Supplementary Materials: Macro Micro Studio: A Prototype Energy Autonomous Laboratory

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1. Project Background, Facilitation, Funding and Limitations of the Research

1.1. Facilitation of the Research

The research was conducted as an interdisciplinary student project lead by the Macro Micro studio, a Masters Unit in Architecture and Planning [1]. The design was delivered by two cohorts of architecture students between September 2011 and June 2013. Following this, a number of students continued beyond their academic studies to assist in completing the construction of the building shell and internal fit-out. The majority of the construction was undertaken by students, with the exception of a number of specialist trades. Parallel quantitative research projects were conducted by MSc students in the departments of Physics and Engineering over the course of three years to support the design studies, including the sizing of the renewable energy system, FEA analysis of the structure, predicted environmental performance of the building using PHPP and a Whole Life Cost and Embodied Carbon analysis. Further input to the research and provision of the Structural Engineering Report (SER) was obtained from a major international engineering consultancy, a major international contractor advised and assisted in some aspects of the construction and Construction Design and Management (CDM) certification was obtained. Site overview was provided from the Universities Estates and Buildings Department. Edinburgh Napier University, Sustainable Construction Institute (SCI) advised and helped facilitate the acquisition of materials and systems for the building frame.

1.2. Project Phasing

In the first year between September 2011 and June 2012, the design was developed from concept to building warrant submission [2]. This initial stage was based on a design brief for a working studio environment for an Architectural Masters unit of 12 students occupying the space. The initial construction was based on a new Scottish manufactured Cross Laminated Timber (CLT) panel that was being prototyped by NorBuild in Forres in conjunction with SCI, using small element low-grade Scottish timber. The CLT was later substituted for a light weight frame due to the CLT being at too early a stage in development. The initial energy strategies and quantification of energy generation defined the PV area, roof angle, battery store and wind turbine size based on predicted data. An important aspect of this work was an economic feasibility study which considered revenue generated from government Feed-In-Tariff's that influenced the development of a business plan to underpin the future funding of the construction.

In the second year between September 2012 and June 2013, the brief was adapted to include wet services, a toilet and kitchen making the building suitable for letting commercially. The toilet was subsequently removed due to space constraints as a relaxation was obtained from Building Standards to use existing toilets on site. The occupant capacity was reduced to four people—considered a more realistic occupancy for the size of the space and in recognition that PH compliance could not be attained with the original occupancy target. A new Building Warrant application was submitted in early January 2013. The move to a lightweight frame facilitated the construction to be prototyped in the Fulton Structures Laboratory in Engineering, before being disassembled and moved to the site. Construction on site commenced in January 2013, with the timber frame being erected by the end of June 2013. Over a further nine months the remainder of the construction was completed, but with a delay in the electrical installation, meant that the final commissioning of the building at its current stage of development wasn't completed until August 2015. At present, research funding is being pursued for the next stages of the research.

1.3. Project Funding

The project was funded primarily through industry in-kind donations of expertise and material of approximately £100,000. A number of main contributors were identified at the start of the project with the remainder being brought on board during the course of the project's development. A business plan was developed, after a failed Kickstarter bid, around revenue generation from rental of the space post-completion and Feed-In Tarrif (FIT's) income from energy generated from the renewable system. The University allocated £30,000 with a return on investment at the end of a three year period following completion. Additional funding was secured from the Scottish Forestry Commission, Creative Scotland, Scottish Funding Council Innovation Awards and a number of charitable trusts of approximately £50,000. This grant funding was developed around discrete elements of research e.g. the visualisation of data and the integration of renewable technologies. Charitable grants were used to pay for consumables and student labour beyond the end of the academic year.

1.4. Challenges and Limitations to the Research

The challenges to the project were exacerbated due to the fluid open-ended nature of the design as a result of having to train new student cohorts, lack of capital funding, uncertainty of industry contributions and the complex interdisciplinary, professional and industry interactions and timescales. The highly experimental nature of the design and technologies meant that many aspects of the project were unknown and with little previous precedent to refer to, increased the risk of failure. Some of these aspects such as the battery and energy management remain unresolved and require further major research investment. Managing the design and construction of a high performance prototype, the health and safety issues associated with unskilled labour coupled to existing demanding academic workloads has resulted in compromises and delayed the completion of the project. Limitations in the value engineering of the system has resulted in performance compromises. The ambition of the project to find solutions to new and non-traditional problems in creative ways captured the interest of industry due to the potential for product development and the considerable exposure brought by the innovative design. Some impact has already resulted from the work; being nominated and winning several design awards; being used as exemplar best practice by numerous suppliers; popular press, professional and web based dissemination has raised public, professional and political awareness of building energy efficiency and renewable energy requirements locally and nationally.

2. PHPP 2007 Results

Passive House Verification

Building:	MM Studio	
Location and Climate:	Dundee	East of Scotland
Street:	Botanic Gardens	
Postcode/City:		
Country:		
Building Type:	Studio	
Home Owner(s) / Client(s):		
Street:		
Postcode/City:		
Architect:		
Street:		
Postcode/City:		
Mechanical System:		
Street:		
Postcode/City:		

Year of Construction:	2012				
Number of Dwelling Units:	1		Interior Temperature:	20.0	°C
Enclosed Volume V_e:	343.0	m^3	Internal Heat Gains:	2.1	W/m^2
Number of Occupants:	1.4				

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area:	47.5	m^2		
	Applied:	Annual method	PH Certificate:	Fulfilled?
Specific Space Heating Demand:	**10**	kWh/(m²a)	**15 kWh/(m²a)**	Yes
Heating Load:	**12**	W/m²	**10 W/m²**	
Pressurization Test Result:		h^{-1}	0.6 h^{-1}	
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):		kWh/(m²a)	120 kWh/(m²a)	
Specific Primary Energy Reduction through Solar Electricity:		kWh/(m²a)		
Frequency of Overheating:	0	%	over 25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m²a)	15 kWh/(m²a)	
Cooling Load:	0	W/m²		

We confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The calculations with PHPP are attached to this application.

Issued on:

signed:

PHPP 2007, Verification | New Masters Studio_amended

Figure S1. Passivhaus verification sheet.

Prototype

South Facing -South Window

Climate

Region	East of Scotland
Latitude	56.45
Longitude	-3.067
Gt (Heating Degree Hours) kKh/a	69
Solar Isolation Total	1077

Areas

Floor Area m2	47.49	m2		
Volume m3	343	m3		
Volume (Ventilation) m3	119	m3		
Area/ Volume Ratio (Gross)	0.65	m2/m3		
Exposed Surface Area m2	225	m2		
Glazing Area (Glass) m2	22.9	m2	10.2%	Glass/Surface
Effective Due South Glazing	13.50	m2	79.6%	Glass/Main Face

U-Values

Walls	0.1077	W/(m2K)
Window	0.7587	W/(m2K)
Ground	0.0981	W/(m2K)
Ave	0.1725	W/(m2K)

Heat Gains
Monthly Method

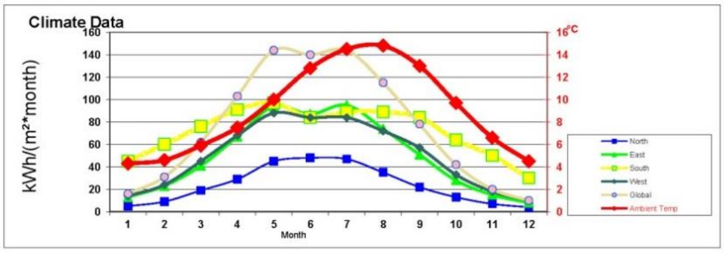
Solar Heat Gain	2372	kWh/a	40	kWh/(m2a)
Internal Heat Gain	507	kWh/a	9	kWh/(m2a)
Ulitlisation Factor	80%	kWh/a		
Heat Gain Total	**2314**	kWh/a	**48.7**	**kWh/(m2a)**

Heat Losses
Monthly Method

Heat Loss Windows	1222	kWh/a	26	kWh/(m2a)
Heat Loss Walls	605	kWh/a	13	kWh/(m2a)
Heat Loss Ground	178	kWh/a	4	kWh/(m2a)
Heat Loss Roof	544	kWh/a	11	kWh/(m2a)
Heat Loss Door	99	kWh/a	2	kWh/(m2a)
Heat Loss Ventilation	185	kWh/a	4	kWh/(m2a)
Heat Loss Total	**2814**	kWh/a	**59**	**kWh/(m2a)**

Heat Demands

Specific Space Heat Demand (Monthly)	500.7	kWh/a	**10.5**	kWh/(m2a)
SSHD (Annual)	10	kWh/a	**10**	kWh/(m2a)
Heat Load	**11.6**	(w/m2)		
Overheating	**0.0**	%		



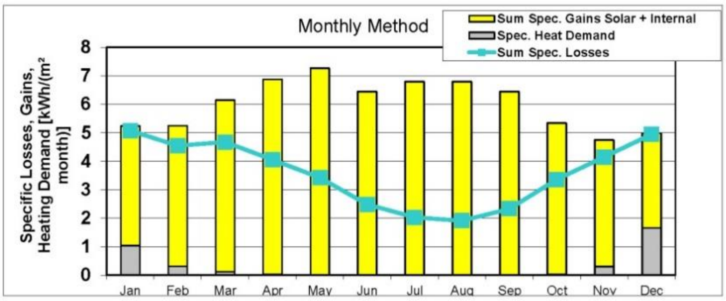


Figure S2. General summary of data and performance .

Passive House Planning

AREA CALCULATION

Building: MM Studio | Heating Demand: 10 kWh/(m²a)

Group No.	Area Group	Temp Zone	Area	Unit	Comments	Building Element Overview	Average U-Value [W/(m²K)]
	Summary						
1	Treated Floor Area		47.49	m²	*Living area or useful area within the thermal envelope*		
2	North Windows	A	3.12	m²	Results are from the Windows worksheet.	North Windows	0.893
3	East Windows	A	0.90	m²		East Windows	0.972
4	South Windows	A	13.50	m²		South Windows	0.723
5	West Windows	A	5.38	m²		West Windows	0.734
6	Horizontal Windows	A	0.00	m²		Horizontal Windows	
7	Exterior Door	A	1.76	m²	*Please subtract area of door from respective building element*	Exterior Door	0.800
8	Exterior Wall - Ambient	A	79.86	m²	*Window areas are subtracted from the individual areas specified in the "Windows" worksheet.*	Exterior Wall - Ambient	0.108
9	Exterior Wall - Ground	B	0.00	m²	*Temperature Zone "A" is ambient air.*	Exterior Wall - Ground	
10	Roof/Ceiling - Ambient	A	78.38	m²	*Temperature zone "B" is the ground.*	Roof/Ceiling - Ambient	0.099
11	Foor slab/ basement ceiling	B	41.67	m²		Foor slab/ basement ceiling	0.098
12			0.00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"*		
13			0.00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"* Factor for X		
14		X	0.00	m²	*Temperature zone "X": Please provide user-defined reduction factor (0 < f, < 1):* 75%		
						Thermal Bridge Overview	Ψ [W/(mK)]
15	Thermal Bridges Ambient	A	0.00	m	*Units in m*	Thermal Bridges Ambient	
16	Perimeter Thermal Bridges	P	26.10	m	*Units in m; temperature zone "P" is perimeter (see Ground worksheet).*	Perimeter Thermal Bridges	-0.017
17	Thermal Bridges Floor Slab	B	0.00	m	*Units in m*	Thermal Bridges Floor Slab	
18	Partition Wall to Neighbour	I	0.00	m²	*No heat losses, only considered for the heating load calculation.*	Partition Wall to Neighbour	
Total Thermal Envelope			224.57	m²		Average Therm. Envelope	0.173

Area No.	Building Element Description	Group No.	Assigned to Group	Quantity	x (	a [m]	x	b [m]	+	User-Determined [m²]	-	User Sub-traction [m²]	-	Subtraction Window Areas [m²]	) =	Area [m²]	Selection of the Corresponding Building Element Assembly	Nr.	U-Value [W/(m²K)]
	Area Input																		
	Treated Floor Area	1	Treated Floor Area	1	x (		x		+	47.49	-				) =	47.5			
	North Windows	2	North Windows	Please complete in Windows worksheet only!												3.1	From Windows sheet		0.893
	East Windows	3	East Windows													0.9	From Windows sheet		0.972
	South Windows	4	South Windows													13.5	From Windows sheet		0.723
	West Windows	5	West Windows													5.4	From Windows sheet		0.734
	Horizontal Windows	6	Horizontal Windows													0.0	From Windows sheet		0.000
	Exterior Door	7	Exterior Door	1	x (	0.88	x	2.00	+		-		) -		=	1.8	U-Value Exterior Door		0.80
1	South Wall	8	Exterior Wall - Ambient	1	x (		x		+	16.95	-		) -	13.5	=	3.5	Cullen Space Stud Wall	1	0.108
2	West Wall	8	Exterior Wall - Ambient	1	x (		x		+	28.50	-		) -	5.4	=	23.1	Cullen Space Stud Wall	1	0.108
3	North West Wall	8	Exterior Wall - Ambient	1	x (		x		+	16.21	-		) -	2.5	=	13.7	Cullen Space Stud Wall	1	0.108
4	North Wall	8	Exterior Wall - Ambient	1	x (		x		+	22.20	-		) -	0.6	=	21.6	Cullen Space Stud Wall	1	0.108
5	East Wall	8	Exterior Wall - Ambient	1	x (		x		+	18.90	-		) -	0.9	=	18.0	Cullen Space Stud Wall	1	0.108
6	South Roof	10	Roof/Ceiling - Ambient	1	x (		x		+	35.61	-		) -	0.0	=	35.6	JJI Roof Plates	2	0.099
7	North West Roof	10	Roof/Ceiling - Ambient	1	x (		x		+	13.47	-		) -	0.0	=	13.5	JJI Roof Plates	2	0.099
8	North Roof	10	Roof/Ceiling - Ambient	1	x (		x		+	15.30	-		) -	0.0	=	15.3	JJI Roof Plates	2	0.099
9	East Roof	10	Roof/Ceiling - Ambient	1	x (		x		+	14.00	-		) -	0.0	=	14.0	JJI Roof Plates	2	0.099
10	Slab	11	Foor slab/ basement ceiling	1	x (		x		+	41.67	-		) -	0.0	=	41.7	Conc Floor Slab 1m Deep	3	0.098
11					x (		x		+		-		) -	0.0	=			0	
12					x (		x		+		-		) -	0.0	=			0	
13					x (		x		+		-		) -	0.0	=			0	
14					x (		x		+		-		) -	0.0	=			0	
15					x (		x		+		-		) -	0.0	=			0	
16					x (		x		+		-		) -	0.0	=			0	
17					x (		x		+		-		) -	0.0	=			0	
18					x (		x		+		-		) -	0.0	=			0	
19					x (		x		+		-		) -	0.0	=			0	
20					x (		x		+		-		) -	0.0	=			0	
21					x (		x		+		-		) -	0.0	=			0	
22					x (		x		+		-		) -	0.0	=			0	
23					x (		x		+		-		) -	0.0	=			0	
24					x (		x		+		-		) -	0.0	=			0	
25					x (		x		+		-		) -	0.0	=			0	
26					x (		x		+		-		) -	0.0	=			0	
27					x (		x		+		-		) -	0.0	=			0	
28					x (		x		+		-		) -	0.0	=			0	
29					x (		x		+		-		) -	0.0	=			0	
30					x (		x		+		-		) -	0.0	=			0	
31					x (		x		+		-		) -	0.0	=			0	
32					x (		x		+		-		) -	0.0	=			0	
33					x (		x		+		-		) -	0.0	=			0	
34					x (		x		+		-		) -	0.0	=			0	
35					x (		x		+		-		) -	0.0	=			0	
36					x (		x		+		-		) -	0.0	=			0	
37					x (		x		+		-		) -	0.0	=			0	
38					x (		x		+		-		) -	0.0	=			0	
39					x (		x		+		-		) -	0.0	=			0	
40					x (		x		+		-		) -	0.0	=			0	
41					x (		x		+		-		) -	0.0	=			0	
42					x (		x		+		-		) -	0.0	=			0	
43					x (		x		+		-		) -	0.0	=			0	
44					x (		x		+		-		) -	0.0	=			0	
45					x (		x		+		-		) -	0.0	=			0	
46					x (		x		+		-		) -	0.0	=			0	
47					x (		x		+		-		) -	0.0	=			0	
48					x (		x		+		-		) -	0.0	=			0	
49					x (		x		+		-		) -	0.0	=			0	
50					x (		x		+		-		) -	0.0	=			0	
A End																			

PHPP 2007, Areas | New Masters Studio_amended

Figure S3. Area calculation sheet.

Passive House Planning

AREA CALCULATION

Building: MM Studio | Heating Demand 10 kWh/(m²a)

Group No.	Area Group	Temp Zone	Area	Unit	Comments	Building Element Overview	Average U-Value [W/(m²K)]
	Summary						
1	Treated Floor Area		47.49	m²	*Living area or useful area within the thermal envelope*		
2	North Windows	A	3.12	m²	Results are from the Windows worksheet.	North Windows	0.893
3	East Windows	A	0.90	m²		East Windows	0.972
4	South Windows	A	13.50	m²		South Windows	0.723
5	West Windows	A	5.38	m²		West Windows	0.734
6	Horizontal Windows	A	0.00	m²		Horizontal Windows	
7	Exterior Door	A	1.76	m²	*Please subtract area of door from respective building element*	Exterior Door	0.800
8	Exterior Wall - Ambient	A	79.86	m²	*Window areas are subtracted from the individual areas specified in the "Windows" worksheet.*	Exterior Wall - Ambient	0.108
9	Exterior Wall - Ground	B	0.00	m²	*Temperature Zone "A" is ambient air.*	Exterior Wall - Ground	
10	Roof/Ceiling - Ambient	A	78.38	m²	*Temperature zone "B" is the ground.*	Roof/Ceiling - Ambient	0.099
11	Foor slab/ basement ceiling	B	41.67	m²		Foor slab/ basement ceiling	0.098
12			0.00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"*		
13			0.00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"* Factor for X		
14		X	0.00	m²	*Temperature zone "X": Please provide user-defined reduction factor (0 < f, < 1):* 75%		
						Thermal Bridge Overview	Ψ [W/(mK)]
15	Thermal Bridges Ambient	A	0.00	m	*Units in m*	Thermal Bridges Ambient	
16	Perimeter Thermal Bridges	P	26.10	m	*Units in m; temperature zone "P" is perimeter (see Ground worksheet).*	Perimeter Thermal Bridges	-0.017
17	Thermal Bridges Floor Slab	B	0.00	m	*Units in m*	Thermal Bridges Floor Slab	
18	Partition Wall to Neighbour	I	0.00	m²	*No heat losses, only considered for the heating load calculation.*	Partition Wall to Neighbour	
Total Thermal Envelope			224.57	m²		Average Therm. Envelope	0.173

Thermal Bridge Inputs

No. of TB	Thermal Bridge Description	Group No.	Assigned to Group	Quantity	x (	User Determined [m]	-	User Subtraction [m]	)=	Length l [m]	Input of Thermal Bridge Heat Loss Coefficient W/(mK)	Ψ W/(mK)
1	Thermal Bridge Foundation	16	Perimeter Thermal Bridges	1	x (	26.10	-		) =	26.10	Thermal Bridge Foundation	-0.017
2					x (		-		) =			
3					x (		-		) =			
4					x (		-		) =			
5					x (		-		) =			
6					x (		-		) =			
7					x (		-		) =			
8					x (		-		) =			
9					x (		-		) =			
10					x (		-		) =			
11					x (		-		) =			
12					x (		-		) =			
13					x (		-		) =			
14					x (		-		) =			
15					x (		-		) =			
16					x (		-		) =			
17					x (		-		) =			
18					x (		-		) =			
19					x (		-		) =			
20					x (		-		) =			
21					x (		-		) =			
22					x (		-		) =			
23					x (		-		) =			
24					x (		-		) =			
25					x (		-		) =			
26					x (		-		) =			
27					x (		-		) =			
28					x (		-		) =			
29					x (		-		) =			
30					x (		-		) =			
31					x (		-		) =			
32					x (		-		) =			
33					x (		-		) =			
34					x (		-		) =			
35					x (		-		) =			
36					x (		-		) =			
37					x (		-		) =			
38					x (		-		) =			
39					x (		-		) =			
40					x (		-		) =			
41					x (		-		) =			
42					x (		-		) =			
43					x (		-		) =			
44					x (		-		) =			
45					x (		-		) =			
46					x (		-		) =			
47					x (		-		) =			
48					x (		-		) =			
49					x (		-		) =			
50					x (		-		) =			
TB End												

PHPP 2007, Areas | New Masters Studio_amended

Figure S4. Area calculation calculation sheet.

Passive House Planning
U-VALUES OF BUILDING ELEMENTS

Building: MM Studio

Wedge Shaped Building Element Layers and Still Air Spaces -> Secondary Calculation to the Right

Assembly No. 1 — Building Assembly Description: Cullen Space Stud Wall

Heat Transfer Resistance [m²K/W] interior R_{si}: 0.13; exterior R_{se}: 0.13

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Gypsum	0.180					3
2.	Gypsum plasterboard	0.210					13
3.	Service void (45mm)	0.244	35x45 timber battens	0.130			45
4.	OSB	0.130					9
5.	Insulation-Icynene	0.039	2x38x44 SW Timber	0.130			202
6.	OSB	0.130					9
7.	Insulation-Icynene	0.039					150
8.							

Percentage of Sec. 2: 5.0%; Percentage of Sec. 3: ; Total: 43.1 cm

U-Value: 0.108 W/(m²K)

Assembly No. 2 — Building Assembly Description: JJI Roof Plates

Heat Transfer Resistance [m²K/W] interior R_{si}: 0.10; exterior R_{se}: 0.10

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Gypsum	0.180					3
2.	Gypsum plasterboard	0.210					13
3.	Service void	0.244	35x45 timber battens	0.130			45
4.	OSB	0.130					9
5.	Insulation-Icynene	0.039	2x70x44 SW Timber	0.130	9mm OSB Web	0.130	245
6.	OSB	0.130					9
7.	Insulation-Icynene	0.039					150
8.							

Percentage of Sec. 2: 5.0%; Percentage of Sec. 3: 1.0%; Total: 47.4 cm

U-Value: 0.099 W/(m²K)

Assembly No. 3 — Building Assembly Description: Conc Floor Slab 1m Deep

Heat Transfer Resistance [m²K/W] interior R_{si}: 0.17; exterior Rse: 0.00

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Conc	0.100					1000
2.	Anhydride Screed	1.150					30
3.							
4.							
5.							
6.							
7.							
8.							

Percentage of Sec. 2: ; Percentage of Sec. 3: ; Total: 103.0 cm

U-Value: 0.098 W/(m²K)

PHPP 2007, U-Values — New Masters Studio_amended

Figure S5. U Values of building elements calculation sheet.

Passive House Planning

HEAT LOSSES VIA THE GROUND

Ground characteristics				Climate data			
Thermal conductivity	λ	2.0	W/(mK)	Av. indoor temp. winter	T_i	20.0	°C
Heat capacity	ρc	2.0	MJ/(m³K)	Av. indoor temp. summer	T_i	25.0	°C
Periodic penetration depth	δ	3.17	m	Average ground surface temperature	$T_{g,ave}$	10.0	°C
				Amplitude of $T_{g,ave}$	$T_{g,^}$	5.3	°C
				Length of the heating period	n	6.7	months
				Heating degree hours - Exterior	G_t	69.0	kKh/a

Building data							
				U-value floor slab/basement ceiling	U_f	0.098	W/(m²K)
Floor slab area	A	41.7	m²	Thermal bridges floor slab/basement ceiling	Ψ_B*l	0.00	W/K
Floor slab perimeter	P	26.1	m	U-value floor slab/basement ceiling incl. TB	U_f'	0.098	W/(m²K)
Charact. dimension of floor slab	B'	3.19	m	Eq. thickness floor	d_t	20.4	m

Floor slab type (select only one)			
	Heated basement or underground floor slab		Unheated basement
x	Slab on grade		Suspended floor

For basement or floor slab below ground							
Basement depth	z		m	U-value below ground wall	U_{wB}		W/(m²K)
Additionally for unheated basements				Height above ground wall	h		m
Air change unheated basement	n		h^{-1}	U-value above ground wall	U_W		W/(m²K)
Basement volume	V		m³	U-value basement floor slab	U_{fB}		W/(m²K)

For perimeter insulation for slab on grade				For suspended floor			
Perimeter insulation width/depth	D	1.10	m	U-value crawl space	U_{Crawl}		W/(m²K)
Perimeter insulation thickness	d_n	0.20	m	Height of crawl space wall	h		m
Conductivity perimeter insulation	λ_n	0.033	W/(mK)	U-value crawl space wall	U_W		W/(m²K)
				Area of ventilation openings	εP		m²
Position of the perimeter insulation	horizontal			Wind velocity at 10 m height	v	4.0	m/s
(check only one field)	vertical	X		Wind shield factor	f_W	0.05	-

Additional thermal bridge heat losses at perimeter							
				Steady-state fraction	$\Psi_{P,stat}$*l	-0.444	W/K
Phase shift	β		months	Harmonic fraction	$\Psi_{P,harm}$*l	-0.444	W/K

Groundwater correction							
Depth of the groundwater table	z_W	3.0	m	Conductance of components with ground contact	C_{reg}	3.64	W/K
Groundwater flow rate	q_W	0.05	m/d	Relative insulation standard	d_t/B'	7.16	-
				Relative groundwater depth	z_W/B'	0.94	-
Groundwater correction factor	G_W	1.0002435	-	Relative groundwater velocity	l/B'	0.26	-

Basement or underground floor slab							
Eq. thickness floor slab	d_t		m	Phase shift	β		months
U-value floor slab	U_{bf}		W/(m²K)	Exterior periodic conductance	C_{pe}		W/K
Eq. thickness basement wall	d_w		m				
U-value wall	U_{bw}		W/(m²K)				
Steady-state conductance	C_S		W/K				

Unheated basement							
Steady-state conductance	C_S		W/K	Phase shift	β		months
				Exterior periodic conductance	C_{pe}		W/K

Slab on grade							
Heat transfer coefficient	U_0	0.09	W/(m²K)	Phase shift	β	1.44	months
Eq. ins. thickness perimeter ins.	d'	11.92	m	Exterior periodic conductance	C_{pe}	2.30	W/K
Perimeter insulation correction	$\Delta\Psi$	-0.02	W/(mK)				
Steady-state conductance	C_S	3.21	W/K				

Suspended floor above a ventilated crawl space (at max. 0.5 m below ground)							
Eq. ins. thickness crawl space	d_g		m	Phase shift	β		months
U-value crawl space floor slab	U_g		W/(m²K)	Exterior periodic conductance	C_{pe}		W/K
U-value crawl space wall & vent.	U_X		W/(m²K)				
Steady-state conductance	C_S		W/K				

Interim results							
Phase shift	β	1.44	months	Steady-State heat flow	Φ_{stat}	27.5	W
Steady-state conductance	C_S	2.76	W/K	Periodic heat flow	Φ_{harm}	4.0	W
Exterior periodic conductance	C_{pe}	1.85	W/K	Heat losses during heating period	Q_{tot}	154	kWh

Ground reduction factor for "Annual heating demand" sheet 0.614

Monthly average ground temperatures for monthly method

Month	1	2	3	4	5	6	7	8	9	10	11	12	Average Value
Winter	10.5	9.8	9.9	10.6	11.8	13.2	14.4	15.0	15.0	14.3	13.1	11.7	12.4
Summer	11.7	11.1	11.1	11.8	13.0	14.4	15.6	16.3	16.2	15.5	14.3	12.9	13.7

Design ground temperature for heating load sheet 9.8 **for cooling load sheet** 16.3

PHPP 2007, Ground

New Masters Studio_amended

Figure S6. Heat losses via ground calculation sheet.

Passive House Planning

REDUCTION FACTOR SOLAR RADIATION, WINDOW U-VALUE

Building: MM Studio

Annual Heating Demand: 10 kWh/(m²a)

Heating Degree Hours: 69.0

Climate: East of Scotland

Window Area Orientation	Global Radiation (Cardinal Points)	Shading	Dirt	Non-Perpendicular Incident Radiation	Glazing Fraction	g-Value	Reduction Factor for Solar Radiation	Window Area	Window U-Value	Glazing Area	Average Global Radiation	Transmission Losses	Heat Gains Solar Radiation
Maximum:	kWh/(m²a)	0.75	0.95	0.85				m²	W/(m²K)	m²	kWh/(m²a)	kWh/a	kWh/a
North	77	0.97	0.95	0.85	0.684	0.50	0.53	3.12	0.89	2.1	84	192	70
East	173	0.75	0.95	0.85	0.650	0.50	0.39	0.90	0.97	0.6	310	60	55
South	386	0.99	0.95	0.85	0.823	0.50	0.66	13.50	0.72	11.1	386	674	1717
West	190	0.98	0.95	0.85	0.854	0.50	0.68	5.38	0.73	4.6	190	272	345
Horizontal	251	1.00	0.95	0.85	0.000	0.00	0.00	0.00	0.00	0.0	251	0	0
		Total or Average Value for All Windows.				0.50	0.63	22.90	0.76	18.4		1199	2187

Quantity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Structural opening: Width	Structural opening: Height	Location: Select area from the Area worksheet	No.	Glazing: Select glazing from the WinType worksheet	No.	Frame: Select window from the WinType worksheet	No.
		Degrees	Degrees		m	m	Select:		Select:		Select:	
1	South Window	180	90	South	1.500	3.000	South Wall	1	Nordan Opening	1	Nordan 0.7 Ntect	1
1	South Window	180	90	South	1.500	3.000	South Wall	1	Nordan Opening	1	Nordan 0.7 Ntect	1
1	South Window	180	90	South	1.500	3.000	South Wall	1	Nordan Opening	1	Nordan 0.7 Ntect	1
1	West Window	270	90	West	2.240	2.400	West Wall	2	Nordan Opening	1	Nordan 0.7 Ntect	1
1	North West W	337	90	North	1.200	2.100	North West Wall	3	Nordan Opening	1	Nordan 0.7 Ntect	1
1	Door Light	23	90	North	0.300	2.000	North Wall	4	Nordan Opening	1	Nordan 0.7 Ntect	1
0	Roof Window	113	65	East	1.200	1.850	East Roof	9	Nordan Opening	1	Nordan 0.7 Ntect	1
0	South Roof L	180	40	South			South Roof	6	Nordan Opening	1	Nordan 0.7 Ntect	1
1	East Window	135	90	East	1.500	0.600	East Wall	5	Nordan Opening	1	Nordan 0.7 Ntect	1
								0		0		0
								0		0		0
								0		0		0
								0		0		0
								0		0		0
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								0		0		0
								0		0		0

Description	g-Value for perpendicular Radiation	U-Value: Glazing	U-Value: Frames	Window Frame Dimensions: Width Left	Width Right	Width Bottom	Width Top	Installation: Left 1/0	Right 1/0	Sill 1/0	Head 1/0	Ψ-Value: Ψ_{Spacer}	$\Psi_{Installation}$	Results: Window Area	Glazing Area	U-Value Window	Glazed Fraction per Window
	-	W/(m²K)	W/(m²K)	m	m	m	m					W/(mK)	W/(mK)	m²	m²	W/(m²K)	%
South Window	0.50	0.58	0.69	0.10	0.10	0.10	0.05	1	0	1	1	0.043	0.040	4.5	3.71	0.73	82%
South Window	0.50	0.58	0.69	0.10	0.10	0.10	0.05	0	0	1	1	0.043	0.040	4.5	3.71	0.71	82%
South Window	0.50	0.58	0.69	0.10	0.10	0.10	0.05	0	1	1	1	0.043	0.040	4.5	3.71	0.73	82%
West Window	0.50	0.58	0.69	0.10	0.10	0.10	0.05	1	1	1	1	0.043	0.040	5.4	4.59	0.73	85%
North West W	0.50	0.58	0.69	0.10	0.10	0.10	0.05	1	1	1	1	0.043	0.040	2.5	1.95	0.81	77%
Door Light	0.50	0.58	0.69	0.10	0.10	0.10	0.05	1	1	1	1	0.043	0.040	0.6	0.19	1.24	31%
Roof Window	0.50	0.58	0.69	0.10	0.10	0.10	0.05	1	1	1	1	0.043	0.040	0.0	0.00		
South Roof L	0.50	0.58	0.69	0.10	0.10	0.10	0.05	1	1	1	1	0.043	0.040	0.0	0.00		
East Window	0.50	0.58	0.69	0.10	0.10	0.10	0.05	1	1	1	1	0.043	0.040	0.9	0.59	0.97	65%

PHPP 2007, Windows

105_Reduction Factor Solar

Figure S7. Solar radiation and window U Value calculation sheet.

Passive House Planning

CALCULATING SHADING FACTORS

Climate: East of Scotland

Building: MM Studio

Latitude: 56.45 °

Orientation	Glazing Area	Reduction Factor
	m²	r_S
North	2.14	97%
East	0.59	75%
South	11.12	99%
West	4.59	98%
Horizontal	0.00	100%

Quantity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Glazing Width	Glazing Height	Glazing Area	Height of the Shading Object	Horizontal Distance
		Degrees	Degrees		m	m		m	m
					w_G	h_G	A_G	h_{Hori}	d_{Hori}
1	South Windows	180	90	South	1.30	2.85	3.7		
1	South Windows	180	90	South	1.30	2.85	3.7		
1	South Windows	180	90	South	1.30	2.85	3.7		
1	West Window	270	90	West	2.04	2.25	4.6		
1	North West Win	337	90	North	1.00	1.95	2.0		
1	Door Light	23	90	North	0.10	1.85	0.2		
0	Roof Window	113	65	East	1.00	1.70	0.0		
0	South Roof Lig	180	40	South	-0.20	-0.15	0.0		
1	East Window	135	90	East	1.30	0.45	0.6		

Description	Window Reveal Depth	Distance from Glazing Edge to Reveal	Overhang Depth	Distance from Upper Glazing Edge to Overhang	Additional Shading Reduction Factor	Horizontal Shading Reduction Factor	Reveal Shading Reduction Factor	Overhang Shading Reduction Factor	Total Shading Reduction Factor
	m	m	m	m	%	%	%	%	%
	o_{Reveal}	d_{Reveal}	o_{Over}	d_{Over}	r_{Other}	r_H	r_R	r_O	r_S
South Windows	0.03	0.050	0.03	0.050		100%	99%	100%	99%
South Windows	0.03	0.050	0.03	0.050		100%	99%	100%	99%
South Windows	0.03	0.050	0.03	0.050		100%	99%	100%	99%
West Window	0.03	0.050	0.03	0.050		100%	99%	99%	98%
North West Win	0.03	0.050	0.03	0.050		100%	98%	99%	97%
Door Light	0.03	0.050	0.03	0.050		100%	91%	99%	90%
Roof Window	0.03	0.050	0.03	0.050		100%	97%	99%	97%
South Roof Lig									75%
East Window									75%

PHPP 2007, Shading

105_Reduction Factor Solar

Figure S8. Shading factors calculation sheet.

Passive House Planning

VENTILATION DATA

Building: MM Studio

Treated floor area A_{TFA}	m²	47	*(Areas worksheet)*
Room height h	m	2.5	*(Annual Heating Demand worksheet)*
Room ventilation volume (A_{TFA}*h) = V_V	m³	119	*(Annual Heating Demand worksheet)*

Ventilation System Design - Standard Operation

Occupancy	m²/P	35				
Number of occupants	P	1.4				
Supply air per person	m³/(P*h)	30				
Supply air demand	m³/h	41				
Extract air rooms		Kitchen	Bathroom	Shower	WC	
Quantity		0	0	0	0	
Extract air demand per room	m³/h	60	40	20	20	
Total extract air demand	m³/h	0				

Design air flow rate (maximum) m³/h 46

Average Air Change Rate Calculation

Type of operation	Daily operation duration h/d	Factors referenced to maximum	Air flow rate m³/h	Air change rate 1/h
Maximum		1.00	46	0.39
Standard	24.0	0.77	36	0.30
Basic		0.54	25	0.21
Minimum		0.40	19	0.16
	Average value	0.77	Average air flow rate (m³/h): 36	Average air change rate (1/h): 0.30

Infiltration Air Change Rate

Wind protection coefficients e and f	Several sides exposed	One side exposed
Coefficient e for screening class		
No screening	0.10	0.03
Moderate screening	0.07	0.02
High screening	0.04	0.01
Coefficient f	15	20

			for annual demand:	for heating load:		
Wind protection coefficient, e				0.00		
Wind protection coefficient, f				0	Net Air Volume for Press. Test V_{n50}	Air Permeability q_{50}
Air change rate at pressure test	n_{50}	1/h		0.00	m³	m³/(hm²)

Type of Ventilation System

				for annual demand:	for heating load:
x	Balanced PH ventilation	*Please check*			
	Pure extract air				
	Excess extract air		1/h	0.00	0.00
	Infiltration Air Change Rate	$n_{V,Res}$	1/h		

Effective Heat Recovery Efficiency of the Ventilation System with Heat Recovery

x	Heat recovery unit within the thermal envelope.
	Heat recovery unit outside of the thermal envelope.

Efficiency of heat recovery	η_{HR}		0.93	Paul Wärmerückgewinnung GmbH - Novus 300
Conductance ambient air duct	Ψ	W/(mK)	0.000	Calculation see secondary calculation
Length ambient air duct		m	0.5	
Conductance exhaust air duct	Ψ	W/(mK)	0.000	Calculation see secondary calculation
Length exhaust air duct		m	0.5	Room temperature (°C): 20
Temperature of mechanical services room		°C		Av. ambient temp. heating p. (°C): 5.9
(Enter only if the heat recovery unit is outside of the thermal envelope.)				Av. ground temp (°C): 10.0

Effective heat recovery efficiency $\eta_{HR,eff}$ **93.0%**

Effective Heat Recovery Efficiency Subsoil Heat Exchanger

SHX efficiency	η^*_{SHX}	
Heat recovery efficiency SHX	η_{SHX}	0%

PHPP 2007, Ventilation — 105_Reduction Factor Solar

Figure S9. Ventilation calculation sheet.

Passive House Planning

SPECIFIC ANNUAL HEATING DEMAND

Climate:	East of Scotland	Interior temperature:	20.0	°C
Building:	MM Studio	Building type/use:	Studio	
Location:	Dundee	Treated floor area A_{TFA}:	47.5	m²

	Building element	Temperature zone	Area m²		U-value W/(m²K)		Temp. factor f_t		G_t kKh/a		kWh/a	per m² treated floor area
1.	Exterior Wall - Ambient	A	79.9	*	0.108	*	1.00	*	69.0	=	593	
2.	Exterior Wall - Ground	B		*		*	0.61	*		=		
3.	Roof/Ceiling - Ambient	A	78.4	*	0.099	*	1.00	*	69.0	=	533	
4.	Foor slab/ basement ceiling	B	41.7	*	0.098	*	0.61	*	69.0	=	173	
5.		A		*		*	1.00	*		=		
6.		A		*		*	1.00	*		=		
7.		X		*		*	0.75	*		=		
8.	Windows	A	22.9	*	0.759	*	1.00	*	69.0	=	1199	
9.	Exterior Door	A	1.8	*	0.800	*	1.00	*	69.0	=	97	
10.	Exterior TB (length/m)	A		*		*	1.00	*		=		
11.	Perimeter TB (length/m)	P	26.1	*	-0.017	*	0.61	*	69.0	=	-19	
12.	Ground TB (length/m)	B		*		*	0.61	*		=		
	Total of all building envelope areas		224.6									kWh/(m²a)
	Transmission Heat Losses Q_T									Total	2577	54.3

			A_{TFA} m²		Clear room height m		m³
Ventilation System:	Effective air volume, V_V		47.5	*	2.50	=	118.7
Effective heat recovery efficiency of heat recovery	η_{eff}	93%					
Efficiency of subsoil heat exchanger	η_{SHX}	0%					

	$n_{V,system}$ 1/h		Φ_{HR}		$n_{V,Res}$ 1/h		1/h
Energetically effective air exchange n_V	0.300	(1	0.93	) +	0.046	=	0.067

	V_V m³		n_V 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Heat Losses Q_V	119	*	0.067	*	0.33	*	69.0	=	182	3.8

		Q_T kWh/a		Q_V kWh/a		Reduction factor night/weekend setback		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	(	2577	+	182	)	1.0	=	2759	58.1

	Orientation of the area	Reduction factor see windows sheet		g-value (perp. radiation)		Area m²		Radiation during heating period kWh/(m²a)		kWh/a	kWh/(m²a)
1.	North	0.53	*	0.50	*	3.12	*	84	=	70	
2.	East	0.39	*	0.50	*	0.90	*	310	=	55	
3.	South	0.66	*	0.50	*	13.50	*	386	=	1717	
4.	West	0.68	*	0.50	*	5.38	*	190	=	345	
5.	Horizontal	0.00	*	0.00	*	0.00	*	251	=	0	
	Available Solar Heat Gains Q_S								Total	2187	46.0

	kh/d		Length Heat Period d/a		Spec. Power q_I W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0.024	*	205	*	2.10	*	47.5	=	490	10.3

			kWh/a	kWh/(m²a)
Free Heat Q_F	Q_S + Q_I	=	2677	56.4
Ratio of Free Heat to Losses	Q_F / Q_L	=	0.97	
Utilisation Factor Heat Gains η_G	$(1 - (Q_F/Q_L)^5)$ / $(1 - (Q_F/Q_L)^6)$	=	85%	
Heat Gains Q_G	η_G * Q_F	=	2264	47.7
Annual Heating Demand Q_H	Q_L - Q_G	=	495	**10**

	kWh/(m²a)		(Yes/No)
Limiting Value	15	**Requirement met?**	**Yes**

For buildings with a gain-loss-ratio above 0.7 you should use the Monthly Method (cf. manual).

PHPP 2007, Annual Heating Demand | 105_Reduction Factor Solar

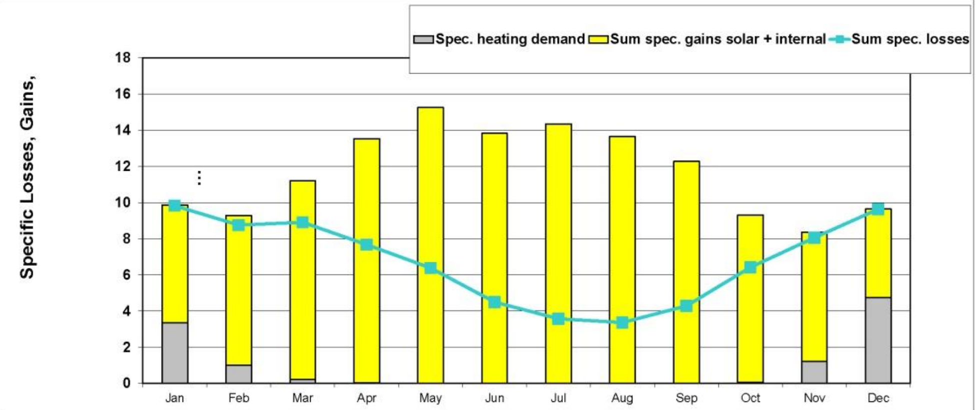
Figure S10. Specific space heat demand calculation sheet.

PASSIVE HOUSE PLANNING

SPECIFIC ANNUAL HEATING DEMAND
MONTHLY METHOD

Climate:	East of Scotland		Interior Temperature:	20 °C
Building:	MM Studio		Building Type/Use:	Studio
Location:	Dundee		Treated Floor Area A_{TFA}:	47 m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - Exterior	11.7	10.3	10.5	9.0	7.4	5.2	4.1	3.9	5.0	7.7	9.6	11.5	96	kKh
Heating Degree Hours - Ground	7.1	6.8	7.5	6.8	6.1	4.9	4.2	3.7	3.6	4.3	5.0	6.2	66	kKh
Losses - Exterior	441	391	396	340	281	196	154	146	190	289	364	435	3622	kWh
Losses - Ground	26	25	27	25	22	18	15	13	13	16	18	23	241	kWh
Sum spec. losses	9.8	8.7	8.9	7.7	6.4	4.5	3.6	3.4	4.3	6.4	8.0	9.6	81.3	kWh/m²
Solar gains - North	4	8	18	27	41	43	42	32	21	12	6	3	258	kWh
Solar gains - East	6	8	11	15	18	16	17	15	13	9	6	4	139	kWh
Solar gains - South	200	267	338	404	431	373	395	395	373	284	222	133	3817	kWh
Solar gains - West	25	44	82	123	160	152	152	131	103	60	33	18	1084	kWh
Solar gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar gains - Opaque	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Internal Heat Gains	74	67	74	72	74	72	74	74	72	74	72	74	874	kWh
Sum spec. gains solar + internal	6.5	8.3	11.0	13.5	15.2	13.8	14.3	13.6	12.3	9.3	7.1	4.9	129.9	kWh/m²
Utilisation factor	100%	94%	79%	57%	42%	33%	25%	25%	35%	69%	96%	100%	54%	
Annual heating demand	158	47	10	0	0	0	0	0	0	2	58	225	501	kWh
Spec. heating demand	**3.3**	**1.0**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.2**	**4.7**	**10.5**	kWh/m²



PHPP 2007, Monthly Method

105_Reduction Factor Solar

Figure S11. Specific annual heating demand calculation sheet.

Passive House Planning

SPECIFIC SPACE HEATING LOAD

Building:	MM Studio	Building type/use:	Studio
Location:	Dundee	Treated floor area A_{TFA}:	47.5 m² — Interior temperature: 20 °C
		Climate (HL):	East of Scotland

	Design temperature		Radiation: North	East	South	West	Horizontal	
Weather condition 1:	-1.4	°C	5	13	53	15	15	W/m²
Weather condition 2:	0.6	°C	5	10	36	11	13	W/m²
Design ground temperature	9.8	°C						

	Building element	Temperature zone	Area m²		U-value W/(m²K)		Factor always 1 (except "X")		TempDiff 1 K		TempDiff 2 K		P_T 1 W		P_T 2 W
1	Exterior Wall - Ambient	A	79.9	*	0.108	*	1.00	*	21.4	or	19.4	=	184	or	167
2	Exterior Wall - Ground	B		*		*	1.00	*	10.2	or	10.2	=		or	
3	Roof/Ceiling - Ambient	A	78.4	*	0.099	*	1.00	*	21.4	or	19.4	=	165	or	150
4	Foor slab/ basement ceiling	B	41.7	*	0.098	*	1.00	*	10.2	or	10.2	=	41	or	41
5		A		*		*	1.00	*	21.4	or	19.4	=		or	
6		A		*		*	1.00	*	21.4	or	19.4	=		or	
7		X		*		*	0.75	*	21.4	or	19.4	=		or	
8	Windows	A	22.9	*	0.759	*	1.00	*	21.4	or	19.4	=	372	or	337
9	Exterior Door	A	1.8	*	0.800	*	1.00	*	21.4	or	19.4	=	30	or	27
10	Exterior TB (length/m)	A		*		*	1.00	*	21.4	or	19.4	=		or	
11	Perimeter TB (length/m)	P	26.1	*	-0.017	*	1.00	*	10.2	or	10.2	=	-5	or	-5
12	Ground TB (length/m)	B		*		*	1.00	*	10.2	or	10.2	=		or	
13	House/DU Partition Wall	I		*		*	1.00	*	3.0	or	3.0	=		or	

Transmission heat losses P_T — Total = 788 or 718

Ventilation system:

	A_{TFA} m²		Clear room height m		m³
Effective air volume, V_V	47.5	*	2.50	=	119

Efficiency of heat recovery of the heat exchanger η_{HR}	93%	Heat recovery efficiency SHX	0%	Efficiency SHX η_{SHX} 1: 0%	or η_{SHX} 2: 0%

	$n_{V,Res}$ (Heating load) 1/h		$n_{V,system}$ 1/h		Φ_{HR}		Φ_{HR}		1/h		1/h
Energetically effective air exchange n_V	0.105	+	0.300	*(1-	0.93	or	0.93	) =	0.126	or	0.126

Ventilation heat losses P_V

V_V m³		n_V 1/h		n_V 1/h		c_{Air} Wh/(m³K)		TempDiff 1 K		TempDiff 2 K		P_V 1 W		P_V 2 W
118.7	*	0.126	or	0.126	*	0.33	*	21.4	or	19.4	=	106	or	96

Total heat loss P_L — $P_T + P_V$ = P_L 1: 894 W or P_L 2: 814 W

	Orientation of the area	Area m²		g-value (perp. radiation)		Reduction factor (see Windows worksheet)		Radiation 1 W/m²		Radiation 2 W/m²		P_S 1 W		P_S 2 W
1.	North	3.1	*	0.5	*	0.5	*	5	or	5	=	4	or	4
2.	East	0.9	*	0.5	*	0.4	*	38	or	26	=	7	or	5
3.	South	13.5	*	0.5	*	0.7	*	53	or	36	=	235	or	160
4.	West	5.4	*	0.5	*	0.7	*	15	or	11	=	27	or	20
5.	Horizontal	0.0	*	0.0	*	0.4	*	15	or	13	=	0	or	0

Solar heat load, P_S — Total = 274 or 189

Internal heat load P_I — Spec. power 1.6 W/m² * A_{TFA} 47 m² = P_I 1: 76 W or P_I 2: 76 W

Heat gains P_G — $P_S + P_I$ = P_G 1: 350 W or P_G 2: 265 W

$P_L - P_G$ = 544 or 549

Heating load P_H = 549 W

Specific heating load P_H / A_{TFA} = 11.6 W/m²

					°C		°C
Input max. supply air temperature	52	°C					
Max. supply air temperature $\vartheta_{Supply,Max}$	52	°C	Supply air temperature without reheating	$\vartheta_{Supply,Min}$	18.5		18.6

For comparison: Heating load transportable by supply air. $P_{Supply\ Air,Max}$ = 392 W specific: 8.3 W/m²

Supply air heating sufficient? (Yes/No): No

PHPP 2007, Heating Load — 105_Reduction Factor Solar

Figure S12. Specific space heating load calculation sheet.

Passive House Planning

S U M M E R

Climate:	East of Scotland	Interior temperature:	20 °C
Building:	MM Studio	Building type/use:	Studio
Location:	Dundee	Treated floor area A_{TFA}:	47.5 m²
Spec. capacity:	132 Wh/K per m² TFA		
Overheating limit:	25 °C		

	Building element	Temperature zone	Area m²		U-value W/(m²K)		Red. factor $f_{T,Summer}$		H_{Summer} Heat conductance
1.	Exterior Wall - Ambien	A	79.9	*	0.108	*	1.00	=	8.6
2.	Exterior Wall - Ground	B		*		*	1.00	=	
3.	Roof/Ceiling - Ambient	A	78.4	*	0.099	*	1.00	=	7.7
4.	Foor slab/ basement ce	B	41.7	*	0.098	*	1.00	=	4.1
5.		A		*		*	1.00	=	
6.		A		*		*	1.00	=	
7.		X		*		*	0.75	=	
8.	Windows	A	22.9	*	0.759	*	1.00	=	17.4
9.	Exterior Door	A	1.8	*	0.800	*	1.00	=	1.4
10.	Exterior TB (length/m)	A		*		*	1.00	=	
11.	Perimeter TB (length/m	P	26.1	*	-0.017	*	1.00	=	-0.4
12.	Ground TB (length/m)	B		*		*	1.00	=	

Exterior thermal conductance, $H_{T,e}$ 35.1 W/K

Ground thermal conductance, $H_{T,g}$ 3.6 W/K

Heat recovery efficiency η_{HR} 93%

Effective air volume V_V = A_{TFA} 47.5 m² * Clear room height 2.50 m = 119 m³

SHX efficiency η^*_{SHX} 0%

Summer ventilation continuous ventilation to provide sufficient indoor air quality

Air change rate by natural (windows & leakages) or exhaust-only mechanical ventilation, summer: 3.10 1/h

Mechanical ventilation summer: 1/h | with HR (check if applicable)

	$n_{L,nat}$ 1/h		$n_{V,system}$ 1/h		Φ_{HR}		$n_{V,Rest}$ 1/h		1/h
Energetically effective air change rate n_V	3.100	+	0.000	* (1 -	0.000	) +	0.000	=	3.100

	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		
Ventilation conduct. ambient $H_{V,e}$	119	*	3.100	*	0.33	=	121.5 W/K
Ventilation conduct. ground $H_{V,g}$	119	*	0.000	*	0.33	=	0.0 W/K

Additional summer ventilation for cooling Temperature amplitude summer 5.1 K

Select: x Window night ventilation, manual
Mechanical, automatically controlled ventilation

Corresponding air change rate 3.75 1/h
(for window ventilation: at 1 K temperature difference indoor - outdoor)

Minimum acceptable indoor temperature 22.0 °C

	Orientation of the area	Angle factor Summer		Shading factor Summer		Dirt		g-value (perp. radiation)		Area m²		Portion of glazing		Aperture m²
1.	North	0.9	*	0.98	*	0.95	*	0.50	*	3.1	*	68%	=	0.9
2.	East	0.9	*	1.00	*	0.95	*	0.50	*	0.9	*	65%	=	0.3
3.	South	0.9	*	0.99	*	0.95	*	0.50	*	13.5	*	82%	=	4.7
4.	West	0.9	*	0.99	*	0.95	*	0.50	*	5.4	*	85%	=	2.0
5.	Horizontal	0.9	*	1.00	*	0.95	*	0.00	*	0.0	*	0%	=	0.0
6	Sum Opaque Areas													0.0

Solar aperture Total 7.8 | 0.16 m²/m²

	Specif. power q_I W/m²		A_{TFA} m²		W	W/m²
Internal heat loads Q_I	2.10	*	47	=	100	2.1

Frequency of overheating $h_{\vartheta \geq \vartheta max}$ **0.0%** at the overheating limit ϑ_{max} = 25 °C

If the "frequency over 25°C" exceeds 10%, additional measures to protect against summer heat waves are necessary.

Caution: Large daily temperature swing. Calculation of overheating frequency is not reliable.

	Solar load kWh/d		1/k		Spec. capacity Wh/(m²K)		A_{TFA} m²		
Daily temperature swing due to solar load	26.0	*	1000	/ (	132	*	47	) =	4.2 K

PHPP 2007, Summer | 105_Reduction Factor Solar

Figure S13. Summer ventilation calculation sheet.

Passive House Planning

CALCULATING SUMMER SHADING FACTORS

Climate: East of Scotland

Building: MM Studio

Latitude: 56.45

Summer!

Orientation	Glazing Area	Summer Shading Factor
	m²	r_S
North	2.14	98%
East	0.59	100%
South	11.12	99%
West	4.59	99%
Horizontal	0.00	100%

Results from the Summer worksheet:
Frequency of Overheating $h_{\vartheta \geq \vartheta max}$ 0.0%

															Input Field Summer	Summer			
Quantity	Description:	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Glazing Width	Glazing Height	Glazing Area	Height of the Shading Object	Horizontal Distance	Window Reveal Depth	Distance from Glazing Edge to Reveal	Overhang Depth	Distance from Upper Glazing Edge to Overhang	Additional Shading Reduction Factor (Summer)	Reduction factor z for temporary sun protection	Horizontal Shading Reduction Factor	Reveal Shading Reduction Factor	Overhang Shading Reduction Factor	Total Summer Shading Reduction Factor
		Degrees	Degrees			m		m	m	m	m	m	m	%	%	%	%	%	%
					w_G	h_G	A_G	h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	r_{other}	z	r_H	r_R	r_O	r_S
1	South Windows	180	90	South	1.30	2.85	3.7			0.03	0.05	0.03	0.05			100%	99%	100%	99%
1	South Windows	180	90	South	1.30	2.85	3.7			0.03	0.05	0.03	0.05			100%	99%	100%	99%
1	South Windows	180	90	South	1.30	2.85	3.7			0.03	0.05	0.03	0.05			100%	99%	100%	99%
1	West Window	270	90	West	2.04	2.25	4.6			0.03	0.05	0.03	0.05			100%	99%	100%	99%
1	North West Windo	337	90	North	1.00	1.95	2.0			0.03	0.05	0.03	0.05			100%	99%	100%	99%
1	Door Light	23	90	North	0.10	1.85	0.2			0.03	0.05	0.03	0.05			100%	93%	100%	93%
0	Roof Window	113	65	East	1.00	1.70	0.0			0.03	0.05	0.03	0.05			100%	99%	100%	99%
0	South Roof Light	180	40	South	-0.20	-0.15	0.0									100%	100%	100%	100%
1	East Window	135	90	East	1.30	0.45	0.6									100%	100%	100%	100%

PHPP 2007, Shading-S

105_Reduction Factor Solar

Figure S14. Summer shading calculation sheet.

Passive House Planning

SUMMER VENTILATION

Building:	MM Studio	Building Type/Use:	Studio	
Location:	Dundee	Building Volume	119	m³

Description	Door	Lower Window	Skylight		Skylight		
Fraction of Opening Duration	50%	50%	50%		100%		
Climate Boundary Conditions							
Temperature Diff Interior - Exterior	4	4	4		1		K
Wind Velocity	1	1	1		0		m/s
Window Group 1							
Quantity	1	1	1		1		
Clear Width	0.88	1.10	1.10		1.10		m
Clear Height	2.00	1.75	2.00		2.00		m
Tilting Windows?	x	x	x		x		
Opening Width (for tilting windows)	0.800	1.100	1.100		1.100		m
Window Group 2 (Cross Ventilation)							
Quantity							
Clear Width							m
Clear Height							m
Tilting Windows?							
Opening Width (for Tilting Windows)							m
Difference in Height to Window 1							m
Single-Sided Ventilation 1 - Airflow Volume	617	783	913	0	445	0	m³/h
Single-Sided Ventilation 2 - Airflow Volume	0	0	0	0	0	0	m³/h
Cross Ventilation Airflow Volume	617	783	913	0	445	0	m³/h
Contribution to Air Change Rate	2.60	3.30	3.84	0.00	3.75	0.00	1/h

Summary of Summer Ventilation Distribution

Description Ventilation Type	Daily Average Air Change Rate	
3 Windows Open 50% Time MAX	9.74	1/h
Night Vent	3.75	1/h
		1/h

PHPP 2007, SummVent | 105_Reduction Factor Solar

Figure S15. Summer ventilation calculation sheet.

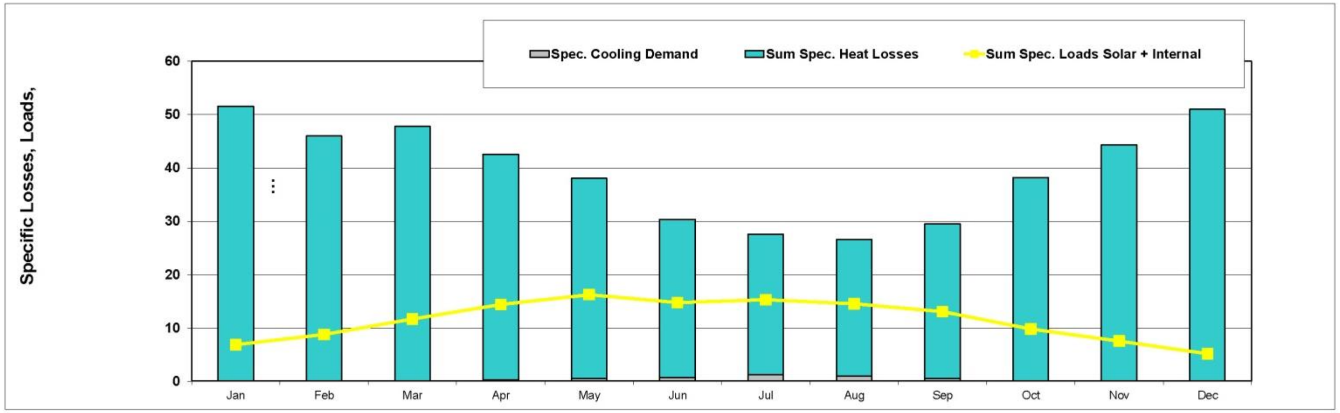
PASSIVE HOUSE PLANNING

SPECIFIC USEFUL COOLING DEMAND
MONTHLY METHOD

Climate: East of Scotland
Building: MM Studio
Location: Dundee

Interior Temperature: 25 °C
Building Type/Use: Studio
Treated Floor Area A_{TFA}: 47 m²

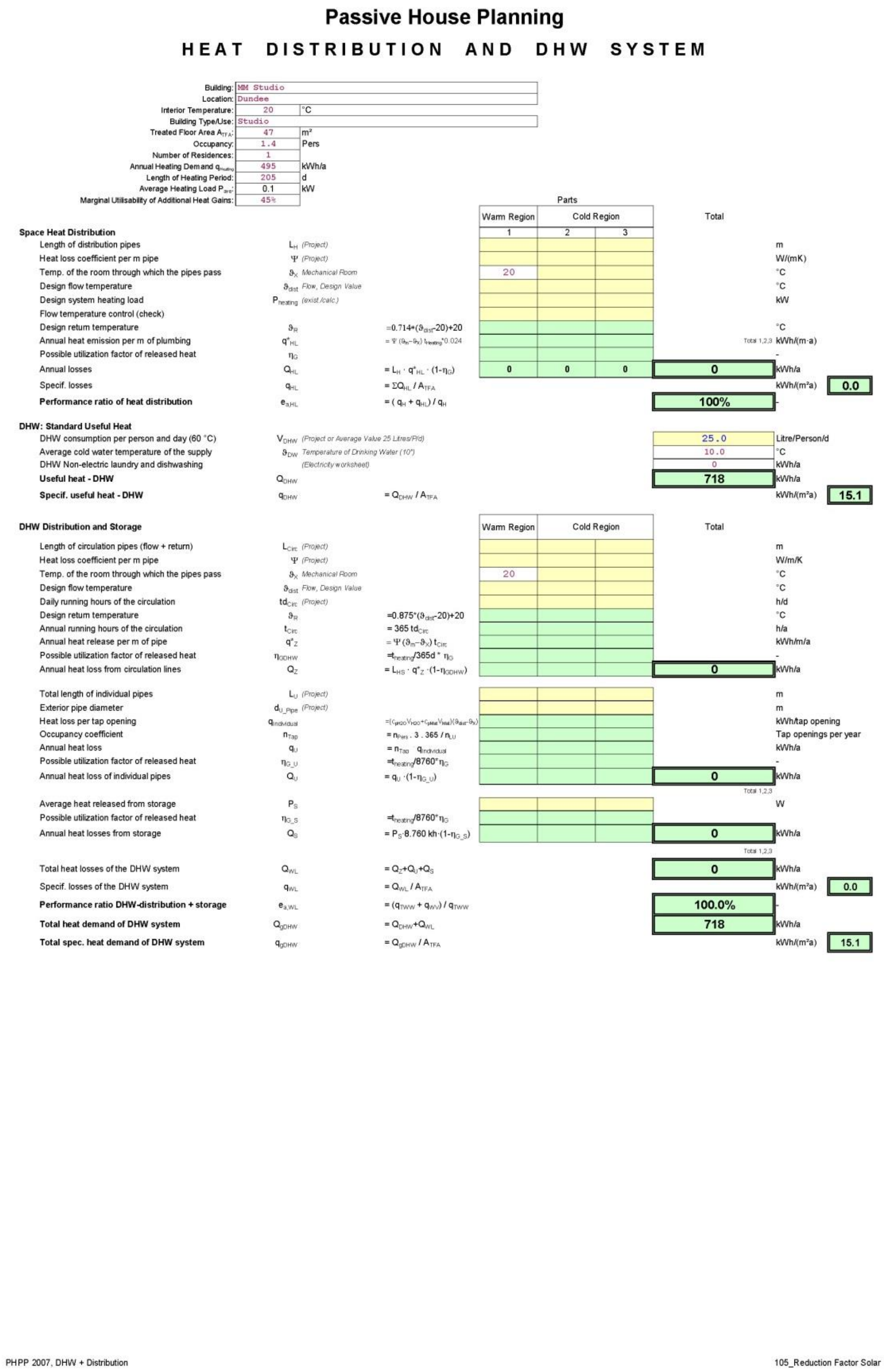
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - Exterior	15.4	13.7	14.2	12.6	11.2	8.8	7.8	7.6	8.6	11.4	13.2	15.3	140	kKh
Heating Degree Hours - Ground	10.8	10.2	11.2	10.4	9.8	8.5	7.9	7.4	7.2	8.0	8.6	9.9	110	kKh
Losses - Exterior	2404	2140	2219	1967	1742	1371	1220	1185	1349	1777	2068	2381	21825	kWh
Losses - Ground	44	42	46	42	40	35	32	30	29	33	35	41	449	kWh
Losses Summer Ventilation	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Sum Spec. Heat Losses	51.6	45.9	47.7	42.3	37.5	29.6	26.4	25.6	29.0	38.1	44.3	51.0	469.0	kWh/m²
Solar Load North	4	9	19	29	44	46	45	34	23	13	7	4	277	kWh
Solar Load East	8	12	16	21	25	22	24	22	18	13	9	5	197	kWh
Solar Load South	211	282	357	427	456	395	418	418	395	301	235	141	4035	kWh
Solar Load West	27	47	88	133	172	164	164	141	111	64	35	20	1165	kWh
Solar Load Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Load Opaque	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Internal Heat Gains	74	67	74	72	74	72	74	74	72	74	72	74	874	kWh
Sum Spec. Loads Solar + Internal	6.9	8.8	11.7	14.4	16.2	14.7	15.3	14.5	13.0	9.8	7.5	5.1	137.9	kWh/m²
Utilisation Factor Losses	13%	19%	24%	33%	42%	47%	53%	53%	43%	26%	17%	10%	29%	
Useful Cooling Energy Demand	0	1	3	11	25	33	56	46	22	3	1	0	202	kWh
Spec. Cooling Demand	**0.0**	**0.0**	**0.1**	**0.2**	**0.5**	**0.7**	**1.2**	**1.0**	**0.5**	**0.1**	**0.0**	**0.0**	**4.3**	kWh/m²



PHPP 2007, Cooling

105_Reduction Factor Solar

Figure S16. Specific useful cooling demand calculation sheet.



Passive House Planning

HEAT DISTRIBUTION AND DHW SYSTEM

Building:	MM Studio	
Location:	Dundee	
Interior Temperature:	20	°C
Building Type/Use:	Studio	
Treated Floor Area A_{TFA}:	47	m²
Occupancy:	1.4	Pers
Number of Residences:	1	
Annual Heating Demand $q_{Heating}$	495	kWh/a
Length of Heating Period:	205	d
Average Heating Load P_{ave}:	0.1	kW
Marginal Utilisability of Additional Heat Gains:	45%	

Space Heat Distribution	Symbol	Note / Formula	Parts: Warm Region 1	Cold Region 2	Cold Region 3	Total	Unit	
Length of distribution pipes	L_H	(Project)					m	
Heat loss coefficient per m pipe	Ψ	(Project)					W/(mK)	
Temp. of the room through which the pipes pass	ϑ_X	Mechanical Room	20				°C	
Design flow temperature	ϑ_{dist}	Flow, Design Value					°C	
Design system heating load	$P_{heating}$	(exist./calc.)					kW	
Flow temperature control (check)								
Design return temperature	ϑ_R	$=0.714*(\vartheta_{dist}-20)+20$					°C	
Annual heat emission per m of plumbing	q^*_{HL}	$= \Psi\,(\vartheta_m-\vartheta_X)\,t_{Heating}*0.024$				Total 1,2,3	kWh/(m·a)	
Possible utilization factor of released heat	η_G						-	
Annual losses	Q_{HL}	$= L_H \cdot q^*_{HL} \cdot (1-\eta_G)$	0	0	0	0	kWh/a	
Specif. losses	q_{HL}	$= \Sigma Q_{HL} / A_{TFA}$					kWh/(m²a)	0.0
Performance ratio of heat distribution	$e_{a,HL}$	$= (q_H + q_{HL}) / q_H$				100%	-	

DHW: Standard Useful Heat	Symbol	Note / Formula	Total	Unit	
DHW consumption per person and day (60 °C)	V_{DHW}	(Project or Average Value 25 Litres/P/d)	25.0	Litre/Person/d	
Average cold water temperature of the supply	ϑ_{DW}	Temperature of Drinking Water (10°)	10.0	°C	
DHW Non-electric laundry and dishwashing		(Electricity worksheet)	0	kWh/a	
Useful heat - DHW	Q_{DHW}		718	kWh/a	
Specif. useful heat - DHW	q_{DHW}	$= Q_{DHW} / A_{TFA}$		kWh/(m²a)	15.1

DHW Distribution and Storage	Symbol	Note / Formula	Warm Region	Cold Region	Cold Region	Total	Unit	
Length of circulation pipes (flow + return)	L_{Circ}	(Project)					m	
Heat loss coefficient per m pipe	Ψ	(Project)					W/m/K	
Temp. of the room through which the pipes pass	ϑ_X	Mechanical Room	20				°C	
Design flow temperature	ϑ_{dist}	Flow, Design Value					°C	
Daily running hours of the circulation	td_{Circ}	(Project)					h/d	
Design return temperature	ϑ_R	$=0.875*(\vartheta_{dist}-20)+20$					°C	
Annual running hours of the circulation	t_{Circ}	$= 365\, td_{Circ}$					h/a	
Annual heat release per m of pipe	q^*_Z	$= \Psi\,(\vartheta_m-\vartheta_X)\,t_{Circ}$					kWh/m/a	
Possible utilization factor of released heat	η_{GDHW}	$=t_{heating}/365d * \eta_G$					-	
Annual heat loss from circulation lines	Q_Z	$= L_{HS} \cdot q^*_Z \cdot (1-\eta_{GDHW})$				0	kWh/a	
Total length of individual pipes	L_U	(Project)					m	
Exterior pipe diameter	d_{U_Pipe}	(Project)					m	
Heat loss per tap opening	$q_{Individual}$	$=(c_{pH2O}V_{H2O}+c_{pMat}V_{Mat})(\vartheta_{dist}-\vartheta_X)$					kWh/tap opening	
Occupancy coefficient	n_{Tap}	$= n_{Pers} \,.\, 3 \,.\, 365 / n_{LU}$					Tap openings per year	
Annual heat loss	q_U	$= n_{Tap} \cdot q_{Individual}$					kWh/a	
Possible utilization factor of released heat	η_{G_U}	$=t_{heating}/8760*\eta_G$					-	
Annual heat loss of individual pipes	Q_U	$= q_U \cdot (1-\eta_{G\_U})$				0	kWh/a	
						Total 1,2,3		
Average heat released from storage	P_S						W	
Possible utilization factor of released heat	η_{G_S}	$=t_{heating}/8760*\eta_G$						
Annual heat losses from storage	Q_S	$= P_S \cdot 8.760\, kh \cdot (1-\eta_{G\_S})$				0	kWh/a	
						Total 1,2,3		
Total heat losses of the DHW system	Q_{WL}	$= Q_Z+Q_U+Q_S$				0	kWh/a	
Specif. losses of the DHW system	q_{WL}	$= Q_{WL} / A_{TFA}$					kWh/(m²a)	0.0
Performance ratio DHW-distribution + storage	$e_{a,WL}$	$= (q_{TWW} + q_{WV}) / q_{TWW}$				100.0%	-	
Total heat demand of DHW system	Q_{gDHW}	$= Q_{DHW}+Q_{WL}$				718	kWh/a	
Total spec. heat demand of DHW system	q_{gDHW}	$= Q_{gDHW} / A_{TFA}$					kWh/(m²a)	15.1

PHPP 2007, DHW + Distribution

105_Reduction Factor Solar

Figure S17. Heat distribution and domestic hot water calculation sheet.

Passive House Planning

ELECTRICITY DEMAND

Building: MM Studio

No. of households	1	HH
Persons	1.4	P
Treated floor area	47	m²
Annual Heating Demand	10	kWh/(m²a)

Solar Fraction of DHW Laundry&Dish	
Marginal Performance Ratio DHW	0%
Marginal Performance Ratio Heating	100%

Prim. Energy Factors:	Electricity	2.6	kWh/kWh
	Natural Gas	1.1	kWh/kWh
Energy Carrier for Space Heating/DHW:			

Column No.	1	2	3			4		5			6			7		8	8a		9		10		11		12		13	14
Application	Used ? (1/0)	Within the Thermal Envelope? (1/0)	Norm Demand			Utilization Factor		Frequency			Reference Quantity			Useful Energy (kWh/a)		Electric Fraction	Non-Electric Fraction		Electricity Demand (kWh/a)		Additional/ Reduced Demand		Marginal Performance Ratio		Solar Fraction		Non-Electric Demand (kWh/a)	Primary Energy-Demand (kWh/a)
Dishwashing	0	1	1.10	kWh/Use		1.00	*	65	/(P*a)	*	1.4	P	=	0	*	100%		=	0									0
Cold Water Connection															*		0%			* (1+	0.30	) *	0.00	*(1-		) =		
Clothes Washing	0	1	1.10	kWh/Use		1.00	*	57	/(P*a)	*	1.4	P	=	0	*	100%		=	0									0
Cold Water Connection															*		0%			* (1+	0.05	) *	0.00	*(1-		) =		
Clothes Drying with:	1	0	3.50	kWh/Use	Residual dampness	0.88	*	57	/(P*a)	*	1.4	P	=	0		0%		=	0									0
Clothesline					0.60								=	0			0%						1.00	*			0	0
Energy Consumed by Evaporation	1	0	0.00	kWh/Use		0.60	*	57	/(P*a)	*	1.4	P	=	0	*		100%			* (1+	0.00	) *	1.00	*(1-	0.77	) =	0	0
Refrigerating	0	1	0.78	kWh/d		1.00	*	365	d/a	*	1	HH	=	0	*	100%		=	0									0
Freezing	0	1	0.88	kWh/d		1.00	*	365	d/a	*	1	HH	=	0	*	100%		=	0									0
or Combined Unit	0	1	1.00	kWh/d		1.00	*	365	d/a	*	1	HH	=	0	*	100%		=	0									0
Cooking with:	1	1	0.25	kWh/Use		1.00	*	500	/(P*a)	*	1.4	P	=	170	*	100%		=	170									441
Electricity					Percentage CFLs										*		0%										0	0
Lighting	1	1	11	W	100%	1.00	*	2.90	kh/(P*a)	*	1.4	P	=	43	*	100%		=	43									113
Consumer Electronics	1	1	150	W		1.00	*	0.55	kh/(P*a)	*	1.4	P	=	112	*	100%		=	112									291
Small Appliances, etc.	1	1	50	kWh		1.00	*	1.00	/(P*a)	*	1.4	P	=	68	*	100%		=	68									176
Total Aux. Electricity														42					42									109
Other:																												
														0					0									0
														0					0									0
														0					0									0
Total														435	kWh				435	kWh	DHW Non-Electric - Laundry&Dish		0			kWh	0	1130
Specific Demand																			9.2	kWh/(m²a)	Non-Renewable Non-Electric DHW Laundry&Dish		0.0			kWh/(m²a)	0.0	23.8
Recommended Maximum Value																			18									50

PHPP 2007, Electricity

105_Reduction Factor Solar

Figure S18. Electricity demand calculation sheet

Passive House Planning

AUXILIARY ELECTRICITY

Building: MM Studio

1	Living Area	47.49	m²
2	Heating Period	205	d
3	Air Volume	119	m³
4	Dwelling Units	1	HH
5	Enclosed Volume	343	m³

Operation Vent. System Winter	4.91	kh/a
Operation Vent. System Summer	3.85	kh/a
Air Change Rate	0.30	h^{-1}
Defrosting HX from		°C

Primary Energy Factor - Electricity	2.6	kWh/kWh
Annual Space Heating Demand	10	kWh/(m²a)
Boiler Rated Power	15	kW
DHW System Heat Demand	718	kWh/a
Design Flow Temperature	0	°C

Column No.	1	2	3		4		5		6		7	8	9	10	11
Application	Used ? (1/0)	Within the Thermal Envelope? (1/0)	Norm Demand		Utilization Factor		Period of Operation		Reference Size		Electricity Demand (kWh/a)	Available as Interior Heat	Used During Time Period (kh/a)	Internal Heat Source (W)	Primary Energy Demand (kWh/a)
Ventilation System															
Winter Ventilation	1	1	0.24	Wh/m³	* 0.30	h^{-1}	* 4.9	kh/a	* 118.735	m³	= 42	considered in heat recovery efficiency			109
Summer Ventilation	0	1	0.24	Wh/m³	* 0.30	h^{-1}	* 3.9	kh/a	* 118.735	m³	= 0	no summer contribution to IHG			0
Defroster HX	1	1	0	W	* 1.00		* 0.2	kh/a	* 1		= 0	* 1.0	/ 4.91	= 0	0
Heating System					Controlled/Uncontrolled (1/0)										
Enter the Rated Power of the Pump				W	1										
Circulation Pump	0	0	96	W	* 0.8		* 4.9	kh/a	* 1		= 0	* 1.0	/ 4.91	= 0	0
Boiler Electricity Consumption at 30% Load				W											
Aux. Energy - Heat Boiler	0	0	55	W	* 1.00		* 0.00	kh/a	* 1		= 0	* 1.0	/ 4.91	= 0	0
DHW system															
Enter Average Power Consumption of Pump				W											
Circulation Pump	0	0	28	W	* 1.00		* 4.3	kh/a	* 1		= 0	* 0.6	/ 8.76	= 0	0
Enter the Rated Power of the Pump				W											
Storage Load Pump DHW	0	0	50	W	* 1.00		* 0.0	kh/a	* 1		= 0	* 1.0	/ 4.91	= 0	0
Boiler Electricity Consumption at 100% Load				W											
DHW Boiler Aux. Energy	0	0	165	W	* 1.00		* 0.0	kh/a	* 1		= 0	* 1.0	/ 4.91	= 0	0
Enter the Rated Power of the Solar DHW Pump				W											
Solar Aux Electricity	0	1	35	W	* 1.00		* 1.8	kh/a	* 1		= 0	* 0.6	/ 8.76	= 0	0
Misc. Aux. Electricity															
Misc. Aux. Electricity	0	1	1200	kWh/a	* 1.00		* 1.0		* 1	HH	= 0	* 1.0	/ 8.76	= 0	0
Total											42			0	109
Specific Demand	kWh/(m²a)		Divide by Living Area:								0.9				2.3

PHPP 2007, Aux Electricity

105_Reduction Factor Solar

Figure S19. Auxiliary electricity calculation sheet

Passive House Planning

PRIMARY ENERGY VALUE

Building:	MM Studio		Building type/use:	Studio	
Location:	Dundee		Treated floor area A_{TFA}:	47	m²
Enter data			Space heating demand incl. distribution:	10	kWh/(m²a)
			Useful cooling demand:	0	kWh/(m²a)

			Final Energy	Primary Energy	Emissions CO_2-Equivalent
			kWh/(m²a)	kWh/(m²a)	kg/(m²a)
Electricity demand (without heat pump)				PE Value	CO_2-Emissions Factor (CO_2-Equivalent)
Covered fraction of space heating demand		*(Project)*	100%	kWh/kWh	g/kWh
Covered fraction of DHW demand		*(Project)*	0%	2.6	680
Direct electric heating	$Q_{H,de}$		10.4	27.1	7.1
DHW production, direct electric (without laundry&dish)	$Q_{DHW,de}$	*(DHW+Distribution, SolarDHW)*	0.0	0.0	0.0
Electric postheating DHW laundry&dish		*(Electricity, SolarDHW)*	0.0	0.0	0.0
Electricity demand household appliances	Q_{EHH}	*(Electricity worksheet)*	8.3	21.5	5.6
Electricity demand - Auxiliary electricity			0.9	2.3	0.6
Total electricity demand (without heat pump)			19.6	50.9	13.3
Heat pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered fraction of space heating demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered fraction of DHW demand		*(Project)*	0%	2.6	680
Energy carrier - Supplementary heating			Electricity	2.6	680
Annual coefficient of performance - Heat pump		*Separate Calculation*			
Total system performance ratio of heat generator		*Separate Calculation*			
Electricity demand heat pump (without DHW laundry&dish)	Q_{HP}		0.0	0.0	0.0
Non-electric demand, DHW laundry&dish		*(Electricity worksheet)*	0.0	0.0	0.0
Total electricity demand heat pump			0.0	0.0	0.0
Compact heat pump unit				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered fraction of space heating demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered fraction of DHW demand		*(Project)*	0%	2.6	680
Energy carrier - Supplementary heating			Electricity	2.6	680
COP heat pump heating		*(Compact worksheet)*	0.0		
COP Heat pump DHW		*(Compact worksheet)*	0.0		
Performance ratio of heat generator (Verification)		*(Compact worksheet)*			
Performance ratio of Heat generator (Planning)		*(Compact worksheet)*			
Electricity demand heat pump (without DHW laundry&dish)	Q_{HP}	*(Compact worksheet)*	0.0	0.0	0.0
Non-electric demand, DHW laundry&dish			0.0	0.0	0.0
Total compact unit		*(Compact worksheet)*	0.0	0.0	0.0
Boiler				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered fraction of space heating demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered fraction of DHW demand		*(Project)*	0%		
Boiler type		*(Boiler worksheet)*			
Performance ratio of heat generator		*(Boiler worksheet)*	0%		
Annual energy demand (without DHW laundry&dish)		*(Boiler worksheet)*	0.0	0.0	0.0
Non-electric demand, DHW laundry&dish		*(Electricity worksheet)*	0.0	0.0	0.0
Total heating oil/gas/wood			0.0	0.0	0.0
District heat				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered fraction of space heating demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered fraction of DHW demand		*(Project)*	0%	0.0	0
Heat source		*(District Heat worksheet)*			
Performance ratio of heat generator		*(District Heat worksheet)*	0%		
Heating demand district heat (without DHW laundry&dish)		*(District Heat worksheet)*	0.0	0.0	0.0
Non-electric demand, DHW laundry&dish		*(Electricity worksheet)*	0.0	0.0	0.0
Total district heat			0.0	0.0	0.0
Other				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered fraction of space heating demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered fraction of DHW demand		*(Project)*	0%	0.2	55
Heat source		*(Project)*	Wood		
Performance ratio of heat generator		*(Project)*			
Annual energy demand, space heating			0.0	0.0	0.0
Annual energy demand, DHW (without DHW laundry&dish)			0.0	0.0	0.0
Non-electric demand, DHW laundry&dish		*(Electricity worksheet)*	0.0	0.0	0.0
Non-electric demand cooking/drying (gas)		*(Blatt Strom)*	0.0	0.0	0.0
Total - Other			0.0	0.0	0.0
Cooling with electric heat pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
				kWh/kWh	g/kWh
Covered fraction of cooling demand		*(Project)*	100%	2.6	680
Heat source			Electricity		
Annual cooling COP					
Energy demand space cooling			0.0	0.0	0.0
Heating, cooling, DHW, auxiliary and household electricity			19.6	50.9	13.3
Total PE Value		50.9	kWh/(m²a)		
Total Emissions CO_2-Equivalent		13.3	kg/(m²a)		(Yes/No)
		Primary Energy Requirement	120	kWh/(m²a)	Yes
Heating, DHW, auxiliary electricity (no household applications)			11.3	29.4	7.7
Specific PE Demand - Mechanical System		29.4	kWh/(m²a)		
Total Emissions CO_2-Equivalent		7.7	kg/(m²a)		
Solar electricity			kWh/a	PE Value (Savings)	CO_2-Emission Factor
Planned annual electricity generation		*Separate Calculation*		kWh/kWh	g/kWh
				0.7	250
Specific Primary Energy Reduction					
PE Value: Reduction through solar electricity			kWh/(m²a)		
CO_2-emissions avoided due to solar electricity			kg/(m²a)		

PHPP 2007, PE Value | 105_Reduction Factor Solar

Figure S20. Primary energy calculation sheet

Passive House Planning

CLIMATE DATA

Standard/regional climate: Select here: Regional climate data

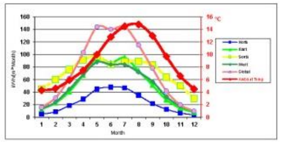
Select region here: User Data

Select regional climate here: East of Scotland

Building:	MM Studio		
Use regional data?	Yes		
Climate building	East of Scotland		
Chosen method for annual heating demand:	Annual method		
Monthly data:	East of Scotland		
Annual data:			
Use annual climate data set	No		
Results:			
Annual heating demand	10.4	kWh/(m²a)	
Heating load	11.6	W/m²	

Transfer to annual method

H_T	205	d/a
G_t	69	kKh/a
North	77	kWh/(m²a)
East	173	kWh/(m²a)
South	386	kWh/(m²a)
West	190	kWh/(m²a)
Horizontal	251	kWh/(m²a)



	Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating Load		Cooling Load
	Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Radiation
Parameters for PHPP calculated ground temperatures:	East of Scotland	Latitude:	56.5	Longitude ° East	-3.1	Altitude m	30		Daily Temperature Swing Summer (K)		5.1	Radiation Data:	kWh/(m²month)	Radiation: W/m²		W/m²
Phase shift months	Ambient Temp	4.3	4.6	5.9	7.5	10.0	12.8	14.5	14.8	13.0	9.7	6.6	4.5	-1.4	0.6	16.4
2.00	North	5	9	19	29	45	48	47	35	22	13	7	4	5	5	60
Damping	East	13	23	41	67	94	87	95	74	51	28	15	8	13	10	163
-1.05	South	45	60	76	91	97	84	89	89	84	64	50	30	53	36	152
Depth m	West	14	24	45	68	88	84	84	72	57	33	18	10	15	11	138
3.32	Global	16	31	62	103	144	140	144	115	78	42	20	10	15	13	236
Shift of average temperature K	Dew Point	1.7	1.3	2.2	3.7	6.2	8.8	10.8	11.4	9.5	6.5	3.9	1.9	3d	3d	3d
1.60	Sky Temp	-6.3	-6.2	-4.8	-3.6	-1.0	2.5	4.8	5.6	3.5	0.3	-3.4	-5.8			3.3
	Ground Temp	10.5	9.8	9.9	10.6	11.8	13.2	14.4	15.0	15.0	14.3	13.1	11.7	9.8	9.8	16.3

PHPP 2007, Climate Data

105_Reduction Factor Solar

Figure S21. Climate data calculation sheet.

Passive House Planning

INTERNAL HEAT GAINS

Building: MM Studio

Utilisation Pattern: Residential building — 2.10 W/m²

Type of Values Used: Standard

No entry required — W/m²

Calculation Internal Heat Household		Persons	1.4	P				Annual Heating Demand	10	kWh/(m²a)		
		Living Area	47	m²				Heating Period	205	d/a		

Column No.	1	2	3		4	5		6	7	8	9	10
Application	Existing (1/0), or number of people	In the Thermal Envelope (1/0)	Norm Consumption		Utilization Factor	Frequency		Useful Energy (kWh/a)	Included in Electricity Balance?	Availability	Used During Time Period (kh/a)	Internal Heat Source (W)
Dishwashing	0	1	1.1	kWh/Use	1.00	65	/(P*a)	0	*	0.30	/ 8.76	= 0
Clothes Washing	0	1	1.1	kWh/Use	1.00	57	/(P*a)	0	*	0.30	/ 8.76	= 0
Clothes Drying with:	1	0	3.5	kWh/Use	0.88	57	/(P*a)	0	*	1.00	/ 8.76	= 0
Clothesline		0	0.0					0		0.80		
Energy Consumed by Evaporation	1	0	0.0	kWh/Use	0.60	57	/(P*a)	0	* (1- 0) *	1.00	/ 8.76	= 0
Refrigerating	0	1	0.8	kWh/d	1.00	365	d/a	0	*	1.00	/ 8.76	= 0
Freezing	0	1	0.9	kWh/d	1.00	365	d/a	0	*	1.00	/ 8.76	= 0
or Combination	0	1	1.0	kWh/d	1.00	365	d/a	0	*	1.00	/ 8.76	= 0
Cooking	1	1	0.3	kWh/Use	1.00	500	/(P*a)	170	*	0.50	/ 8.76	= 10
Lighting	1	1	11.0	W	1.00	2.9	kh/(P*a)	43	*	1.00	/ 8.76	= 5
Consumer Electronics	1	1	150.0	W	1.00	0.55	kh/(P*a)	112	*	1.00	/ 8.76	= 13
Household Appliances/Other	1	1	50.0	kWh	1.00	1.0	/(P*a)	68	*	1.00	/ 8.76	= 8
Auxiliary Appliances (cf. Aux Electricity Sheet)												= 0
Other Applications (cf. Electricity Sheet)	0	0.0						0	*	0	/ 8.76	= 0
Persons	1	1	80.0	W/P	1.00	8.76	kh/a	951	*	0.55	/ 8.76	= 60
Cold Water	1	1	-5.0	W/P	1.00	8.76	kh/a					= -7
Evaporation	1	1	-25.0	W/P	1.00	8.76	kh/a	-297	*	1.00	/ 8.76	= -34
Total											W	**54**
Specific Demand											W/m²	**1.14**
Heat Available From Internal Sources									204.5 d/a		kWh/(m²a)	**5.6**

PHPP 2007, IHG — 105_Reduction Factor Solar

Figure S22. Internal heat gains calculation sheet.

References

1. Burford, N; Robertson, C. Prototype Zero Energy Studio: A research-led, student-centred live build project. Available online: http://macromicrodundee.wordpress.com (accessed on 20 May 2016).
2. Macro Micro Studio Blog. Available online: http://macromicrodundee.wordpress.com (accessed on 18 May 2016).