TRANSFORMING SOCIAL HOUSING NEIGHBOURHOODS INTO SUSTAINABLE CARBON NEUTRAL DISTRICTS

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ABSTRACT

In the context of European and Flemish demonstration projects and living labs several social housing neighbourhoods in Belgium are transformed into sustainable carbon neutral districts. The neighbourhoods are located in different Flemish cities and consist of various housing typologies constructed during the 20th century, eg terraced and semi-detached houses built in the 1950’s, multifamily appartment blocks built in the 1970’s or a century old historically valuable urban street. Tailor-made solutions for retrofitting building envelope and systems were developed in order to reach a very low energy demand that is compensated by renewable energy supply. The main goal of the projects is to reach the high energy performance targets and quality of life in reality, that is during operation and occupancy. In order to evaluate the actual operation of the buildings and building systems during the first years of occupancy of the neighbourhood, energy monitoring and commissioning activities are performed. They include monitoring of energy use and temperatures, surveys of the occupants and quality assurance tests. In this key note lecture an overview is given of solutions developed for the different neighbourhoods, and the approach and findings of commissioning and monitoring activities are discussed. The findings show that commissioning of building systems and monitoring during occupancy are a vital part of the completion and operational lifetime of a building project, and a valuable contribution to achieve the targeted quality.

KEY WORDS:

1. INTRODUCTION

This paper gives an overview of the results of the European demonstration Project ECO-Life (2010-2016). The goal of the project was to transform a number of social housing neighbourhoods in Kortrijk, Belgium into a sustainable carbon neutral community. In a carbon neutral community the building energy use is covered or compensated on a yearly basis by carbon neutral renewable energy generated within the community. The energy use includes all energy use for space heating, space cooling, hot tapwater and auxiliary energy. The household electricity use of the individual households is not taken into consideration in the definition. The metric of the balance is CO_2-equivalents and the balancing period is one year. This means that the net amount of CO_2-equivalents released on a yearly basis should be zero (in a normal year). Accepted zero-carbon energy supply sources are for example solar energy, geothermal energy and biomass from sustainable and reliable origin. The scope of the zero-balance is the community scale, so the energy generation can take place in or on the building or building site, but also in another place within the community. The buildings and energy supply in the neighbourhood can be connected to collective networks and to the national electricity network, so the community is not autonomous.

The ECO-Life project in Belgium consists of 274 dwellings, located on 4 sites. Here only the largest site is discussed: the Venning district, where a neighbourhood of single family social houses built in the 1950’s was partly replaced by new multi-family buildings and new housing blocks, and partly refurbished to current standards and confort (Figure 1). Based on the ECO-Life targets and guided by energy performance calculations different energy concepts have been defined for the demonstration buildings and systems within the community.

The four multi-family buildings in Venning Phase 1 are newly built in the south of the Venning neighbourhood. Buildings A, B and C are multi-family buildings with respectively 22, 22 and 26 apartments with one or two bedrooms. The apartments are reached through elevated outdoor galleries on the north façade, while private terraces are oriented to the south. Building D has 6 apartments on the ground floor, equipped for disabled occupants, and 6 duplex apartments on top of them with 3 bedrooms each.

The Venning Phase 2 new building blocks are located north of Venning Phase 1 and include 64 single-family dwellings. They are disclosed by the surrounding streets with communal parking lots and new footpaths in between the buildings. Six building blocks consist of 4 up to 9 new single-family terraced and detached houses with a private garden. There is a mix of houses with 2, 3, 4 and 5 bedrooms, for 3 up to 8 occupants. Two blocks have apartments for disabled occupants on the ground floor and duplex apartments on top of them, similar to building D of Venning Phase 1.
In Venning Phase 3 50 larger dwellings from the original neighbourhood have been completely renovated to today's building standards. The dwellings are located in between the Venning Phase 2 dwellings. There are 12 building blocks with 3 up to 8 single-family terraced and semi-detached dwellings with 3 bedrooms and a private garden. The original dwellings were stripped to the load-bearing walls and floors. The plan lay-out was adapted and the roof construction, the insulation and air-tightness layers, windows and glazing, shading and finishing layers were newly installed.

The building design in all 3 phases was guided by the passive house standards aiming at a net space heating energy demand of 15 kWh/m²/year, leading to building envelope U-values below 0.15 W/m²K and an airtightness n_{50} of 0.6 h^{-1}. Living rooms are oriented as much as possible to the south, while both fixed and movable shading elements were applied to reduce the overheating risk. The buildings in Phase 1 are equipped with collective balanced mechanical ventilation systems with heat recovery and air tight ventilation ducts (class C). Half of the houses in Phase 2 and 3 have individual balanced mechanical ventilation systems with heat recovery, while the other half have individual demand-controlled ventilation system with natural supply and mechanical exhaust. The dwellings equipped with a demand-controlled ventilation system typically have a higher predicted net space heating demand compared to the passive house standard, up to 25 kWh/m²/year, but a lower use of auxiliaries. The Venning district heating network supplies heat to the dwelling substations for space heating and domestic hot water production. The heating system consists of radiators in the main rooms and, in case of houses with balanced mechanical ventilation, a heating coil to preheat the supply air if necessary. Grid-connected photovoltaic systems are provided on the rooftops of all buildings.

The heating plant of the Venning district heating system is located in the centre of the Venning neighbourhood. The main heating generation system is a 950 kW_{th} biomass boiler that uses wood chips as energy source. Secondly, a mini-CHP that uses rapeseed oil, produces auxiliary electricity and heat for the district heating system (e.g. for pumps, controls, storage losses…). This system has an installed capacity of 9 kW_{el} and 14 kW_{th}. In addition to these biomass-based systems, a 450 kW gas condensing boiler serves as a back-up system. Every dwelling is connected to the heating plant through a local district heating network consisting of thermally insulated pipes which supply hot water to the dwelling substations. It is a low-temperature network with supply temperatures around 60-70°C.

Figure 1: Aerial view of the original (left) and transformed (right) Venning district.

2. MONITORING APPROACH

Different levels of metering were identified to follow up on the performances: general metering in all dwellings (heat use, electricity use, living room temperature), detailed metering in a sample of dwellings (domestic hot water use, auxiliary energy use, a.o.) and additional metering in a small sample for in-depth studies, such as end-user comfort evaluations and performance assessment of the ventilation systems.

The projects in the Kortrijk ECO-Life community have been completed step by step and therefore not for all demonstration buildings and systems two full years of monitoring data are available. The buildings in Venning Phase 1 have data for at least 2 years. The actual operation of these buildings was investigated during the first year of occupancy. During the commissioning process a number of defects in building airtightness and in the operation of the ventilation systems were revealed, and subsequently repaired by the contractors. The commissioning therefore proved to be very valuable to improve the performance of the buildings and systems [1, 2].

For a consistent overview of the energy monitoring, data of the last year of operation are used from June 1 2015 till May 31 2016 for assessment of the demonstration projects. During this year all Venning demonstration buildings were fully occupied and renewable energy systems were operational. It was the first year that the Venning plant served the entire neighbourhood (Phases 1, 2 and 3) and operated the biomass boiler. The CHP-unit however has been operational only since June 2016 and is therefore not included in the analysis.

The monitoring data are first analysed in order to present the yearly primary energy balance taking into account the following energy services:

- Primary energy use for space heating (related to transmission and ventilation heat loss reduced by solar and internal heat gains)
- Primary energy use for domestic hot water
- Primary energy use to compensate for network heat losses (district heating and collective heating)
- Primary fan energy use
- Primary energy use for household electricity (plug loads)
- Displaced primary energy use as a result of local electricity production by photovoltaic systems

The first three services relate to the biomass and gas consumed by the district heating plant. The last three services relate to electricity use or production. The primary energy use is applied in order to have the same metric for different energy carriers thus enabling a representative yearly energy balance. It is also the metric used to specify energy performance requirements in Flemish EPB-regulation (Energy performance and indoor climate in buildings). To convert the metered electricity use to primary energy use a primary energy factor of 2.5 is used, representative of the Belgian electricity mix and a default in EPB-calculations in Flanders.

Heating energy needs

The heating energy needs are measured by the meters for total heat use installed at the network side of the substation of each dwelling. As an example, Figure 2 shows the metered monthly heat and electricity use for the buildings in Venning phase 2. In order to disaggregate the metered heat use into the heating energy need for space heating and domestic hot water, the evolution of the total heat use over the 12 months of the year is considered. The constant heat use measured during the summer months is considered to represent the energy need for domestic hot water, while the remaining part is the energy need for space heating. This latter part is further corrected for both degree days and indoor temperature.

Space heating energy figures were normalised by dividing each figure by the number of degree days in the period over which that energy was used. These values were subsequently multiplied by a single "normal year" degree-day value: for Belgium this is 2363 degree days for an average-year, representative of the last 30 years' climatic data. This gives a normalised equivalent of the original *kWh* figures that can, in theory, be compared. Since the weather during the monitoring winter months was typically mild (Figure 3), this correction resulted in an energy use figure substantially higher than the actual monitored energy use (increase by ~30%).

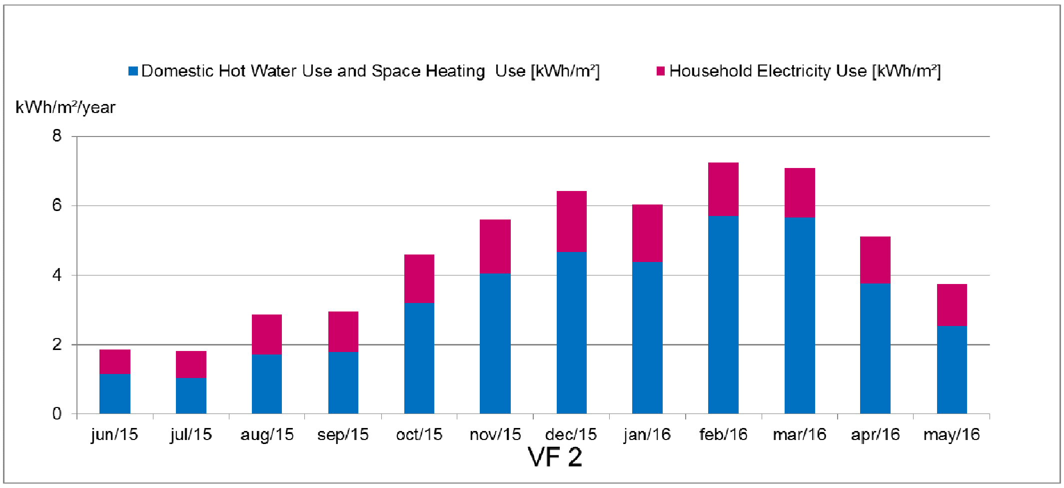

Figure 2: Monthly Heat and Electricity Use in Venning Phase 2, uncorrected values (kWh/m²/year)

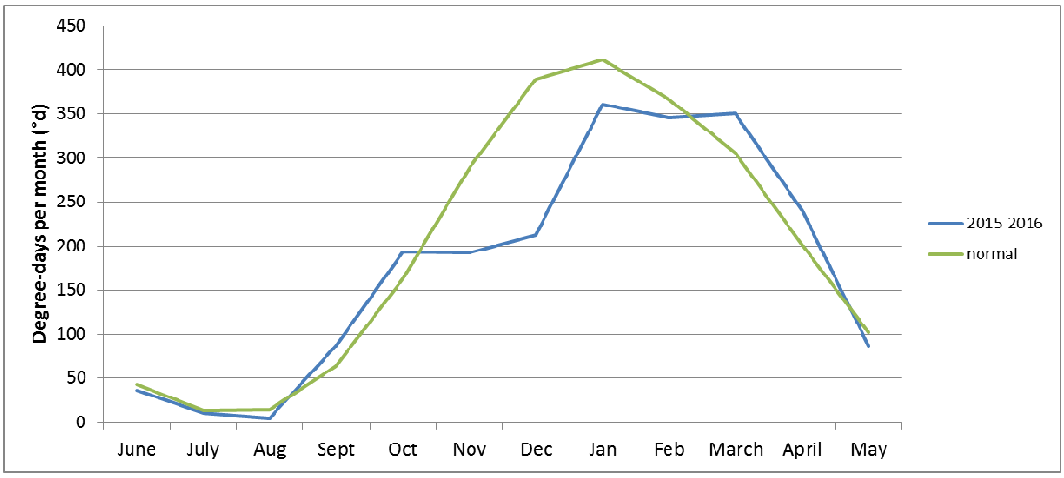

Figure 3: Monthly heating degree days in 2015-2016 compared to average climate in Belgium (base 16.5°C)

In addition to the heating degree day normalisation, the monitored data were also corrected for indoor temperature. The indoor climate monitoring showed elevated temperatures in a number of dwellings compared to the standard comfort temperature of 21°C. Correcting for indoor temperature excludes the user influence on indoor temperature and makes the monitored energy use easier to compare to benchmarks. The correction of the heat demand was based on the simple ratio of the difference between 21°C and outdoor temperature and the difference between the actual indoor temperature and outdoor temperature. In general this correction resulted in a normalised figure lower than the uncorrected energy use.

The metered heating energy need represents the gross heating energy demand. To convert these values into net heating energy demands they are multiplied by a system efficiency of 0.863 (default value for efficiency of dwelling heating system and substation).

Network heat losses and production efficiencies

The heat distributed by the Venning district heating network was monitored at the central plant for each branch of the network (Venning Phase 1, 2 and 3). The heat losses in the network were defined by subtracting the total metered heat use of the dwellings from the metered heat supplied by the plant. Figure 4 shows this comparison. On a yearly basis the network heat losses in Venning Phase 1, 2 and 3 represent 40%, 37% and 31% respectively of the total heat distributed by the heating plant.

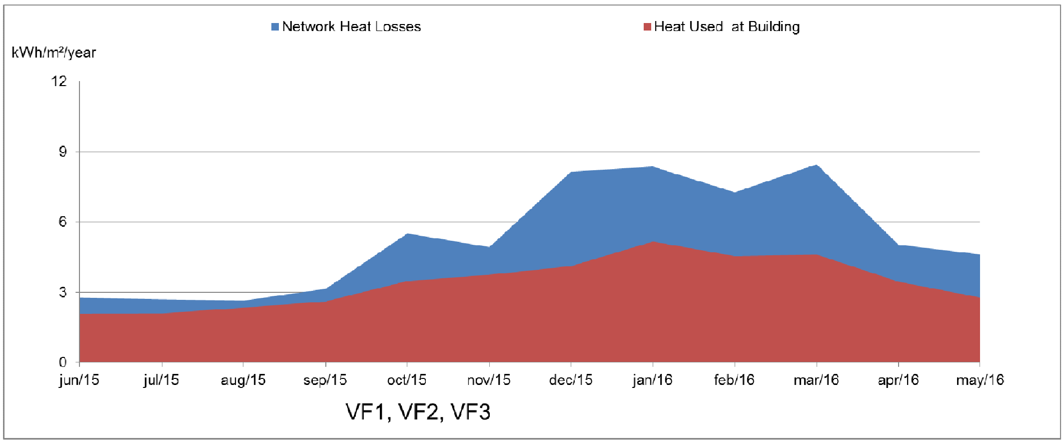

Figure 4: Total heat use in the Venning neighbourhood (Venning phase 1, 2 and 3) and the associated network heat losses (2015- 2016).

The production efficiencies of the different heat generation systems (biomass boiler, back-up gas boiler) were defined using the metered resource consumption of the systems (wood chip deliveries and metered gas consumption respectively). The energy generated by the energy systems was related to the estimated amount of heat supplied by the district and collective heating networks. This way the production efficiencies also include the effect of heat losses of storage tanks present in the heating plant. For the conversion of resource consumption into generated energy a heating value of 3.8-4.8 kWh/kg was used for wood chips, based on technical specifications of the wood chip deliveries, and 11.50 kWh/m³ (higher heating value) was used for natural gas, provided by the regional gas utility company. This way a seasonal efficiency of 67% was derived for the biomass boiler, and 87% for the back-up condensing gas boiler (Venning)

Fan energy use

The electricity monitoring data of the individual ventilation systems and of the collective air handling units enabled to define the fan energy use. Furthermore the operational supply and extract flow rates were measured in a sample of different systems and dwellings. This way the average specific fan power (SFP) of each type of system could be defined. This information was extrapolated to define the fan energy use in all demonstration buildings. The following SFP-values were measured:

- individual mechanical ventilation systems with heat recovery (Venning Phase 2 and 3):
  SFP = 0.51 W/(m³/h) (SFP4)
- individual demand-controlled ventilation systems with natural supply and mechanical exhaust (Venning Phase 2 and 3): SFP = 0.17 W/(m³/h) (SFP2)
- collective air handling units with rotary wheel heat recovery (Venning Phase 1):
  SFP = 0.32 W/(m^3/h) (SFP3, in line with design specifications)

Electricity generated by PV-installations

The first photovoltaic panels were installed on Venning Phase 1, building block C. At the time of reporting, this is the only PV installation for which data from the electricity grid operator is available. For the other PV installations, the generated electricity is extrapolated from building block C, based on the installed PV capacity at the other installations.

In building block C, a 35,28 kWp PV installation is connected to an energy meter. An overview of the electricity grid operator for building block C shows the total energy generated by the PV panels, the energy injected into the grid, as well as the energy extracted from the grid (when the PV panels do not generate enough energy). The evaluated period runs from January 2015 to December 2015, but during some months in this period, a unexpected low production (and injection) is registered, resulting in an annual energy production of 24 445 kWh. The low production during some months is probably due to additional works on the electrical installation, during which the PV installation was shut off.

As this would result in a too pessimistic annual energy production, a first correction is made. For every month, the electricity production was normalised to the total horizontal radiation measured by the pyranometer onsite. A small fluctuation during the year is expected, due to the changing solar angles. Unusual low values of the production compared to the solar radiation were corrected taking in mind the yearly fluctuation, and a corrected energy production was calculated resulting in an annual energy production of 36 527 kWh.

A second correction takes into account the solar radiation during the period, which was higher than during an average year, and would result in a too optimistic annual energy production. An average solar radiation was extracted from the EPBD calculation methodology in Belgium. The correction resulted in an annual energy production of 34 371 kWh, or 974 kWh/kWp. In extrapolating these values to other installations, there can of course be differences in the type of PV panels installed on the different buildings, as well as in their orientation or angle, but these differences are rather limited for the majority of the installations.

3. ENERGY USE TARGETS

National regulation

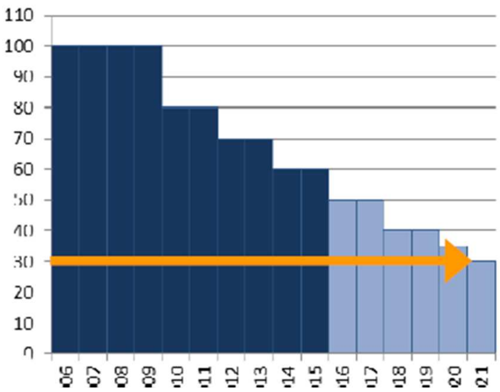

Figure 5: Evolution of energy performance requirements in Flanders, Belgium (E-level), as a function of year of building permit.

The reference building is a building of the same type as the demonstration building, meeting the minimal energy performance requirements of the national regulation in the year of the ECO-Life project start. The EPBD (European Energy Performance in Buildings Directive) came into force in 2006 in the regional Flemish regulation on Energy Performance and Indoor Climate in Buildings (EPB). The requirements concern both energy efficiency of the building and indoor climate (summer comfort and ventilation), and are specified in a number of sub-requirements to which all new and renovated buildings have to comply:

- thermal insulation: maximum U-value of building envelope components and maximum K-level (measure for the volumetric transmission heat loss through the building envelope)
- maximum net energy demand for heating
- maximum E-level (measure for total primary energy use of the building)
- minimum ventilation requirements
- maximum value of overheating indicator (summer comfort), only for residential buildings

Since the year of the project start the energy performance requirements have been strengthened year after year, as Figure 5 shows. The requirements of the year 2010 have been taken as a reference, since the project started in 2010 and the majority of building permits for the Kortrijk ECO-Life community were issued in 2010 and 2011 (with exception of Venning Phase 3 (2012)). In 2010 and 2011 the maximum value of the E-level amounted to E80. In order to achieve this requirement, buildings of the type of the demonstration buildings should have a net space heating demand in the order of 70 kWh/m²/year, when the building is equipped with standard building systems. This energy demand represents a theoretical energy demand calculated according to the Belgian EPBD-methodology and based on a constant indoor temperature of 18 °C in the entire insulated volume of the dwelling. The value of 70 kWh/m²/year was also introduced in the energy performance regulation in 2012 as a maximum limit for the net energy demand for space heating.

Therefore this value is also representative for the requirements of demonstration buildings with a building permit issued in 2012 or later.

The reference building is assumed to be heated by a gas-fired condensing boiler, with a seasonal installation efficiency of 85% (higher heating value as a reference). A simple exhaust ventilation system is assumed in the reference scenario, without demand-control or heat recovery. For the household electricity use Eurostat figures are used as a reference, showing on average a final electricity use of 3500 kWh per household of 2 parents and 1 child.

ECO-Life targets

In order to meet the ECO-Life targets of carbon neutrality, the energy use in the demonstration buildings needs to be lower than the National regulation targets. For new demonstration buildings the passive house standards are taken as a reference, aiming at a net space heating energy demand of 15 kWh/m²/year, or almost 80% better than national regulations. For refurbished demonstration buildings a performance 50% better than national regulations is needed, aiming at a net space heating energy demand of 35 kWh/m².

To translate the ECO-Life targets into design specifications for energy performance, the Flemish EPB-software has been used. It is mandatory to use this software to demonstrate compliance to the EPBD regulations in the Flanders region of Belgium. The energy performance of new and renovated buildings needs to be assessed at the moment of completion of the works by an EPB-assessor, who collects the as-built information, creates the necessary input in the EPB-software, and evaluates whether the building meets the requirements. The EPB-declarations with the results are uploaded to a database managed by the regional authorities. The EPB-input files of all demonstration projects in the Kortrijk ECO-Life community have been provided by the EPB-assessors (E-ster and BuroII) and the predicted performances have been used as the ECO-Life design specifications for comparison of monitoring results.

4. MONITORING RESULTS

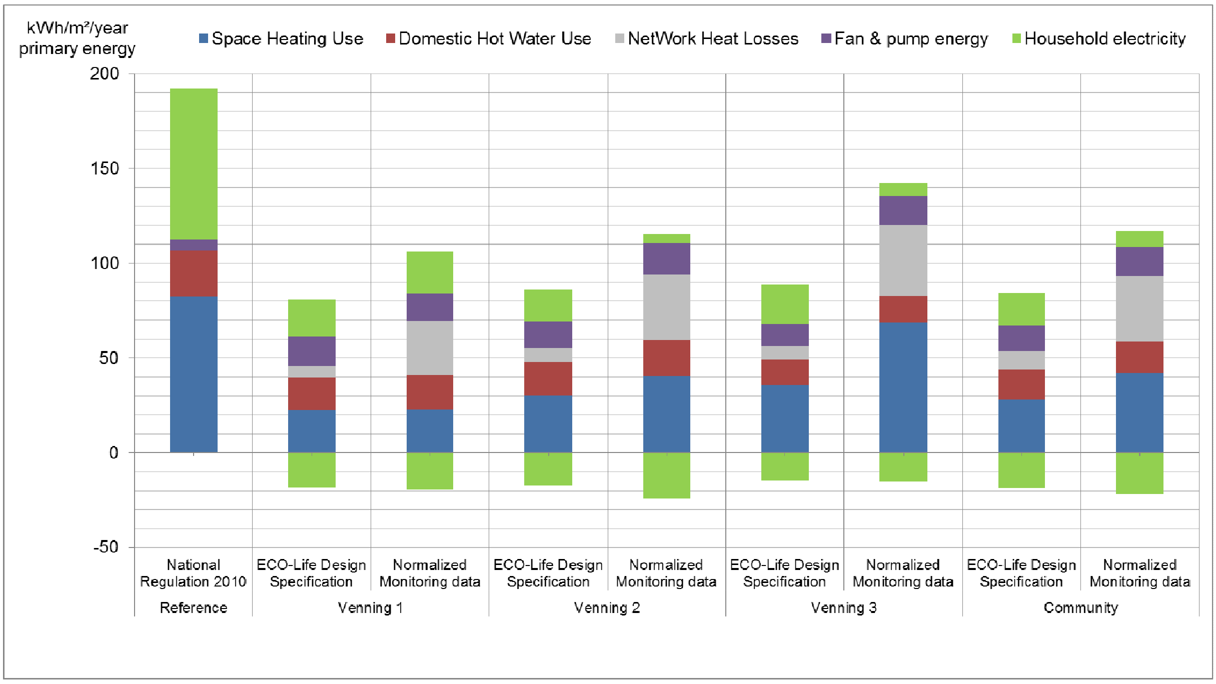

Figure 6 Yearly primary energy balance of the Kortrijk ECO-Life community (June 2015 -May 2016), with negative values representing primary energy generated by PV-installations.

Figure 6 gives an overview of the results of the final year of monitoring. The monitoring data are compared to the National regulations and to the ECO-Life design specifications extracted from the EPB-declarations of the buildings, as explained above.

The bar-graph shows the yearly primary energy balance (top of bar), with the negative values representing the primary energy generated by PV-installations. The negative portion of the bar thus represents the part of the energy use that is balanced by PV-production on a yearly basis, while the full height of the bar (positive + negative portion) represents the total primary energy use.

The monitored primary energy balance in the community is 117 kWh/m²/year, which is 39% smaller than if the community were built and refurbished according to the national building regulations in force at the time of building permit. Compared to the ECO-Life design specifications the monitored primary energy use in the Kortrijk ECO-Life community is 39% higher.

When household electricity is not included in the balance, the primary energy balance is 87 kWh/m²/year, 23% smaller compared to national regulations, and 80% higher than ECO-Life design specifications.

As the figure shows, the monitored energy use is higher than expected according to the ECO-Life design specifications mainly because of 3 reasons: (1) high network heat losses in district and collective heating networks, (2) low production efficiencies and (3) higher energy demand for space heating in some demonstration buildings. These results highlight the importance of proper commissioning and operation of heating systems. In the last year of monitoring, which is also the first year that all the dwellings were connected to the Venning district heating system, it has been necessary to solve different problems related to the operation of the district heating system. Due to commissioning problems with the control actuators (VFD-pumps, motorized 3-way valves), the system has operated at elevated return water temperatures compared to the design of 35°C. Moreover the supply water temperature was not yet controlled as a function of ambient temperature. After adjusting the settings of some of the actuators the situation has recently improved, but the commissioning is ongoing at time of reporting and should be completed by the end of summer 2016. As an illustration Figure 7 compares the measured water temperatures before and after adjusting the settings in the Venning district heating network.

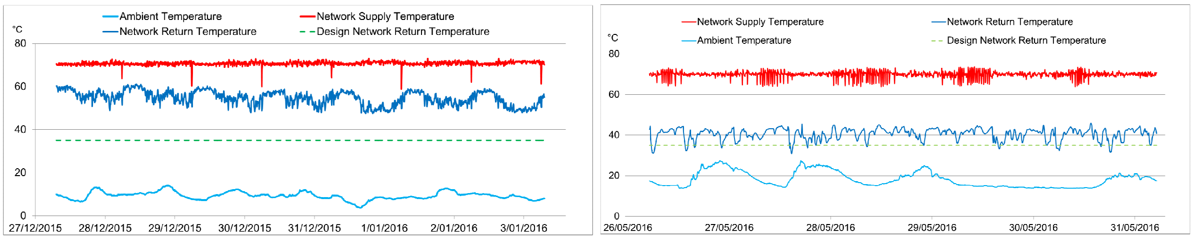

Figure 7: Operational temperatures of the network during one week of December 2015, and one week of May 2016 (after adjusting control settings).

Furthermore, several technical issues regarding the wood chips feeding system have limited the possibility to use the biomass boiler as a main unit at Venning heat plant. When the problem with the wood chips feeding system was solved and the heat demand had increased, the level of heat production by the biomass boiler has progressively increased. As a result of the intermittent operation and the high peak capacity of the boiler compared to the typical heat demand, the biomass boiler has mainly been working in part load. Control issues however reduced the flexibility of the unit to operate during part load conditions.

It is expected that the future operation of the Venning heating systems will improve after final commissioning of the systems, and that the network distribution efficiency and system production efficiency will increase. An increase of the distribution efficiencies to a value of 87% is feasible according to heat loss calculations. At full operation the primary energy balance in the community would decrease with 25% compared to the current monitoring results, moving the energy balance closer to the ECO-Life design specifications.

Figure 8 compares both the normalised and the actual monitored net space heating demand to the targets. Similar to the analysis of the yearly primary energy balance, the monitoring results show a much better performance compared to the National regulation targets (in between 32% and 78% lower space heating demand), but without meeting the ECO-Life targets in every building. Note that the actual monitored space heating demand is lower than the normalised demand and is closer to the ECO-Life targets, even though the monitored indoor temperatures were on average higher than standard comfort temperatures.

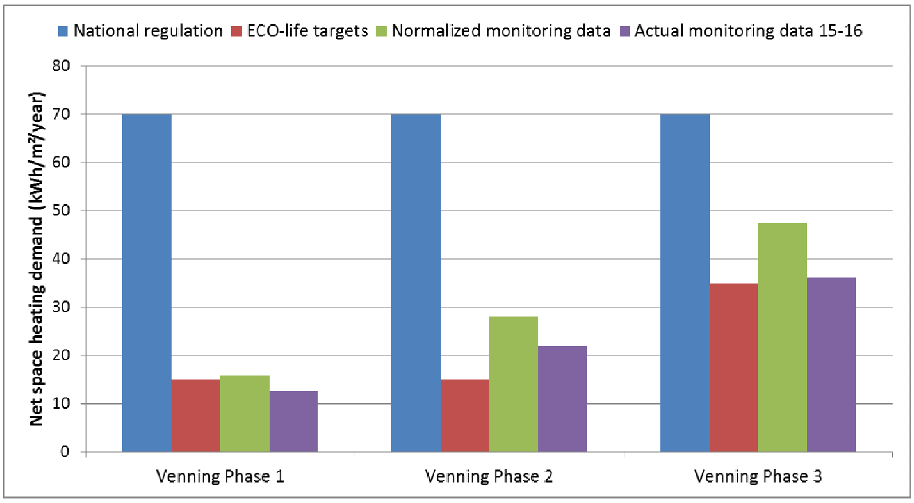

Figure 8: Comparison of monitored space heating demand and project targets.

The difference in energy use for space heating compared to ECO-Life targets can be caused by multiple factors. The energy use for space heating is affected by user behaviour and outdoor climate conditions. Although the energy use is corrected for heating degree days and indoor temperature, this may not be sufficient to normalise the metered energy use in low-energy houses in a correct way. Apart from indoor and outdoor temperature, also solar radiation, operation of windows and ventilation systems, etc… play a role. Furthermore the use of the standard heating degree days in Belgium with base temperature 16,5°C may lead to an overestimation of outdoor temperature influence on space heating demand in low-energy houses.

All demonstration buildings were designed with the same energy saving measures for the building envelope (insulation, airtightness, solar shading), taking the passive house requirements as a guideline. In reality, large differences in airtightness were measured during blowerdoor testing. While Venning Phase 1 reached on average the air change rate goal at 50 Pa pressure difference of 0,6 h^{-1}, this was not the case for Phase 2 and 3 where on average n_{50}-values of 1,6 h^{-1} and 3,8 h^{-1} were measured respectively, causing higher infiltration heat losses. Possibly, there were also some flaws in the solution of thermal bridges, resulting in higher transmission heat losses than designed. Although thermographic inspections demonstrated a good overall installation quality of thermal insulation, they also revealed a number of local areas with increased heat loss.

In Phase 1, all dwellings were equipped with a heat recovery ventilation system, while in Phase 2 and Phase 3, this is only the case for half of the dwellings. The other half is equipped with a demand-controlled exhaust ventilation system. The detailed monitoring results indicated there were no significant differences between the space heating energy needs in both types of dwellings. However, the measured extraction effectiveness of the rotary heat exchangers was lower than according to product specifications.

5. CO_2-MONITORING OF THE COMMUNITY

The environmental impact of the ECO-Life project is expressed in terms of CO_2-emissions due to the production of heat and electricity for the operation of the buildings. The CO_2 balance is a balance between the CO_2 emission from the buildings and the CO_2 displaced by energy production from renewable energy sources. For the estimation of the CO_2 emission from the buildings, it is assumed that the energy used is entirely produced by typical (largely non-renewable) systems. For the Belgian situation, this is a gas condensing boiler with efficiency of 85% for heat generation, and the electricity is taken from the national electricity grid. The CO_2 displacement is calculated from the energy used by the actual renewable energy systems in the ECO-Life project (e.g. the electricity produced by the PV systems and the biomass fuelled to a biomass system). Remark that even if in the ECO-Life project the required heat is immediately produced by a biomass boiler, in the CO_2 emissions it is assumed that it was produced with gas, and the production from the biomass boiler is dealt with in the CO_2 displacement.

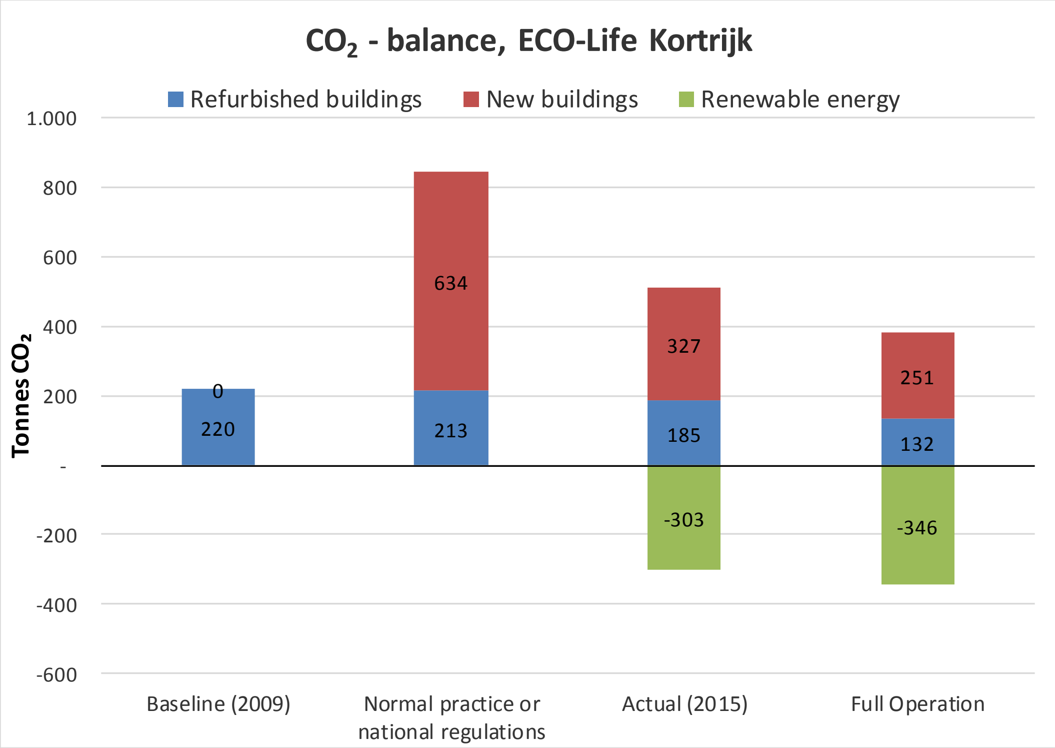

Figure 9: CO_2-Balance in community.

In Figure 9, the CO_2 emissions from new and refurbished buildings (positive y-values) and CO_2 displacement from Renewable Energy Systems (negative y-values) are presented for all project phases. In 2015 the CO_2 emissions are reduced with about 40% in comparison to normal practice. In total about 511 tonnes of CO_2 would be emitted (if all systems were replaced by typical non-renewable systems). On the other hand about 303 tonnes of CO_2 was displaced by the renewable energy systems. That is 59% of the CO_2-emissions. If household electricity is not included in the CO_2-balance, the displaced CO_2 covers 73% of the emissions.

It is clear that the actual balance of the ECO-Life community is not yet carbon neutral. However, this is largely caused by the fact that the biomass plant, which is the most powerful RES-system in the community, still experienced operational problems in the last year of monitoring,

It is expected that the performance will increase significantly after all commissioning tasks have been completed. Therefor an extra column has been added to the CO_2-balance, representing the expected balance in full operational conditions. The expected distribution efficiencies would be about 0.87 for Venning district heating plant. Also a full operation of the mini-CHP is taken into account (=7.6% of the energy production), and a production of 83% of the energy with the biomass boiler. In these fully operational conditions, the CO_2-emissions would decrease with about 25% in comparison to the actual conditions, and 55% in comparison to the normal practice. Moreover, the CO_2 displacement would rise and cover about 90% of the CO_2 emissions of the ECO-Life buildings. If household electricity would be excluded from the CO_2-balance, the displaced CO_2 would exceed the emissions by 20% in full operation.

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