

# The Methodology for Designing Residential Buildings with a Positive Energy Balance—Case Study

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**Abstract:** The article presents the results of the application of an original methodology for designing residential buildings with a positive energy balance in accordance with the principles of sustainable development. The methodology was verified using a computational example involving the selection of a compromise solution for a single-family residential building with a positive energy balance located in Warsaw, Poland. Three different models of decision-makers' preferences were created, taking into account selected decision sub-criteria. Three technical solutions were identified, permissible according to the principles and guidelines for designing buildings with a positive energy balance. As a result of the performed calculations, the final order of the analyzed variants was obtained, from the most preferred to the least accepted solution. Variant 2 is definitely the most advantageous solution, being the best in a group of 20 to 26 evaluation sub-criteria—depending on the adopted model of the decision-maker's preferences. Its ranking index  $R_i$  ranged from 0.773 to 0.764, while for the other variants it was much lower and varied from 0.258 to 0.268 for variant 1, and from 0.208 to 0.226 for variant 3. The methodology used for the case study proved to be applicable. The developed methodology facilitates the process of designing residential buildings with a positive energy balance, which is an extremely complex process.

**Keywords:** plus energy buildings; planning methodology; multicriteria analysis

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**Supplementary A – Visualizations of the analyzed single-family residential buildings.**

1). *Variant no. 1*



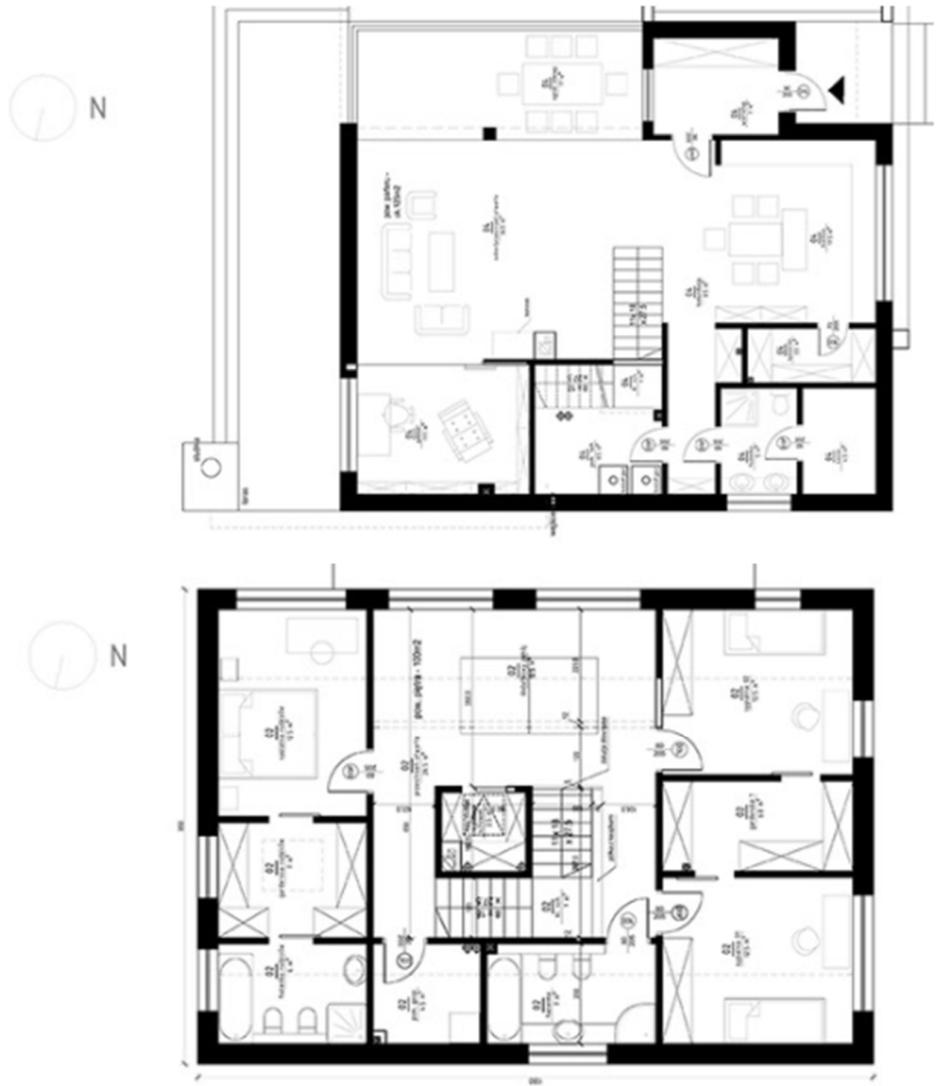


Figure S1. Variant no. 1.

2). Variant no. 2



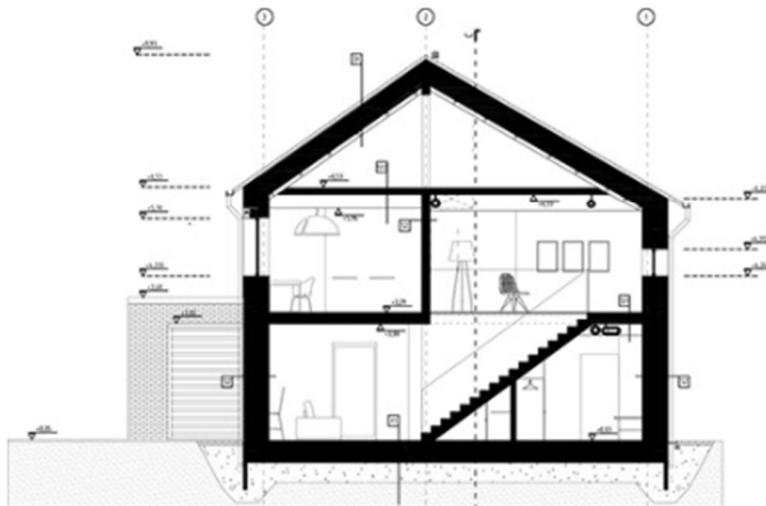
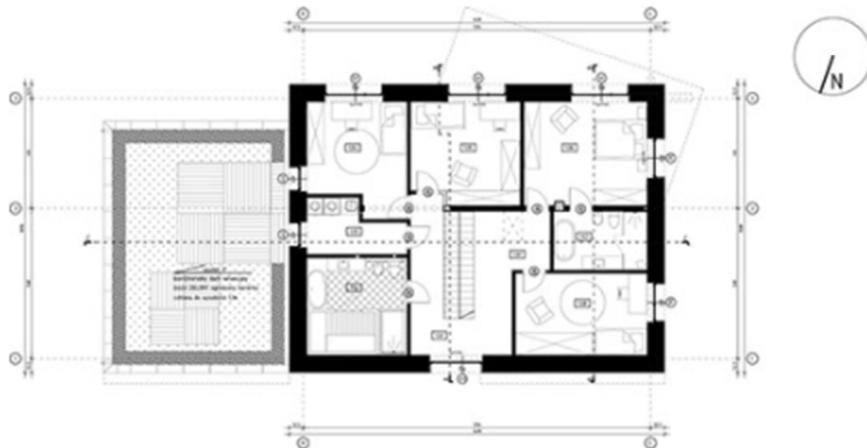
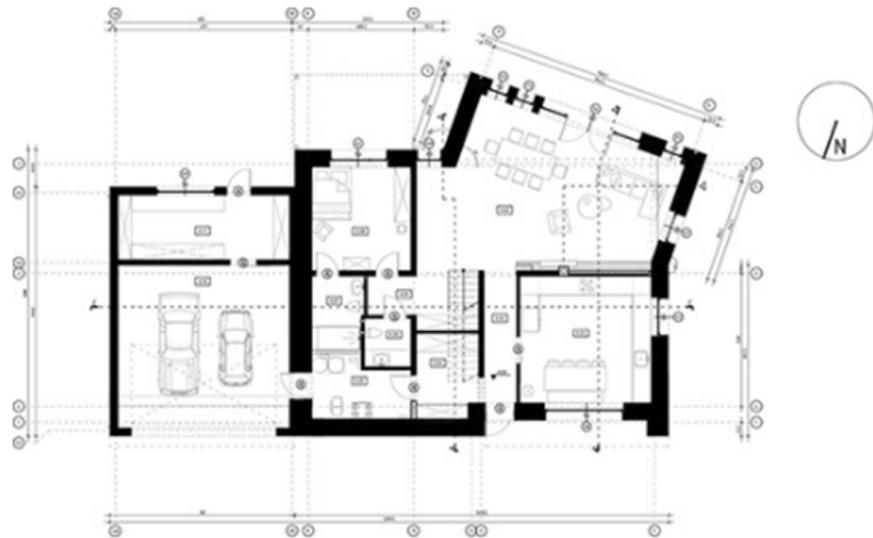


Figure S2. Variant no. 2.

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3). *Variant no. 3*



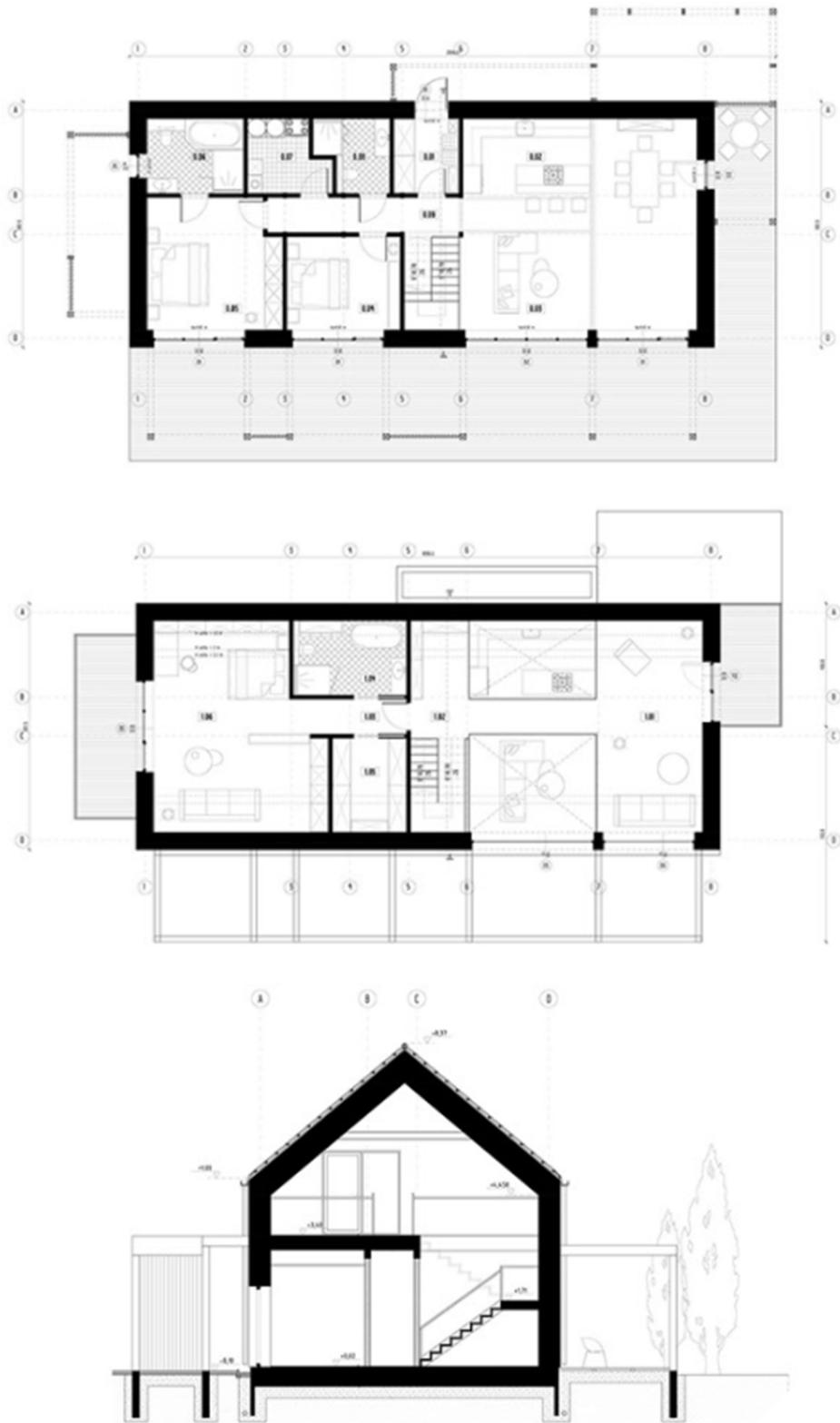


Figure S3. Variant no. 3.

The above materials belong to Pasywny m2 design studio.

**Supplementary B—Calculation of the values of variables, i.e., the values of decision criteria for individual variants of permissible solutions for single-family residential buildings.**

1). *Technical criterion*

All calculations of individual technical criteria were performed using an original spreadsheet created in MS Excel.

**Table S1.** Shape factor (A/V).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Shape factor (A/V)</b>	<b>(A/V)<sub>i</sub></b>	<b>0.607</b>	<b>0.679</b>	<b>0.623</b>	<b>m<sup>2</sup>/m<sup>3</sup></b>
Area of building envelope	A <sub>ext</sub>	642.38	761.54	664.04	m <sup>2</sup>
external volume of the building	V <sub>ext</sub>	1057.96	1121.95	1065.83	m <sup>3</sup>

**Table S2.** Total building completion time (T<sub>BLD</sub>).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Total building completion time (T<sub>BLD</sub>)</b>	<b>T<sub>BLD,i</sub></b>	<b>3.083</b>	<b>3.167</b>	<b>2.917</b>	<b>years</b>
preparation stage time	T <sub>PREP,i</sub>	1.50	1.00	1.50	years
“phase zero” execution time	T <sub>ZERO,i</sub>	0.25	0.25	0.25	years
“pre-shell stage” execution time	T <sub>PSHELL,i</sub>	0.50	1.00	0.50	years
“shell stage” execution time	T <sub>SHELL,i</sub>	0.25	0.25	0.25	years
technical installations completion time	T <sub>INSTAL,i</sub>	0.42	0.50	0.25	years
renewable energy installation completion time	T <sub>RES,i</sub>	0.17	0.17	0.17	years

**Table S3.** Difficulties in implementation (D<sub>IMP</sub>).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Difficulties in implementation (D<sub>IMP</sub>)</b>	<b>D<sub>IMP,i</sub></b>	<b>30</b>	<b>29</b>	<b>32</b>	<b>pts</b>
difficulties in preparation stage	D <sub>PREP,i</sub>	7	3	7	pts
difficulties in “phase zero”	D <sub>ZERO,i</sub>	5	5	5	pts
difficulties in “pre-shell stage”	D <sub>PSHELL,i</sub>	3	5	5	pts
difficulties in “shell stage”	D <sub>SHELL,i</sub>	7	7	5	pts
difficulties in building technical installations	D <sub>INSTAL,i</sub>	5	6	7	pts
difficulties in building renewable energy installations	D <sub>RES,i</sub>	3	3	3	pts

**Table S4.** Total service life of the building (T<sub>LIFE</sub>).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Total service life of the building (T<sub>LIFE</sub>)</b>	<b>T<sub>LIFE,i</sub></b>	<b>44</b>	<b>69</b>	<b>43</b>	<b>-</b>
life cycle of the structure	T <sub>BUD,i</sub>	50	80	50	years
life cycle of technical installation	T <sub>INSTAL,i</sub>	20	25	15	years
weight for life cycle of the structure	w <sub>1</sub>	0,8	0,8	0,8	-
weight for life cycle of technical installation	w <sub>2</sub>	0,2	0,2	0,2	-

**Table S5.** Total service life of renewable energy installation ( $T_{RES}$ ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Total service life of renewable energy installation (<math>T_{RES}</math>)</b>	$T_{RES,i}$	<b>20</b>	<b>25</b>	<b>17.5</b>	-
life cycle of RE installation for centr. heating	$T_{RES,CH,i}$	15	25	10	years
life cycle of RE installation for DHW	$T_{RES,DHW,i}$	15	25	10	years
life cycle of RE installation for cooling	$T_{RES,COOL,i}$	15	25	10	years
life cycle of RE installation for electricity	$T_{RES,ELECTR,i}$	25	25	25	years
weight for life cycle of RE instal. for CH	$w_1$	0.2	0.2	0.2	-
weight for life cycle of RE instal. for DHW.	$w_2$	0.2	0.2	0.2	-
weight for life cycle of RE instal. for cooling	$w_3$	0.1	0.1	0.1	-
weight for life cycle of RE instal. for electricity	$w_4$	0.5	0.5	0.5	-

## 2. Energy criterion

All calculations of individual energy criteria were performed using the Passive House Planning Package (PHPP) version 9.6b and an original spreadsheet created in MS Excel.

**Table S6.** Total primary energy consumption ( $PE_{TOTAL}$ ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Total primary energy consumption (<math>PE_{TOTAL}</math>)</b>	$PE_{TOTAL,i}$	<b>64.55</b>	<b>36.62</b>	<b>73.57</b>	<b>kWh/(m<sup>2</sup>year)</b>
PE for heating, ventilation and domestic hot water preparation	$PE_{H+V}$	PHPP	PHPP	PHPP	kWh/(m <sup>2</sup> year)
PE for cooling	$\Delta PEC$	PHPP	PHPP	PHPP	kWh/(m <sup>2</sup> year)
PE for lighting	$\Delta PEL$	PHPP	PHPP	PHPP	kWh/(m <sup>2</sup> year)
PE for other home appliances	$\Delta PEA$	PHPP	PHPP	PHPP	kWh/(m <sup>2</sup> year)

**Table S7.** Total usable energy consumption ( $UE_{TOTAL}$ ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Total usable energy consumption (<math>UE_{TOTAL}</math>)</b>	$UE_{TOTAL,i}$	<b>39.61</b>	<b>28.82</b>	<b>38.30</b>	<b>kWh/(m<sup>2</sup>year)</b>
UE for heating and ventilation	$UE_H$	13.54	12.51	15.00	kWh/(m <sup>2</sup> year)
UE for DHW preparation	$UE_W$	10.50	8.17	9.37	kWh/(m <sup>2</sup> year)
UE for cooling	$\Delta UE_C$	5.67	0.43	3.60	kWh/(m <sup>2</sup> year)
UE for lighting	$\Delta UE_L$	0.62	0.48	0.65	kWh/(m <sup>2</sup> year)
UE for other home appliances	$\Delta UE_A$	9.29	7.22	9.68	kWh/(m <sup>2</sup> year)

**Table S8.** Total final energy consumption ( $FE_{TOTAL}$ ).

Parameter	Symbol	Variante 1	Variante 2	Variante 3	Unit
<b>Total final energy consumption (<math>FE_{TOTAL}</math>)</b>	$FE_{TOTAL,i}$	<b>26.90</b>	<b>15.26</b>	<b>30.65</b>	<b>kWh/(m<sup>2</sup>year)</b>
FE for heating, ventilation and domestic hot water preparation	FEH+V	14.08	6.74	18.05	kWh/(m <sup>2</sup> year)
FE for cooling	$\Delta FEC$	2.91	0.80	2.27	kWh/(m <sup>2</sup> year)
FE for lighting	$\Delta FEL$	0.62	0.48	0.65	kWh/(m <sup>2</sup> year)
FE for other home appliances	$\Delta FEA$	9.29	7.22	9.68	kWh/(m <sup>2</sup> year)

**Table S9.** Total generated usable renewable energy ( $UE_{RES}$ ).

Parameter	Symbol	Variante 1	Variante 2	Variante 3	Unit
<b>Total generated usable renewable energy (<math>UE_{RES}</math>)</b>	$UE_{RES,i}$	<b>96.96</b>	<b>91.40</b>	<b>92.96</b>	<b>kWh/(m<sup>2</sup>ZABUDROK)</b>
generated electric usable renewable energy	$UE_{RES,ELECTR,i}$	63.83	58.02	65.39	kWh/(m <sup>2</sup> BUILDROK)
generated usable renewable heat	$UE_{RES,HEAT,i}$	25.98	32.22	19.70	kWh/(m <sup>2</sup> BUILDROK)
generated usable renewable cold	$UE_{RES,COLD,i}$	7.15	1.15	7.87	kWh/(m <sup>2</sup> BUILDROK)
usable area	$A_{US}$	206.64	265.61	198.12	m <sup>2</sup>
building area	$A_{BUILD}$	153.69	163.32	149.58	m <sup>2</sup> BUILDyear
usable electricity generated		9810.10	9476.20	9781.88	kWh/year
generated total usable renewable heat – central heating		2868.17	3668.47	2290.56	kWh/year
electricity consumption for generating usable renewable heat – central heating		838.44	592.10	558.56	kWh/year
generated total usable renewable heat – DHW		2956.02	3011.64	2634.12	kWh/year
electricity consumption for generating usable renewable heat – DHW		993.12	825.06	1419.90	kWh/year
total usable renewable cold generated		1487.68	198.23	1407.95	kWh/year
electricity consumption for generating usable renewable cold		388.43	10.43	230.81	kWh/year

**Table S10.** Total transmitted final renewable energy ( $FE_{RES}$ ).

Parameter	Symbol	Variante 1	Variante 2	Variante 3	Unit
<b>Total transmitted final renewable energy (<math>FE_{RES}</math>)</b>	$FE_{RES,i}$	<b>27.67</b>	<b>33.21</b>	<b>24.79</b>	<b>kWh/(m<sup>2</sup>BUILDROK)</b>
final renewable electricity transmitted	$FE_{RES,ELECTR,i}$	27.67	33.21	24.79	kWh/(m <sup>2</sup> BUILDyear)
final renewable heat transmitted	$FE_{RES,HEAT,i}$	0.00	0.00	0.00	kWh/(m <sup>2</sup> BUILDyear)
final renewable cold transmitted	$FE_{RES,COLD,i}$	0.00	0.00	0.00	kWh/(m <sup>2</sup> BUILDyear)
usable area	$A_{US}$	206.64	265.61	198.12	m <sup>2</sup>
building area	$A_{BUILD}$	153.69	163.32	149.58	m <sup>2</sup> BUILDyear
final electricity generated		9810.10	9476.20	9781.88	kWh/year
final electricity consumed		5558.05	4052.33	6073.23	kWh/year

### 3). Exergy criterion

The calculations of individual exergy criteria were made using the Passive Building Design Package (PHPP) version 9.6b and the Annex 49 Pre-Design Tool version 10 spreadsheet, as well as an original spreadsheet created in MS Excel.

**Table S11.** Sum of exergy losses of the building and its installation ( $B_L$ ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Sum of exergy losses of the building and its installation (<math>B_L</math>)</b>	$B_{L,i}$	2,987	2,352	4,883	kW
internal exergy losses for the i-th building variant and its technical installations	$\delta B_{(L,i)}$	Annex 49	Annex 49	Annex 49	kW
external exergy losses for the i-th building variant and its technical installations	$\delta B_{(E,i)}$	Annex 49	Annex 49	Annex 49	kW
sum of exergy losses of the building and its installation (b) - heating season	$B_{L,i} - \text{winter}$	2986.88	2351.50	4882.83	W
sum of exergy losses of the building and its installation (b) - cooling season	$B_{L,i} - \text{summer}$	n/a	n/a	n/a	W

**Table S12.** Sum of exergy generated by renewable energy sources ( $B_{GEN,RES}$ ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Sum of exergy generated by renewable energy sources (<math>B_{GEN,RES}</math>)</b>	$B_{GEN,RES,i}$	7.122	7.107	6.904	kW
exergy generated by renewable heat source	$B_{GEN,H,i}$	37.12	263.53	56.23	W
exergy generated by renewable cold source	$B_{GEN,C,i}$	n/a	n/a	n/a	W
exergy generated by renewable electricity source	$B_{GEN,E,i}$	7085.07	6843.92	6847.31	W

**Table S13.** Cumulative consumption of primary exergy ( $B_{P^*}$ ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Cumulative consumption of primary exergy (<math>B_{P^*}</math>)</b>	$B_{P,i}^*$	23 776.10	17 334.98	26 559.61	kWh/a
cumulative consumption of primary exergy by the heat source	$B_{P,H,i}^*$	12445.97	7663.60	15878.45	kWh/a
cumulative consumption of primary exergy by the cold source	$B_{P,C,i}^*$	2572.69	913.94	1923.72	kWh/a
cumulative consumption of primary exergy by the electricity source	$B_{P,E,i}^*$	8757.44	8757.44	8757.44	kWh/a
driving exergy of the system for heat source installation	$B_{DRV,H,i}^*$	2909.45	1791.49	3711.84	kWh/a
driving exergy of the system for cold source installation	$B_{DRV,C,i}^*$	601.41	213.65	449.70	kWh/a
driving exergy of the system for electricity source installation	$B_{DRV,E,i}^*$	2047.19	2047.19	2047.19	kWh/a
exergy efficiency of electricity production	$\eta_{b,el}$	0.286	0.286	0.286	-
exergy efficiency of electricity transmission	$\eta_{tr}$	0.877	0.877	0.877	-
exergy efficiency of electricity generation	$\eta_{b,BCoal}^*$	0.932	0.932	0.932	-

**Table S14.** Utilization of the generated renewable energy ( $UTIL_{RES}$ ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Utilization of the generated renewable energy (UTIL<sub>RES</sub>)</b>	<b>UTIL<sub>RES,i</sub></b>	<b>1.77</b>	<b>2.34</b>	<b>1.61</b>	<b>-</b>
total final renewable energy generated for the i-th building	FE <sub>RES,i</sub>	47.47	35.68	49.37	kWh/(m <sup>2</sup> year)
total final energy consumption for the i-th building variant	FE <sub>TOTAL,i</sub>	26.90	15.26	30.65	kWh/(m <sup>2</sup> year)
usable area	A <sub>US</sub>	206.64	265.61	198.12	m <sup>2</sup>
building area	A <sub>BUILD</sub>	153.69	163.32	149.58	m <sup>2</sup> <sub>BUILD</sub> year
total final renewable energy generated for the i-th building	FE <sub>RES,i</sub>	63.83	58.02	65.39	kWh/(m <sup>2</sup> <sub>BUILD</sub> year)

**Table S15.** Use of natural strategies for heating, cooling and lighting (N<sub>ST</sub>).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Use of natural strategies for heating, cooling and lighting (N<sub>ST</sub>)</b>	<b>N<sub>ST,i</sub></b>	<b>12</b>	<b>14</b>	<b>12</b>	<b>pts</b>
score for the use of natural strategies for heating	N <sub>ST,H,i</sub>	4	5	4	pts
score for the use of natural strategies for cooling	N <sub>ST,C,i</sub>	3	5	4	pts
score for the use of natural strategies for lighting	N <sub>ST,L,i</sub>	5	4	4	pts

#### 4. Economic criterion

The calculations of individual economic criteria were carried out in an original spreadsheet created in MS Excel on the basis of data obtained from previously performed calculations in the Passive House Planning Package (PHPP), version 9.6b. The economic data are valid as of the first half of 2019.

The following assumptions were made for the calculations:

(a) The entire amount of electricity from the photovoltaic installation will be consumed by the prosumer, some on the basis of direct self-consumption calculated individually for each of the variants, while the remaining part – using the current legal regulations of a 0.8 kWh discount for every 1.0 kWh sent to the grid, will be used, for example, to power an electric car or for other household purposes not directly related to the building.

**Table S16.** Internal return rate of renewable energy sources (IRR<sub>RES</sub>).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Internal return rate of renewable energy sources (IRR<sub>RES</sub>)</b>	<b>IRR<sub>RES,i</sub></b>	<b>10.179</b>	<b>10.133</b>	<b>9.465</b>	<b>%</b>
net present value for the i-th project	NPV <sub>i</sub>	17 775.59	17 140.51	14 863.93	PLN
no. of years of NPV analysis, years	t	15	15	15	years
cash flow of the i-th project in its "l-th" year of operation	CF <sub>l,i</sub>	4 210.68	4 098.85	4 165.43	PLN/year
total initial investment costs for the i-th project	I <sub>0,i</sub>	43 750	42 750	46 000	PLN
effective rate of return for the considered market – discount rate,	R	0.020	0.020	0.020	-
internal rate of return for the i-th project	IRR <sub>i</sub>	10.179	10.133	9.465	%
incomings related to the functioning of the l-th system in the i-th year	INC <sub>l,i</sub>	4 510.68	4 398.85	4 465.43	PLN/year
annual variable cost of operation of the l-th system in the i-th year	C <sub>VAR,l,i</sub>	0	0	0	PLN/year

annual fixed cost of operation of the l-th system in the i-th year	$C_{FIX,i}$	300	300	300	PLN/year
annual income tax rate for the l-th system in the i-th year	$t_{INC,i}$	0	0	0	-
total annual energy generated by RE installation	$E_{RES,i}$	9 810.10	9 476.20	9 781.88	kWh/year
linear efficiency loss of PV		0.01	0.01	0.01	-
direct self-consumption - share		0.18	0.22	0.15	-
direct self-consumption - amount		1 765.82	2 084.76	1 467.28	kWh/year
amount of energy sent to the grid		8 044.28	7 391.43	8 314.60	kWh/year
discount		0.8	0.8	0.8	-
amount of energy consumed from the grid		6 435.42	5 913.15	6 651.68	kWh/year
unit price for electricity		0.55	0.55	0.55	PLN/kWh
value of the directly consumed electricity		971.20	1 146.62	807.00	PLN/year
value of electricity consumed under the discount		3 539.48	3 252.23	3 658.42	PLN/year
inflation rate of the prices of goods and services on the market - discount rate		0.02	0.02	0.02	-
inflation rate of the prices of electricity		0.03	0.03	0.03	-

**Table S17.** Total operational cost (TOC).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Total operational cost (TOC)</b>	<b>TOC<sub>i</sub></b>	<b>157 910</b>	<b>165 900</b>	<b>174 917</b>	<b>PLN</b>
annual fixed cost of operating the i-th system in the l-th year	$C_{FIX,i}$	8 165	9 462	8 609	PLN/year
annual variable cost of operation of the i-th system in the l-th year	$C_{VAR,i}$	-236	-1 131	175	PLN/year
effective rate of return for the considered market – discount rate	R	0.02	0.02	0.02	-
no. of years of economic analysis, years	t	25	25	25	years
annual fixed costs					
annual equipment depreciation	$C_{DEPREC,i}$	2 750	3 600	2 800	PLN/year
annual renovation costs	$C_{REN,i}$	2 000	2 500	2 000	PLN/year
annual service and repair costs	$C_{SER+NAP,i}$	700	600	1 100	PLN/year
annual insurance costs	$C_{INSUR,i}$	500	500	500	PLN/year
annual cost of property taxes	$C_{TAX,i}$	163	210	157	PLN/year
annual interest costs	$C_{KREDYT,i}$	0	0	0	PLN/year
annual fixed operating costs - other	$C_{FIXother,i}$	2 052	2 052	2 052	PLN/year
annual variable costs					PLN/year
annual energy costs (subscription)	$C_{ENERGY,i}$	180	180	180	PLN/year
annual profits from RES	$C_{PROFRES,i}$	-1 817	-2 713	-1 406	PLN/year
annual water and sewage costs	$C_{WAT-SEW,i}$	1 402	1 402	1 402	PLN/year
annual variable operating costs - other	$C_{VARother,i}$	0	0	0	PLN/year
annual cost- garbage collection		576	576	576	PLN/year
annual cost- building security		1 476	1 476	1 476	PLN/year
property tax rate		0.79	0.79	0.79	PLN/m <sup>2</sup>
usable area		206.64	265.61	198.12	m <sup>2</sup>
amount of final energy consumed		5 558.05	4 052.33	6 073.23	kWh/year
amount of final energy from RES		9 810.10	9 476.20	9 781.88	kWh/year
direct self-consumption		1 765.82	2 084.76	1 467.28	kWh/year
self-consumption under discount		3 792.23	1 967.57	4 605.95	kWh/year
self-consumption under discount (including losses)		4 740.29	2 459.46	5 757.43	kWh/year
excess energy for other needs (not related to the building)		3 303.99	4 931.97	2 557.16	kWh/year

unit price of electricity	0.55	0.55	0.55	PLN/kWh
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**Table S18.** Analysis of the building's life-cycle cost (LCC).

Parameter	Symbol	Variante 1	Variante 2	Variante 3	Unit
<b>Analysis of the building's life-cycle cost (LCC)</b>	<b>LCC<sub>i</sub></b>	<b>120.36</b>	<b>15.11</b>	<b>212.03</b>	<b>PLN/m<sup>2</sup></b>
Analysis of the building's life-cycle costs (LCC)		24 870	4 012	42 006	PLN
building acquisition/ construction costs	C <sub>acquis, i</sub>	1 087 500	1 446 750	1 005 750	PLN
operating costs of the structure	C <sub>ownership, i</sub>	103 928	109 186	115 121	PLN
cost of demolition or changing the building's function	C <sub>disuse, i</sub>	-1 166 557	-1 551 924	-1 078 865	PLN
usable area	A <sub>US</sub>	206.64	265.61	198.12	m <sup>2</sup>

**Table S19.** Total prime cost of investment (TC<sub>INV</sub>).

Parameter	Symbol	Variante 1	Variante 2	Variante 3	Unit
<b>Total prime cost of investment (TC<sub>INV</sub>)</b>	<b>TC<sub>INV, i</sub></b>	<b>1 087 500</b>	<b>1 446 750</b>	<b>1 005 750</b>	<b>PLN</b>
investment costs incurred for the construction of the building to the finishing stage (without installation)	C <sub>INV, BLD, i</sub>	900 000	1 235 000	830 000	PLN
investment costs incurred for the construction of the installation of the building's technical equipment	C <sub>INV, INS, i</sub>	118 750	149 000	104 750	PLN
investment costs incurred for the construction of RE installations	C <sub>INV, RES, i</sub>	43 750	42 750	46 000	PLN
other investment costs related to the construction implementation	C <sub>INV, OTHER, i</sub>	25 000	20 000	25 000	PLN

**Table S20.** Dynamic generation cost of renewable energy installation (DGC<sub>RES</sub>).

Parameter	Symbol	Variante 1	Variante 2	Variante 3	Unit
<b>Dynamic generation cost of renewable energy installation (DGC<sub>RES</sub>)</b>	<b>DGC<sub>RES, i</sub></b>	<b>0.332</b>	<b>0.035</b>	<b>0.652</b>	<b>PLN/[kWh/(m<sup>2y</sup> ear)]</b>
investment costs + operating costs from LCC	C <sub>II, i</sub> + C <sub>EL, i</sub>	120	15	212	PLN/year
effective rate of return for the considered market – discount rate	R	0.02	0.02	0.02	-
no. of years of economic analysis, years	t	15	15	15	years
measure of the result (effect) expressed in physical units obtained in particular years for the i-th solution (total transmitted final renewable energy (F <sub>RES</sub> ))	E <sub>i</sub>	27.67	33.21	24.79	kWh/(m <sup>2</sup> year)

### 5. Social criterion

The calculations of individual social criteria were performed using an original spreadsheet created in MS Excel. The score for a particular solution variant is given by a designer of sanitary installations and/or an architect and/or an energy auditor.

**Table S21.** Compliance with the thermal comfort parameters (TC).

Parameter	Symbol	Variante 1	Variante 2	Variante 3	Unit
<b>Compliance with the thermal comfort parameters (TC)</b>	<b>TC<sub>i</sub></b>	<b>4.692</b>	<b>5</b>	<b>3.24</b>	<b>pts</b>
indoor air temperature	C <sub>CC, in, i</sub>	5	5	4	pts

temperature of surrounding surfaces	CCC <sub>tss,i</sub>	5	5	2	pts
humidity content	CCC <sub>hum,i</sub>	3	5	4	pts
weight 1	W11	0.466	0.466	0.466	-
weight 2	W12	0.38	0.38	0.38	-
weight 3	W13	0.154	0.154	0.154	-

**Table S22.** Compliance with air quality parameters (AQ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Compliance with air quality parameters (AQ)</b>	<b>AQ<sub>i</sub></b>	<b>4.679</b>	<b>5</b>	<b>4.385</b>	<b>pts</b>
no. of fresh air changes	CCC <sub>exc,i</sub>	5	5	5	pts
manner of fresh air distribution	CCC <sub>dis air,i</sub>	4	5	4	pts
physical pollution (dust)	CCC <sub>phys pol,i</sub>	5	5	4	pts
weight 1	W21	0.385	0.385	0.385	-
weight 2	W22	0.321	0.321	0.321	-
weight 3	W23	0.294	0.294	0.294	-

**Table S23.** Compliance with acoustic comfort parameters (KA).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Compliance with acoustic comfort parameters (AC)</b>	<b>AC<sub>i</sub></b>	<b>4.343</b>	<b>5</b>	<b>3.686</b>	<b>pts</b>
sound power level	CCC <sub>noise,i</sub>	4	5	3	pts
acoustic absorption of the interior	CCC <sub>absorp,i</sub>	5	5	5	pts
weight 1	W31	0.657	0.657	0.657	-
weight 2	W32	0.343	0.343	0.343	-

**Table S24.** Compliance with visual comfort parameters (VC).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Compliance with visual comfort parameters (VC)</b>	<b>VC<sub>i</sub></b>	<b>5</b>	<b>4.454</b>	<b>3.454</b>	<b>pts</b>
access and use of natural light	CCC <sub>light,i</sub>	5	4	3	pts
degree of overshadowing natural light	CCC <sub>shadow,i</sub>	5	5	4	pts
weight 1	w41	0.546	0.546	0.546	-
weight 2	w42	0.454	0.454	0.454	-

**Table S25.** Impact of the building and its installations on the surrounding environment (I<sub>ENV</sub>).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Impact of the building and its installations on the surrounding environment (I<sub>ENV</sub>)</b>	<b>CS I<sub>ENV,i</sub></b>	<b>7</b>	<b>5</b>	<b>7</b>	<b>Pts</b>
spatial and landscape impact of the building on the surrounding environment	I <sub>VIS, i</sub>	3	3	3	Pts
acoustic impact of the building on the surrounding environment	I <sub>ACOU, i</sub>	3	1	3	Pts
pollution emitted by the building and its technical installations	I <sub>POL, i</sub>	1	1	1	Pts

## 6. Environmental criterion

The calculations of individual environmental criteria were performed using an original spreadsheet created in MS Excel on the basis of data obtained from previously carried out calculations in the Passive House Planning Package (PHPP), version 9.6b.

**Table S26.** Lice-cycle analysis of the building (LCA).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Lice-cycle analysis of the building (LCA)</b>	$C_{ENV LCA, i}$	<b>51.30</b>	<b>60.62</b>	<b>60.06</b>	<b>Pt/m<sup>2</sup></b>
Lice-cycle analysis of the building (LCA)		10 600	16 100	11 900	Pt
phase of manufacturing building materials and products		8 200	12 400	7 900	Pt
construction phase (preparation of the site, execution of individual construction elements, e.g., foundations, walls, ceilings, roof)		8 600	12 900	8 200	Pt
building utilization phase (profits from electricity transmission)		-9 600	-14 300	-7 400	Pt
Demolition phase		3 400	5 100	3 200	Pt
Usable area	$A_{UZ}$	207	266	198	m <sup>2</sup>
Building area	$A_{BUILD}$	154	163	150	m <sup>2</sup>
excess energy for other needs (not related to the building)		3 303.99	4 931.97	2 557.16	kWh/year
excess energy for other needs (not related to the building) - period of 100 years		330.40	493.20	255.72	MWh
excess energy for other needs (not related to the building) - period of 100 years		9 581.58	14 302.72	7 415.78	Pt

**Table S27.** Carbon dioxide emission ( $E_{CO_2}$ ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Carbon dioxide emission (<math>E_{CO_2}</math>)</b>	$E_{CO_2, i}$	<b>214.640</b>	<b>121.748</b>	<b>244.621</b>	<b>kg<sub>CO2</sub>/m<sup>2</sup></b>
CO <sub>2</sub> emission for all energy needs of the building in the l-th year	$E_{CO_2, il}$	14.31	8.12	16.31	kg <sub>CO2</sub> /m <sup>2</sup>
no. of years of environmental analysis, years	t	15	15	15	years

**Table S28.** Coherence of renewable energy sources ( $C_{RES}$ ).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Coherence of renewable energy sources (<math>C_{RES}</math>)</b>	$C_{RES, i}$	<b>8</b>	<b>14</b>	<b>9</b>	<b>pts</b>
scoring for coherence of RES in relation to heat demand	$C_{RES, HD, i}$	2	5	3	pts
scoring for coherence of RES in relation to cold demand	$C_{RES, CD, i}$	2	5	2	pts
scoring for coherence of RES in relation to electricity demand	$C_{RES, ED, i}$	4	4	4	pts

**Table S29.** Energy payback time of RES (EPBT).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Energy payback time of RES (EPBT)</b>	<b>EPBT<sub>i</sub></b>	<b>7.10</b>	<b>6.78</b>	<b>9.49</b>	<b>years</b>
energy invested over entire life cycle of RE installation	E <sub>INV,i</sub>	69 605.58	64 251.30	92 835.63	kWh
annual energy generated by RES	E <sub>RES,i</sub>	9 810.10	9 476.20	9 781.88	kWh/year
area of photovoltaic installation	A <sub>RES, PV, i</sub>	64.02	59.10	53.69	m <sup>2</sup>

**Table S30.** Greenhouse gas emission payback time (GPBT).

Parameter	Symbol	Variant 1	Variant 2	Variant 3	Unit
<b>Greenhouse gas emission payback time (GPBT)</b>	<b>GPBT<sub>i</sub></b>	<b>7.10</b>	<b>6.78</b>	<b>9.49</b>	<b>lata</b>
greenhouse gas emissions related to energy consumption invested over the lifespan of RE installation	GHG <sub>INV,i</sub>	37 030.17	34 181.69	49 388.55	kgCO <sub>2</sub> -eq
annual value of GHG emissions avoided from the amount of energy generated by RE installation	GHG <sub>RES,i</sub>	5 218.97	5 041.34	5 203.96	kgCO <sub>2</sub> -eq
energy invested over the lifespan of RE installation	E <sub>INV,i</sub>	69 605.58	64 251.30	92 835.63	kWh
annual energy generated by RE installation	E <sub>RES,i</sub>	9 810.10	9 476.20	9 781.88	kWh/year
CO <sub>2</sub> emission index		0.532	0.532	0.532	kgCO <sub>2</sub> -eq/kWh