EnerPHit & Passive House School

Final Design Submission

ARCH 2181: Retrofit Technology Project

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DT774a PG Dip DAER
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School Project

Introduction and Project Outline

The aim of this project is to demonstrate the function of PHPP (Passive House Planning Package) software as a key design tool when planning buildings to achieve EnerPHit or Passive House. PHPP serves as the basis for verification of EnerPHit and the Passive House standard. Using PHPP it is undertaken to:

- Assess the energy performance of the existing building
- Propose a retrofit solution to achieve EnerPHit standard
- Propose a new build solution to achieve Passive House standard

Baseline Performance & Design Targets

	Baseline Building	EnerPHit Targets	Passive House Targets
Annual heating demand kWh/m²/y	127	25 OR	15 OR
Heating load W/m²	57	10	10
Overheating frequency %	0.3	<10% @25°	<10% @25°
Primary energy kWh/m²/y	51	130	120
Air Tightness N_{50}	4.6	1	0.6

Baseline Building Description

The subject building is a 2 storey primary school consisting mainly of 8 no. classrooms, gym and ancillary areas with all the classrooms south facing. The Architectural response incorporated passive solar design, natural ventilation and natural daylight with a focus on thermal performance and energy use.

Baseline School Building PHPP Energy Assessment & Analysis

South elevation

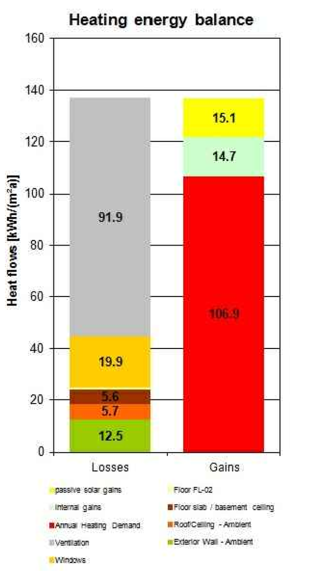
North elevation

PHPP as an Energy Assessment Tool

The energy performance of the school was assessed using PHPP. In the verification sheet, the certification type is selected from the EnerPHit for retrofit or Passive House option. Results are then presented against the requirements of the selected standard and the success/failure to meet each criteria is shown.

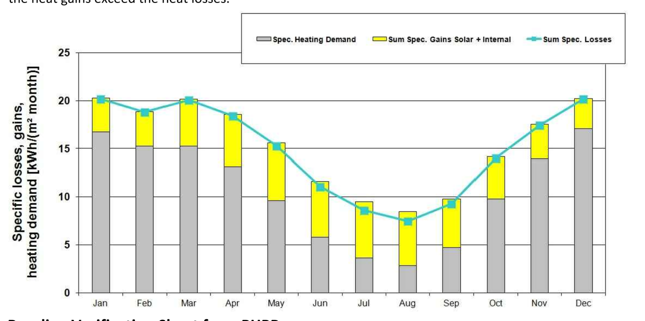
Heating Balance - Gains vs Losses

Further analysis can then be carried out via the Annual Heat Demand sheet and the heating balance graph. The graph gives a concise and visual breakdown of the heat losses and gains in kWh/m² and is useful in giving the designer an overview of the building's performance. An initial design strategy can be formulated by identifying problem areas and reasons for high energy demand. In the baseline case it is obvious that ventilation is the most significant area of interest. Losses through ventilation also indicate the airtightness of the building. The school is naturally ventilated meaning there is very little control over ventilation heat losses. Immediately it is apparent that the first step in a retrofit strategy, to reduce energy demand, should start with reducing the ventilation losses. After the ventilation losses are addressed it can be deduced that the windows and external walls could be looked at in more detail. The roof is already insulated to Passive levels and although the floor is performing poorly, it would be costly disruptive and to upgrade for comparatively small reductions in overall building fabric heat losses.



Monthly Method - Specific Annual Heating Demand

The specific annual heat demand is determined in PHPP using the monthly method. This section of PHPP uses climate data and occupancy patterns, along with internal and external gains, to determine the space heating loads. The monthly method can also be a good indicator of overheating as it clearly shows when the heat gains exceed the heat losses.



Baseline Verification Sheet from PHPP

			Requirements	Fulfilled?
	Treated floor area	1691.9 m²		
Space heating	Annual heating demand	127 kWh/(m²a)	25 kWh/(m²a)	no
	Heating load	57 W/m²		-
Space cooling	Overall specific space cooling demand	kWh/(m²a)		-
	Cooling load	W/m²		-
	Frequency of overheating (> 25 °C)	0.3 %		-
Primary Energy	Space heating and cooling, dehumidification, household electricity	251 kWh/(m²a)	256 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	194 kWh/(m²a)		-
	Specific primary energy reduction through solar electricity	kWh/(m²a)		-
Airtightness	Pressurization test result n_{50}	4.6 1/h	1 1/h	no

Achieving EnerPHit

Initially the design approach taken to reach EnerPHit was one which would minimize intrusive and extensive building works while addressing the key heat loss areas. However, the EnerPHit air tightness requirement of N_{50} 1 means extensive internal works is unavoidable if we are to confidently achieve this level. Since the air tightness works will need access to ceilings and roof spaces it therefore makes sense to specify a centralized MVHR system rather than a decentralized option such as the 'AirMaster' HRV. These units would make sense in retrofit situations where intrusive internal works are avoidable or undesired. It is anticipated that all works will be carried out during the summer months, thus having no impact on the school year. Reaching EnerPHit is essentially a ventilation solution. By addressing the air tightness and introducing mechanical ventilation with heat recovery we are 93% of the way to achieving our goal. The air tightness criteria must be satisfied so the big decision seems to be choosing the most suitable, efficient MVHR system. Pumping the existing external wall cavity with insulation with improve the energy performance of the building fabric. In addition this measure will raise internal surface temperatures and reduce risk of surface condensation and mould growth. Replacing the existing poorly performing window frames throughout with a passive house standard alternative is the final step needed to achieve the EnerPHit Annual Heating demand criteria of 25kWh/m². Meeting the Primary Energy criteria is easily done by introducing daylight responsive dimmer/off lighting in areas with external windows and occupant responsive lighting to the circulation areas and toilets. These 5 steps will take the building to EnerPHit but further measures have been taken to address the overheating potential and ensure that the building environment is comfortable for the occupants at all times. I have anticipated that the building, even after the retrofit, will have additional heat losses from thermal bridges. These losses might increase the heating demand by 10%. Reaching an annual heating demand of 21 kWh/m² allows a buffer zone to absorb thermal bridge losses.

EnerPHit Retrofit Design Process

Step	Improvement Measure	Annual Heating Demand kWh/m²/y	Heating Load W/m²	Overheating % (>25°C)	Primary Energy kWh/m²/y	Comments/Values
Baseline		127	57	0.3	251	
Step 1 - Ventilation	Air Tightness N_{50} 1	83	31	2.9	199	See Air Tightness strategy spec. and drawings
Step 2 - Ventilation	MVHR – Aerosilent centro 1200 x 4 units to meet supply air demand 3600m³/h. Building divided into 4 zones	32	19	2.9	141	Set air change rate to standard (0.77 ach/h) during occupied times and minimum air changes (0.60 ach/h) at other times
Step 3 - U-Values (Ext. Wall)	Pump air cavity with ecobeads or similar 15mm plaster internally	30	18	4.0	138	U-Value = 0.212 W/m²K. This will help raise the internal surface temperatures
Step 4 - Windows (Frames)	Munster joinery Ecoclad 120+ frames	24	16	8.6	132	The existing frames are a significant thermal bridge with a very poor U-Value
Step 5 - Electricity (lighting control)	Light responsive dimmers/off to rooms with external windows. PIR light detectors to circulation/toilets	24	16	8.6	108	
Step 6 - Windows (glazing)	Replace solar therm triple glazing throughout. Planitherm Ultra N double glazing to classrooms	23	16	11.0	131	The existing glazing is performing reasonably well and the EnerPHit target has been reached. However, it makes sense to upgrade the glazing spec. along with the frames. This results in overheating frequency above the 10% threshold and an increase in Primary Energy
Step 7 - Ventilation	In the summer tab under the MVHR to provide minimum air changes of 0.3 ach/h during summer months. Heat recovery set to summer bypass	21	16	11.0	131	This step solves the overheat problem on paper but shouldn't be relied on. Revert

It should be noted that overheating of 11% at 25°C is 17% at 23°C. This is a significant duration of time for the internal building environment to be uncomfortable for the occupants. The overheating is caused by unwanted solar gains during summer time. A better solution to relying on the MV would be to prevent these gains from getting into the building. This can be done by permanent and temporary shading to selected south facing windows. Natural ventilation through windows and minimum air changes through the mechanical ventilation can then be use as further options to cool the building. It could be argued that as this building is a school and will be closed during the summer time and we therefore don't need to worry about overheating during these times.

Step	Improvement Measure	Annual Heating Demand kWh/m²/y	Heating Load W/m²	Overheating % (>25°C)	Primary Energy kWh/m²/y	Comments/Values
Step 8 - Thermal Mass	In the summer tab change the thermal mass of the building to reflect the mixed construction	21	16	7.5	131	Overheating at 23°C is 19.6%. Continue
Step 9 - Shading	Temporary summer shading device to high level windows in classrooms	21	16	3.9	131	Overheating at 23°C is 11.8%. Continue
Step 10 - Shading	External shading shelf at 2250mm to classroom windows	21	16	2.9	131	This will improve the visual comfort levels in the areas next to the window. Overheating at 23°C is 11.0%. Continue
Step 11 - Summer Ventilation	Single sided daytime ventilation by opening windows in classroom for 30ms each day. Openings restricted to 150mm	21	16	0.7	131	Overheating at 23°C is 9.8%. Continue
Step 12 - Summer Ventilation	Set MVHR to summer bypass and to provide the minimum air changes of 0.3 ach/h	21	16	0.1	131	Summer tab in PHPP. Overheating at 23°C is 2.1%

PHPP Verification of EnerPHit Building RetroPHit

			Requirements	Fulfilled?
	Treated floor area	1691.9 m²		
Space heating	Annual heating demand	21 kWh/(m²a)	25 kWh/(m²a)	yes
	Heating load	16 W/m²		-
Space cooling	Overall specific space cooling demand	kWh/(m²a)		-
	Cooling load	W/m²		-
	Frequency of overheating (> 25 °C)	0.9 %		-
Primary Energy	Space heating and cooling, dehumidification, household electricity	122 kWh/(m²a)	127 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	72 kWh/(m²a)		-
	Specific primary energy reduction through solar electricity	kWh/(m²a)		-
Airtightness	Pressurization test result n_{50}	1.0 1/h	1 1/h	yes

EnerPHit building retrofit (acc. to heating demand)? yes

Proposed Fabric Thermal Conductivity

	Baseline Building	EnerPHit Retrofit
External Walls	0.255 W/m²K	0.212 W/m²K
Ground Floor Type 1	0.352 W/m²K	0.352 W/m²K
Ground Floor Type 2	0.309 W/m²K	0.309 W/m²K
Roof Type 1	0.113 W/m²K	0.113 W/m²K
Roof Type 2	0.107 W/m²K	0.107 W/m²K
Roof Type 3	0.110 W/m²K	0.110 W/m²K
Floor Soffit (rear entrance door)	0.332 W/m²K	0.119 W/m²K
Windows	1.63 W/m²K	0.98W/m²K

Achieving Passive House

The proposed design is based around achieving the basic principles of Passive House construction:

Thermal Insulation: Opaque external building components to have U-Values less than 0.15 W/m²K.
Passive House Windows: Insulated window frames with low-e argon filled glazing. g-values around 50%.
Ventilation Heat Recovery: Mechanical Heat recovery ventilation with at least 75% efficiency.
Air Tightness of the Building: Uncontrolled leakage through gaps smaller than 0.6 of the total building volume per hour during an pressure test at 50 pascal.
Avoid Thermal Bridges: Edges, corners, connections and penetrations detailed to avoid thermal bridges.

Designing and building this school anew, and to Passive House standard is a much easier challenge than retrofitting to reach EnerPHit standard. It would also be a more cost efficient option when you consider the original school building construction cost together with the costs (which will be extensive) for the EnerPHit retrofit. Key construction items, such as air tightness, can be detailed in advance with the construction monitored and tested at various building phases. Using the EnerPHit retrofit strategy, I have taken further measures beyond Passive House standard to ensure occupant comfort and reduce the carbon footprint of the building. It was a concern that both the EnerPHit and Passive House solutions incurred an increased Primary Energy demand over the baseline building. Thus, I have sought efficiencies through daylight and occupant responsive lighting design together with low energy light fittings. Low energy electrical equipment and computers will also help reduce the Primary Energy demand.

Passive House New Building - Design Process

Step	Improvement Measure	Annual Heating Demand kWh/m²/y	Heating Load W/m²	Overheating % (>25°C)	Primary Energy kWh/m²/y	Comments/Values
Baseline		127	57	0.3	251	
Step 1 - Ventilation	Air Tightness N_{50} 0.6	77	29	2.8	192	See Air Tightness strategy spec. and drawings
Step 2 - Ventilation	MVHR – Aerosilent centro 1200 x 4 units to meet supply air demand 3600m³/h. Building divided into 4 zones	28	18	5.4	140	Set air change rate to standard (0.77 ach/h) during occupied times and minimum air changes (0.60 ach/h) at other times
Step 3 - Summer Ventilation	Mechanical ventilation to provide minimum summer air changes of 0.3 ach/h	28	18	5.4	136	Summer tab in PHPP
Step 4 - U-Values (external walls)	Weberitherm XM external wall insulation system on 215mm concrete block structure	21	14	5.8	120	U-Value = 0.119 W/m²K
Step 5 - U-Values (ground floor)	200mm Kingspan K3 insulation under 150mm floor slab	17	13	6.0	121	U-Value = 0.94/0.98 W/m²K
Step 6 - U-Values	Wrap EWI under soffit over rear entrance door	16	13	6.0	121	U-Value = 0.119 W/m²K
Step 7 - Thermal Mass	Heavyweight wall and floor construction	15	13	5.4	121	Summer tab in PHPP
Step 8 - Electricity (lighting control)	Light responsive dimmers/off to rooms with external windows. PIR light detectors to circulation/toilets	15	13	5.4	116	

Although we have met the Passive House criteria, the design process should continue to ensure comfort of the construction and design standards. The following steps are inexpensive but will contribute significantly to the quality of the finished building and to the comfort of the internal environment.

Step	Improvement Measure	Annual Heating Demand kWh/m²/y	Heating Load W/m²	Overheating % (>25°C)	Primary Energy kWh/m²/y	Comments/Values
Step 9 - Windows (frames)	Munster joinery Ecoclad 120+ frames	13	12	5.4	112	We are at Passive House standard with inefficient window frames. Any new building attaining PH would be expected have better performing components
Step 10 - Windows (glazing)	Low-e argon filled double glazing throughout. Planitherm Ultra N double glazing to classrooms	10	11	5.7	112	There is no need to reduce heat losses further and therefore the expense of triple glazing is not necessary. A pane double-glazing unit for a Passive House design. The higher light transmission glazing in the classrooms will improve daylighting. Overheating is creeping up
Step 10 - Shading	Temporary summer shading device to high level windows in classrooms	10	11	4.7	112	Overheating at 23°C is 13.3%. Continue
Step 11 - Shading	External shading shelf at 2250mm to classroom windows	10	11	3.9	112	Overheating at 23°C is 12.2%. Continue
Step 12 - Summer Ventilation	Single sided daytime ventilation by opening windows in classroom for 30ms each day. Openings restricted to 150mm	10	11	0.8	112	Overheating at 23°C is 8.3%
Step 13 - Electricity	High efficiency lighting throughout	10	11	0.8	91	3.0 W/m²
Step 14 - Electricity	High efficiency equipment	10	11	0.6	86	Select low energy options for kitchen, laundry, classroom and office equipment

PHPP Verification of Passive House

			Requirements	Fulfilled?
	Treated floor area	1691.9 m²		
Space heating	Annual heating demand	10 kWh/(m²a)	15 kWh/(m²a)	yes
	Heating load	11 W/m²	10 W/m²	
Space cooling	Overall specific space cooling demand	kWh/(m²a)		-
	Cooling load	W/m²		-
	Frequency of overheating (> 25 °C)	0.6 %		-
Primary Energy	Space heating and cooling, dehumidification, household electricity	85 kWh/(m²a)	120 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	43 kWh/(m²a)		-
	Specific primary energy reduction through solar electricity	kWh/(m²a)		-
Airtightness	Pressurization test result n_{50}	0.6 1/h	0.6 1/h	yes

Passive House? yes

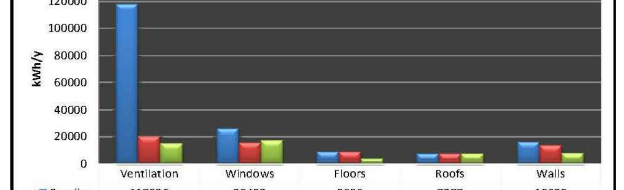
Proposed Fabric Thermal Conductivity

	Baseline Building	Passive House
External Walls	0.255 W/m²K	0.119 W/m²K
Ground Floor Type 1	0.352 W/m²K	0.098 W/m²K
Ground Floor Type 2	0.309 W/m²K	0.094 W/m²K
Roof Type 1	0.113 W/m²K	0.113 W/m²K
Roof Type 2	0.107 W/m²K	0.107 W/m²K
Roof Type 3	0.110 W/m²K	0.110 W/m²K
Floor Soffit (rear entrance door)	0.332 W/m²K	0.119 W/m²K
Windows	1.63 W/m²K	0.98 W/m²K

Certification of Proposed Building Components

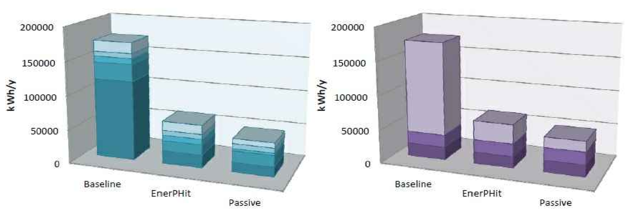
EnerPHit Retrofit	Passive House	Lambda λ W/mK	Location
Kingspan Ecobeads		0.033	External walls
	Kingspan K3 insulation	0.020	Ground Floors
Quinn-lite B5 blocks	Quinn-lite B5 blocks	0.12	External walls
	Weberitherm XM EWI	0.025	External walls
Kingspan Ecoclad+	Kingspan Ecoclad+		Windows
Haubler glass			Windows
Aerosilent centro 1200	Aerosilent centro 1200		MVHR
Armaflex insulation	Armaflex insulation	0.031	Exhaust/intake ductwork

Proposed Heat Loss Reductions



	Ventilation	Windows	Floors	Roofs	Walls
Baseline	157896	21482	8180	7277	16029
EnerPHit	19679	15371	8180	7277	13327
Passive	14143	17172	3329	7277	7467

Heating Energy Balance

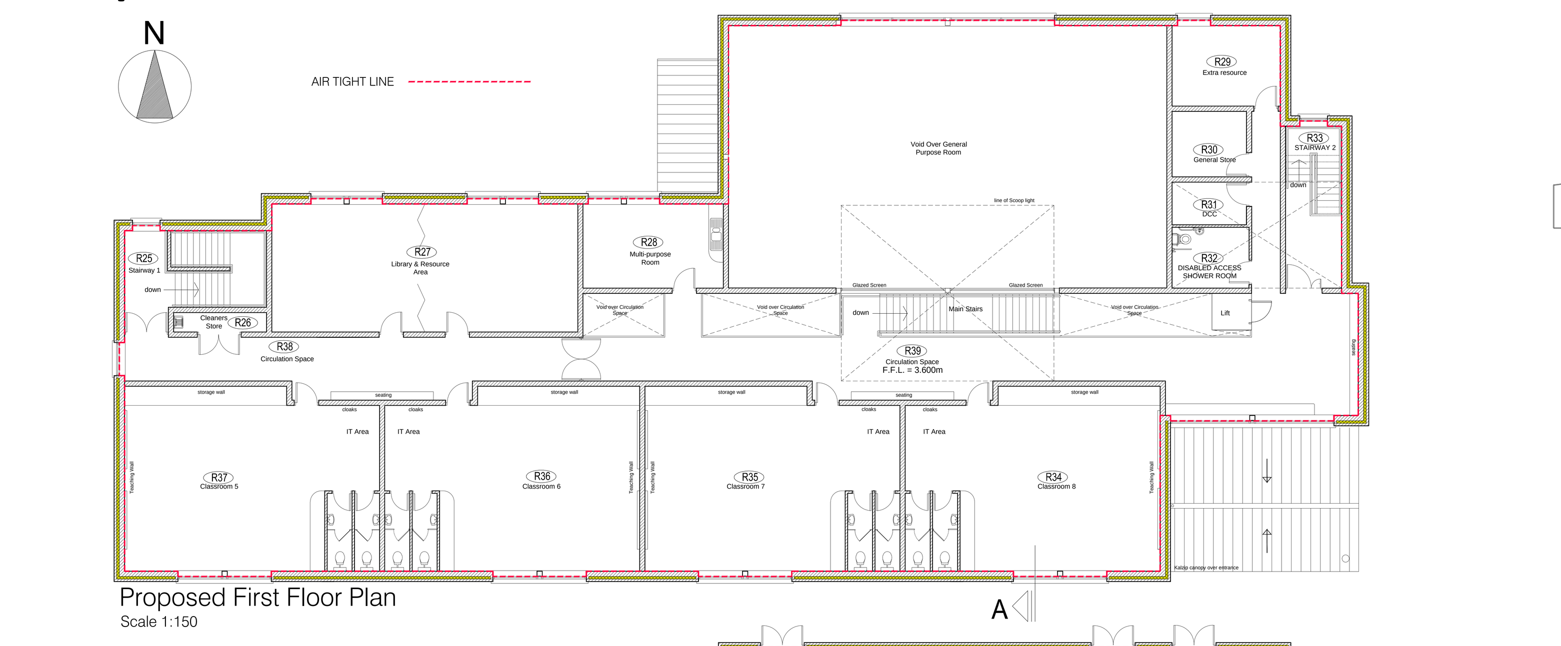


Annual Heating Demand Savings

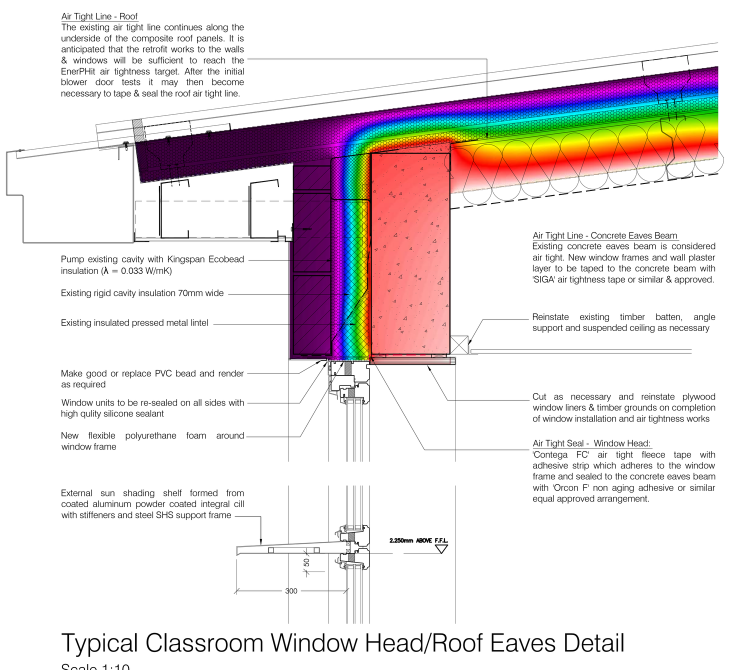
EnerPHit Retrofit: 83.5%

Passive House: 92.1%

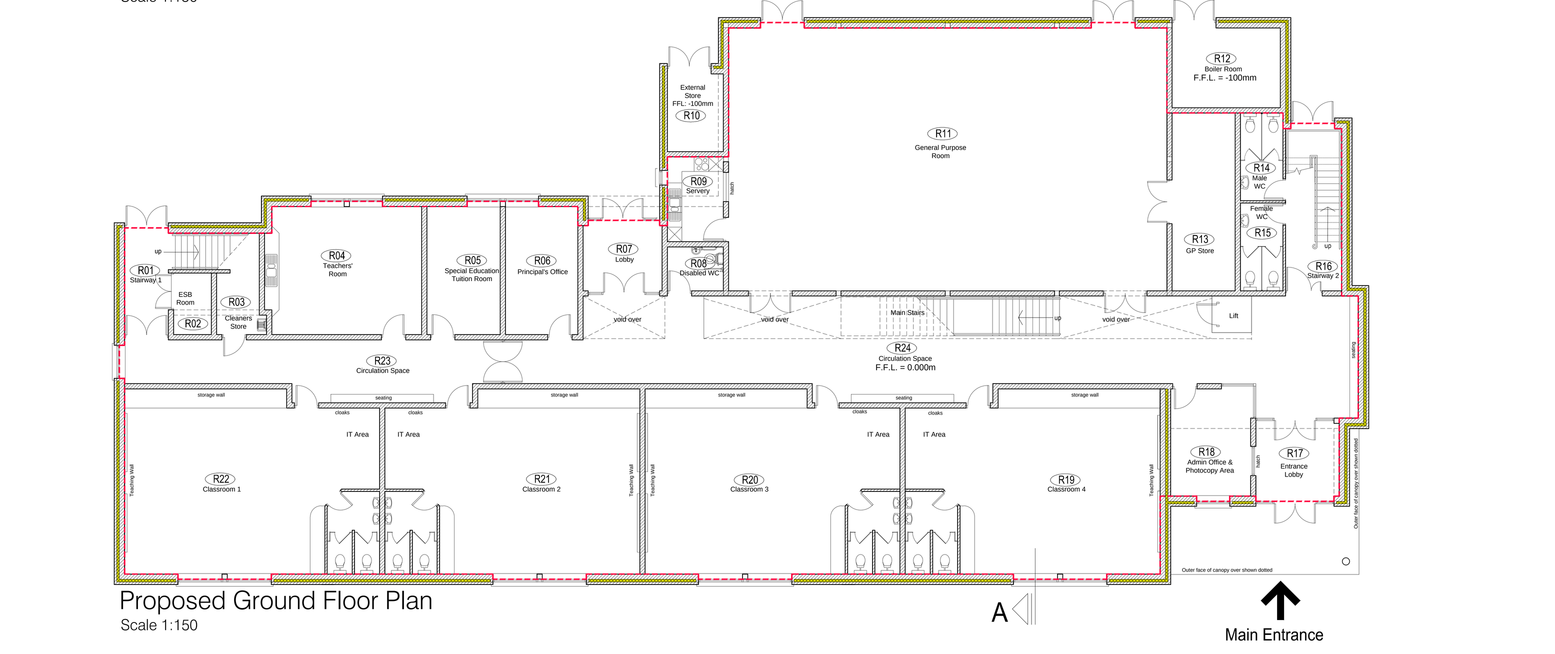
Proposed EnerPHit Retrofit Plans, Elevations, Section and Details



Proposed First Floor Plan
Scale 1:150

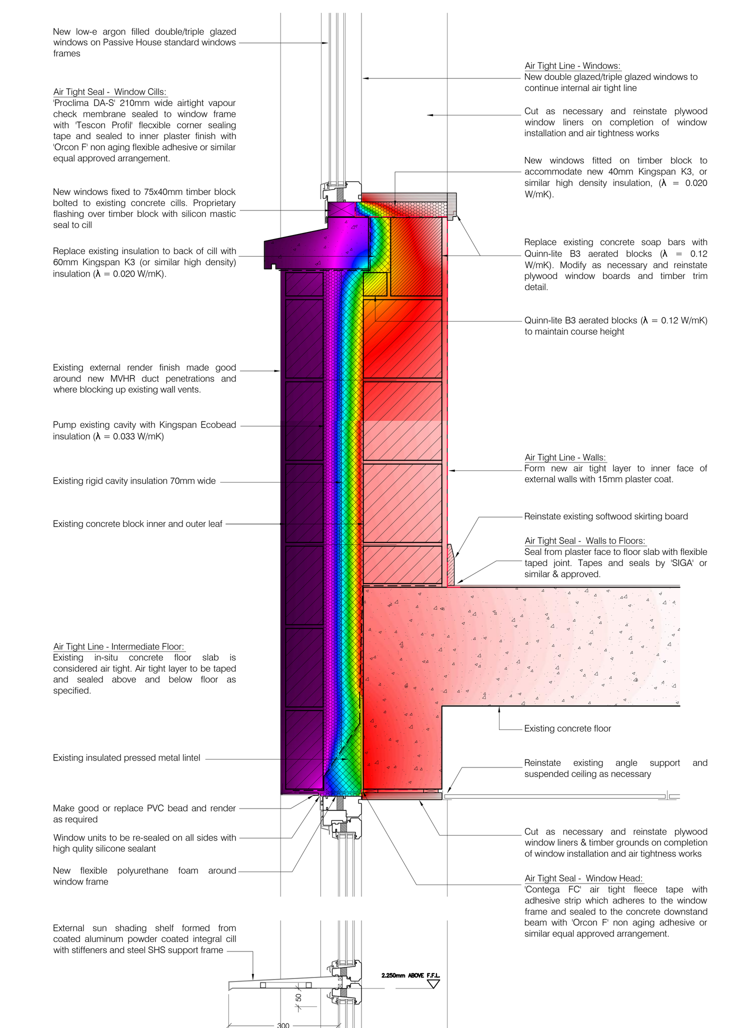


Typical Classroom Window Head/Roof Eaves Detail
Scale 1:10



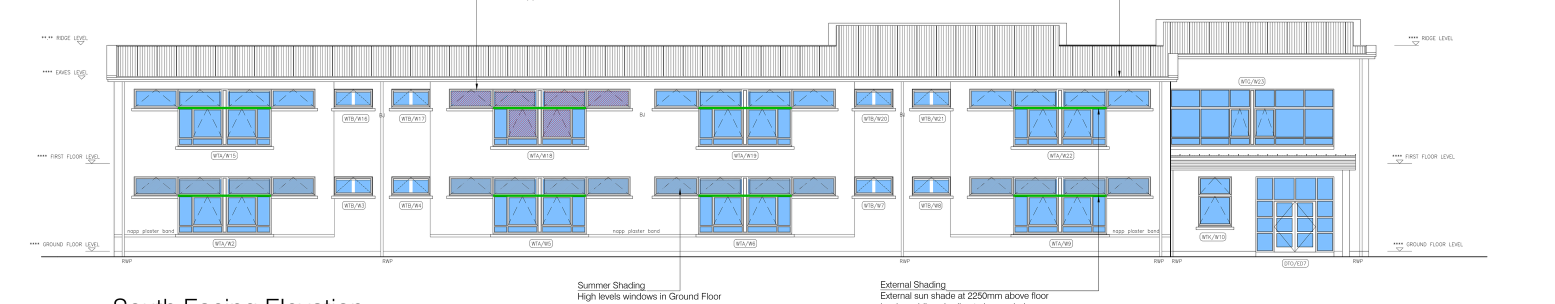
Proposed Ground Floor Plan
Scale 1:150

Main Entrance

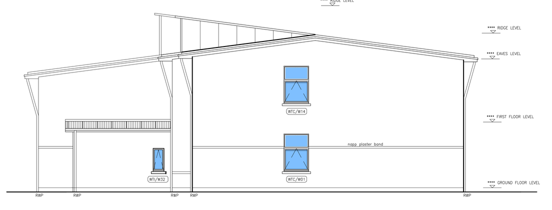


Typical Classroom Window Head/Intermediate Floor Detail
Scale 1:10

North Facing Elevation
Scale 1:150

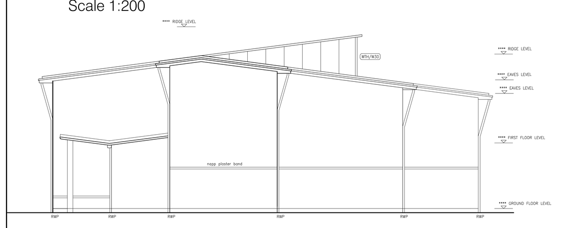


South Facing Elevation
Scale 1:150

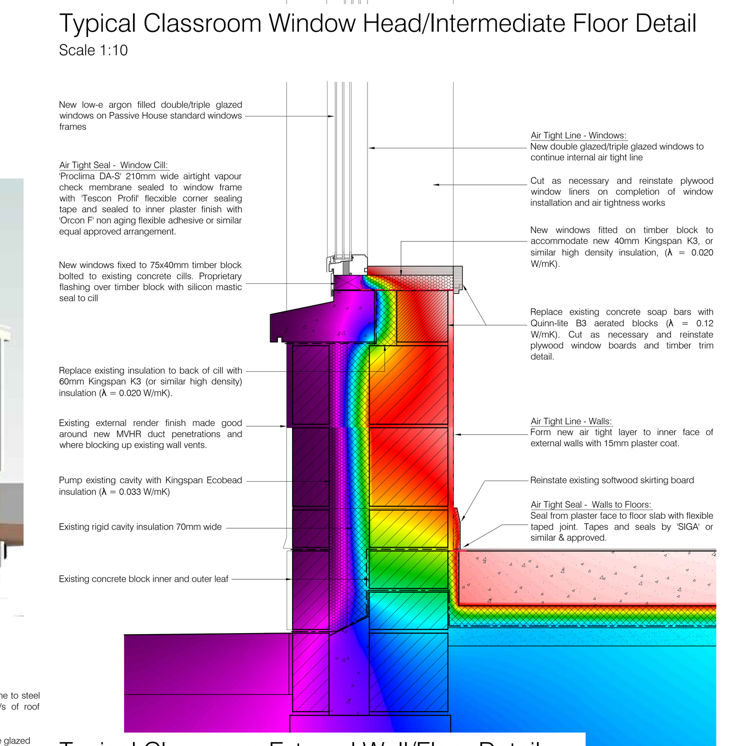


West Facing Elevation
Scale 1:200

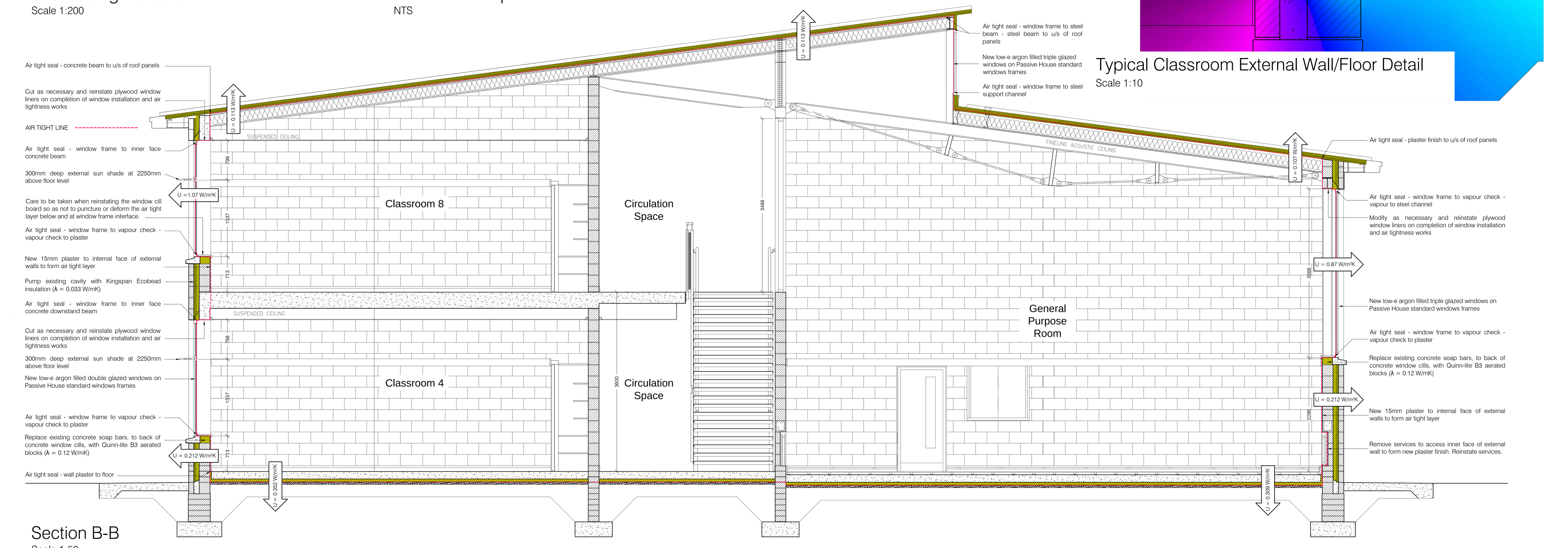
Sectional Perspective
NTS



East Facing Elevation
Scale 1:200



Typical Classroom External Wall/Floor Detail
Scale 1:10



Section B-B
Scale 1:50

Linear Thermal Bridge & Surface Temperature Analysis

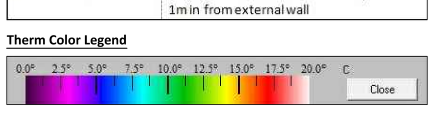
Thermal bridge analysis was carried out on some of the key junctions for the proposed EnerPHit retrofit using the LBNL Therm software package. The heat loss values obtained from the software were used to calculate the **Psi** and **fRsi** values for the junctions analysed. The calculation of Psi values for Passive House input differs from the standard methods used in DEAP in two key ways: 1) the exterior temperature is set at -10°C and 2) the heat loss is measured at the exterior of the thermal envelope. This analysis has used the DEAP method and the conventions of BR 497.

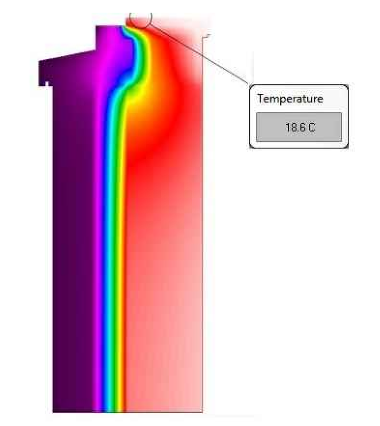
Linear Thermal Transmittance Ψ (psi)	Temperature Factor (f_{Rsi})
Calc: Ψ = L2d – (Ux * Lx) – (Uy * Ly)	Calc: f_{Rsi} = (Tsi – Te) / (Ti – Te)
Unit: W/m K	Tsi = Lowest surface temp
Rate of heat flow per degree per unit length of the bridge, which is not accounted for in the U-values of the building elements containing the bridge	To limit risk of mould growth and surface condensation problems, f_{Rsi} >= 0.75 [TGD L]

Other Building Junctions

Junction	Comments/suggested remedial works
Window/door jamb	Insulate reveal, behind window liner
Door threshold	No insulation behind concrete threshold / provide external insulation below ground
Internal walls/floor	No perimeter floor insulation / dryline walls 1m in from external wall

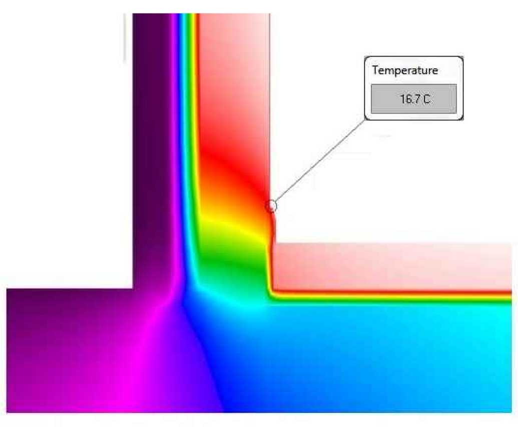
Therm Color Legend





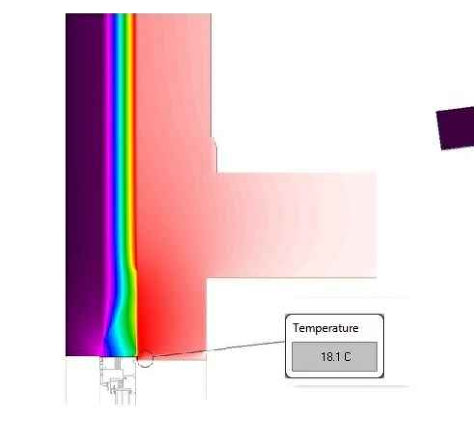
LTB01 – Window Cill

	Ψ	f_{Rsi}	Tsi	Ti	Te	Ux	Uy
Existing	0.212	0.68	13.6°C	20°C	0°C	-	0.3106
Retrofit	0.148	0.93	18.6°C	20°C	0°C	-	0.2185



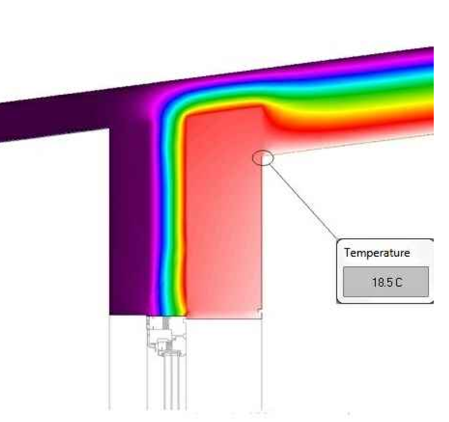
LTB02 – Ground Floor Junction

	Ψ	f_{Rsi}	Tsi	Ti	Te	Ux	Uy
Existing	-0.173	0.81	16.2°C	20°C	0°C	0.3308	0.3106
Retrofit	-0.170	0.83	16.7°C	20°C	0°C	0.3308	0.2185



LTB03 – Intermediate Floor (includes ψ of window head)

	Ψ	f_{Rsi}	Tsi	Ti	Te	Ux	Uy
Existing	0.429	0.79	15.9°C	20°C	0°C	-	0.3106
Retrofit	0.330	0.90	18.1°C	20°C	0°C	-	0.2185



LTB04 – Eaves (includes ψ of window head)

	Ψ	f_{Rsi}	Tsi	Ti	Te	Ux	Uy
Existing	0.349	0.79	15.9°C	20°C	0°C	0.1149	0.3106
Retrofit	0.317	0.92	18.5°C	20°C	0°C	0.1149	0.2185

Daylighting Analysis, Overheating, Solar Gains & Shading

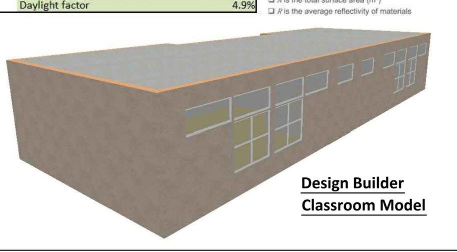
Daylight analysis of the classrooms were undertaken using Design Builder software. A daylight factor of between 4.5 - 5.5% is required by the Department of Education for classrooms areas and the existing classrooms meet this requirement. The main consideration for the EnerPHit retrofit was therefore not to negatively effect daylight levels in the classrooms. Choosing triple glazing with a lower light transmission factor is one such upgrade which could potentially reduce the DF. With this consideration in mind it was decided to maintain double glazing in the classrooms, but to replace the glazing with one that allows better light transmission.

Existing Classroom Daylight Factor Calculation

Daylight factor calculator		
A_w	Window area (m²)	11.669
VLT	Visible light transmittance of glazing (0>VLT>1)	0.7
Theta	Visible sky angle (degrees)	63
A	Total surface area	230
R	Reflectivity of materials (0>R>1)	0.74
	Daylight factor	4.9%

$$DF = \frac{A_w . VLT . \Theta}{A.(1-R^2)}$$

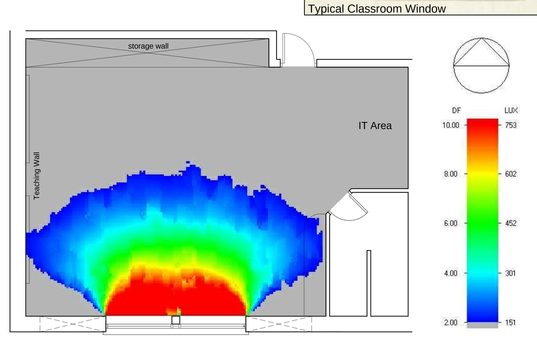
- DF is the daylight factors in %
- VLT is the visible light transmittance of the glazing
- Aw is the window area (m²)
- θ is visible sky angle (in °)
- A is the total surface area (m²)
- R is the average reflectivity of materials



Design Builder Classroom Model

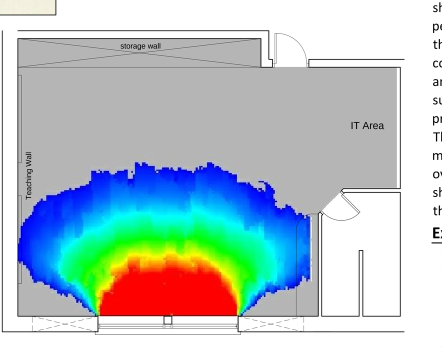
Existing Classroom 67m²
Average DF: 2.335%

Typical Classroom Window



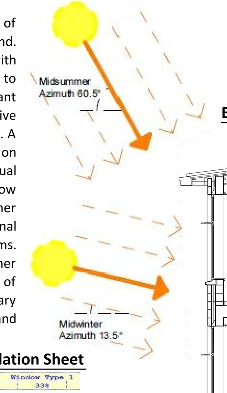
Daylight Analysis of Typical Classroom
NTS

EnerPHit Classroom 67m²
Average DF: 3.026%



Daylight Analysis of Typical Classroom
NTS

Utilization of solar gains is a key strategy of Passive House to reduce heating demand. The existing school was orientated with the main occupancy areas facing south to maximize solar gain. It was important therefore not to introduce excessive shading which would impact these gains. A permanent sun shade has been used on the classroom windows to improve visual comfort in the area beneath the window and also to reduce the effects of summer sun. The roof overhang provides additional protection to the first floor classrooms. The school will be closed during summer months but if required, prevention of overheating can be achieved by temporary shading to the high level windows and through summer ventilation.



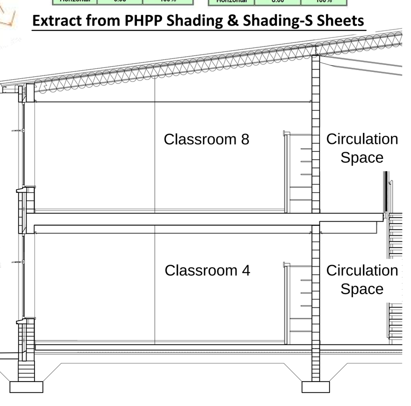
General Shading

Orientation	Glazing area m²	Reduction factor r_S
North	66.22	82%
East	0.00	100%
South	79.52	92%
West	4.21	79%
Horizontal	0.00	100%

Summer Shading

Orientation	Glazing area m²	Summer shading factor r_S
North	66.22	89%
East	0.00	100%
South	79.52	63%
West	4.21	88%
Horizontal	0.00	100%

Extract from PHPP Shading & Shading-S Sheets



Classroom Section
Scale 1:100

Extract from PHPP Summer Ventilation Sheet

Description	Window Type 1		Window Type 1
Fraction of Opening Duration	33%		33%
Climate Boundary Conditions			
Temperature Diff Interior - Exterior	4		4
Wind Velocity	1		1
Window Group 1			
Quantity	32		16
Clear Width	1.70		1.15
Clear Height	0.65		1.15
Tilting Windows?	x		x
Opening Width (for tilting windows)	0.150		0.150
Single-Sided Ventilation 1 - Airflow Volume	1253	0	1067
Single-Sided Ventilation 2 - Airflow Volume	0	0	0
Cross Ventilation Airflow Volume	1253	0	1067
Contribution to Air Change Rate	0.13	0.00	0.11

Summary of Summer Ventilation Distribution

Description Ventilation Type	Daily Average Air Change Rate
Classroom window ventilation daytime	0.24 1/h

Systems - Mechanical Ventilation With Heat Recovery

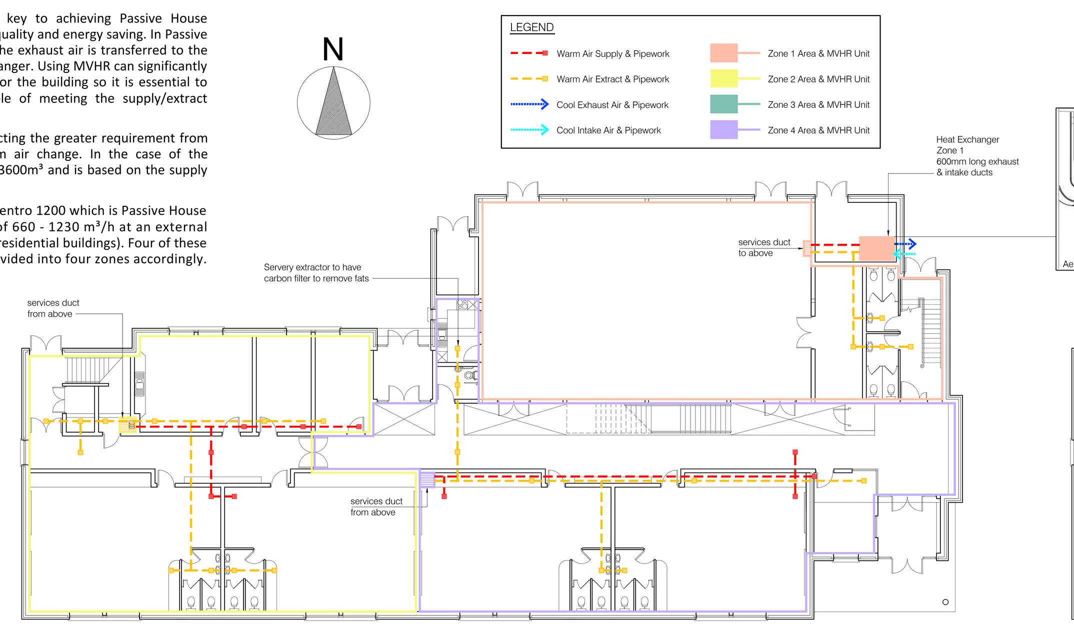
Efficient heat recovery ventilation is key to achieving Passive House standard, allowing for good indoor air quality and energy saving. In Passive House, at least 75% of the heat from the exhaust air is transferred to the fresh air again by means of a heat exchanger. Using MVHR can significantly increase the Primary Energy demand for the building so it is essential to select the most efficient system cable of meeting the supply/extract demand for the building.

The ventilation system is sized by selecting the greater requirement from fresh air, extract air or the minimum air change. In the case of the proposed school the design air flow is 3600m³ and is based on the supply air requirement.

The MVHR selected is the Aerosilent Centro 1200 which is Passive House Institute certified for air flow rates of 660 - 1230 m³/h at an external pressure of 235 Pa (requirements non residential buildings). Four of these units are required with the building divided into four zones accordingly.

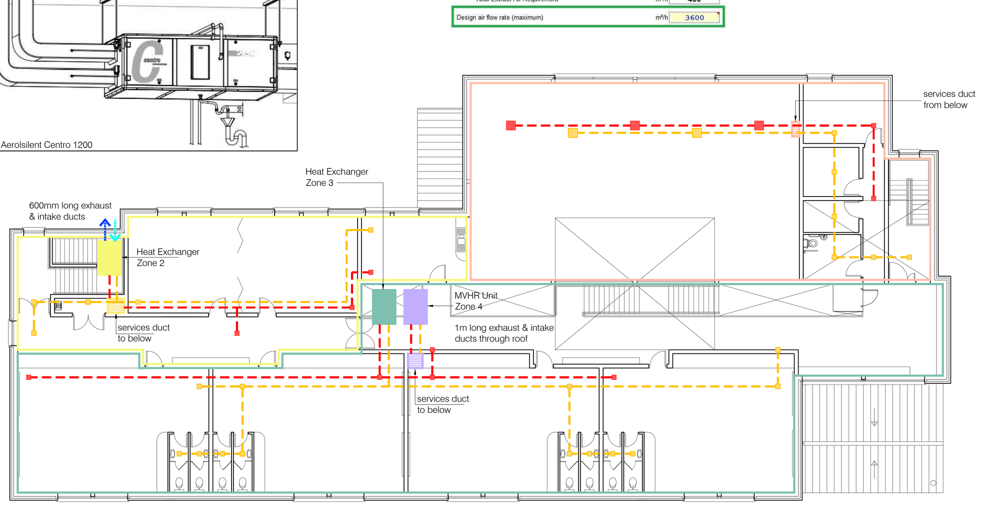
The relevant MVHR specifications are as follows:

- Heat recovery efficiency - 83%
- Electrical efficiency - 0.45 Wh/m³
- Operational range - 660 - 1230 m³/h
- Exhaust/Intake duct lengths - 3.2m
- Ψ value of ambient/exhaust air ducts 0.338 W/mK



Proposed Ground Floor MVHR Schematic Plan
Scale 1:200

Extract from PHPP Ventilation Sheet - Design air flow calculation



Proposed First Floor MVHR Schematic Plan
Scale 1:200