between model and measurement in both trend and values.

7.2 Energy Demand in Energy Efficient Dwellings

Also energy efficient dwellings demand energy. The data for determination of energy demand is collected by three monitoring processes; Internet (monthly data collection), Interview (yearly data collection) and Detail monitoring (hourly measurements). The monitoring is carried out over a period of 24 months. Inevitably, the number of people participating to monitoring activities through 'Internet' and 'Interview' varied each month. Sufficient amount of monitoring data are still achieved as average 25% of dwellings were included in the overall data collection. Additionally, in 20 building units hourly measurements are conducted with data loggers that are connected to household devices and located for temperature readings. In this section, the average energy consumption is presented according to each building type from three sources where available. The monthly measurements of energy demand in terms of space heating, DHW and electricity for each Best category is given in Appendix-B.

7.2.1 Energy demand for heating

Majority of dwellings have started providing data input through internet monitoring site in the first quarter of 2010. The highest level of participation was observed in 2010 and 2011, but there were still participants until May 2012. The interview process has started in 2010 August and conducted 3 times until May 2012. Detail monitoring includes 20 dwellings in total. The monitoring fraction acquired for each building type is given in Table 27 (for number of dwellings see Table 15).

Table 27 – Fraction of monitoring of single family dwellings for energy demand for heating.

Area / Building type	Interview	Internet	Detail monitoring
Columbuskwartier	**30.2%**	**9.3%**	**2.1%**
Passive House (BEST 17)	--	12.8%	--
Solar House (BEST 4)	30.2%	5.8%	2.1%
ECO House (BEST 3)	--	--	--
Noorderplassen-west	**24.8%**	**4.2%**	**0.9%**
ECO House (BEST 7)	24.1%	4.4%	0.9%
Solar House (BEST 8)	25.6%	4.1%	--

By using different sources data is collected for around 25% of dwellings for all dwelling types. For example for Passive Houses 'Internet' provided data collection for almost 13% of buildings whereas there were no participants here for the 'Interview' method. The results from monitoring with 'Internet' and 'Interview' are in agreement with each other as presented in Table 29. The average heat demand measured with data loggers from 20 dwellings is lower. However, when it is considered that there are few samples within this set the difference of the measurements compared to other monitoring sources is not significant.

The size of the dwellings is different for the two areas as well as for the proposed and actual constructed dwellings. Proposed floor areas were based on the Dutch (official) reference dwellings. The community Columbuskwartier has even smaller passive and Solar Houses then expected. For the rest the dwellings are significantly larger then expected, especially in the community Noorderplassen-west. It is not clear why these large differences occur, especially for Eco Houses. Only guesses can be made. Noorderplassen-west was developed in good economic times, hence with consumer wishes for larger dwellings. While Columbuskwartier, developed much later, already started to feel the influence of the financial and economic crises. Higher ambitions on energy-saving bring extra costs but the benefits are (still) hardly seen by the average consumer. Reduction of floor area allows the developer to reduce costs and compete with houses with lower ambitions on energy saving.

Table 28 – Size of average gross floor area for single dwellings (m^2).

Building type	CRR	Commissioned	Ratio
Columbuskwartier	**121.1**	**144.9**	**120%**
Passive House (BEST 17)	112.3	107.3	96%
Solar House (BEST 4)	112.7	109.3	97%
ECO House (BEST 3)	130.3	184.2	141%
Noorderplassen-west	**115.7**	**174.4**	**151%**
ECO House (BEST 7)	116.3	177.9	153%
Solar House (BEST 8)	112.1	151.9	136%

Note:
(1) CRR represent the average proposal values for the dwellings.

Solar Houses are characterized with a number of energy saving measures. Thus, the actual energy demand to be higher than the proposed values is surprising. However the difference is not significant. For ECO-houses the proposed level of heat energy consumption is accomplished and even remained lower. The most ambitious energy performance was targeted for Passive Houses. Those are designed with a consumption proposal of 16.5 kWh/m^2/year. This was a challenging target to meet. Hence, the actual average heating demand is measured as 20.4 kWh/m^2/year. Still the average actual consumption of Passive Houses is significantly low among all building types. In general, the proposed levels of energy consumption are accomplished.

Table 29 – Average annual energy demand for space heating for single dwellings (kWh/m^2).

Building type (Annual heating in kWh/m^2)	CRR(1)	Interview	Internet	Data logger
Columbuskwartier	**33.7**	**39.4**	**27.6**	**24.1**
Passive House (BEST 17) (2)	16.5		20.4	
Solar House (BEST 4)	33.7	39.4	34.9	24.1
ECO House (BEST 3)	--	--	--	--
Noorderplassen-west	**45.0**	**42.0**	**44.2**	**39.5**
ECO House (BEST 7)	55.5	49.4	48.0	39.5
Solar House (BEST 8)	34.5	34.7	40.3	

Note:
(1) CRR represent the average proposal values for the dwellings that were monitored with interview. Therefore proposed values shall be evaluated in comparison to interview data not to internet data with the exception of PH.
(2) The proposal values of Passive Houses are presented for the dwellings included in the internet monitoring. The proposal shall be compared to internet monitoring results

Difference between two sustainable districts is observed in energy demand of Solar Houses. Although same level of energy demand was foreseen in both districts, the commissioned dwellings in Noorderplassen-west performed better than same type of houses in Columbuskwartier, at least according to the interviews. The internet-data indicates the opposite. Furthermore, there is also the effect of the larger floor areas in Noorderplassen-west.

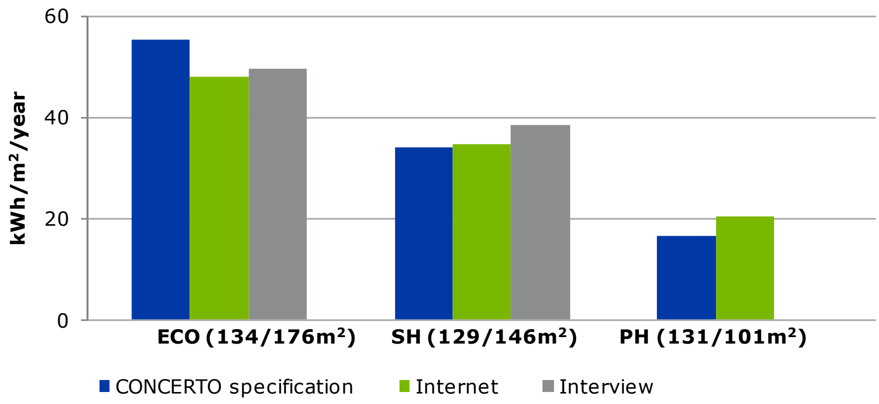


Figure 23 - Average annual energy demand for space heating per square meter for all building types

Additionally the effect of dwelling size and absolute energy use per dwelling type is analyzed (see Figure 23 and Figure 24). The figures provide a comparison of proposed energy demand and measurements based on internet and interview methods. The average proposed and commissioned building floor area is included in parenthesis next to building type label. Both ECO and Solar Houses are constructed bigger than the proposed values for floor area. The average commissioned floor area of Passive Houses is smaller than the proposed values.

Figure 23 displays that for ECO houses the commissioned energy demand per unit floor area is lower than the proposed levels; the Solar Houses maintain to reach the goals with a slight difference; and Passive Houses commissioned energy demand per unit floor area is, although slightly, higher than the proposed levels. This result implies that it gets more difficult to accomplish the performance goals as the energy performance ambition gets higher. Referring to Table 23 the issue also is linked to the high interior temperatures for better insulated dwellings (e.g. Solar Houses). After a certain threshold the higher insulation levels provide less energy savings. Thus the higher energy performance ambitions are withheld by implied higher interior temperatures.

When the average size of the building types are brought into the discussion, the comparison of energy performance levels provides a distinctive picture. Figure 24 presents the average energy use for each building type. It is seen that the favourable situation of ECO-houses in terms of energy use per unit floor area, is tempered due to large floor area of these buildings. Whereas on the opposite end of the scale, due to its low floor area Passive Houses maintains the average absolute energy demand in line with the proposal values despite its high energy demand per unit floor area. The comparison of the energy use per unit floor area and per dwelling indicates that the energy-use for space heating tends to decrease per unit floor area when the dwelling becomes bigger. It is possible that bigger dwellings have a higher ratio of less heated spaces (e.g. more or bigger bedrooms) compared to smaller dwellings. Thus, the size of the building is a major determinant of the absolute energy demand.

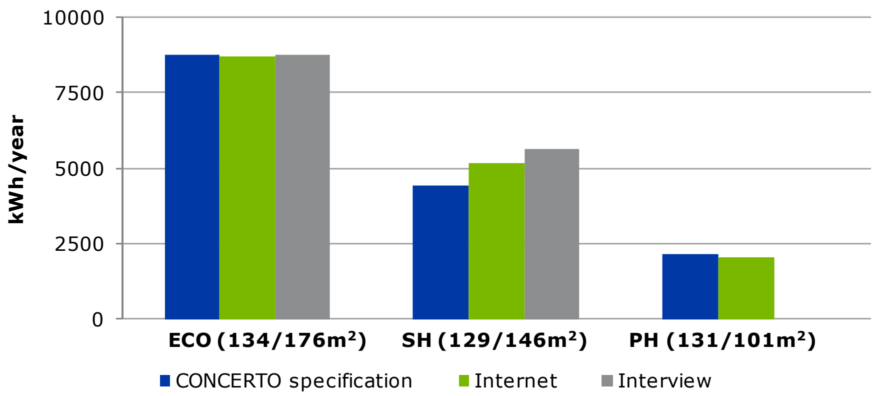


Figure 24 - Average annual energy demand for space heating per dwelling for all building types

However, it should be considered that the *proposed* values are a theoretical estimation of the energy consumption for space heating. They are based on the standard NEN 5128 and amongst others only take normalised occupant behaviour into account.

Figure 25 provides further insight. The *proposed* as well as the *monitored* values for the average annual energy consumption for space heating are compared with the calculated EPC in both cases. For the *monitored* values, the EPC is calculated for the actual constructed dwelling. The positive effect of (proposed and monitored) PV-systems on the EPC is eliminated for Solar Houses and Passive Houses in Columbuskwartier since PV is not related to space heating. The remaining energy use behind the corrected EPC mainly represents space heating. Other included energy uses, such as lighting, fans and pumps are fairly constant per square meter of floor area, at least theoretically.

It is seen that there is a very strong correlation (R^2-value=0.99) between the *monitored* heat demand and the EPC (based on the actual constructed dwelling). This is in line with the concept of the Energy Performance coefficient, a strong relation between (primary) energy demand and energy performance coefficient. The correlation between heat demand and EPC for *proposed* values is lower. Especially the *proposed* values for Solar Houses deviate from the linear trend. Based on these results, it seems that in the case of Solar Houses the *proposed* energy demand is underestimated with respect to its EPC level.

Thus, comparison of *monitored* performance with *proposed* values may fail to provide conclusive results in energy performance (of Solar Houses). The data also show that the ECO houses consume less energy for space heating per square meter than expected (proposed) while Solar Houses and Passive Houses consume (a little bit) more energy for space heating per square meter than expected (proposed). The size of the dwelling does not seem to be a factor. Both Eco Houses and Solar Houses are larger then planned while one uses more and the other uses less heat then expected. Another explanation comes from working towards the physical boundary of zero energy use. The closer you reach the boundary, the harder the next step is. The Passive Houses solve this by paying extra attention to both the construction and the use of the dwelling. That could explain why the *monitored* values for space heating are still close to the *proposed* values. Another explanation comes from the observed variation in heat demand, especially for Solar Houses. The monitoring through interview shows an average heat demand of 38 kWh/m^2 for Solar Houses while the interview data show an average heat demand of only 32 kWh/m^2 (84%) which is more in line with the linear EPC-relation.

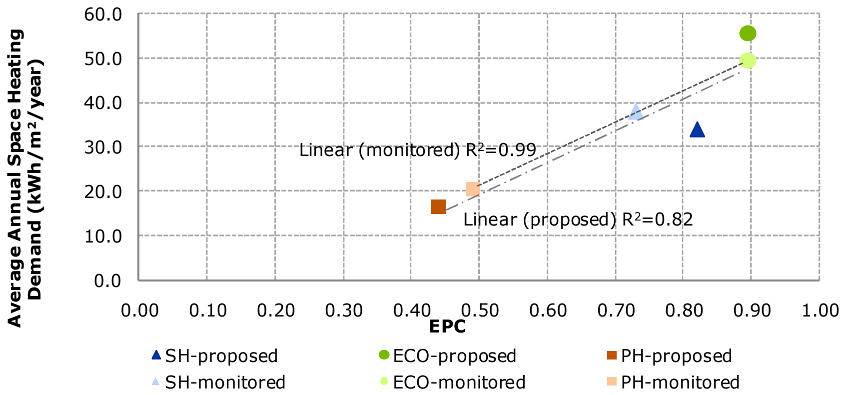


Figure 25 – Relation between EPC and average annual heat demand for proposed and monitored values.

Figure 23 and Figure 24 also provides insight to the influence of occupant behaviour to the energy consumption. Data collection through 'Internet' is based on people who volunteered for this more time consuming process, thus requires a bigger effort from the occupants. It is anticipated that people who participated to this kind of data recording are more conscious about their energy consumption. The differences in heat demand per m^2 and per building reflect this motivation. Internet data is lower than the Interview both for Eco Houses and Solar Houses. The difference shows that user behaviour contributes to energy saving, thus more attention is required for the use of the building by the occupants in order to benefit from the potential energy efficiency.

Although values may differ among districts, Solar Houses still have a lower heat demand than ECO-houses. Energy demand of Passive Houses remains to be the lowest among all building types. Thus, it is concluded that the goal of achieving relative effect of various energy strategies within building types was accomplished. The monitoring data suggests that method of design with planned control of construction process has a direct effect on energy demand for space heating.

7.2.2 Domestic hot water

DHW is mostly distributed together with space heating. When the transmission is combined then the energy demand for DHW is calculated based on the number of occupants as explained in section

6.3.2. Only in Noorderplassen-west there are sub-station networks with CTW system where DHW is transferred to the dwellings in separate pipes and the dwellings are equipped with separate DHW meters (see Figure 5). On such dwellings the energy demand for DHW is calculated based on the flow of hot water measured at dwellings. The monitoring is conducted through internet. Table 30 presents the monitoring fraction for single-family dwellings in Noorderplassen-west.

Table 30 – Fraction of monitoring of single family dwellings for energy demand for DHW.

Building type	Internet
Noorderplassen-west	**1.5%**
ECO	0.8%
SH	2.2%

Although the data are limited due to low fraction of number of monitored dwellings the results suggest certain pattern when compared with assessed DHW demand within cRRescendo proposal. Table 31 presents the average energy demand for DHW and the proposed values for the same set of dwellings that were participating to the monitoring.

Table 31 – Average energy demand for DHW in single family dwellings (kWh/year/person).

Building type	CRR$^{(1)}$	Internet	NEN 7120
Noorderplassen-west	**1394**	**845**	**890**
ECO	1408	750	
SH	1379	941	

Note:
(1) CRR represent the average proposal values for the dwellings that were monitored with internet The proposed values are based on NEN 5128.

The results of monitoring indicate that the actual average consumption was significantly lower than proposed; almost halved for ECO-houses. Comparison of proposed values with monitoring results clearly shows that the proposed values overestimate the DHW demand in single family houses both for ECO-houses and Solar Houses as lower demand is measured in actual situation. This is laos recognized in the new standard NEN 7120 which rates DHW based on the number of occupants based on the amount of usable floor area.

7.2.3 Energy demand for electricity

The average number of buildings that are included in the monitoring of electricity demand is presented in Table 32. The share of observed dwellings are close to monitoring fraction of space heating as the interview is carried instantly for both energy flows. The monitoring data for Passive Houses are collected by internet. For the rest of the buildings a high percentage of monitoring data are collected by interviews.

Table 32 – Fraction of monitoring of single family dwellings for energy demand for electricity.

Building type	Interview	Internet
Columbuskwartier	**31.3%**	**8.5%**
ECO	--	--
PH	--	11.1%
SH	31.3%	6.0%
Noorderplassen-west	**25.3%**	**4.2%**
ECO	24.2%	4.3%
SH	26.4%	4.1%

Almost the same level of electricity consumption was anticipated for all types of dwellings in both districts. The proposed values are in very good agreement with the measurements from Solar Houses in Columbuskwartier. The comparison of internet data with proposed values shows that unlike other building types the electricity demand for Passive Houses stayed lower than proposed values. In Noorderplassen-west, the actual values recorded by monitoring remained higher both for ECO and Solar Houses. This is also confirmed by the average demand based on internet data.

This variation can be explained by the difference of average floor area between proposed and actual values. The actual floor area is significantly higher than proposed values for dwellings in Noorderplassen-west, as presented in section 3.3. The Passive Houses, on the other hand, are constructed smaller than anticipated in the proposal. Thus, it can be concluded that there is a strong correlation between area and electricity demand for all types of energy efficient buildings.

Table 33 – Average energy demand for electricity in single family dwellings (kWh/year/building).

Building type	CRR (1)	Interview	Internet
Columbuskwartier	**3138**	**3184**	**2893**
Passive House (BEST 17) (2)	3246		2845
Solar House (BEST 4)	3138	3184	2941
ECO House (BEST 3)	--	--	--
Noorderplassen-west	**3129**	**4409**	**4965**
ECO House (BEST 7)	3106	4790	4537
Solar House (BEST 8)	3151	4029	5393

Note:
(1) CRR represent the average proposal values for the dwellings that were monitored with interview. Therefore proposed values shall be evaluated in comparison to interview data not to internet data with the exception of PH.
(2) The proposal values of Passive Houses are presented for the dwellings included in the internet monitoring. The proposal shall be compared to internet monitoring result.

Electricity demand is subject to fluctuations both on a seasonal basis, across the week, during the day and even on smaller time-scales. To examine these demand trends, data of a higher frequency is required. Hourly electricity consumption data for 20 dwellings is measured by detail monitoring by use of data-loggers that are connected to household devices. The data is filtrated to exclude errors in data recording. The weekly average consumption pattern of each dwelling is calculated by averaging weekly data recorded during the whole monitoring period. Figure 26 shows an example. In all cases a pattern occurs that shows little demand during the night, a small peak at the start of the day followed by a relatively constant demand during the day and an increase at the start of the evening, starting with a peak.

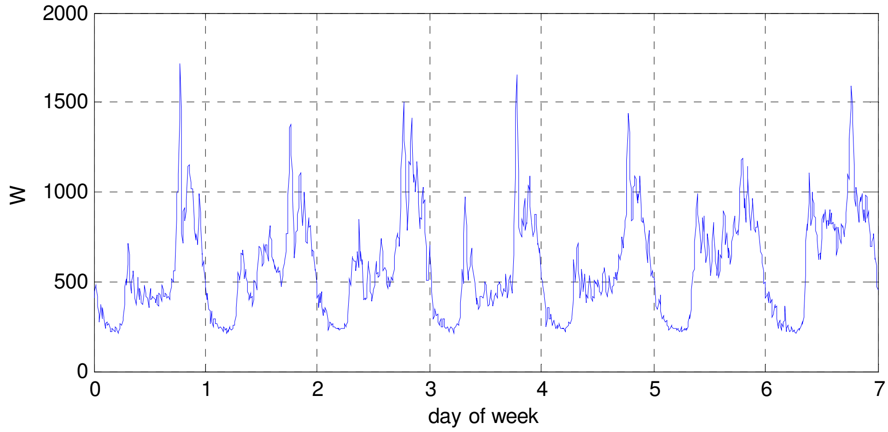


Figure 26 – An example of the average weekly electricity consumption pattern of a single dwelling in Almere.

Typically during the week days the demand increases in morning hours (around 8:00 am) when occupants wake up and begin using electrical equipment. After a fall during mid day the second consumption peak occurs around 5:00-5:30 pm. as occupant arrive back from work, school etc. During the evening, demand usually remains on a high level with little variation due to numerous household activities (cooking, watching TV, etc) before people eventually go to sleep.

By the analysis of detail monitoring data three distinct groups of consumers are identified according to the level of electricity consumption: low, mid and high electricity consumption. Figure 27 shows the relative consumption patterns of all groups with respect to each other, where 1,0 represents the average consumption value of any of the three levels. Two similarities are visible in all groups: (1) all three groups show a similar weekly pattern, such as the one described above, (2) the lowest electricity power or base load in all three groups is about half of the average electric power (which corresponds with 1,0).

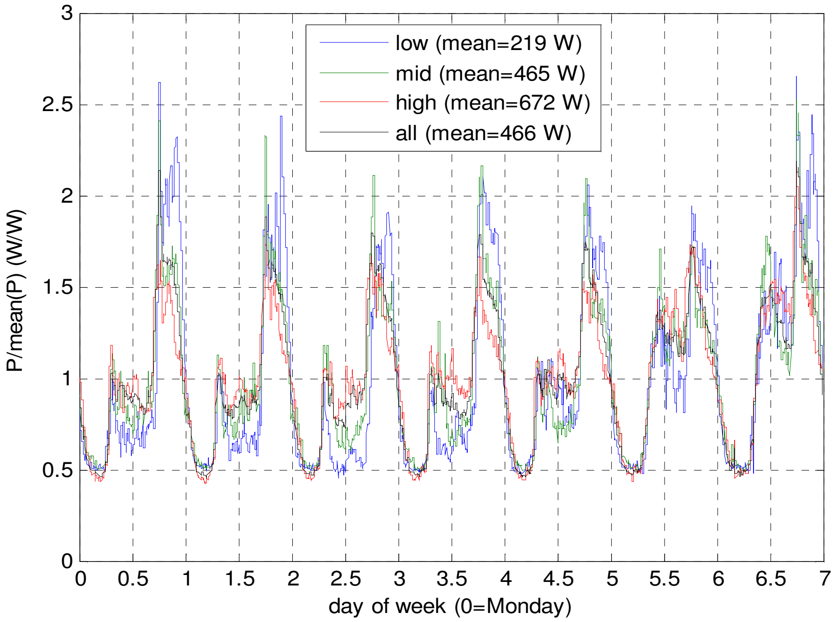


Figure 27 – Average weekly electricity consumption patterns normalized to the average electric power for three groups of consumers within the detailed monitoring in Almere.

In addition to the distinct level of average consumption, the three groups also differ in terms of the fluctuation within the pattern. The fluctuation is found to be inversely proportional with the level of average consumption. The relative highest demand of the group with low electricity consumption is higher while its relative lowest demand is lower than the other groups. Thus the fluctuation of consumption pattern within low level of electricity consuming group is significantly larger compared to the other two groups. The second biggest fluctuation is found in the group with mid level electricity consumption. The lowest fluctuation between minimum and maximum consumption thresholds is observed in the group with a high level of electricity consumption.

The electricity consumption pattern and the groups are likely to represent certain occupancy types. The group with a low level of electricity consumption can be explained by occupants who are not at home during the day (office hours), thus have little electricity consumption during the day followed by high consumption in the evening when activities occurs simultaneous (lighting, cooking, TV, (dish) washing, etc). The group with a high level of electricity consumption show less fluctuation. It is likely that these houses are occupied by at least one of the occupants also during the day, possibly carrying out the activities requiring electricity over the whole day which results in an increased base load. The group with a mid level of electricity consumption lies somewhat in between, either by occupancy hours, number of occupants or number of electrical devices.

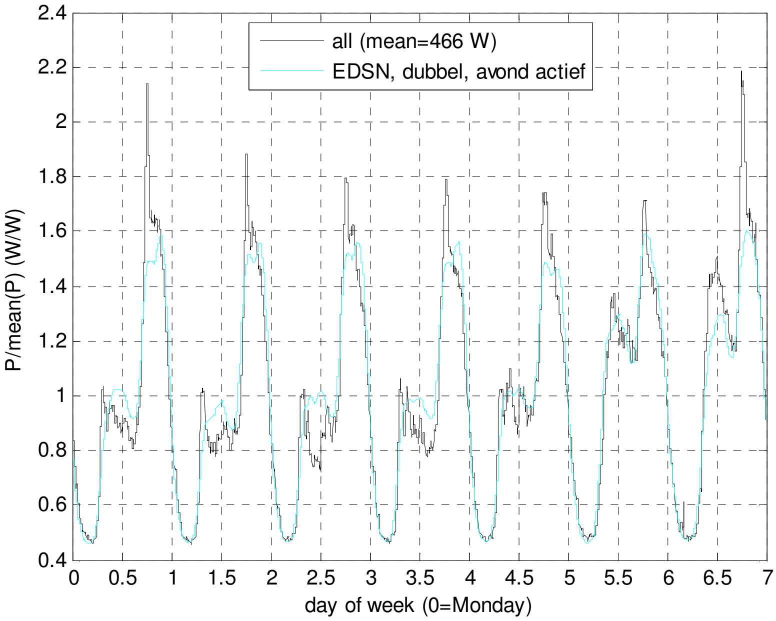


Figure 28 – Normalized average weekly electricity use pattern, comparison of Almere and The Netherlands.

The average electricity consumption within the detailed monitoring is also compared with the average electricity consumption of Netherlands according to the data from EDSN as shown in Figure 28. Among the three main types of electricity contracts, the one that resembles the situation in Almere most, is selected for comparison (Double meter, Active evening). Although the relative consumption pattern is largely similar, a clear peak of electricity consumption is visible in Almere at the start of the evening. This is related to the district heating. Typical Dutch households have their warm meal in the evening and use natural gas for cooking. Areas with district heating (often) do not have also a gas-infrastructure next to district heating and rely on electricity for cooking. High electricity consumption in Almere at the start of the evening reflects the electricity use for cooking a warm meal.

7.3 Rational Use of Energy

The heat losses that occur through the district heating network depend basically on the properties of the distribution system. It is characterized as a function of the temperature difference between the water and its surrounding; depth of the pipes from the ground surface; the surface area of the distribution pipes and insulation. Moreover, the initial analysis of data indicates that the characteristics of dwellings which create the demand for energy on a distribution system also influence the relative heat losses. Thus, while the specific heat demand (in kWh/m^2) decreases, the relative heat losses increase. At given point a limit is reached were it is no longer economic or efficient to supply heat by district heating. This section is an attempt to analyze these factors.

In the first part analysis includes the data on energy supply and demand which is recorded from five sub-stations monthly. The results presented here include the analysis of heat distribution to the sustainable areas of Almere to consider whether they are near or below the economic threshold. The individual data regarding to each sub-station is presented in Appendix-C. In second part the data recorded during monitoring is compared with calculation results based on method in NVN 7125:2011.

7.3.1 Results and discussion based on monitoring data

This section provides detailed analysis on monitoring data results with regards to differences between sub-station types, and factors influence distribution losses.

The data set for determination of heat loss includes monthly recordings of heat supply from 5 sub-stations. The demand of heat within these sub-station networks is calculated based on the monitored dwellings within each network. The heat supply and the heat demand are analysed between beginning of June 2010 and end of May 2012. The method is based on determining the difference of energy per unit floor area between the heat supply to the area from sub-stations and heat demand measured at dwellings.

a) Heat Distribution system

Results include data on two types of distribution networks; ITW system in area of sub-station ADH1WR2 and CTW system in the areas of remaining sub-stations. The average monthly heat demand and heat loss are presented in Table 34.

Table 34 – Average heat demand and loss related to various sub-stations.

Sub-station code	Gross Floor Area (m^2)	Avg. Monthly Demand 1/6/2010-31/5/2011(1) (kWh/m^2)	Avg. Monthly Demand 1/6/2011-31/5/2012(1) (kWh/m^2)	Avg. Monthly Loss 1/6/2010-31/5/2011(2) (kWh/m^2)	Avg. Monthly Loss 1/6/2011-31/5/2012(2) (kWh/m^2)
ABX3WR1 (CTW)	59948	5.97	5.57	2.07	1.64
ABX3WR2 (CTW)	36795	4.36	4.23	3.62	2.23
ABX6WR2 (CTW)	46867	5.56	5.56	2.51	1.21
ABX6WR3 (CTW)	32026	4.02	3.24	2.11	2.04
ADH1WR2 (ITW)	43522	4.54	4.08	4.01	4.20

Note:
(1) Demand for total energy use: including space heating and DHW.
(2) Loss for total energy use: including space heating and DHW.

Heat loss ratio is calculated as the ratio of heat loss to heat demand to determine the performance of each network. The average heat loss ratio for CTW systems is 48% whereas it is calculated as 95%

for ITW systems. Previous study indicates the relative heat loss in a network with very low demand can be as high as 80%, if no special measures are taken. In a special approach where pipes are carefully designed for lower dimensions, the heat losses are reduced towards 32% for the same line heat density (Zinko, Bohm, Kristjansson, Ottosson, Rama, & Sipila, 2008). Similarly, the monitoring data in Almere shows that the design of heat distribution systems should be improved for energy efficient dwellings to provide acceptable heat loss ratios. Otherwise the loss ratio with regards to heat demand yields high percentages.

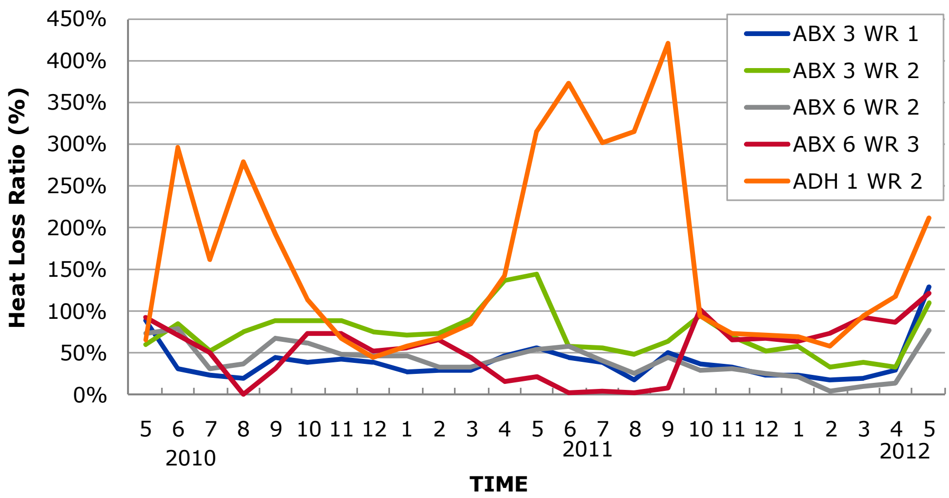


Figure 29 – Monthly rate of energy loss on distribution networks, total for DHW and space heating.

Figure 29 presents the monthly rate of distribution losses to total heat demand of dwellings. Throughout the year the different fluctuation of energy loss ratio is clearly observed between ITW (ADH1WR2) and CTW systems. Between May and October, the loss ratio of ITW is significantly higher than the energy loss ratios observed in CTW system. For this period, the non-heating period, the difference lies in the way that the two types of networks provide heating with regards to the change in energy use pattern in dwellings. The requirement for space heating in energy efficient dwellings is very low if not zero between May and October. Therefore, the temperature of supply water for space heating is set back to 40 °C. On the other hand, DHW is required for showers, washing etc. The supply temperature (65 °C) is kept constant for reasons of prevention of Legionella-disease, both for heating and non-heating seasons.

In a CTW system it is possible to hold or minimize the distributed of energy for space heating when it is not required. In the meanwhile heat for DHW is still provided with the separate piping system. CTW systems reduce distribution loss by operating only when hot water is needed, at the expense of greater system complexity. Thus, the energy is supplied only for the specific demand and the energy lost in the distribution relative to the demand is kept relatively constant throughout the year.

In ITW systems a single distribution pipe supplies heat both for DHW and space heating. The supplied heat is then used for required household services. The actual heating of the tap water is performed in heat exchanger unit in the domain of the consumer. Thus, throughout the year the supply temperature is constant at 65 °C due to DHW requirement. Despite the decreased demand for space heating in dwellings between May and October, the supply temperature is kept constant. As the demand is very low in this period, the ratio of heat loss is observed to be 4 times more than its level in the heating season as seen in Figure 29.

Moreover, in ITW systems as the water is heated at the dwellings with a heat exchanger and a small storage unit, water is not heated instantly at the time of DHW demand; instead a certain amount of hot water is stored as a reservoir of heated water in each dwelling. While the hot water is kept readily available, energy is partially transferred to the surrounding, causing standby losses. The energy company reports this loss as approximately 3 GJ/year for each dwelling. This energy is registered as a part of the consumed heat. In the heating season the standby losses are still beneficial. In the cooling (or non-heating) season, the waste heat due to the standby losses may possibly create undesired overheating and/or increase cooling demand. In 2011/2012, new houses were equipped with improved more energy efficient heat exchangers, reducing standby losses 1 GJ/year.

b) Period of construction

Table 35 - Distribution losses with regards to period and properties of sub-station network

Sub-station code	Avg. Floor area (m^2)	Urbanization Ratio(1)	Avg. EPC	Avg. Loss ratio(2) 2010/2011	Avg. Loss ratio(2) 2011/2012
ABX 3 WR 1	189.11	0.52	0.91	35%	29%
ABX 3 WR 2	172.75	0.52	0.91	83%	53%
ABX 6 WR 2	156.75	0.42	0.88	45%	22%
ABX 6 WR 3	153.97	0.65	0.74	52%	63%
ADH 1 WR 2	136.86	0.43	0.64	88%	103%

Note:
(1) Urbanization ratio calculated according to built floor area for each network as of July 2012.
(2) Loss ratio for total energy use: including space heating and DHW.

As mentioned earlier the fact that the districts were partially under development during the cRRescendo monitoring process enables to observe various use patterns through time. An observation is based on the results of first and second year of monitoring period as given in Table 35.

Figure 30 presents the difference in phase of development for each sub-station network. It is known that the heat distribution area of sub-station ABX6WR3 is (at that time) a recent developed area in Noorderplassen-west. ADH1WR2 is one of the sub-stations in Columbuskwartier which is also a recent urban development. Both of the areas have been developed with a high rate of new buildings until mid 2011. Between June 2010 and June 2011, each week a large number of newly constructed buildings were surrendered and started to be used by their occupants. At the beginning of their occupancy the heat demand for the buildings were higher than their normal demand levels. This is due to the fact that new buildings require a drying period with an increased level of energy use. Used building methods involve the use of large amounts of water (concrete, mortar, plaster). Some surplus water is still present when the building is accepted and has to be removed by heating and/or ventilation. Water can also be trapped in insulation materials, reducing its performance. Due to drying of the new building and/or reduced performance, an increased heat demand in the first year is expected. The extra energy use is likely to depend on the date of acceptance. Drying in winter results in a higher heat demand then drying in summer.

Between June 2011 and June 2012 almost all monitored dwellings were surrendered for over one or two years. The energy use became relatively more stable than the previous year. The energy use was much more related to the daily heating requirements of the occupants themselves. This change in heat demand is reflected in the ratio of heat loss in these two periods. With the stabilized heat demand in energy efficient dwellings with their normal use resulted in an increase in the rate of distribution loss for those areas.

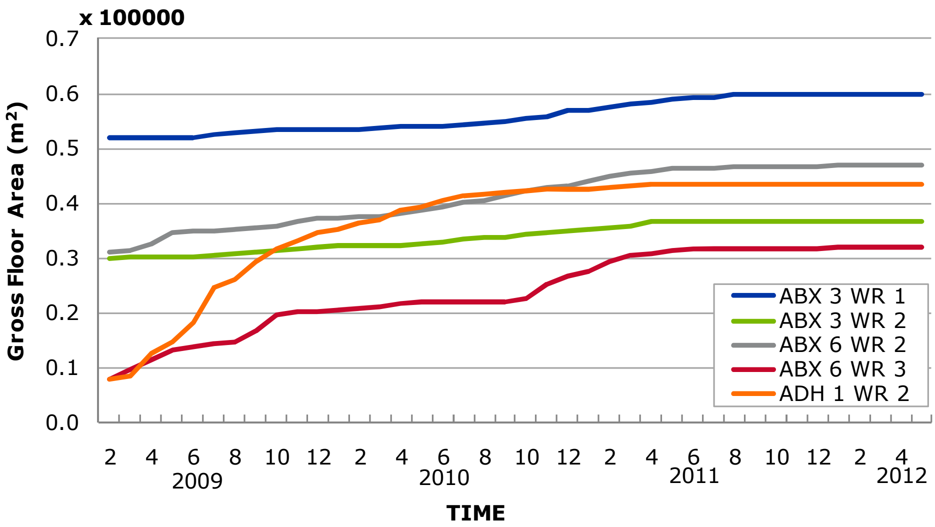


Figure 30 – Rate of urban development in sub-station areas.

Another effect of different time of construction is reflected in the energy performance of buildings. Through time the building energy performance requirements defined by the national law changes towards higher performance, thus the allowed energy use decreases. The first developed areas have lower energy performance than the last ones. This is reflected in higher EPC level. Areas which be-long to the heating network of sub-station ABX6WR3 and ADH1WR2 are also typically characterized by the high percentage of energy efficient Solar Houses, 52% and 80% respectively. The differences are recognizable in Table 35, especially between areas with lower energy performance (ABX3WR1 and ABX3WR2) and areas with higher energy performance ADH1WR2. It can be seen that with the exception of ABX3WR2 the ratio of heat loss is inversely proportional with the energy performance of buildings. The newly developed areas tend to have higher heat loss ratio as a result of better energy efficiency of dwellings.

A relation between urbanization ratio and distribution loss ratio was expected. Urbanization ratio is determined as the ratio of total building floor area to the urban area. It is anticipated that as the urban area gets denser, higher urbanization ratio, the heat loss decreases. However, this relation is not observed directly in the cRRescendo data set.

a) Space heating and DHW

Within CTW systems it was possible to monitor heat supply and demand for space heating and DHW separately. Thus heat loss for each service type could be calculated as presented in Table 36. A comparison between losses for space heating and DHW shows that a large share of the distribution losses relates to the space heating. The total energy use for space heating is bigger then for DHW and has also a larger percentage of distribution losses.

Table 36 – Distribution losses with regards to two periods and separately for DHW and space heating.

Avg. Annual Loss ratio	Space Heating		DHW	
	2010/2011	2011/2012	2010/2011	2011/2012
ABX 3 WR 1	41%	37%	8%	2%
ABX 3 WR 2	106%	70%	24%	10%
ABX 6 WR 2	59%	30%	-3%	-5%
ABX 6 WR 3	72%	92%	11%	19%

Figure 31 and Figure 32 presents heat loss calculated for 4 sub-station networks regarding to space heating and DHW, respectively. The total distribution loss ratio is highly determined by the loss within space heating. Thus the seasonal variation of losses within space heating network is similar to distribution loss ratio presented for total heat loss in previous section. In the period between May and October the loss ratio increases due to decreased space heating demand. As the energy efficient dwellings have significantly low demand for space heating also for winter months the average loss ratio is considerably high; 70% and 57% for first and second year respectively. The loss ratio for the distribution network of ABX6WR3 presents a different pattern than the other sub-station areas, especially during the summer months of 2011. The number of buildings connected to this sub-station has increased approximately 30% within first half of 2011. Summer months of 2011 were the first months where occupants started to live in their new houses, hence there was an increased heat demand. Higher heat demand with a very little loss resulted in low loss ratio as in Figure 31.

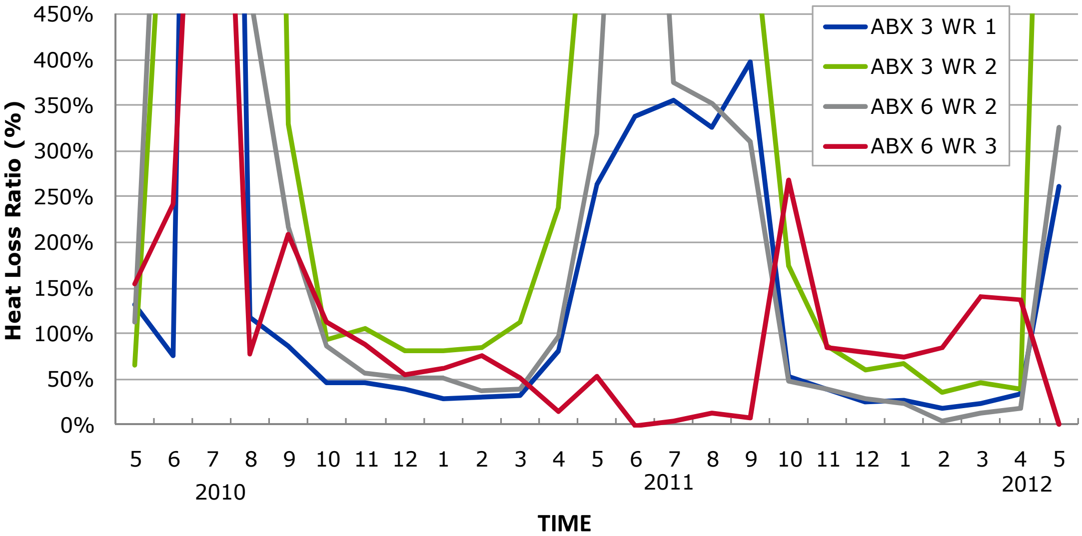


Figure 31 – Monthly rate of energy loss on distribution networks for space heating.

Heat energy supply for DHW measured at each sub-station. For the period prior to September 2010, a high fluctuation is observed within supply data. As a result Figure 32 shows that peaks and negative values of distribution loss are revealed. There is a high possibility of typing errors during the recording of data from the screen of the measurement device to data collection sheets by the technicians. Although less likely it is also possible that measurement device revealed some error values during this period and were left unrecognized. As the monitoring was in its initial stage and maintenance frequency of control devices is low the errors are plausible.

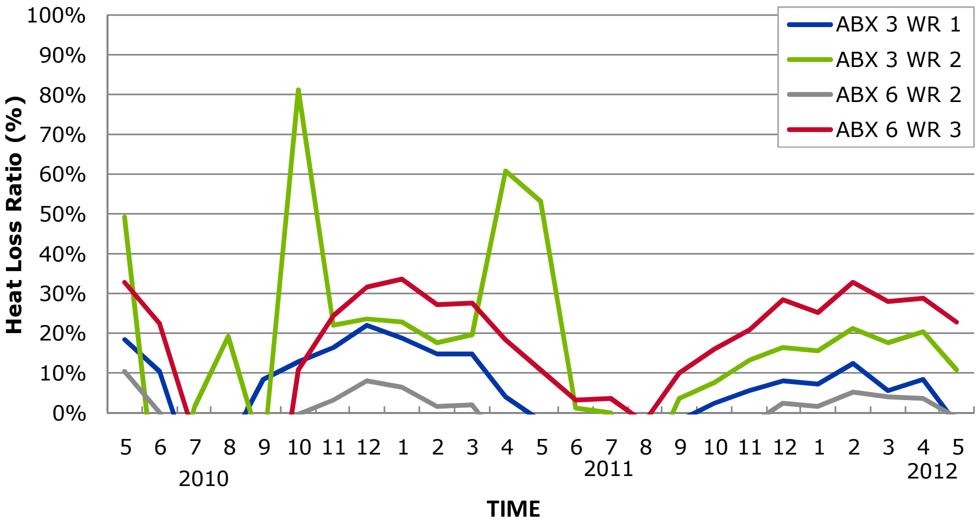


Figure 32 – Monthly rate of energy loss on distribution networks for DHW.

The DHW demand was calculated based on the number of occupants for each dwelling as there is few data within monitoring about measured energy use for DHW. Although the estimation is even improved to reflect DHW use in energy efficient dwellings for the specific areas with the method explained in section 5.1, it is highly likely that results overestimate real demand. Accompanied by the possible mistakes in energy supply measurements energy loss below zero were revealed for summer months. As the errors do not have systematic trend, it was not possible to provide corrective strategy at the analysis stage. Therefore the possible errors are noted and extra information from NUON is asked.

7.3.2 Results and discussion based on theoretical model

The heat distribution network of sub-station ABX3WR1 is used as a case study in order to compare measured with theoretical distribution losses. The monthly energy losses of space heating system is calculated for two years period between 1 June 2010 and 30 May 2012 based on the model provided in NVN 7125:2011. Figure 33 provides the comparison heat loss based on model results and actual data calculated based on the monitoring.

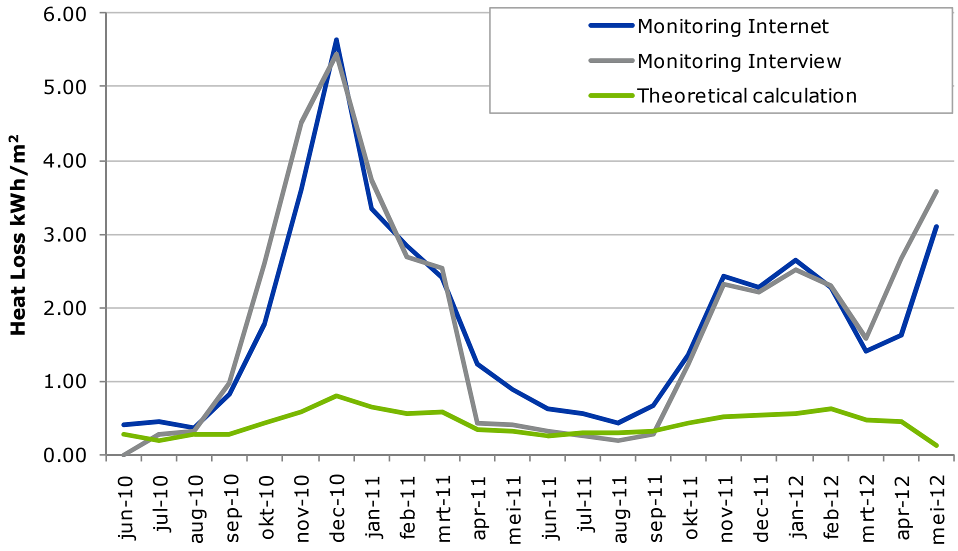


Figure 33 – Distribution losses for space heating in network of sub-station ABX 3 WR 1.

It is seen that during the summer months the theoretical model and the monitoring provide good agreement. However, there is a significant difference between theoretical and measured heat loss for the period September to April, where there is a high heat demand. On the average the difference of the total annual heat loss between the two methods is 16.5 kWh/m^2 floor area.

The difference between theoretical model parameters and real conditions are investigated in order to come up with an explanation between theory and reality. The possible differences and the relative effect of each are quantified as follows.

7.3.2.1 Extrapolation of monitoring data to complete sub-station area.

The sub-station network of sub-station ABX3WR1 is located in Noorderplassen-west. Data from the sub-station covers by definition all (100%) dwellings in use in this area. Of course, the number of dwellings varies in time in areas under construction, but this has been taken into account in the analyses (see 6.3.4.1). This supplied heat is related to the heat demand of the attached dwellings. The monitoring fraction of the heat demand does not cover 100% of the (attached) dwellings. So, extrapolation was needed. This extrapolation of heat demand is based on the amount of connected floor area.

The monitoring for heat demand provided a high fraction as presented in section 7.2.1. Monitoring with interview covers 24.8% of all dwellings. The annual heat demand collected by interview reflects yearly consumption data. This data are interpolated to provide monthly heat demand by use of heating degree days weight factors. The weight factors are developed specifically based on the heat demand data of the energy efficient dwellings within this study (see section 5.2). Figure 33 provides a good match between interpolated yearly interview data and monthly measured internet data. Thus, the accuracy and representativeness of the monthly heat demand data is considerably high. The extrapolation of monitored data to the whole area is considered to be highly reliable as it is based on the dwelling area that is acquired from building permits.

7.3.2.2 Effect of sampling

Although it is known that monitoring with interview covers a high rate of the total population (24.8%) there is the possibility that monitoring sample does not reflect actual heat demand. It can be assumed that the measured average heat demand differs from the actual average. For example because by participating in the monitoring, occupants reveal a energy conscious behaviour. To quantify the effect of this possibility Table 37 presents the result of a statistical analysis on theoretical population and sample size assuming an average energy use of 40 GJ/year with a standard deviation of 24 GJ/year.

Table 37 – Effect of sample size on measurement mean of energy demand.

Population Size	Sample Size	Ratio of sample mean above population mean	Probability
300	75	5	20.3
300	75	10	4.5
300	75	25	<0.01
300	20	5	35
300	20	10	22
300	20	25	2.7
100	50	5	27
100	50	10	11
100	50	25	0.1

The probability that the heat demand based on monitoring sample reveals a value that is 25% larger than the true average, in order to explain the difference between theory and reality, is very small in all cases. The probability of finding a value that is 10% or more above the actual average is about 4.5% or higher. The chance of finding a difference of 5% or more is substantial.

Figure 34 presents the scenario where the probability of finding a difference of 5% between measured and actual average heat demand is reflected into the results. Monthly (average) demand is increased 5% and the re-calculated distribution heat loss is plotted against the heat loss based on original measurements and theoretical calculation. It is seen that the monthly heat loss, especially for winter months decreased, providing a better agreement with the theoretical models result. The difference of average yearly total heat loss between theoretical model result and monitoring result decreased 15% of the initial difference.

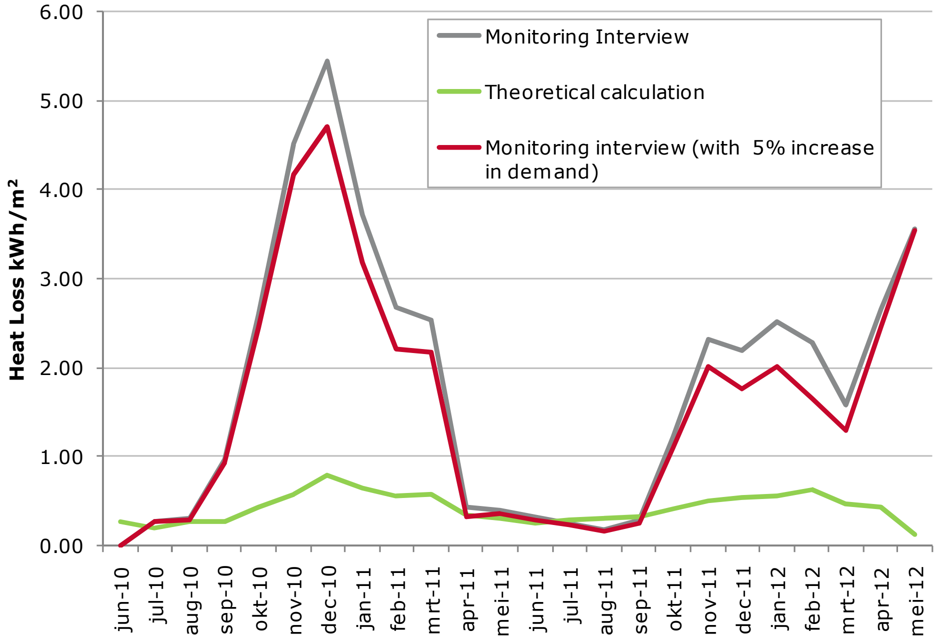


Figure 34 – Effect of 5% increase in heat demand to reflect monitoring sample bias on heat loss difference between calculation and measurements.

The annual difference of loss between model and monitoring based methods is approximately 11 GJ/dwelling. The average space heating demand within this sub-station network is measured as 52 GJ/year/dwelling. Extra heat loss represents 20% of the heat demand which is a considerably high. This study indicates that the possible sampling effect within the monitoring data of heat demand may only provide a partial explanation of the difference between the two methods.

7.3.2.3 Sub-station controls and set point temperatures

The set-point of the supply temperatures are 75 °C and 40 °C for winter and summer respectively. Those are official levels reported by NUON and used in the theoretical model. However, it is possible that those levels are not always maintained and actual set-point temperatures are different. The settings of sub-station controls are checked once a year. In the mean time the settings are open to human intervention. During a site visit it was reported that there have been complaints from residents about comfort-levels which lead the energy company to increase the supply temperature setpoint for summer. In case the set-point for summer raises from 40 °C to 50 °C, the distribution loss increases and the difference between the model and the monitoring decreases 6.5%. Although this does not explain the difference by itself alone, it shows that fluctuation in supply temperature settings due to human intervention or occupant demand is an influencing heat losses.

7.3.2.4 Heat losses through sub-station building

The model result reflects only the heat losses through the pipe network. It is natural that heat losses through pipes create the largest share; however other components of the distribution system also contribute to undesired transmission of heat to the surrounding environment. The sub-station building is a brick structure with 3 meters width and 5.7 meters depth, 3 meters height. The thermal conductance is estimated as 560 W/K according to model as presented in Appendix-D.

The internal air temperature of the building is assessed based on fluctuation of the heat provided by the distribution pipes and control devices within the building and the outside temperature. As an average, internal temperature is assumed as low as 20 °C in winter and as high as 27 °C in summer. The yearly total energy loss through sub-station building shell is calculated at 1.05 kWh/m^2 floor area which accounts for 25% of the theoretical distribution losses of the pipes themselves. This issue is not taken into account in the current theoretical method as described in NVN 7125:2011. It can be seen that for an accurate estimation of the distribution losses it is important to consider also the losses from buildings and other components of the distribution system.

7.3.2.5 Pipe installation or leakage

Defects on distribution system or environmental conditions around piping systems are among the primary factors that affect the amount of heat loss from heat distribution system. Damages during installation are among possible causes of leakages and thus excessive heat loss. Those are fairly easy to detect with the pre-installed electrical wire in the pipe casing to measure the electrical resistance of the pipes. In case of leakage the difference in resistance provides a detection system. Therefore it is assumed that (big) leakages are not a cause of the observed difference, since they are easy to depict and appropriate actions will be taken.

7.3.2.6 Environmental conditions in the ground

Seasonal variation of environmental conditions in the ground is not straightforward to determine. Potential field conditions include both the effect of precipitation and evaporation, causing wetting/drying of the soil. The type of soil and moisture content, groundwater conditions, drainage patterns are listed as the major environmental conditions effecting performance of the pipes. Thus, those conditions determine how frequently the ground water level remain at the level where piping system is installed, how easy transmission of heat is in the ground and how long the accumulated surface water will remain in soil around the pipe (Govan & Demetroulis, 1987).Those factors are not taken into consideration by the calculation model proposed in NVN 7125:2011. It is likely that one or more of those factors are possible cause of discrepancies between estimations based on theoretical calculation and actual measurements in the sub-station area of ABX3WR1.

Based on the monitoring data and known effect of environmental conditions of pipe insulation, the results indicate that the actual effective thermal transmittance level of pipe insulation diverges from standard values (initially accepted as 0.03 W/mK) due to deterioration of thermal insulation of the piping by the ingress of water due to environmental seasonal variations. It is highly possible that water ingress occurs not all over the pipe but on the nodes where two different pipes connect or where one pipe splits into two or more other pipes. The connections are maybe less water proof then the pipe itself, thus more vulnerable to excessive heat loss. To quantify the effect of environmental conditions around the pipe system, the actual effective thermal transmittance of pipe insulation that could explain the observed difference between the (theoretical) model and the monitoring, is calculated based on distribution losses acquired by monitoring (see.Table 38).

The thermal transmittance of soil varies as a function of its water content as well as porosity. Previous study shows that thermal transmittance of soil increases with an increase in water content. Based on equations, for tightly packed sand with a porosity of 0.322, thermal transmittance was 2.9 W/mK whereas for loosely packed sand with porosity of 0.388, thermal transmittance was 2.5 W/mK. The experimental result has confirmed the calculations (Sakaki, Limsuwat, Illangasekare, & Smits, 2009). Due to the environmental conditions the soil thermal transmittance is assumed as 2.8 W/mK in this study. The monthly measured loss and expected actual effective thermal transmittance is presented in Table 18.

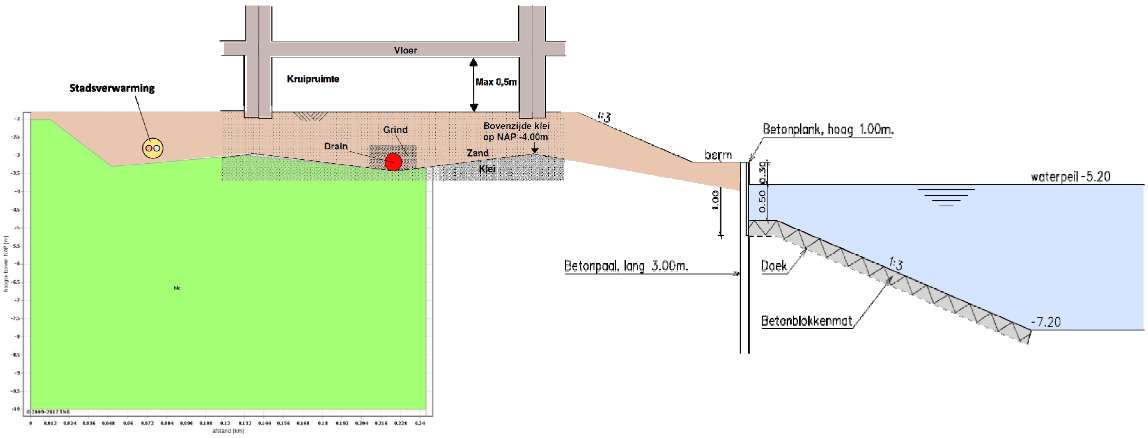


Figure 35 – Relative position of the levels of the floor (vloer), district heating (stadsverwarming), drainage (drain), the old seabed (green) and open water (waterpeil) in Almere.

The situation of the monitored district as a land re-claimed from sea makes Almere susceptible to underground water level variations. The old seabed forms a level at -4.0 m+NAP. Following the reclamation of land the surface is covered with sand. Figure 35 shows a section of ground, indicating the old seabed level (green area in the image) based on measurements conducted by TNO (TNO DINO-loket). Thus, level variations of the old seabed may disturb drainage and create traps for water. The district heating pipes are situated above the clay level, however may be subject to water accumulation.

Drainage system in the area of pipe installation normally transfers the water away from the area. The condition of drainage systems, whether they are fully operational or partially blocked and therefore less effective is not known for the specific sub-station area. The differences between loss ratios of sub-station areas without any solid relation to parameters that characterize the urban properties (see Table 35) indicates that unmonitored factors such as possible partial defects on drainage system may be among causes in high loss ratio in certain areas.

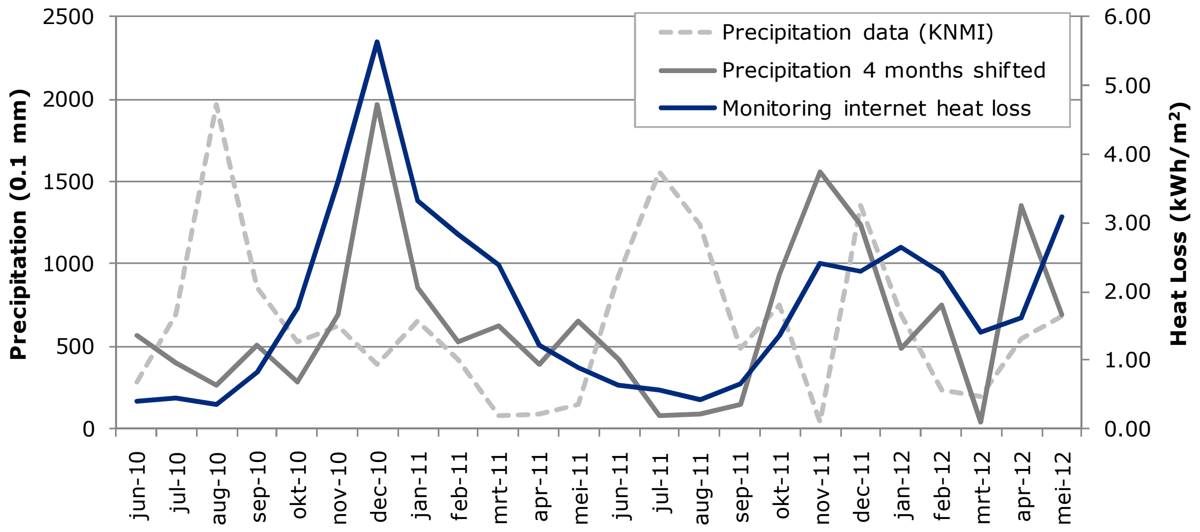


Figure 36 – Monthly plot of precipitation and heat losses through the district heating pipe network

Figure 36 displays the monthly fluctuation of heat losses plotted against precipitation data (source KNMI). It can be seen that a significant agreement can be observed between the patterns if the precipitation is plotted with four months delay. The similar patterns provide an indication that precipitation has an effect on the heat loss through the pipes. Additionally it is known that precipitation itself is a major factor on the fluctuation of soil water content. As argued above, data shows that due to topographic properties, condition of reclaimed/refilled land and possible ineffective drainage, rain water accumulates in the soil. Two environmental factors, namely the monthly precipitation and monthly evaporation and one system design factor, the drainage, are considered for the calculation of the ground water balance due to precipitation (GWB).

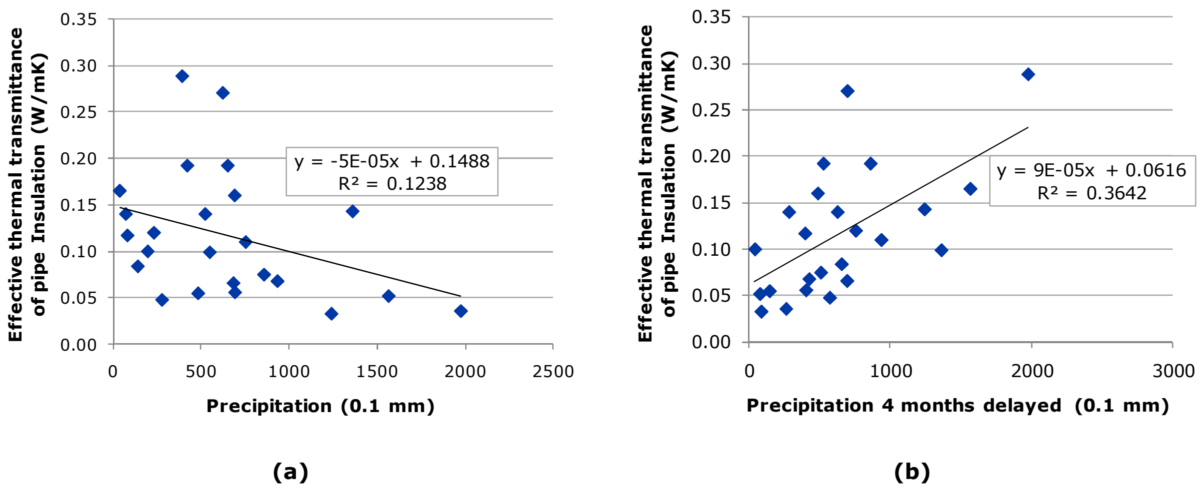


Figure 37 – Correlation between assessed effective thermal transmittance of pipe line and precipitation.

The monthly amount of precipitation and evaporation was available from the Royal Dutch Meteorological Institute KNMI (Appendix-E). Water entering the ground runs down due to the effect of gravity. For calculation of the water entering to soil and evaporating from ground it is considered that a certain amount of ground surface in an urban area is covered by buildings, pavements and roads rather than open land. The rain on paved surfaces are collected by the sewage system and drained before it reaches the ground. However, still as a part of the bigger environmental system the water accumulated in the soil is higher than what is only received by the urban area, receiving infiltrated ground water also from the surrounding open field. Thus a coefficient for precipitation is (f_p) introduced into the assessment to reflect the partial infiltration of rain water into the soil. Evaporation from the ground is affected by the same principle. The difference is that evaporation is a slower process than infiltration. As KNMI database only provides evaporation for open land another coefficient (f_e) is used for determining the amount of monthly evaporation in an urban area.

The drainage value and the weighted precipitation and evaporation within the GWB-mechanism are determined by analyzing a range of possibilities in which those factors are varied. The underlying assumption in the model is that over time, a stable GWB-pattern occurs. So, the factors can not be chosen freely but are somehow related to each other. The variable set is chosen in such a way that (1) the system does not lead to total drying or flooding of the area on the long term and (2) providing a seasonal variation in the GWB. The coefficient for precipitation (f_p) is determined as 0.8 or 80%. Although the paved surface is higher then 20%, it also reflects the influence of the surrounding open fields on the ground water balance in the urban area. The weight of evaporation (f_e) is determined as 0.5 or 50%. The (constant) drainage rate is estimated at 35 mm/month. The results are calculated with an iterative process as follows. The GWB is determined by the GWB and precipitation of the previous month.

$$GWB_t = GWB_{t-1} + f_p \cdot P_{t-1} - D - f_e \cdot E_t \qquad (18)$$

With:

GWB	Ground water balance due to accumulation of rain water in month t
t	Month of a year
P	Monthly precipitation (Source KNMI)
D	Drainage enabled by existing drainage property of the soil limited to maximum 10 mm monthly.
E	Monthly evaporation of water from soil (Source KNMI).
f_p	Coefficient of precipitation based on the ratio of precipitation that is infiltrated to the ground directly
f_e	Coefficient of evaporation based on the ratio of evaporation in urban area compared to open land

Starting from September 2009 for each month the calculated amount of drained water and the amount that is evaporated from soil is extracted from the total sum. The minimum ground water balance is limited to zero as negative amount is not possible. The results of the assessment are presented in Table 38.

The model shows robust results that are sensitive to total ground water balance but not to variations in the initial assumptions.

Table 38 – Observed effective thermal transmittance of the distribution system and precipitation water accumulation in the soil.

Time	Observed effective thermal transmittance of pipe insulation [W/mK]	Heat Loss based on internet monitoring process [kWh/m^2]	Rain water balance in soil [mm]
jun-10	0.05	0.40	0.0
jul-10	0.06	0.45	0.0
aug-10	0.04	0.36	0.0
sep-10	0.08	0.82	100.0
okt-10	0.14	1.77	119.7
nov-10	0.27	3.61	122.2
dec-10	0.29	5.63	134.6
jan-11	0.19	3.33	127.1
feb-11	0.19	2.83	138.0
mrt-11	0.14	2.40	117.0
apr-11	0.12	1.22	48.6
mei-11	0.08	0.88	0.0
jun-11	0.07	0.63	0.0
jul-11	0.05	0.56	0.0
aug-11	0.03	0.43	55.1
sep-11	0.06	0.66	92.8
okt-11	0.11	1.36	81.6
nov-11	0.17	2.42	100.3
dec-11	0.14	2.28	65.3
jan-12	0.16	2.65	134.8
feb-12	0.12	2.27	147.3
mrt-12	0.10	1.39	110.7
apr-12	0.10	1.61	66.2
mei-12	0.07	3.10	30.2

The actual effective thermal transmittance of pipe insulation that could explain the observed difference between the (theoretical) model and the monitoring, is calculated based on distribution losses acquired by monitoring in the area of sub-station ABX3WR1. A correlation study between monthly precipitation, ground water balance and assessed effective thermal transmittance of the pipe line shows that precipitation alone fails to explain the variation of observed effective thermal transmittance of the pipeline (see Figure 37(a)). When the model is extended to include accumulated effect of precipitation as ground water balance, drainage based on water stored in soil throughout the months and evaporation, the model explains 51% of the variation in the observed effective thermal transmittance of pipeline (see Figure 38).

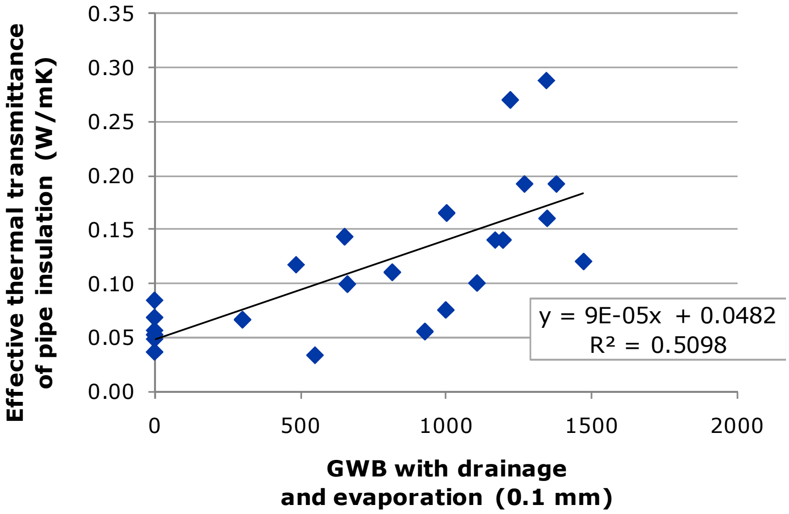


Figure 38 – Correlation between assessed effective thermal transmittance of pipe line and ground water balance.

For further analysis the sensitivity of the model is analyzed with respect to the basic assumptions. It is inevitably required to consider the ground water storage at an initial point. The ground water storage is calculated starting from the end of September 2009, which refers to end of summer period of the year before from the beginning of analysed period. The initial water content in September 2009 is assumed to be between 50-100 mm to reflect the low water content at the end of summer. By considering the water balance for a period that is well in advance from the beginning of the analysis date, the effect of this assumption for initial ground water balance is minimized. Thus, it has virtually no effect on the results of the study as the final correlation does not vary depending on the initial value. The value is set to 80 mm.

Accumulation of rain water around heat distribution pipe system is likely in the area of ABX 3 WR 1. It should be noted that as well as the thermal transmittance of the pipe, the thermal transmittance of soil will possibly be affected by the fluctuations of excessive water. It is also likely that between the cycles of wetting and drying the slow recovering of soil properties has more effect on the system than the effect of precipitation. However, this study does not aim to explain such dynamics; it could be subject to a new study. Moreover, the model presented above assumes the piping system is affected by the water balance in a uniform manner. In reality, due to the variations in topography, soil conditions and various elements that compose the distribution system, the piping system would not be affected homogenously throughout the network. A detailed investigation of soil conditions and the pipe network may provide more insight to the relation between heat losses and the actual causes.

8 Conclusions

The components of monitoring are characterized by various system properties on energy supply and demand sides. The performance of each system, parameters effecting demand, energy generation and the energy transmission systems are analyzed in this research. The results and the discussions regarding to each topic are provided in chapter 7. This chapter summarizes major conclusions and provides recommendations for design, development and analysis of those.

8.1 Method of Analysis

The approach for evaluating energy efficiency of buildings possibly differ for high performance buildings as conventional methods may fail to reflect influential factors that are intrinsic to building design. The assumptions underlying in basic factors of energy analysis are investigated and alternative methods were proposed for a more rational and realistic assessment of building performance.

Domestic hot water use is important for accurate analysis but is hardly measured due to the lack of separate meters, thus it had to be estimated in most cases. Firstly, the calculation method of DHW is analyzed. It is found that especially for small houses the relation between floor area and number occupants is different from what is suggested in NEN 7120. The difference is more significant in Columbuskwartier due to the fact that the majority of houses in Columbuskwartier are smaller than 90 m^2. The assumption of number of occupants based on NEN 7120 tends to overestimate the domestic hot water demand. Thus new correlation equation is developed and used in this study.

Secondly, the weight factors for heating degree days have been analyzed in order to provide a more accurate heat use distribution over a year. The effect of passive solar contribution is historically considered by use of weighting factors for heating degree days throughout the periods of the year. As the design of energy efficient buildings focus on use of solar gains and energy conservation, the correct calculation of the effect of solar gains is crucial. The study on weight factors revealed that historical weight factors were not adequate anymore for energy efficient dwellings. New, proposed weight factors resulted in a better expression of energy performance for energy efficient buildings. The new weight factors show a shift in heating season and a different distribution of heating degree days over the year. The new, proposed weight factors are recommended for energy efficient buildings.

Thirdly, the possibility of a revised base temperature for energy efficient dwellings is analysed by using the mean internal temperature of the 20 dwellings. The results show that energy efficient dwellings tend to have 2 °C higher average interior temperature. A base temperature of 20 °C would be more appropriate for energy efficient dwellings. This was not taken into account in the studies on weight factors of heating degree days.

8.2 Renewable Energy Supply

The flow of energy in Solar Island is measured from May 2010 to June 2011. An average of ratio between Q_{sup-IR} and Q_{sup-SI} indicates that annually 32% of the energy received as solar irradiation is converted to heat energy in Solar Island. The total yield of the Solar Island is between 8440-8928 GJ for a normal year. In each month for certain period renewable energy was abundant and it is transferred to Almere as well as Noorderplassen-west. The annual share of solar energy provided to Almere and Noorderplassen-west can be provided within a range based on the measurement errors. The annual share of solar energy is 57-61% for Almere and 34-38% for Noorderplassen-west.

The energy yield of solar collector in Solar Island is 1.18-1.25 GJ/m^2. Individual collectors typically have a yield of 1.1-1.4 GJ/ m^2. In case the individual collector option was chosen, the payback period is 17 to 18 years compared to the Solar Island option from the point of view from the house owners.

The electricity production of stand alone PV systems in Columbuskwartier is monitored by interviews and internet. The PV-yield is also assessed by calculations where the actual solar irradiation, the size, the orientation and tilt angle of the PV-system, the technology of the PV cells and the inverter type are considered. The average measured PV-yield is 70% of the theoretical yield. A case-by-case analysis over PV yield measurements shows that approximately 20% of systems are diagnosed with a faulty installation or an incorrect meter reading. Structural causes such as location or construction of PV systems and occasional errors in measurement or model parameters can cause differences in expected and monitored results.

8.3 Energy Demand of High Performance Buildings

The results from monitoring through internet and by interview are in agreement with each other

The actual energy demands and level of accomplishment compared to cRRescendo proposal values differs for each category of energy efficient building. Solar and Passive Houses are characterized with ambitious energy performance targets. Thus, the measured heat energy demand for ECO and Solar Houses is somewhat higher than the proposed values. It should be considered that the *proposed* values are a theoretical estimation of the energy consumption for space heating; based on standardized occupant behaviour. Thus, comparison of *monitored* performance with *proposed* values may fail to provide conclusive results in energy performance (of Solar Houses).

The differences in heat demand per m^2 reflect the energy performance (coefficients) for the different building categories. The data also show that the ECO houses consume less energy for space heating per square meter than proposed while Solar Houses and Passive Houses consume (a little bit) more energy for space heating per square meter than expected (with the additional remark that Passive Houses are constructed *smaller* then expected). The energy-use for space heating tends to decrease per m^2 when the dwelling is bigger. However, a more through explanation of the issue is found in the ambition of energy demand for each dwelling type. The higher the aim for energy efficiency is the harder to accomplish it.

More attention is required for the construction process and for the use of the building by the occupants in order to benefit from the potential energy efficiency. Data collected monthly which requires a bigger effort from the occupants, is lower for Eco Houses as well as for Solar Houses. It is anticipated that people who volunteered to this kind of data recording are more conscious about their energy consumption, thus this motivation results in better energy saving.

Comparison of proposed values with monitoring results clearly shows that the proposed values overestimate the DHW demand in single family houses both for ECO-houses and Solar Houses as lower demand is measured in actual situation. This was solved by taking into account the real correlation between the number of occupants and the floor area instead of the one proposed by NEN 7120.

Electricity consumption is measured by three different monitoring method; monthly (with internet), yearly (with interview) and detailed (with data-loggers) data collection. The variation in proposed and actual consumption can be explained by the difference of proposed and actual average floor area. There is a strong correlation between area and electricity demand for all types of energy efficient buildings. Moreover, the hourly data collection in 20 dwellings is used to examine electricity consumption patterns. Three distinct groups of consumers are identified according to electricity consumption levels; low, mid and high electricity consumption. A similar weekly consumption pattern is observed in all groups, with peaks in the morning and afternoon. The fluctuation of the energy consumption between highest and lowest thresholds is inversely proportional with the level of average consumption. The low average electricity consumers have the most extreme threshold for consumption thresholds where as the fluctuation pattern is flatter for high average electricity consumers. The electricity consumption pattern and the groups are likely to represent certain occupancy types; the low being occupants are not in the house during office hours, but high consumption the in evening due to simultaneous electricity requiring activities; and high being continuous electricity consumption throughout the day (children or elderly).

8.4 Rational Use of Energy

It is plausible that, very high distribution loss indicates a non-rational use of energy for dwellings with a low energy demand. Therefore, the energy loss at sub-station level was analyzed in detail.

Heat loss ratio is calculated as the ratio of heat loss to heat demand to determine the performance of each network. The average heat loss ratio for CTW is 48% whereas it is calculated as even 95% for ITW system.

The distribution heat losses are calculated for heat distribution area of ABX3 WR01 based on the method given in NVN 7125:2011. A significant difference between the monitoring data and theoretical calculation is observed. A detailed analysis showed that the divergence maybe due to the difference in the assumptions to derive losses based on measurement data and theoretical model; the difference between theoretical model parameters and real conditions. Those are investigated and the relative effect of each are quantified in this study.

The heat losses through the sub-station building are not considered according to NVN 7125:2011. The yearly total energy loss through sub-station building shell is calculated as 1.05 kWh/m^2/year. It is recommended that for an accurate estimation of the distribution losses the method should consider the losses from buildings and other components of the distribution system.

It is also concluded that there is significant possibility that precipitation and evaporation influence the heat losses. Seasonal water fluctuations in the soil may cause performance loss of the pipeline. Thus the actual heat losses are significantly higher than the standard NEN 7125 estimates. A more effective drainage system in the area and inspection of soil properties are recommended to avoid heat losses caused by the consequences of precipitation for the performance of the pipe insulation.

Reference sources

Govan, F. A., & Demetroulis, N. M. (1987). Design Criteria for Underground Insulated Piping systems. In F. P. Matthews, Thermal Insulation: Materials and Systems, ASTM STP 922 (pp. 43-51). Philadelphia: American Society for Testing and Materials.

Sakaki, T., Limsuwat, A., Illangasekare, T. H., & Smits, K. M. (2009). Kathleen M. Smits Determination of the thermal conductivity of sands under varying moisture, drainage/wetting, and porosity conditions- applications in near-surface soil moisture distribution analysis. Hydrology days.

Zinko, H., Bohm, B., Kristjansson, H., Ottosson, U., Rama, M., & Sipila, K. (2008). District heating distribution in areas with low heat demand density ANNEX VIII. International Energy Agency.

http://concertoplus.eu/

Appendix A Solar Island measurements

A 1 – Flow of energy (uncorrected data) between Solar Island, Noorderplassen-west and city of Almere, in GJ

Date	Q_{EU}	$Q_{sup\text{-}RES:NPW}$	$Q_{sup\text{-}RES:Almere}$
mei-10	125.1	45.9	66.7
jun-10	1646.0	517.2	1035.9
jul-10	1832.5	473.4	1434.7
aug-10	944.7	178.8	743.9
sep-10	714.8	0.0	583.7
okt-10	471.3	0.0	519.2
nov-10	58.1	0.0	0.0
dec-10	4.1	0.0	0.0
jan-11	67.2	0.0	0.0
feb-11	191.0	43.5	5.4
mrt-11	1027.4	696.1	189.4
apr-11	1628.6	823.5	689.5
mei-11	1517.8	666.2	749.3
jun-11	1275.6	501.5	693.8

Appendix B Measured monthly energy demand in dwellings

B 1 – Monthly energy demand for space heating in kWh/m²/month (corrected data for DHW and heating degree days). Monitoring method: Internet.

Date	Best 1	Best 2	Best 4	Best 5	Best 6	Best 7	Best 8	Best 17
mrt-10			3.38		6.25	5.72		
apr-10	6.05		4.85	5.67	2.41	2.50		
mei-10	1.92		1.55	1.53	1.20	1.12		
jun-10	0.23		0.00	0.12	0.76	0.35		
jul-10	2.95		-0.84	0.00	0.33	-0.10	-0.59	-2.94
aug-10	-0.06	-0.05	-0.27	0.01	0.16	0.20	0.35	-0.12
sep-10	0.93	-0.03	0.21	0.05	0.14	0.56	0.27	0.40
okt-10	2.95	0.77	1.75	3.11	1.39	3.09	2.36	1.38
nov-10	7.91		4.66	5.15	3.75	6.46	6.17	3.10
dec-10	11.67		7.77	7.23	5.22	9.17	9.02	5.52
jan-11	12.91		7.37	6.44	5.05	9.52	8.66	5.08
feb-11	10.46		6.41	7.88	4.98	8.72	7.16	5.11
mrt-11	6.63		4.56	4.03	3.77	6.53	4.56	3.89
apr-11	1.07		1.44	1.66	1.11	2.28	1.36	1.32
mei-11	-0.33		-0.15	0.00	0.04	0.49	-0.07	
jun-11	-0.57		-0.35	0.00	0.20	0.26	-0.14	
jul-11	-0.24		-0.01	0.00	0.06	0.11	-0.06	
aug-11	-0.27		-0.33	0.00	0.05	0.09	-0.17	
sep-11	-0.71		-0.36	0.03	0.09	0.24	0.03	
okt-11	1.58		2.47	1.04	0.99	2.43	1.65	
nov-11	6.55		4.34	5.28	2.87	5.89	4.59	
dec-11	8.31		7.02	8.35	4.74	9.66	8.01	
jan-12	8.91		6.40	8.50	4.77	9.99	7.96	
feb-12	7.90		6.94	3.70	3.59	9.45	7.30	
mrt-12	5.43		4.37	1.85	1.86	6.64	4.88	
apr-12	2.10		3.00	0.95	1.14	4.19	2.66	
mei-12			0.68	0.22	0.00	0.89	0.12	

B 2 – Monthly energy demand for space heating in kWh/m^2/month (corrected data for DHW and heating degree days). Monitoring method: Interview

Date	Best 1	Best 2	Best 4	Best 5	Best 6	Best 7	Best 8
jul-10	-2.06	-4.30	-2.87			0.40	
aug-10	-0.67	-0.52	-0.94	0.29	0.29	0.15	0.19
sep-10	-0.11	0.13	-0.42	0.57	0.56	0.46	0.42
okt-10	2.58	3.59	1.70	2.63	2.61	2.62	2.03
nov-10	7.21	9.35	5.54	5.79	5.76	5.99	4.54
dec-10	12.31	15.71	9.87	9.16	9.11	9.63	7.20
jan-11	12.17	15.65	9.63	9.32	9.27	9.74	7.31
feb-11	11.30	14.56	8.91	8.73	8.68	9.10	6.84
mrt-11	8.10	10.60	6.24	6.59	6.55	6.81	5.15
apr-11	2.65	4.04	1.50	3.36	3.35	3.26	2.56
mei-11	-0.32	0.11	-0.79	0.89	0.89	0.71	0.62
jun-11	-0.82	-0.73	-1.22	0.75	0.48	0.34	0.32
jul-11	-0.48	-0.42	-0.71	0.41	0.17	0.17	0.15
aug-11	-0.64	-0.52	-0.89	0.39	0.16	0.13	0.14
sep-11	-0.63	-0.61	-1.00	0.76	0.31	0.37	0.30
okt-11	2.16	0.52	1.35	3.53	1.42	2.63	1.67
nov-11	6.49	2.29	5.00	7.78	3.13	6.09	3.78
dec-11	10.79	3.97	8.52	12.32	4.95	9.74	6.01
jan-12	11.13	4.15	8.86	12.54	5.04	9.94	6.12
feb-12	11.08	4.24	8.97	12.04	4.84	9.58	5.90
mrt-12	7.14	2.45	5.40	8.86	3.56	6.86	4.29
apr-12	3.24	0.99	2.29	4.52	1.82	3.43	2.17

B 3 – Monthly energy demand for space heating in kWh/m^2/month (corrected data for DHW and heating degree days). Monitoring method: Detail monitoring

Date	Best 1	Best 4	Best 5	Best 7
jan-11	14.38	6.40	6.26	6.55
feb-11	12.19	5.94	7.86	7.77
mrt-11	8.24	4.18	4.29	5.77
apr-11	1.20	1.58	1.37	1.98
mei-11	-1.31	0.42	0.00	0.29
jun-11	-1.87	-0.01	0.00	-0.01
jul-11	-0.77	-0.12	0.00	0.00
aug-11	-0.86	-0.23	0.00	-0.03
sep-11	-1.13	-0.13	0.00	0.20
okt-11	0.29	0.65	1.56	2.37
nov-11	6.04	2.60	7.20	5.44
dec-11	8.44	5.11	8.09	8.50
jan-12	8.56	4.81	7.03	8.72
feb-12	7.92	5.28	4.48	7.98
mrt-12	6.56	3.16	0.49	5.76
apr-12	3.53	1.97	0.45	3.73

B 4 – Monthly electricity demand in kWh/m^2/month. Monitoring method: Internet

Date	Best 1	Best 2	Best 4	Best 5	Best 6	Best 7	Best 8	Best 17
mrt-10			1.00		1.59	2.47		
apr-10	1.41		1.31	0.84	1.10	2.10		
mei-10	1.49		1.63	0.92	1.45	1.92		
jun-10	1.70		1.20	0.90	1.41	1.84		
jul-10	2.43		1.35	1.01	1.57	1.41	2.19	1.01
aug-10	1.47	1.14	1.87	0.78	1.23	1.55	1.57	1.89
sep-10	1.34	1.06	1.86	1.02	1.12	1.78	2.10	2.03
okt-10	1.82	1.03	1.98	0.94	1.36	1.91	2.38	2.53
nov-10	1.82		1.94	1.02	1.66	2.13	2.42	2.58
dec-10	2.22		2.24	1.13	1.99	2.32	2.59	2.85
jan-11	3.01		2.15	1.16	1.85	2.27	2.25	2.69
feb-11	2.70		1.83	0.94	1.59	1.87	2.70	2.29
mrt-11	3.15		1.95	1.01	1.52	1.84	2.29	1.89
apr-11	2.79		1.71	0.92	1.37	1.62	2.04	1.54
mei-11	3.01		1.57	0.97	1.12	1.74	2.17	
jun-11	2.21		1.58	0.95	1.19	3.60	2.19	
jul-11	2.69		1.74	1.27	1.34	3.82	2.21	
aug-11	2.61		1.66	1.15	1.13	1.61	1.99	
sep-11	2.26		1.77	1.15	1.35	1.70	2.24	
okt-11	2.74		2.01	1.28	1.70	1.90	2.36	
nov-11	2.86		2.20	1.51	1.56	2.04	2.40	
dec-11	3.45		2.38	1.56	2.02	2.25	2.73	
jan-12	3.32		2.26	1.56	1.84	2.18	2.49	
feb-12	2.88		2.06	1.50	1.58	2.11	2.14	
mrt-12	3.20		2.46	1.73	1.72	2.01	1.90	
apr-12	2.93		1.99	1.62	1.42	1.80	2.07	
mei-12			1.91	1.60	1.63	2.29	2.69	
jun-12			0.17					

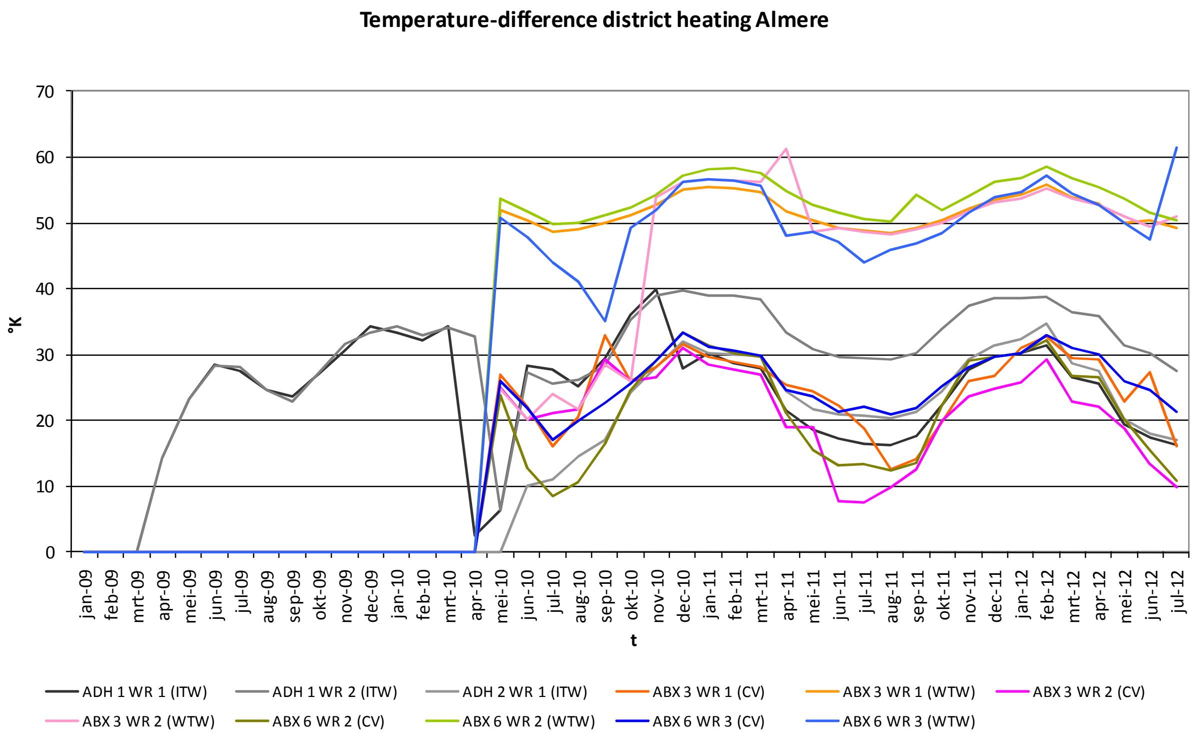
B 5 – Monthly electricity demand in kWh/m²/month. Monitoring method: Interview

Date	Best 1	Best 2	Best 4	Best 5	Best 6	Best 7	Best 8
jul-10	2.46	3.01	1.79			2.09	
aug-10	2.30	2.32	1.81	2.93	1.77	2.21	2.15
sep-10	2.23	2.24	1.75	2.84	1.71	2.14	2.08
okt-10	2.30	2.32	1.81	2.93	1.77	2.21	2.15
nov-10	2.23	2.24	1.75	2.84	1.71	2.14	2.08
dec-10	2.30	2.32	1.81	2.93	1.77	2.21	2.15
jan-11	2.30	2.32	1.81	2.93	1.77	2.21	2.15
feb-11	2.08	2.09	1.64	2.65	1.60	2.00	1.94
mrt-11	2.30	2.32	1.81	2.93	1.77	2.21	2.15
apr-11	2.23	2.24	1.75	2.84	1.71	2.14	2.08
mei-11	2.36	2.32	1.80	2.93	1.77	2.21	2.18
jun-11	2.40	1.55	1.82	3.24	1.68	2.17	2.09
jul-11	2.49	1.55	1.94	3.36	1.62	2.27	2.17
aug-11	2.49	1.55	1.94	3.36	1.61	2.27	2.17
sep-11	2.41	1.50	1.88	3.25	1.56	2.19	2.10
okt-11	2.49	1.55	1.94	3.36	1.61	2.27	2.17
nov-11	2.41	1.50	1.88	3.25	1.56	2.19	2.10
dec-11	2.49	1.55	1.94	3.36	1.61	2.27	2.17
jan-12	2.49	1.55	1.94	3.36	1.61	2.27	2.17
feb-12	2.25	1.40	1.75	3.04	1.46	2.03	1.96
mrt-12	2.57	1.60	2.00	3.47	1.66	2.32	2.24
apr-12	2.41	1.50	1.88	3.25	1.56	2.18	2.10
mei-12						2.83	

B 6 – Monthly energy demand for DHW in kWh/pers/month. Monitoring method: Internet

Date	Best 5	Best 6	Best 7	Best 8
mrt-10			82.65	
apr-10			81.38	
mei-10			64.21	
jun-10			58.16	
jul-10			37.05	
aug-10			40.54	
sep-10			56.62	
okt-10			66.84	
nov-10			81.80	
dec-10			87.35	
jan-11			89.30	
feb-11			71.45	
mrt-11			74.83	
apr-11	154.29	29.04	75.67	43.71
mei-11	165.90	18.83	64.91	30.64
jun-11	106.59	23.68	56.88	64.26
jul-11	211.53	33.21	52.90	60.78
aug-11	138.95	23.35	51.62	56.55
sep-11	191.78	29.22	59.46	70.05
okt-11	221.66	42.17	64.69	74.48
nov-11	214.51	35.46	65.64	90.99
dec-11	221.66	40.40	75.48	94.02
jan-12	221.66	65.53	74.45	94.02
feb-12	207.36	46.34	64.96	61.52
mrt-12	221.66	41.06	60.31	65.76
apr-12	214.51	38.79	56.24	63.64
mei-12			38.65	65.76
jun-12			0.92	

Appendix C Monitoring data for sub-stations



Appendix D Calculation model for heat losses through sub-station building

The heat loss for the sub-station ABX 3 WR 1 is calculated based on NPR 2917 V2.02. One of the main results is the calculation of the transmission losses of the construction:

Definition	A·U	l·Psi	LD	LS	HU	HT
	[W/K]	[W/K]	[W/K]	[W/K]	[W/K]	[W/K]
Front side	44.23	--	45.43	0	0	45.43
Back side	39.96	--	41.16	0	0	41.16
Left side	73.26	--	75.46	0	0	75.46
Right side	73.26	--	75.46	0	0	75.46
Roof	48.51	--	50.16	0	0	50.16
Floor	3.14	--	0	273.97	0	273.97
Total	282.35	0	287.67	273.97	0	561.64

ECOFYS
sustainable energy for everyone

Appendix E Monthly precipitation and evaporation

Date	Monthly precipitation (mm)	Monthly evaporation (mm)
sep-09	35.9	55.6
okt-09	60.1	27.9
nov-09	116.2	9.0
dec-09	60.9	6.4
jan-10	32.6	7.5
feb-10	57.0	10.0
mrt-10	40.2	36.1
apr-10	26.1	71.4
mei-10	50.7	76.4
jun-10	28.1	105.8
jul-10	69.4	113.9
aug-10	197.2	71.2
sep-10	85.8	45.5
okt-10	52.5	28.0
nov-10	62.5	9.0
dec-10	39.5	5.2
jan-11	65.3	8.2
feb-11	42.4	12.6
mrt-11	7.6	39.9
apr-11	8.5	78.9
mei-11	14.4	94.3
jun-11	93.4	93.8
jul-11	156.3	82.1
aug-11	124.0	69.9
sep-11	48.5	52.9
okt-11	75.4	30.0
nov-11	4.1	13.3
dec-11	135.9	6.6
jan-12	69.2	8.4
feb-12	23.5	15.7
mrt-12	20.0	40.8
apr-12	55.1	51.0
mei-12	68.5	90.2

Source: KNMI

sustainable energy for everyone

sustainable energy for everyone

ECOFYS Netherlands B.V.

Kanaalweg 15G
3526 KL Utrecht

T: +31 (0) 30 662-3300
F: +31 (0) 30 662-3301

E: info@ecofys.com
I: www.ecofys.com