Monitoring Results

IEA SHC TASK 56 | Building Integrated Solar Envelope Systems for HVAC and Lighting

Monitoring Results

Deliverable DC.4

Authors: Ochs Fabian, Elisa Venturi, Mara Magni, Dermentzis Georgios, Zissis Ioannidis, Stratos Ru

April, 2020
DC.4, DOI: 10.18777/ieashc-task56-2020-0007

IEA Solar Heating and Cooling Technology Collaboration Programme (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is *"To enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050."*

The members of the IEA SHC collaborate on projects (referred to as Tasks) in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

Research topics and the associated Tasks in parenthesis include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat for Industrial or Agricultural Processes (Tasks 29, 33, 49, 62, 64)
- Solar District Heating (Tasks 7, 45, 55)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42, 58)

In addition to our Task work, other activities of the IEA SHC include our:

- ➢ International Conference on Solar Heating and Cooling for Buildings and Industry
- ➢ SHC Solar Academy
- ➢ Solar Heat Worldwide annual statics report
- ➢ Collaboration with solar thermal trade associations

Country Members

Australia	France	South Africa
Austria	Germany	Spain
Belgium	Italy	Sweden
Canada	Netherlands	Switzerland
China	Norway	Turkey
Denmark	Portugal	United Kingdom
European Commission	Slovakia	

Sponsor Members

European Copper Institute	ECREEE
International Solar Energy Society	RCREEE
EACREEE	SACREEE

For more information on the IEA SHC work, including many free publications, please visit www.iea-shc.org

Contents

1 Introduction

In Deliverable D C.4 two Demo buildings are presented. The first one is a multi-family house built in Innsbruck, Austria according to the Passive House standard. The second one is a library located in Varennes, Quebec, Canada designed as net zero energy building. Demo buildings are illustrated and monitoring results are reported.

2 An-der-Lan Demo building

In this chapter the An-der-Lan Demo building, located in Innsbruck, Austria is presented. First of all, the description of the building is provided. Information on the structure of the building, components of the envelope and technical system are given according the real building elements. Afterward, monitoring results of the actual system and energy simulation results of alternative scenario are presented. Finally, an economic analysis based on the results of the alternative scenario and considering several monthly and annual primary energy factors is shown.

2.1 Demo building description

The building under consideration is a new small residential complex with 14 flats and several common rooms. The heating system is completely electric in order to keep the investments costs low and to reduce the distribution losses. The poor efficiency of the electric system is compensated by the integration of a large PV area in the south façade. Values of the building structures presented in sections 2.1.1-2.1.8 are taken from the datasheet of the actual materials and components used in the demo building.

2.1.1 Geometry and Floor Plan

The building consists of six stories and a basement, as shown in **Figure 1**. The staircase and all the spaces in the basement, except the bathrooms, are not heated. The energy reference area is 1204.9 m^2. The rooms in each floor are listed in **Table 1.**

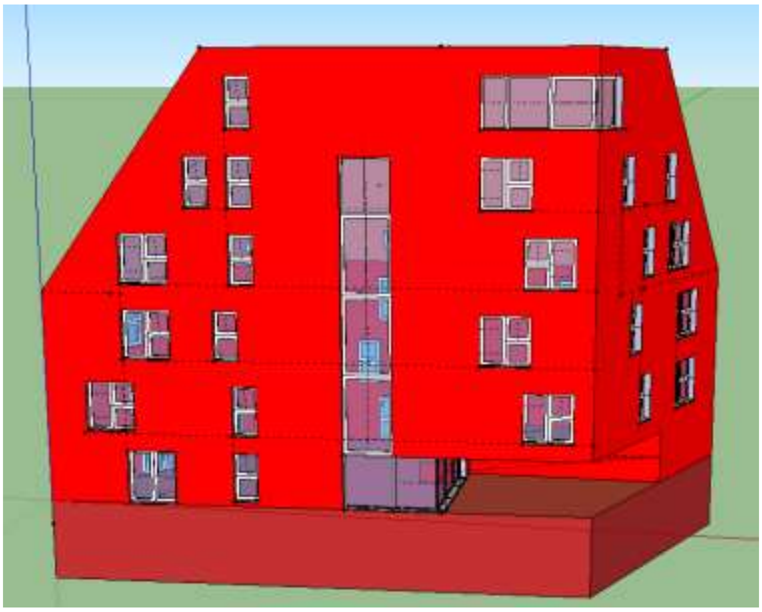

Figure 1: On the left: Sketch-Up model of the multi-storey building; on the right: side view (west) of the multi-storey building.

Table 1: List of the rooms in each floor

Zone	Rooms
Basement	Therapy room with kitchen, basement, storage room, 2 technical rooms, 3 WCs, 2 showers, 2 changing rooms
Ground floor	Living room, storage closet, office, conference room, WC, equipment room, waste room, terrace

First floor	4 apartments
Second floor	4 apartments
Third floor	4 apartments
Fourth floor	2 apartments, WC, shower, changing room
Fifth floor	Therapy room, WC, shower

The plan of the first floor is shown in **Figure 2**. The second floor has the same plan as the first one. On the third floor, the dimensions of the rooms are smaller due to the slope of the walls, while the fourth-floor presents larger areas. The total, heated and treated areas (evaluated as the sum of heated area and 60% of traffic area) for each floor are shown in **Table 2**. The walls and window constructions are reported in section **0** and **0**, respectively.

Figure 2: Plan of the first floor

Table 2: Total and heated area for each floor

Zone	Total area [m²]	Heated area [m²]	Treated area [m²]
Basement	180.1	40.3	124.2
Ground floor	142.0	86.4	119.7
First floor	181.1	168.1	175.9
Second floor	181.0	167.9	175.8
Third floor	146.7	133.6	141.5
Fourth floor	102.7	89.6	97.5
Fifth floor	66.3	61.4	64.3

2.1.2 Building assemblies

Opaque structures

The wall constructions of the opaque structures are listed in the following tables (from **Table 3** to **Table 9**). The emissivity factor is 0.94 for all the walls. For the wall against the ground and for the south façade with the photovoltaic modules, the absorption factor is 0; for all the other walls it varies between 0.60 and 0.70.

Table 3 shows the construction of external walls facing North, East and West. A different construction is provided for the external wall facing South (see **Table 4**). In particular for the south façade, only 18,6 m^2 of the area have R_{se}

= 0.04 m²K/W (outdoor), while for the rest of the surface R_{se} = 0.13 m²K/W (ventilated) was adopted due to the PV modules.

All the vertical walls towards the ground present the same construction (see **Table 5**).

Due to the presence of the terrace in the ground floor (see **Figure 1**), there are two constructions of the floor (one in the basement and one in the first floor - towards the terrace) and two constructions of the ceiling (one in the fifth floor and one in the basement - towards the ground floor). These are shown in **Table 6**, **Table 7**, **Table 8** and **Table 9**.

Table 3. Construction of external wall (towards North, East and West)

Material	S [m]	λ [W/(mK)]	r [kg/m³]	c_p [J/(kgK)]	U-value [W/(m²K)]
Concrete	0.003	1.000	900	2000	**0.125** (R_{se} = 0.04; R_{si} = 0.13)
Reinforced concrete slab	0.05	2.300	2400	1000	
Reinforced concrete	0.15	2.300	2400	1000	
PUR insulation	0.2	0.026	32	1400	
Reinforced concrete slab	0.05	2.300	2400	1000	

Table 4. Construction of external wall (towards South)

Material	s [m]	λ [W/(mK)]	r [kg/m³]	c_p [J/(kgK)]	U-value [W/(m²K)]
Concrete	0.003	1.000	900	2000	**0.124** (R_{se} = 0.13; R_{si} = 0.13) or **0.125** (R_{se} = 0.04; R_{si} = 0.13)
Reinforced concrete slab	0.05	2.300	2400	1000	
Reinforced concrete	0.15	2.300	2400	1000	
PUR insulation	0.2	0.026	32	1400	
Reinforced concrete slab	0.05	2.300	2400	1000	

Table 5. Construction of vertical walls towards the ground

Material	s [m]	λ [W/(mK)]	r [kg/m³]	c_p [J/(kgK)]	U-value [W/(m²K)]
Concrete	0.003	1.000	900	2000	**0.181** (R_{se} = 0.00; R_{si} = 0.13)
Reinforced concrete slab	0.05	2.300	2400	1000	
Reinforced concrete	0.2	2.300	2400	1000	
XPS insulation	0.2	0.038	30	1450	
Reinforced concrete slab	0.05	2.300	2400	1000	
Mat	0.01	1.000	1000	1000	

Table 6. Construction of basement floor

Material	s [m]	λ [W/(mK)]	r [kg/m³]	c_p [J/(kgK)]	U-value [W/(m²K)]
Pavement	0.013	1.300	2200	840	**0.170** (R_{se} = 0.00; R_{si} = 0.17)
Pavement	0.065	1.400	2200	840	
Eps sound insulation	0.03	0.033	100	1300	
Insulation	0.087	0.050	160	1500	
Bitumen sheet	0.005	0.170	1000	840	

Reinforced concrete	0.3	2.300	2400	1000	
Insulation	0.1	0.035	40	1450	

Table 7. Construction of floor in the first floor (towards the terrace)

Material	s [m]	λ [W/(mK)]	r [kg/m³]	c_p [J/(kgK)]	U-value [W/(m²K)]
Parquet floor	0.014	0.160	700	1000	**0.120** (R$_{se}$ = 0.04; R$_{si}$ = 0.17)
Pavement	0.065	1.600	2000	1000	
EPS sound insulation	0.03	0.044	30	1500	
Insulation	0.07	0.050	108	1250	
Reinforced concrete	0.2	2.300	2400	1000	
Reinforced concrete slab	0.05	2.300	2400	1000	
PUR insulation	0.15	0.026	32	1400	
Reinforced concrete slab	0.05	2.300	2400	1000	

Table 8. Construction of roof

Material	s [m]	λ [W/(mK)]	r [kg/m³]	c_p [J/(kgK)]	U-value [W/(m²K)]
Gravel	0.05	0.700	1500	880	**0.123** (R_{se} = 0.04; R_{si} = 0.10)
Fibre fleece	0.01	0.500	300	792	
Bitumen sheet	0.01	0.170	1000	840	
PUR insulation	0.2	0.026	35	1470	
Vapour barrier	0.005	0.170	1000	840	
Reinforced concrete	0.2	2.300	2400	1000	
Concrete	0.003	1.000	900	2000	

Table 9. Construction of basement roof (towards the terrace)

Material	s [m]	λ [W/(mK)]	r [kg/m³]	c_p [J/(kgK)]	U-value [W/(m²K)]
Concrete	0.003	1.000	900	2000	**0.171** (R_{se} = 0.04; R_{si} = 0.10)
Waterproof layer	0.25	2.300	1600	1000	
Bitumen vapour barrier	0.005	221.000	1000	840	
Insulation	0.2	0.036	40	1450	
Shelter layer	0.01	0.500	225	1800	
Slab	0.055	2.300	1500	1080	

Transparent structures

In the building there is a total of 109 windows. Most of them (85) have the same characteristics, but different dimensions. The rest have different properties. **Table 10** shows a summary of the most relevant characteristics of the windows of the building. The majority of windows have dimension 1 m x 1.01 m, but values range from 0.45 m to 2.02 m for the width and from 0.86 m to 3.20 m for the height.

Table 10. General thermal characteristics of the windows

Number of windows	Orientation	g-value [-]	U_{glass} [W/(m²K)]	U_{frame} [W/(m²K)]	Frame width [m]
81	North, East, South and West	0.50	0.52	0.96	0.080
10	South and East	0.54	0.60	0.85	0.040
7	North and West	0.50	0.52	0.96	0.060
5	North and West	0.50	0.52	0.97	0.080
4	East	0.54	0.60	0.85	0.080
1	South	0.50	0.52	0.90	0.080
1	Horizontal	0.60	0.60	0.90	0.080

2.1.3 Internal gains

The building is conceived to be occupied by 24 persons: 14 residents (1 for each apartment) and 10 operators.

The final value of internal gains (people, appliances and lighting) is 2.68 W/m² and it is considered constant during the year.

2.1.4 Ventilation and infiltration

An air change rate of 0.02 [1/h] due to infiltration through the façade is assumed (corresponding to a blower door test result of n_{50} = 0.28 [1/h] and considering a wind protection coefficient of 0.07). This value is considered constant throughout the year.
A total volume flow of fresh air of 1292 m³/h is supplied to the building through a balanced mechanical ventilation unit with a specific fan power of 0.45 W/m³/h.
A heat recovery unit with a sensible effectiveness of 0.747 is considered.

2.1.5 Shadings

Shadings for horizon, reveals and overhang are considered. Values change based on the window and on the heating/cooling period. A summary of the shadings' characteristics is shown in **Table 11**.

Table 11: Values of the shadings

Orientation	Glazing area [m²]	Reduction factor heating period	Reduction factor cooling period
North	17.33	50%	58%
East	31.27	51%	56%
Sud	72.54	79%	78%
West	20.42	54%	66%
Horizontal	0.71	25%	20%

Internal shadings have been installed some months after the building construction, but they are not considered in the following evaluations.

2.1.6 Reference heating system

In the building, the heating system is electric. This system allows to avoid a dedicated room for heating technology and to reduce considerably distribution losses, which are particularly relevant for the DHW preparation (no distribution – ascending pipes). In each room electric surfaces of different size are installed. The total power installed for the heating system is 29.3 kW. The detailed description of the installed heaters is shown in **Table 26** in **Appendix 1**. A mechanical ventilation system with heat recovery is also installed, which is reducing the heating demand.

2.1.7 Hot water demand

The system for the preparation of the DHW is electric too. In the bathroom of each apartment a boiler of 50 litres is installed. Moreover, for the common area, three boilers of 120 litres are provided. For sake of simplicity, in the PHPP a unique thermal storage of 1000 l is considered. The properties of the storages are shown in **Table 27** in **Appendix 1**. It is considered inside the thermal envelope (temperature of the mechanical room equal to 20°C) and the typical storage tank temperature is assumed at 60°C.

2.1.8 Photovoltaic system

A relatively large photovoltaic (PV) system on the south façade is modelled to provide electric power. Three electric batteries are available for daily storage.

Figure 3 shows a simplified scheme of the electric energy flows. If there is no building energy demand, the electricity generated by the PV system is stored in the batteries, otherwise it is directly transferred to the building. Electricity will then be fed into the grid when the batteries can no longer store energy and at the same time there is no building energy demand. If the PV system is not able to meet the building's energy requirements either directly or via the batteries, energy from the grid will be used. When the battery charge level reaches the lower limit (deep discharge), energy from the grid is supplied to the batteries.

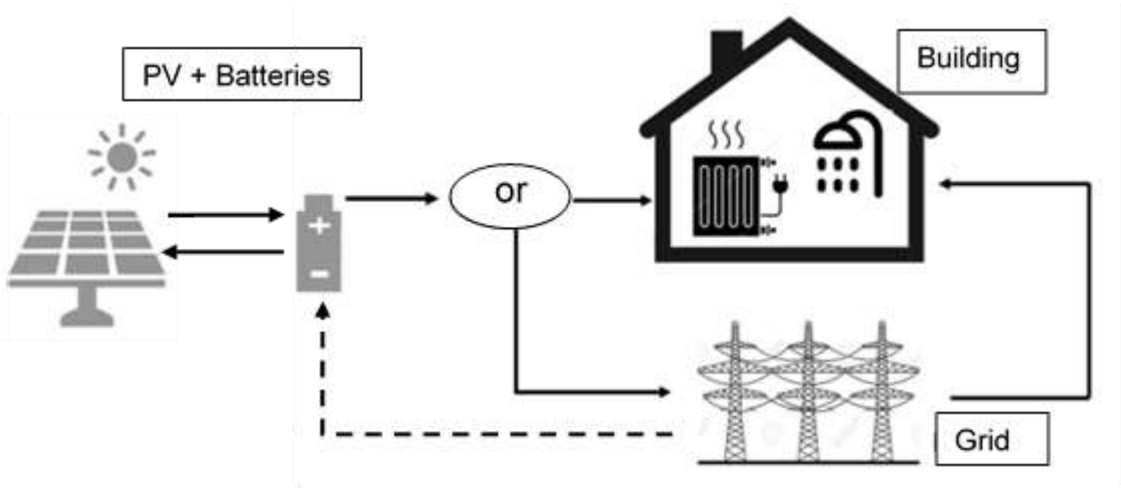

Figure 3: Simplified scheme of energy flows

The PV modules are made of monocrystalline silicon. 106 standard PV modules have each a peak power of 280W, while the 7 additional PV modules have special dimensions and a peak power of each 335W. Parameters of the PV modules, the inverter and the batteries are depicted in **Table 12**, **Table 13** and **Table 14**.

Table 12: Characteristics of the photovoltaic modules

	Type 1 of PV modules	Type 2 of PV modules
Cell type	Monocrystalline silicon	Monocrystalline silicon
Dimensions [mm x mm x mm]	1668 x 994 x 40.5	1988 x 994 x 40.5
Maximum power [W]	280	335
Voltage at maximum power point [V]	31.82	37.99
Current at maximum power point [A]	8.80	8.82
Open circuit voltage (V_{oc}) [V]	38.34	46.08
Short circuit current (I_{sc}) [A]	9.36	9.33
Efficiency [%]	16.8 %	17.0 %
Temperature coefficient of P_{max} [%/K]	- 0.42	- 0.42
Temperature coefficient of V_{oc} [%/K]	- 0.32	- 0.32
Temperature coefficient of I_{sc} [%/K]	0.047	0.047
NOCT [°C]	47 ± 2	47 ± 2

Table 13: Characteristics of the inverter

	Inverter
Nominal power [W]	25000
Maximum efficiency [%]	98 %

Table 14: Characteristics of the batteries

	Inverter
Total energy [kWh]	7.0
Usable energy [kWh]	6.6
Capacity [Ah]	63
Maximum power [kW]	3.5
Peak power (for 10 seconds) [kW]	5.0

Due to the relatively special architecture of the building, the installed PV area is smaller than the available façade area (see **Table 15**). The available area in the south façade without windows is 286 m^2, while the PV area is 190 m^2. The PV area could be theoretically increased by specific modules, e.g. with triangular shape or smart jalousie with solar panel. However, this would considerably increase the investment costs. On the east and west façades, a total of 237 m^2 would still be available for additionally PV.

Table 15: Available south, west and east façade area and installed PV area with standard modules

	Area [m^2]		
	Façade	**Façade without windows**	**PV**
South	374	286	190
East	184	144	(104)
West	242	215	(133)

2.1.9 Climate

The building is located in Innsbruck. Climate values from the software Meteonorm are implemented in the PHPP. Moreover, monitored climate data are available for 2019 from ZAMG. **Figure 4** and **Figure 5** show the external temperature and the horizontal radiation according the standard values in the PHPP, Meteonorm and ZAMG in 2019.

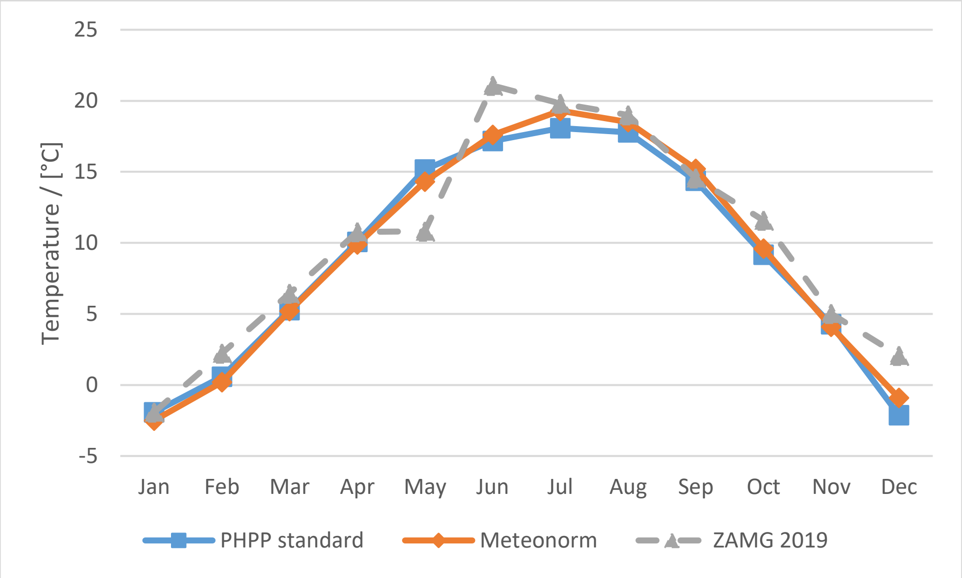

Figure 4: Monthly average ambient temperature

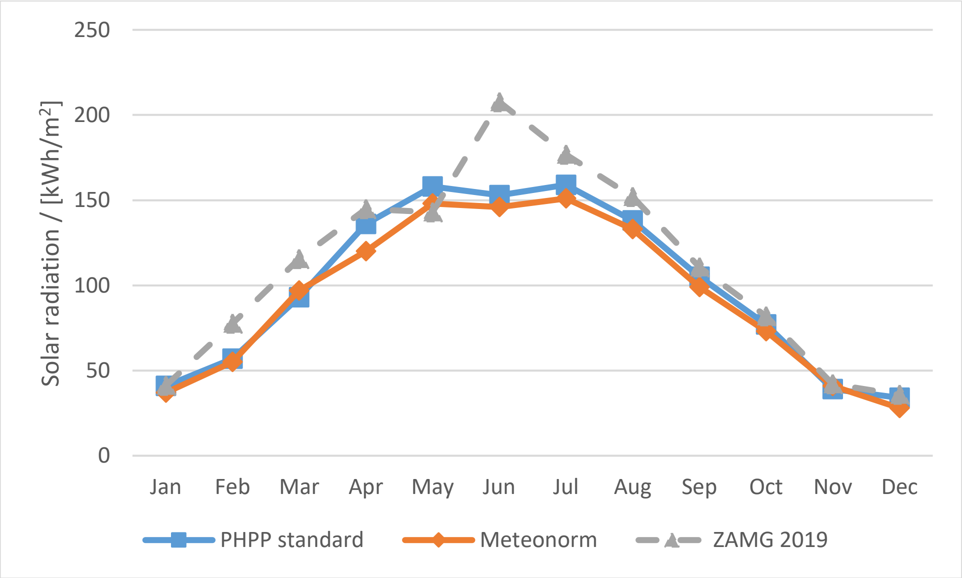

Figure 5: Monthly global horizontal radiation

2.2 Monitoring

2.2.1 Description of monitoring system

A detailed monitoring system is installed, which includes the measurement of the temperature in every apartment and common room of the building. In addition, the energy demand of the building is measured by electric energy meters every 15 minutes. Energy for heating, DHW and appliances is monitored for each individual dwelling and common room. Moreover, energy for ventilation, lift and electric car charging station is provided. Data are analysed for the year 2019. Unfortunately, the total energy demand of the building is not available because there are some loads which are not measured:

- heating in the bathroom in the ground floor
- appliances of all the rooms in the underground, which are:
    - therapy room (momentarily not used)
    - 2 technic rooms
    - a complex of bathrooms and changing rooms
    - storage room
    - basement

Since a scarce use of the basement rooms is expected, it is foreseen these missing measurements will play a minor role in the total energy consumption. The energy consumption for heating, DHW and the sum of household appliances and the ventilation system as well as other general consumers (e.g. elevator) is analysed and reported in monthly values.

.

2.2.2 Analysis of monitoring data

Monitored data are also post-processed in order to be used in the PHPP (Passive House Planning Package). PHPP applies monthly energy balance in order to evaluate buildings' performance. By means of the PHPP, the heating demand is calculated on the basis of various inputs. First, the PHPP is used to estimate the monthly heating demand at the standard temperature. In this case, the indoor temperature is assumed to be constant at 20°C and the outdoor temperature is calculated as a monthly average from measured data. Then the monthly heating demand is evaluated by inserting the actual temperatures into the PHPP tool. A weighted average indoor temperature is evaluated taking into account the temperatures of the apartments and rooms (measurement data) and their boundary conditions. The outside temperature is taken as the monthly average of the measured data.

Figure 6 shows the monthly electric energy demand for heating, DHW and appliances (including auxiliary energy) referred to the energy reference area (1204.9 m²). As expected, the heating energy follows the trend of the ambient temperature, which decreases from January to August. It should be emphasized that energy consumption for space heating was also measured in June, July and August, although the average ambient temperature is around 20°C. However, this avoidable energy demand in summer has a minor role in the total heating demand. Finally, evaluated values from the PHPP are shown. The monitored heating demand is always higher than the expected values. Results are discussed in more detail below. In general, however, the hot water demand for drinking water is within the range of the expected value and the household electricity demand is rather slightly lower than the Austrian average for one household. Quite low values of DHW and appliances can be explained by the quite large surface of the common rooms in the building, which are used for a limited time.

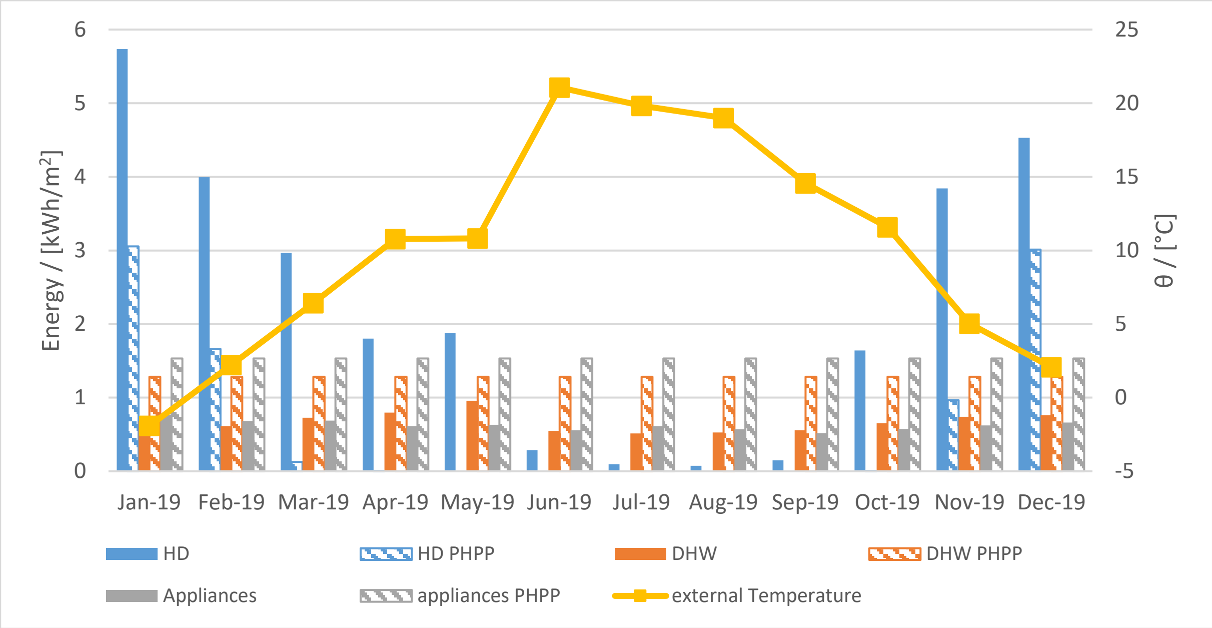

Figure 6: Measurement data of the energy demand and the external temperature

The measurement data of the individual apartments were also examined in detail. **Figure 7** shows the annual load duration curve of heating demand (sorted output per unit area) for each apartment and common room. In particular, it can be seen that one apartment and one office have an unusual high heating demand. Furthermore, it was found that two apartments have a significantly higher DHW demand than the other apartments.

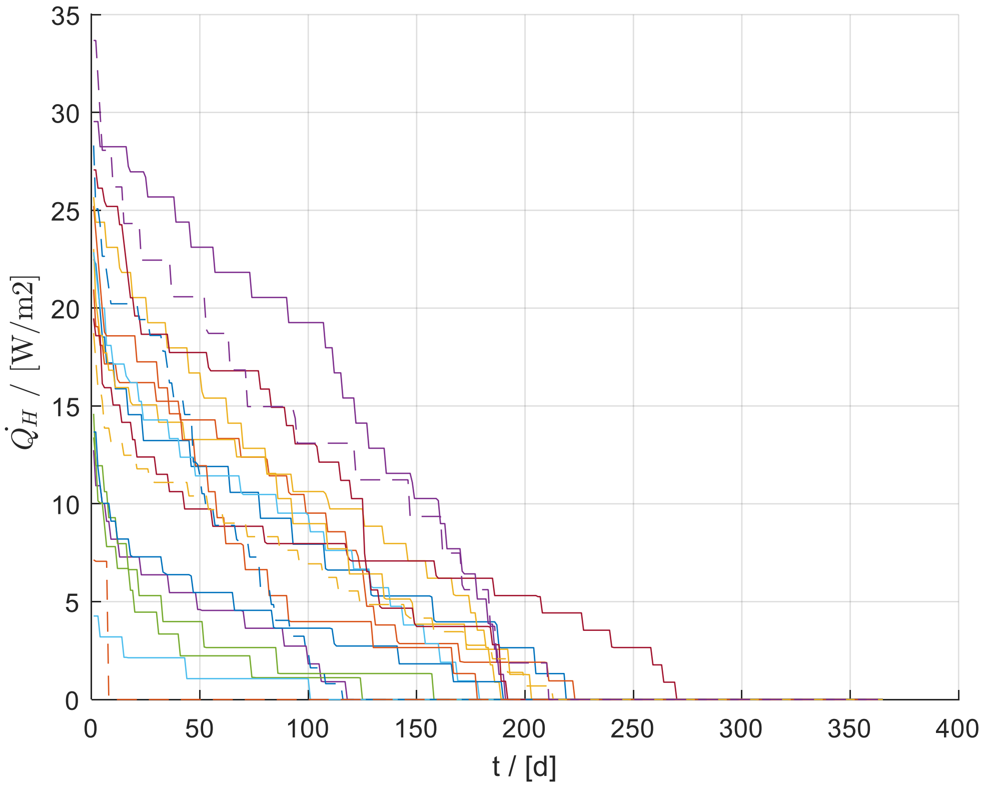

Figure 7: Daily heating output related to room area (for the year 2019)

The PV system is analysed by means of the measured data and the comparison with the simulation data as well. **Table 16** reports the supply cover factor (SCF) and the load cover factor (LCF) with and without batteries. They allow a slightly higher self-consumption, but not a significant improvement of the overall performance.

Table 16: SCF and LCF with and without battery from monitoring data

	With battery	Without battery
SCF	76%	64%
LCF	30%	25%

Every month, part of the energy generated by the PV is fed into the grid, while electricity is also bought from the grid, see **Error! Reference source not found.**. As expected, the use of the grid is significantly higher in the winter season than in summer, see **Figure 8**. It is recognizable that there is a power flow from the grid to the batteries when the charging state falls down below a threshold (around 11%). Moreover, **Figure 8** shows the evaluated value of the PV yield. It can be seen that the PV production was estimated rather conservatively from the PHPP calculations, but the trend agrees relatively well with the measured data. The influence of the climate (standard climate or real measured climate) is minor.

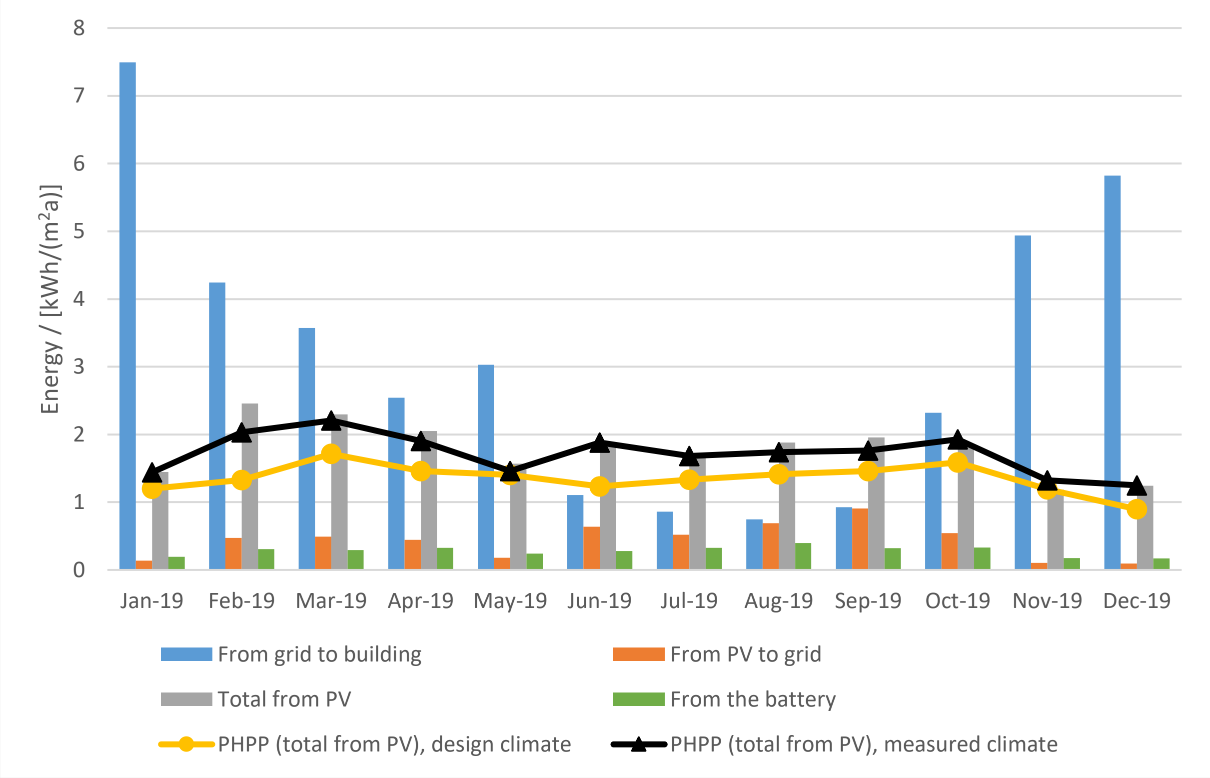

Figure 8: Evaluation of electric balance (monthly values)

Finally, the results of the PHPP referred to different inputs, are discussed. The evaluated heating demand in 2019 according to PHPP is 8.8 kWh/m^2 with design indoor and outdoor conditions and 9.3 kWh/m^2 with actual values for indoor and outdoor conditions. Measured data show a significantly higher energy requirement for space heating, equal to 27.0 kWh/m^2. The influence of the indoor temperatures, which is about 23.9 °C and therefore significantly higher than the design values according to PHPP (20 °C), is compensated by the more moderate real outdoor climate. The reasons for the significantly higher measured heating demand could not be yet fully identified. However, it can be assumed that the following aspects have a contribute:

- User behaviour (mainly window ventilation, but also shading)
- Use of cellar rooms (excess temperature in the cellar)
- Structural aspects (thermal bridges, groundwater influence, etc.)

2.3 Study of alternative systems

2.3.1 Overview of simulation studies

Using the PHPP results, a parametric study is performed aiming to compare the investigated system (direct electricity for heating and DHW in combination with PV - case A) with other system variants. On one hand, improvements such as shower water heat recovery or a larger PV system are investigated (cases B and C) and on the other hand, variants with a central heat pump system are investigated (cases D, E and F). **Table 17** shows the different variants. In all the investigated cases, the PHPP design value of 8.8 kWh/(m²a) and a hot water demand of 25 l/d/P at 60 °C are assumed.

Table 17: Description of the considered cases

Case	System description	PV
A	Direct electric system	32.0 kWp – South façade
B	System of case A plus shower drain-water heat recovery	32.0 kWp – South façade
C	System of case A	62.6 kWp – South, East & West façade
D	Reference centralized air-source heat pump (4-pipe distribution system)	-
E	Reference centralized groundwater-source heat pump (4-pipe distribution system)	-
F	System of case D	11.8 kWp – South façade (=minimum PV for annual electricity supply like A)

In the cases D, E and F, a centralized heat pump was used with a 4-pipe distribution system (2 pipes connected to floor heating and 2 pipes for DHW supply assuming fresh water station in each flat). The sink temperature of the heat pump is 35 °C for space heating and 52 °C for DHW supply. In particular, case F presents the minimum PV area in order to get the same energy request as in case A. In cases A, B and C, the set point in the electric boilers is 60 °C. In all cases, electricity is the only source of energy that is required. Properties of the installed components have been described in the previous sections **2.1.7** and **2.1.8**, the efficiencies of the additional components are shown in **Table 18**.

Table 18: Properties of the considered components

Efficiency shower drain-water heat recovery (referred to the useful energy)	41%
COP A/W HP (A7/W35)	3.7
COP W/W HP (B0/W35)	4.3

2.3.2 Results of the comparison of variants

The load cover factor (LCF) and the supply cover factor (SCF) are evaluated for the cases including the PV system. Values evaluated from the PHPP and monitoring data (case A) are shown in **Table 19**.

Table 19: LCF and SCF for cases with PV system

Case	PHPP		Monitoring data	
	LCF	SCF	LCF	SCF
A	36%	100%	30%	76%
C	67%	100%	-	-
F	17%	100%	-	-

The PHPP overestimates the factors compared to the monitoring data. In particular, the SCF is always 100% because it is assumed that all the produced energy from the PV is actually self-consumed.

In the following sections, all the results are obtained from PHPP.

Figure 9 demonstrates the monthly specific electricity consumption and production for case C with the largest PV system and case E with the lowest electricity demand. In case C, even with PV installed in three facades of the building, the electricity from PV is not enough to cover the whole electricity demand. Thus, additionally electricity from the grid is required anyway. The monthly consumption in case E decreases, compared to case C, more significantly in winter months (in which the renewable energy production is low) than in summer months.

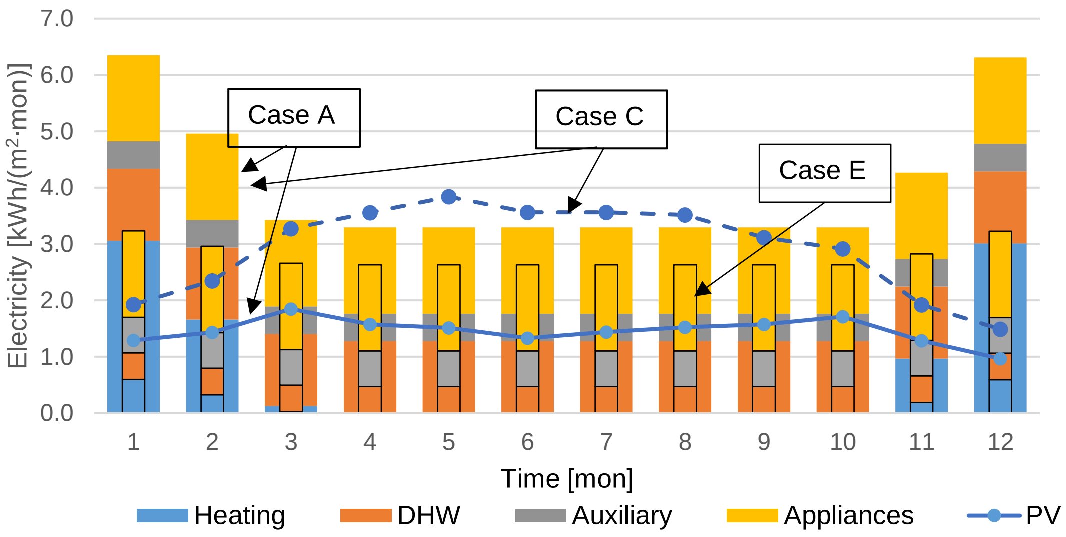

Figure 9: Monthly share of electricity consumption and PV electricity generation for cases C and E

Based on the results of **Figure 9**, **Figure 10** shows the annual specific electricity consumption and PV production for all cases. The lowest electricity demand is in case E. Comparing case B and A, the shower drain water heat recovery decreases the electricity consumption by 5%, while the reduction to the electricity for DHW is 15%. In case E, the electricity consumption for heating (8.8 kWh/(m²a)), DHW (15.4 kWh/(m²a)) and auxiliaries (5.8 kWh/(m²a)) can be balanced annually, if a PV system same as in case C is installed. This would allow the net zero energy standard (NZEB) to be achieved (excluding household electricity). The best result is achieved with a groundwater heat pump. However, groundwater is not available everywhere and therefore cannot be generally recommended as a variant. The building with an air-source heat pump without PV would even have a slightly higher annual electricity consumption than the reference variant. An 11.8 kWp PV system would be necessary to achieve the same annual electricity supply. However, the variant with the air-source heat pump also has a significantly lower winter electricity supply without PV, see **Figure 10**.

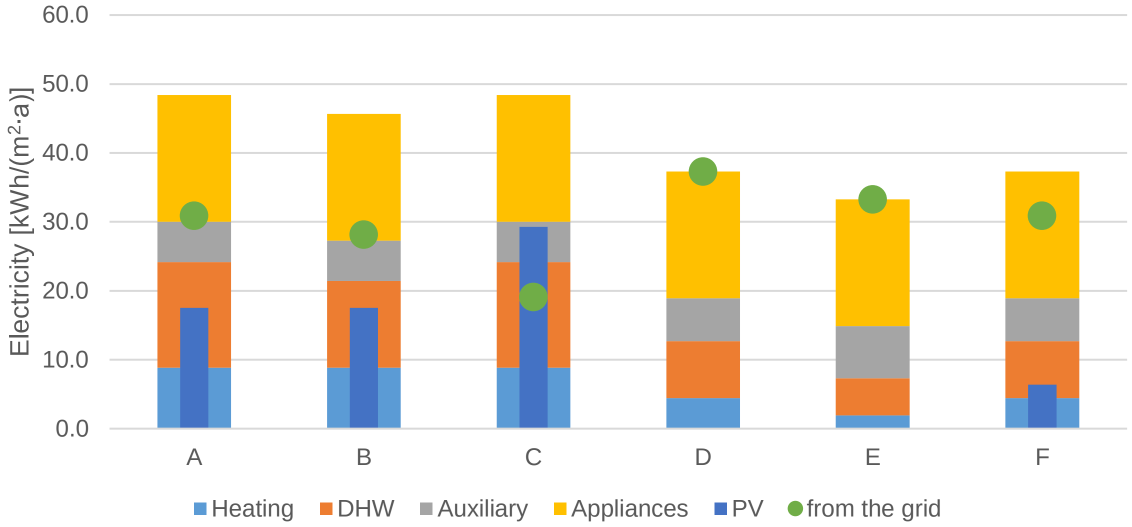

Figure 10: Electricity consumption for heating, DHW, auxiliary and appliances and PV power generation in the five investigated cases

Table 20 Error! Reference source not found. shows the annual electricity consumption. It can be seen that variant A (reference system with electric heating, electric boiler and PV) has a lower annual electricity consumption than variants D (central air HP) and E (groundwater HP). Variant F (air HP) with an 11.8 kWp PV system has a comparable annual electricity supply as variant A with 32 kWp.

Table 20: Annual electricity consumption (kWh/(m²a)) of the investigated variants

	A	B	C	D	E	F
Annual consumption [kWh/m²]	48.4	45.7	48.4	37.2	33.3	37.2
Year PV yield [kWh/m²]	17.5	17.5	35.0	0.0	0.0	6.4
Annual electricity consumption [kWh/m²]	30.9	28.1	14.9	37.2	33.3	30.7

In order to include the time of the year where electricity is purchased in the evaluation - in winter electricity savings are more valuable than in summer, in which there is a higher share of renewable energies - it is recommended to consider the seasonal or monthly composition of the electricity mix by means of primary energy conversion factors. **Figure 11** compares the considered variants on the basis of primary energy demand. Both constant non-renewable primary energy factors (1.32 for Austria, OIB 2015) and monthly factors (scenario "10-10-10", low share of RES in the electricity mix, and "10-30-30" scenario, higher share of RES in the electricity mix) are considered (see **Appendix 2** for the detailed values). It can be seen that the trend of technology ranking can change when taking into account the composition of the electricity mix, i.e. when using monthly conversion factors. The variants with heat pumps with a lower electricity purchase in winter have a comparable or lower primary energy purchase demand a higher grid electricity purchase (20 % in the case of the air HP and 8 % in the case of the GW HP).

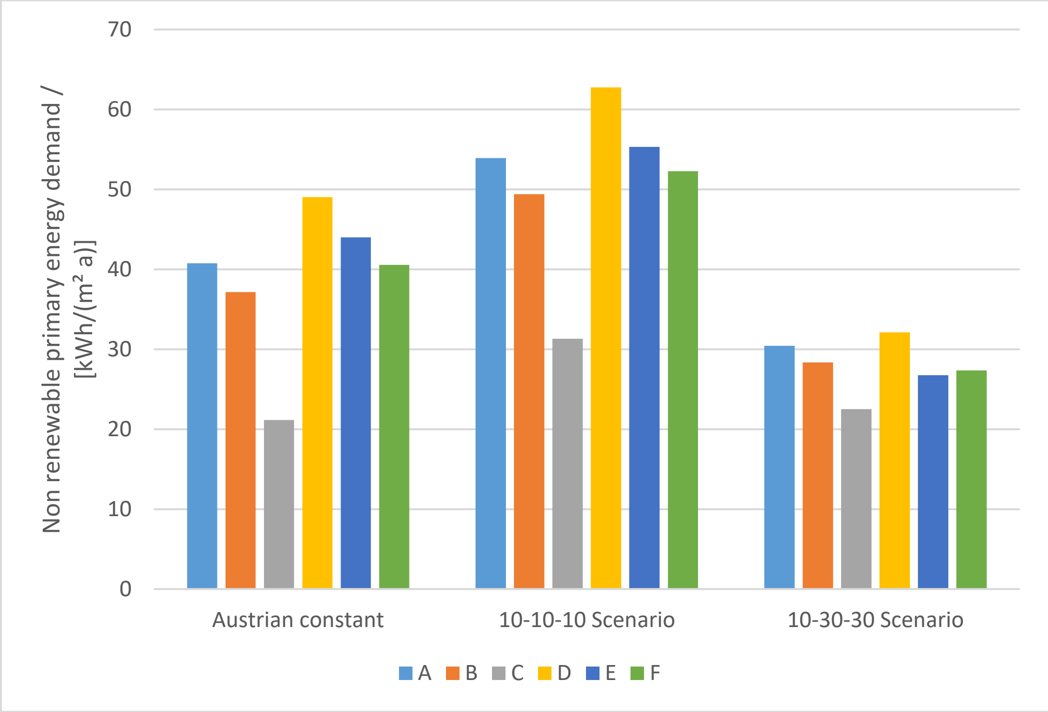

Figure 11: Primary energy demand of the investigated variants A to F with constant and monthly primary energy conversion factors (for two different scenarios of the electricity mix)

The ranking of the considered cases according to the primary energy demand changes when different PE conversion factors are considered. Nevertheless, the extreme cases (C with the lowest PE demand and D with the highest) are always confirmed with all the PE conversion factors. Case A and F show the same PE demand when the constant PE conversion factor is considered, but case F has better performance with monthly f_{PE} (especially with10-30-30 scenario). Indeed, case A is third in the ranking with the constant f_{PE}, but it reaches the fifth position with the 10-30-30 scenario.

Table 21 shows the annual PE demand depending on the two scenarios of f_{PE} (both with monthly and annual values) on the considered case and the primary energy savings (expressed as percentage related to the reference case).

With monthly PE conversion factors, those technologies which contribute to savings also in winter, such a HP and shower drain heat recovery, get better savings compared to those which mainly contribute in summer, as PV.

Table 21. Annual PE demand and relative deviation of PE (respect to the reference case) of the considered cases

	PE [kWh/(m²a)]						ΔPE [%]				
	A	**B**	**C**	**D**	**E**	**F**	**ΔPE (B)**	**ΔPE (C)**	**ΔPE (D)**	**ΔPE (E)**	**ΔPE (F)**
Monthly f_{PE1}	53.9	49.4	31.3	62.8	55.3	52.3	9%	72%	-14%	-3%	3%
Monthly f_{PE2}	30.4	28.3	22.5	32.1	26.8	27.3	7%	35%	-5%	14%	11%
Annual f_{PE1} = 1.64	50.7	46.2	26.3	61.0	54.7	50.4	10%	93%	-17%	-7%	1%
Annual f_{PE2} = 0.77	23.6	21.5	12.3	28.4	25.5	23.5	10%	93%	-17%	-7%	1%

Finally, the adoption of HP would allow the possibility of cooling in summer without additional technology. The combination with the PV system would allow the direct use of the produced PV energy. With a decentral electric system, this is obviously not possible.

2.4 Economic evaluation

In addition to the energetic evaluation of the concepts, also an economic evaluation of the different variants was performed. The economic analysis is carried out for the same cases illustrated in Section 2.3.1 and it is based on the Equivalent Annual Cost (EAC), according to Equation (1).

$$EAC = \frac{IC \cdot r}{1-(1+r)^{-N}} \quad (1)$$

Where:

- IC is the investment costs for the technology
- r is the teal interest rate (3%)
- N is the number of consideration period (20 years)

The electricity price is assumed to be 0.2 €/kWh and an energy price escalation rate of 2% is considered.

In order to better compare the considered technologies, an additional case is considered and assumed as the reference. The reference case has direct electric heating without PV.

The specific annual costs for investment (including installation), maintenance and operation of the system for the different cases are shown in **Figure 12**. The implementation of heat pump leads to higher investment costs, but it allows a reduction of maintenance and operation costs (comparison of REF with D or E), for a global minor expense in the 20-years period.

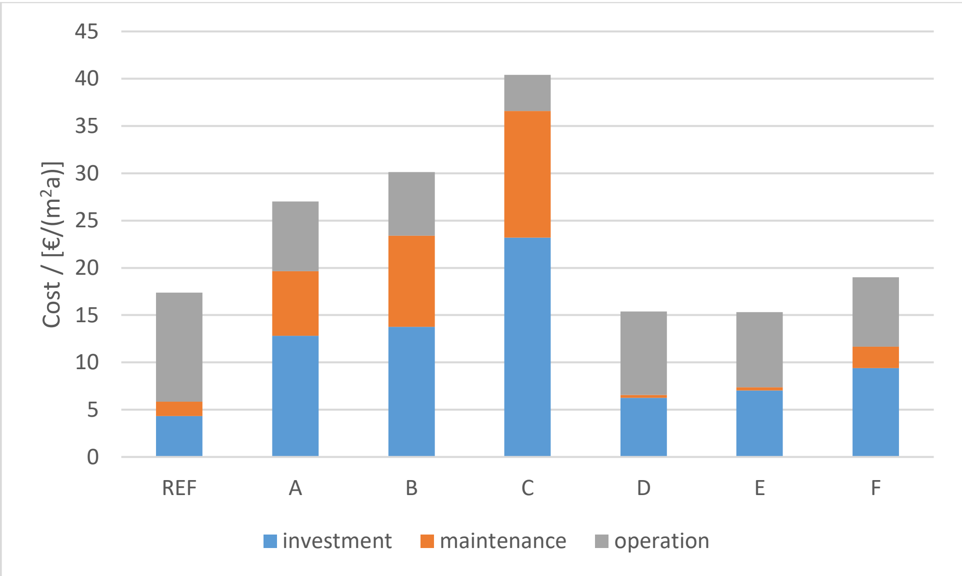

Figure 12: Specific annual costs for the considered cases

Results of the economic analysis are shown in **Figure 13**. Primary energy consumption and total costs are expressed as a difference between each alternative and the reference case. On the x-axis the reduction of primary energy is presented, while y-axis shows the additional costs. Values are obtained with the European non-renewable primary energy factor (2.3).

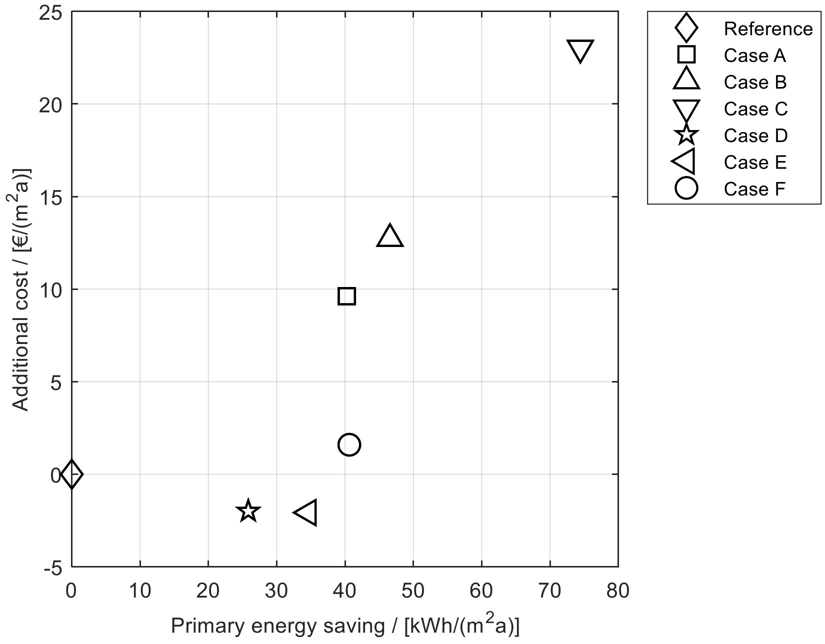

Figure 13: Comparison of additional costs and primary energy savings (referred to the reference case: direct electric heating without PV) for the considered cases

The largest PV installation combined with the electric heating system (case C) leads to the highest primary energy savings, but to the highest additional costs too. The economic advantage of the HP is clear when case A and case F are compared. The same primary energy saving is achieved with the two systems, but case F shows lower additional costs in the 20-years period. This economic convenience is possible despite the higher investment costs, because of the lower required energy (and consequently lower operation costs) allowed by the HP. Different heat pumps lead to similar cost's saving (case D and case E), but the implementation of a groundwater heat pump allows further primary energy savings.

Cases with heat pump (D, E, F) present the lowest increase of costs with respect to the reference system. Without PV system, cost savings with respect to the reference system are possible. Contrariwise, cases with direct electric heating and PV feature the highest increase of costs compared to the reference case. However, this additional expense leads to further primary energy saving in case the PV is added in all three facades.

The primary energy savings are the same for the case A (the solution that was realized) and case F (air HP instead of DE heating and smaller PV system, designed to have the same net electricity demand as the realized one`, however, the LCC of case F are significantly lower.

The trend changes if different scenarios for the (future) electricity mix are considered by means of applying monthly primary energy factors. In accordance with the energy analysis in Section 2.3.2, non-renewable primary energy factors are considered here. **Figure 14** compares the results of annual non-RE primary energy (including the appliances) calculated with constant i.e. annual and with two different monthly primary energy factors (scenarios "10-10-30" and "10-30-30", described in Appendix 2). The European factor of 2.3 is significantly higher than the Austrian factor of 1.32 (OIB-6, 2015). In order to see the influence of averaging the monthly factors also the non-RE PE is calculated for the two scenarios (fPE1: "10-10-10" and fPE2: "10-30-30").

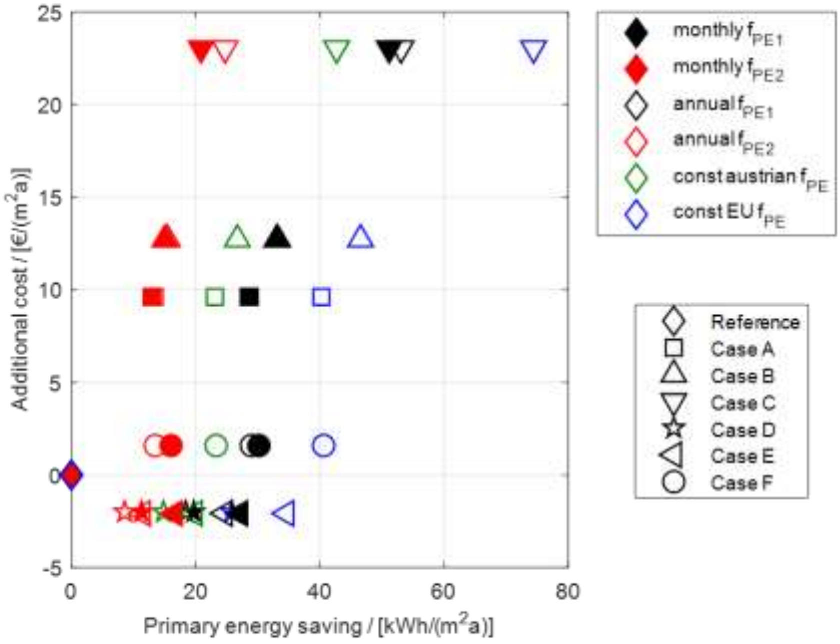

Figure 14: Comparison of additional costs and primary energy savings (referred to the reference case: direct electric heating without PV) for the considered cases, including appliances. Several primary energy conversion factors are considered

The choice of the scenario (i.e. PE conversion factor) significantly influences the results. With a future electricity mix with high shares of RE (i.e. “10-30-30” scenario”) primary energy savings are in a relative narrow range. Contrarily, the European PE conversion factor (2.3) leads to a large possible primary energy savings (between 35 kWh/(m^{2}a) and almost 80 kWh/(m^{2}a)). While with constant PE conversion factors the case A and F show equal PE savings, it can be seen that with monthly conversion factors, case F outperforms case A with respect to both, PE savings and costs.

In conclusion, the An-der-Lan demo building in PH quality, with DE heating and large PV façade performs better than a building with air HP without PV. However, the monitoring showed differences between the predicted and measured energy demand, mainly because of higher heating demand. A heat pump would compensate such higher demands better than in case of DE heating. Moreover, the energetic and economic analysis, taking into account alternative technologies considering a 20-years period (including investment, installation, maintenance and operation), showed that the realized solution is not cost optimal, but instead the solution with heat pump and a smaller PV system would outperform the existing one. The application of batteries leads to a slightly higher self-consumption (SCF = 76% with and SCF = 64% without batteries) but with regard to the additional costs not to significant improvement of the overall performance (LCF = 30% with and LCF = 25% without batteries).

3 Varennes Library Demo building

3.1 Demo Building description

The Varennes library is the first institutional Canadian NZE building (designed as net zero, the energy balance will be monitored over five years starting 2016, while improvements are also being implemented). It is located in the city of Varennes, Quebec, Canada and has a net floor area of 2100 m2. The building design was the product of an integrated design process (IDP) from a team consisting of municipal representatives, CanmetENERGY researchers, academics and industry partners.

Figure 15 shows several views of the exterior and interior of the building, as well as its mechanical system. **Figure 16** shows a schematic cross section indicating architectural and mechanical systems.

Figure 15: Varennes Library tagged images. (1) entrance, southwest view; (2) north façade; (3) south façade; (4) second floor, facing west; (5) second floor middle section, facing south; (6) ground floor facing south; (7-8) mechanical room; (9) south façade; (10) official opening ceremony, from left to right: Dr. Konstantinos (Costa) Kapsis, Dr. Andreas K. Athienitis, Major Martin Damphouse, Vasken Dermadiros and Remi Dumoulin. (A) forced convected BIPV and BIPV/T area; (B) naturally converted BIPV portion (out of view); (C) west façade, vine supports; (D) two car charging station; (E) skylights on norther roof; (F) fixed exterior louvers, solar shading; (G) geothermal boreholes; (H) ceiling fans; (I) motorized windows; (J) displacement ventilation integrated to bookshelves/stacks; (K) underfloor ventilation diffuser; (L) hydronic radiant slab; (M) geothermal heat pumps; (N) BIPV/T heat into air-handling unit(AHU); (O) AHU. (Dermardiros et al. 2019)

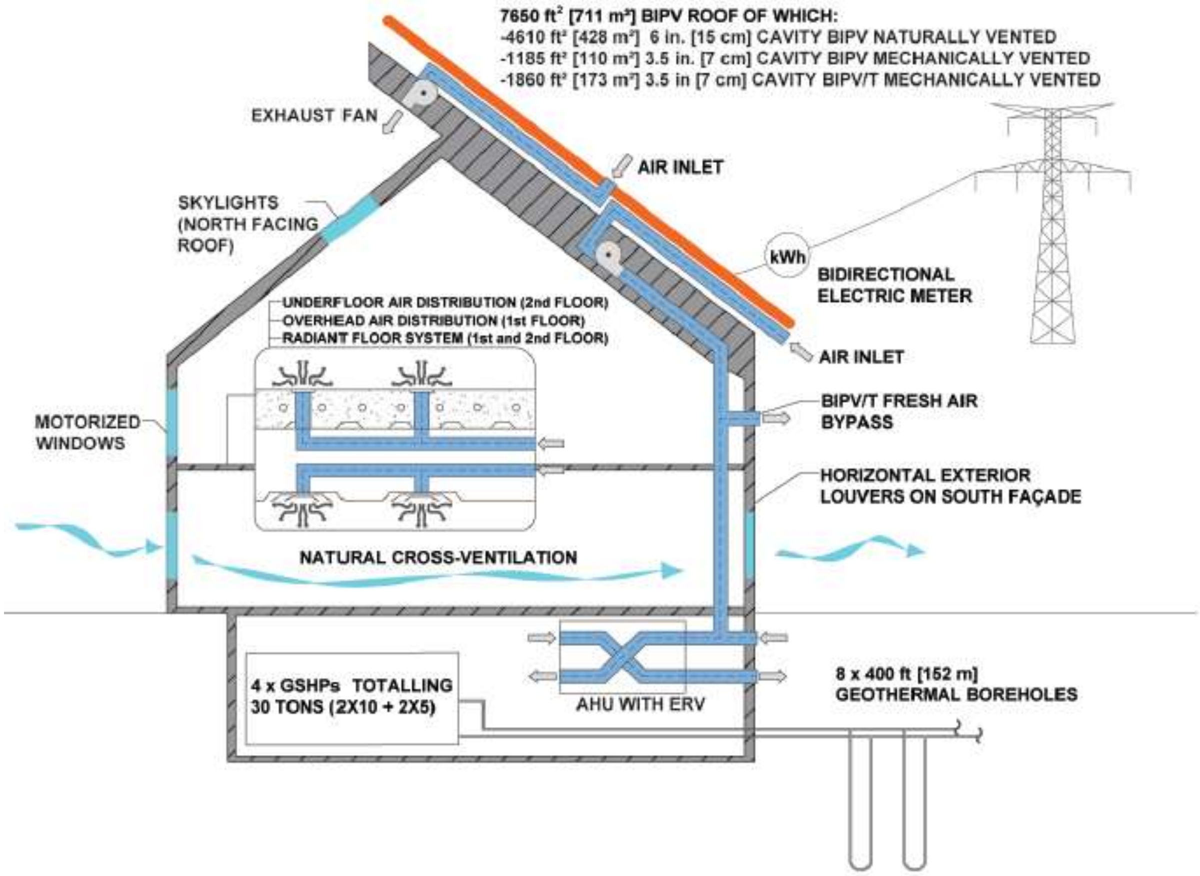

Figure 16: Simplified schematic of the technologies used in the Varennes Library. (Dermardiros et al. 2019)

3.1.1 Architectural Features

The two key concepts which determined the overall shape of the building and the integration of the various technologies were:

1. The estimated annual energy consumption of a highly energy efficient library building was estimated around 70 kWh/m2/year, with a resulting energy consumption of 147000 kWh per year. To reach site net zero with PV generated electricity, an optimally oriented PV system of 110-120 kW system would be required, generating approximately 1200 kWh/y per kW installed based on solar potential maps from Natural Resources Canada. A 700-800 m2 roof area would be required to facilitate such a system.
2. The depth of the building would have to be 6-10m to promote deep daylight penetration and night free-cooling through motorized windows on opposite facades.

Table 22 summarizes the architectural features of the building:

Table 22: Architectural features of the building (Dermardiros et al. 2019)

Architectural	
Site	Varennes, Québec, Canada
ASHRAE climate zone	6
Net floor area, ft^2 (m^2)	22,600 (2100)
Width/depth, ft (m)	180/56 (5(5.3/17.1)
Roof tilt, degrees	37
Window type, S	Double-glazed argon low-e wood-frame
Window type, N/E/W/skylight	Triple-glazed argon low-e wood-frame
Window-to-wall ratio, S/N/E/W,%	30/10/20/30
Shading, S, fixed louvers	6.5in. (165 mm) wide, 20° tilted toward window 10 in. (250 mm) center-to-center (c/c), 4in. (100 mm) from glass
U-factor, window, S, Stu/h·ft^{2o}F (W/m^{2}K)	0.45 (2.56)
SHGC, window, S	0.58
U-factor, window, N/E/W/skylight	0.32 (1.82)
Solar heat gain coefficient (SHGC), window, N/E/W/skylight	0.47
R-value, wall, h·ft^{2o}F/Btu (m^{2}K/W)	29.0 (5.1)
R-value, roof, h·ft^{2o}F/Btu (m^{2}K/W)	47.7 (8.4)

All facades feature triple-glazed, low-e, argon filled, wood-frame windows to minimize thermal losses in the winter, apart from the south façade which features double-glazed, low-e, argon-filled windows to maximize passive solar gains. The windows sizes were selected accordingly to provide sufficient view to the exterior, while reducing excessive thermal gains or losses or potential visual discomfort.

3.1.2 Mechanical system

Space conditioning is provided by a radiant slab located on the southern perimeter and an underfloor air displacement (UFAD) systemfor the upper floor, while the first floor uses overhead diffusers. A ground source heat pump and an air-based, open-loop BIPV/T system reduce energy consumption for heating and have the potential of exporting excess heat to neighboring buildings (public pool in the summer, residential buildings in the winter). The key features of the mechanical system are summarized in **Table 23**.

Table 23: Mechanical features of the building (Dermardiros et al. 2019)

Mechanical	
Main system, type	Centralized dedicated outdoor air system (DOAS) modulated based on CO_2
Main system, features	Ground source heat pump (GSHP), energy recovery ventilator (ERV), solar thermal recovery
Distribution system, first floor	four-pipe fan coil, overhead diffuser
Distribution system, second floor	four-pipe fan coil, underfloor air distribution (UFAD), displacement diffuser
Distribution system, S/E/W perimeter	Radiant slab, 5 in. (125 mm) thick, heat + cool
Cathedral area, second floor	Ceiling fans
Natural ventilation	Motorized windows
BIPV/T area, ft^2 (m^2) (no. Units)	1860 (173) (66)
BIPV/T maximum air volume, cfm (L/s)	2420 (1140)
Domestic water	Low-flow fixtures

3.1.3 Energy production

The library features a 110.5 kW roof-mounted BIPV array, of 711 m^2 PV area and consisting of 425 panels. 258 of these PV panels (428 m^2) are naturally ventilated through a 150mm air gap between the PV and the metal roofing. The remaining 167 panels (280 m^2) are mechanically ventilated through a 70 mm air gap with use of a variable speed fan. The details of the electrical system are shown in **Table 24**. From 173 m^2 of the fan assisted system (66 panels) the pre-heated air is recovered and can be introduced in the building as pre-heated ventilation air (**Figure 17**). This system is known as BIPV/Thermal (BIPV/T). Approximately 6835 kWh are harvested during the heating season (November-April). The BIPV/T covers 16% of the roof, while if it covered the whole roof, 6.5 times more heat could theoretically be recovered and potentially fed to a thermal micro-grid to assist neighboring buildings.

The BIPV/T system was designed to maintain an average channel air velocity of approximately 1 m/s, which was found to be a good compromise between maximizing heat transfer while reducing pressure loss. In the summer the mechanical ventilation under the panels is turned for a minimum of 30 min whenever the air temperature at the end of the cavity reaches 25°C, with the air exhausted to the outside.

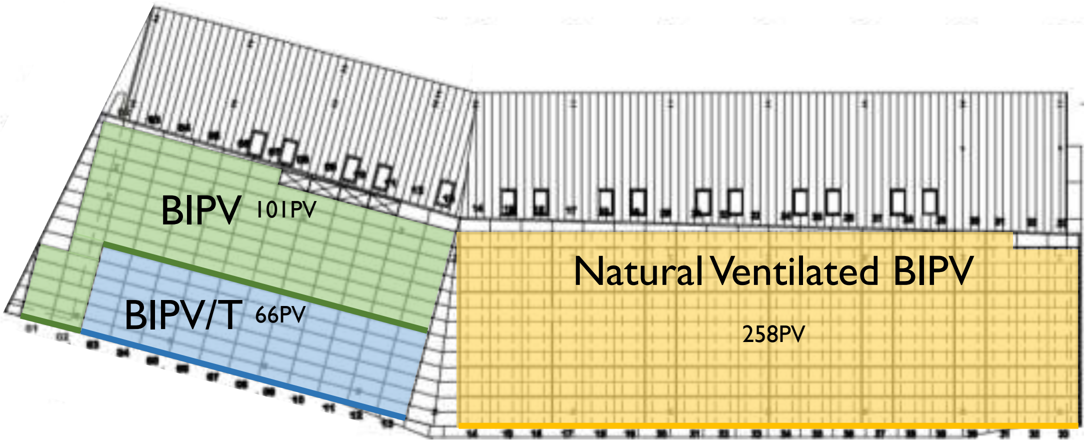

Figure 17: Top view of the roof with the different modes of BIPV. Naturally ventilated BIPV on the right and Mechanically ventilated on the left. The front section of the left side has thermal recovery (BIPV/T).

Table 24: Electrical features of the building (Dermardiros et al. 2019)

Electrical	
On-site photovoltaic (PV), nominal capacity, kWp	110.5
PV panel, unit capacity (W) and no. Units	260, 425
Inverter capacity, kw (kW/unit) (no. Units)	100 (10) (10)
Lighting, typical type, controls	T8 fluorescent, 1–2 tube luminaires, digital addressable lighting interface (DALI) system
Lighting power density (LPD), W/ft^2 (W/m^2)	0.71 (7.64)
Other features	Electric vehicle (EV) charging station (2 cars), no coffee machines, no vending machines, no refrigerated water fountains

3.2 Monitoring

3.2.1 Monitored EUI

The finalized building energy use intensity (EUI) was estimated at 85 kWh/m^2/y. The first year monitoring following its inauguration indicated an EUI of 78.1 kWh/m^2/y, which has since dropped to 70 kWh/m^2/y. If the renewables generation is considered over time, the net EUI is around 14.5 kWh/m^2/y.

Figure 18 demonstrates the EUI and net EUI in a one-year sliding window.

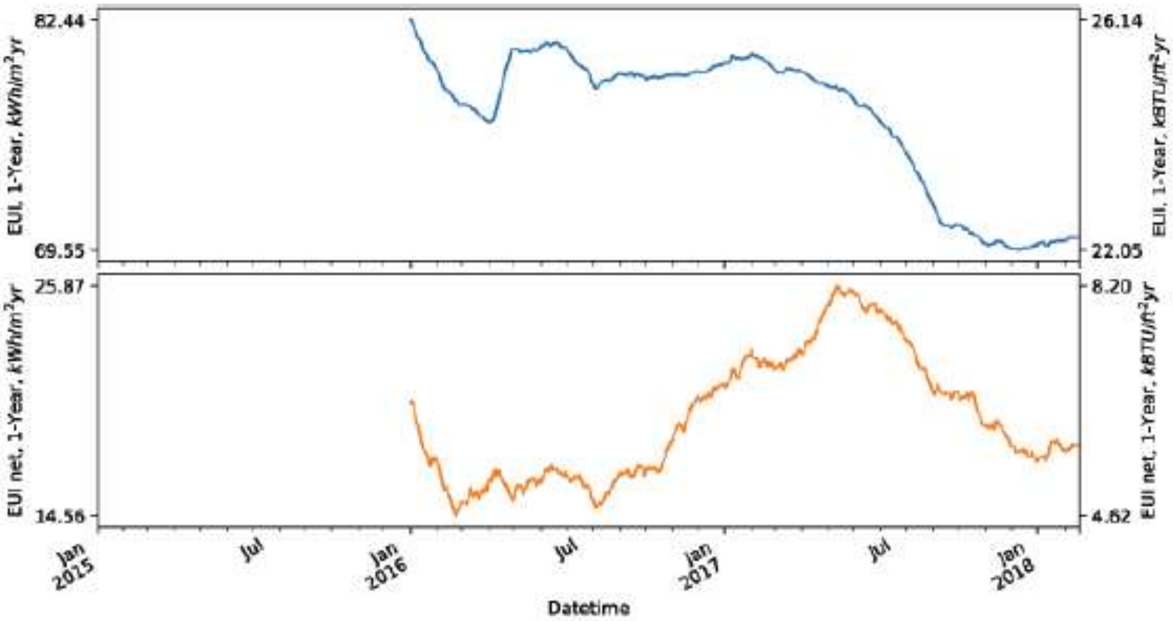

Figure 18: Energy use intensity (EUI) over time on a one-year sliding window. Each point on the chart represents he EUI value for the previous one-year period. (Top) gross EUI; (Bottom) net EUI including photovoltaic panel production. (Dermardiros et al. 2019)

3.2.2 Monitored Energy Balance

The electricity consumption and production of the Varennes Library is monitored since January of 2016. In **Figure 19**, the energy balance for the years 2016 to 2018 are depicted. The energy consumption for these three years is between 60 kWh/m²/year and 75 kWh/m²/year, while the energy production is between 48 kWh/m²/year and 53 kWh/m²/year, leaving a deficit between 11 kWh/m²/year to 21 kWh/m²/year.

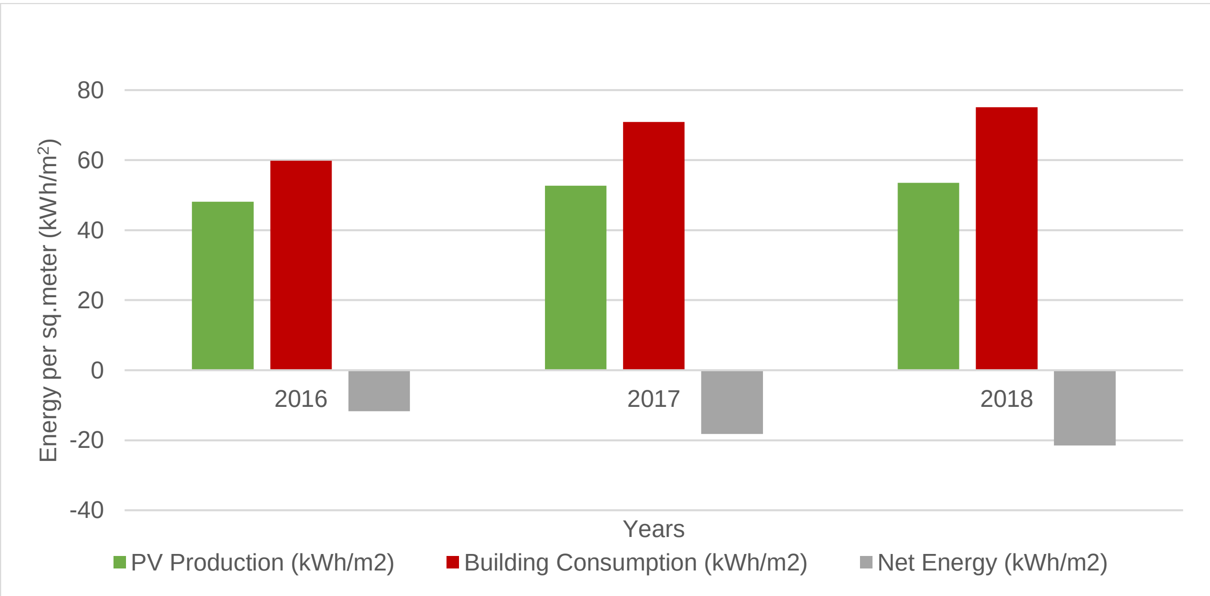

Figure 19: Energy balance per square meter for the years from 2016 to 2018, showing the PV production, the building consumption and the net energy balance in kWh/m².

In **Figure 20** the measurement data of the energy demand, the energy production and the ambient temperature is shown. The highest electricity consumption can be during the winter months, while there is also a peak during

July of 2018. The electricity production is higher than the consumption between the months of May and September while the ambient temperature ranges from -20 °C to 25 °C with a peak on July and a low on January.

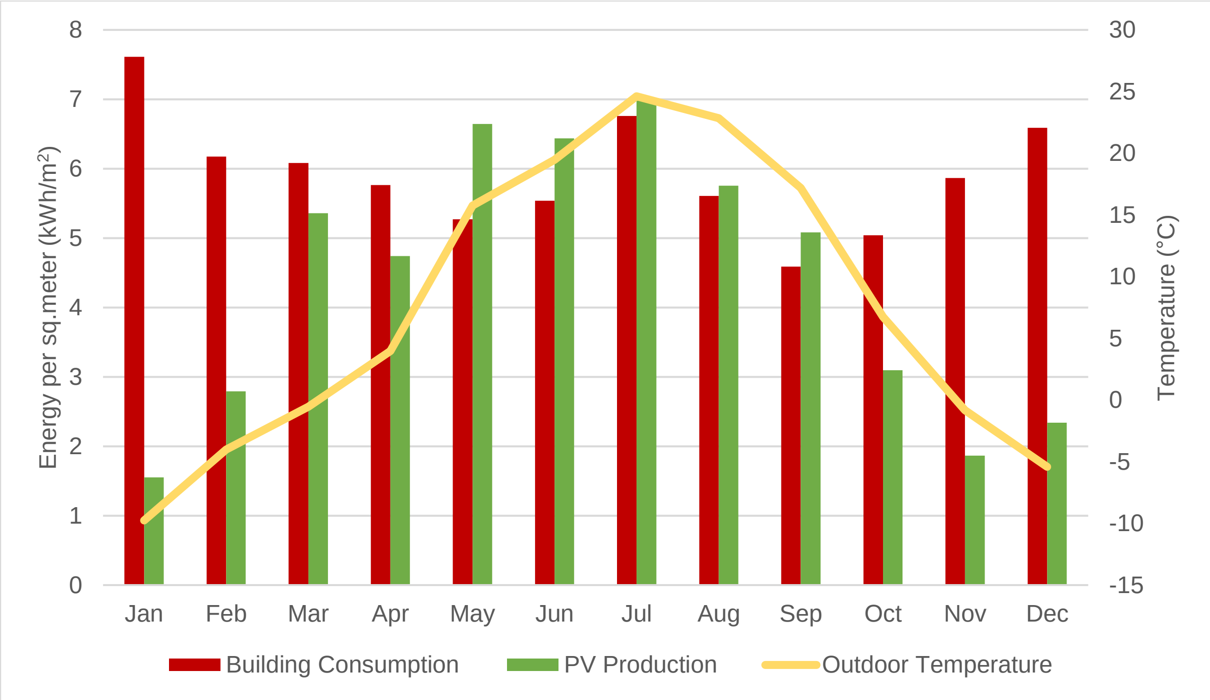

Figure 20: Energy balance per square meter for the year of 2018, showing the PV production, the building consumption in kWh/m² and ambient temperature.

In the following set of figures (**Figure 21**), the average day values of the ambient temperature, the electricity consumption and the electricity production are shown for each month, starting from October 2017 to September of 2018. January is the coldest month and July is the warmest. The highest consumptions and production matches those depicted in **Error! Reference source not found.** but the average pattern each month follows is shown here.

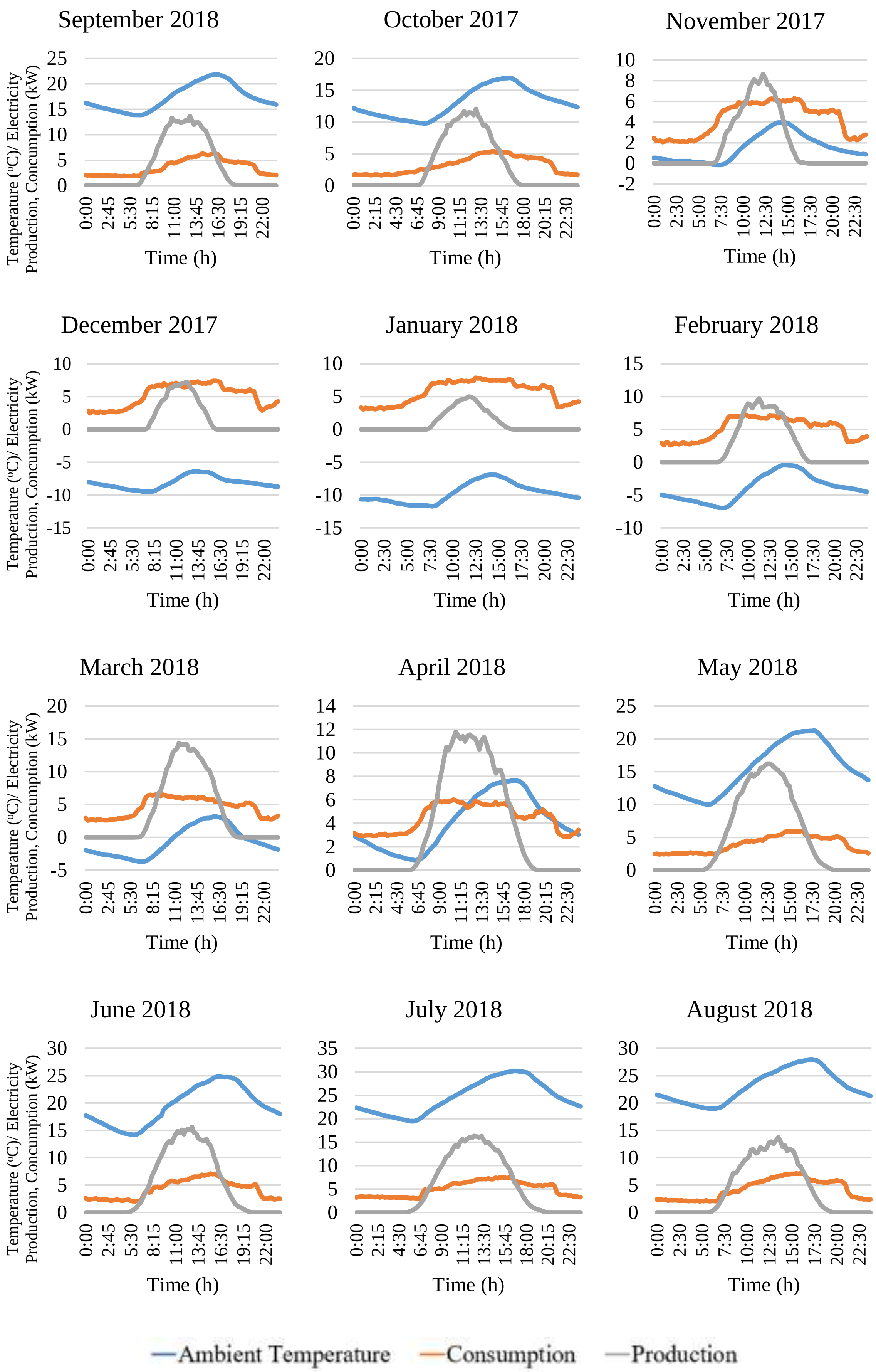

Figure 21: A set of 12 figures representing 12 months of the year starting from October 2017 to September 2018.

3.2.3 End-use breakdown

Table 25 shows the energy breakdown for the period between June 1, 2016 and May 31, 2017. For a portion of that period, individual luminaires, although addressable and dimmable, were running on a fixed schedule and at full intensity. The lighting power has since been reduced through dimming. The radiant floor slab requires the fan coil units require a significant amount of power for pump and fan operation. Energy intensive equipment such as refrigerated vending machines, water fountains and coffee makers were excluded from the original design.

Table 25: Energy breakdown for the period between June 1, 2016 and May 31, 2017 (Dermardiros et al. 2019).

Category	Energy, kWh (% of total)
Consumption	163,920 (100%)
Lights	40,980 (25%)
Heating/cooling	47,540 (29%)
Pumps	32,780 (20%)
Fans	32,780 (20%)
Other	9840 (6%)
Production	110,150 (67%)
Difference	53,770 (33%)

4 Conclusion

The evaluation of the performances of a residential and a non-residential demo building with BISES is presented in this report (DC.4 of IEA SHC Task 56). The residential building An-der-Lan is a multi-apartment Passive House located in Austria with direct electric heating and a large PV façade that should cover a large share of the electricity demand. The other building, the Varennes library was planned as a NZEB with BIPV and BIPVT located in Canada. The evaluation follows as close as possible the methodology suggested in the framework of the task. In case of the residential case study in addition to the monitoring a comparison with alternative concepts is presented and a techno-economic evaluation is performed.

For both buildings a discrepancy between planning and real performance was observed. The Varennes Library demo building did not achieve the Net Zero Energy (NZE) standard and indicates the difficulty to achieve an off-grid building concept. The NZE concept aims at achieving the energy balance on an annual basis and it is obvious that on monthly basis there is a significant mismatch, i.e. in the winter period the building energy consumption is significantly greater than the energy produced by the building (i.e. by means of the photovoltaic system), instead in summer the opposite trend is observed. Generally, difficulties in reaching the NZE building standard can be found in case of large buildings due to the unfavourable ratio between the available area for renewable system and the volume and treated area of the building.

In addition, a BIPVT system can produce a significant amount of heat and alleviate part of the HVAC system load. However, without the provision for thermal storage, large amount of the recovered heat is wasted.

The An-der-Lan demo building instead shows an expected performance of the PV system but a greater heating demand compared to the design value, mainly due to the occupancy behaviour and to the increased set point temperature. A techno-economic analysis showed that a concept with heat pump and a small PV system outperforms the current concept.

It is noteworthy that results of both monitoring projects can hardly be compared and transfer of the conclusions to other projects is hardly possible. This is because both projects differ significantly with respect to type and use of the building and also with respect to the climate. The presence of a standard monitoring system would support to enable comparison of the monitoring data and the development of such a standardized monitoring system is highly recommended. A standardized building management system (BMS) can support future systematic monitoring which would allow for improved commissioning and operation of such buildings. Fault detection and adjusting control strategies during commissioning of the buildings can significantly contribute to primary energy savings. Nevertheless, difficulties in adjusting the system strategies after the construction may be encountered, especially in large institutional buildings.

Finally, it was recognised that there is still a lack of experience in the building community regarding such innovative technologies such as BIPV.

Literature reference

Evaluation of Efficiency and Renewable Energy MMeasures Considerinf the Future Energy Mix. Fabian Ochs, Georgios Dermentzis. 2018. Syracuse, NY, USA : 7th International Building Physics Conference, 2018.

Passivhaus Institut. Passipedia. [Online] Passivhaus Institut. [Cited: 23 January 2020.]

V. Dermardiros, A. K. Athienitis and S. Bucking (2019), "Energy Performance, Comfort, and Lessons Learned from an Institutional Building Designed for Net Zero Energy." ASHRAE Transactions, vol. 125, no. 1, 2019, p. 682+.

Appendix 1

Table 26 shows the electric radiators installed in each floor.

Table 26: Emitters installed in the building

Floor	Emitters	Total nominal power [W]
Basement	4 x 500 W 2 x 750 W	3500
Ground floor	1 x 250 W 2 x 500 W 2 x 750 W	2750
First floor	4 x 250 W 1 x 1000 W 3 x 1250 W	5750
Second floor	4 x 250 W 1 x 1000 W 3 x 1250 W	5750
Third floor	1 x 50 W 3 x 250 W 3 x 1000 W 1 x 1250 W	5050
Fourth floor	2 x 250 W 1 x 500 W 3 x 1000 W	4000
Fifth floor	1 x 250 W 1 x 1000 W 1 x 1250 W	2500

The comparison of the thermal characteristics of the installed DHW storages and the lumped one considered in the PHPP is shown in **Table 27**.

Table 27: Characteristics of the storages (installed in the building and considered in the PHPP)

	Installed storages		**PHPP**
	Apartment	Common area	"Lumped" storage
Number of storages	14	3	1
Volume [l]	50	120	1000
Heat loss ratio [W/K]	0.9	1.2	2.4

Appendix 2

Both constant and monthly factors are considered in the primary energy assessment. For Austria, the total primary energy factor is 1.91 and the non-renewable is 1.32 (OIB-6, 2015 and 1.02 since 2019). The monthly primary energy factors are shown in **Table 28**. 10-10-10-10 scenario considers a share of 10 % hydro, 10 % wind, 10 % PV and 70 % fossil in the electricity mix, while the 10-30-30 scenario considers a share of 10 % hydro, 30 % wind, 30 % PV and 30 % fossil in the electricity mix.

Table 28: Monthly primary energy factors (see D.C1 for details)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10-10-10	2.01	1.96	1.89	1.60	1.33	1.20	1.18	1.28	1.53	1.78	1.92	2.01
10-30-30	1.53	1.42	1.23	0.50	0.08	0.08	0.08	0.08	0.33	0.98	1.33	1.54