

Liverpool John Moores University and Zenova Group Ltd. AKT Project 2022-2023

Exploring the performance of **thermal barrier coatings**
in a retrofit environment

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Project Overview



Aim:

To evaluate the performance a low profile, **novel thermal barrier coating** for use in retrofit applications

Objectives:

- **Collect and compare** pre and post installation data for - surface and ambient temperatures, humidity, U-value and air quality.
- **Install Thermal material coating** in 1920's exemplar house.
- Evaluate any change in **energy performance** of the room.
- **Produce report** on findings

Basic Methodology



Steps:

1. **Record** Baseline Data: Room response to heating and cooling, U-Value, thermal imaging
2. **Apply** Zenova thermal coating
3. **Record** post installation performance
4. **Compare** Findings



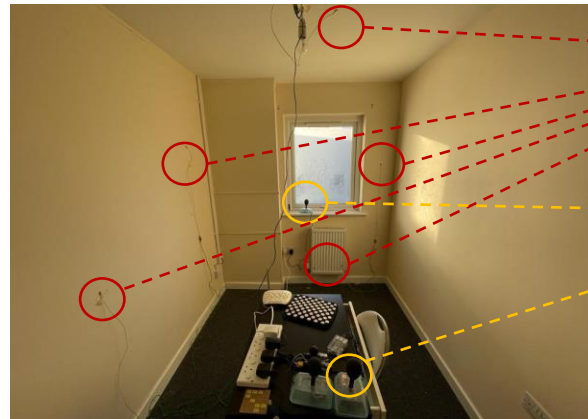
Pre-Installation Data Collection



Baseline Room

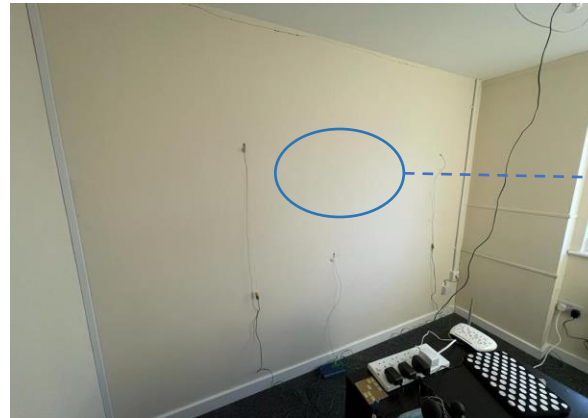


Sensor and Monitoring Installation



Surface Temperature Sensors

Ambient Temperature and Humidity Sensors



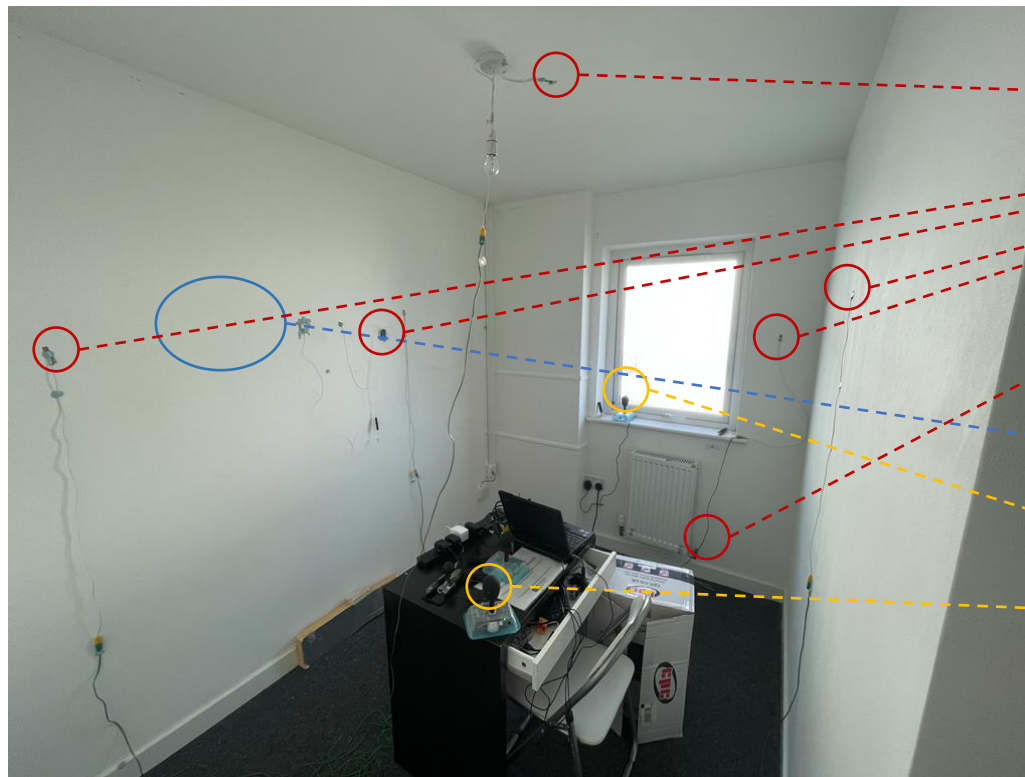
U-Value Monitors



Post-Installation Data Collection



Post Installation Room



Surface Temperature Sensors

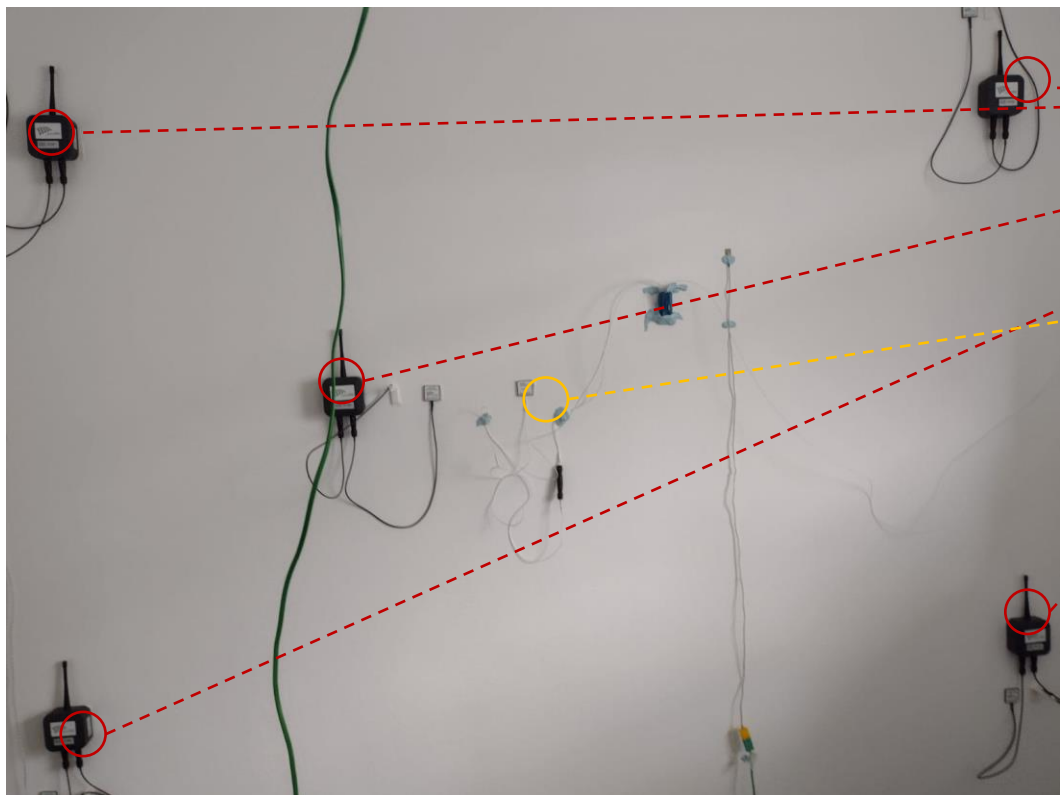
U-Value Monitor

Ambient Temperature and Humidity Sensors

U-value Final Test (multi probe)

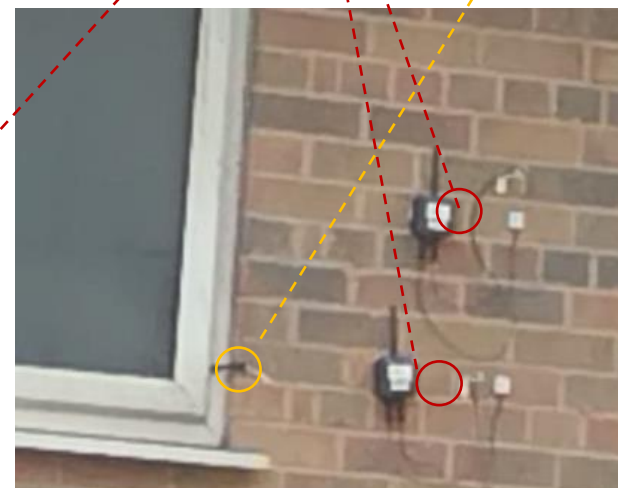


Post Installation Room



U-Value Monitor Wireless

U-Value Monitor Wired

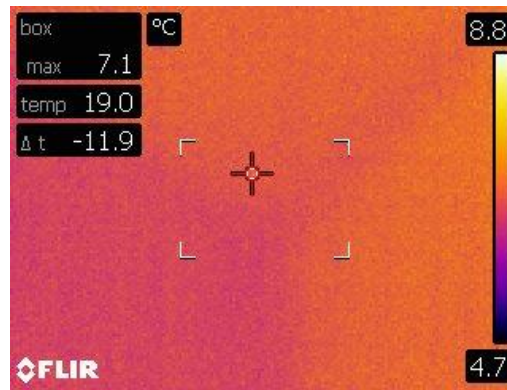


Outdoor Sensors

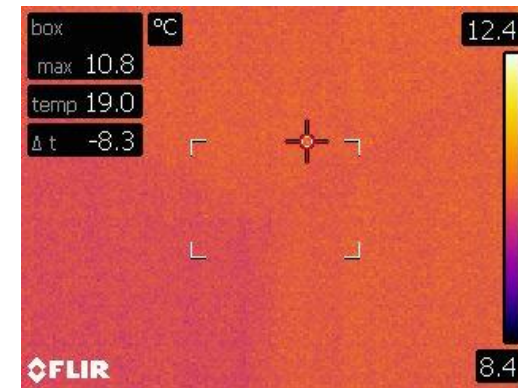
Thermal Camera Imaging



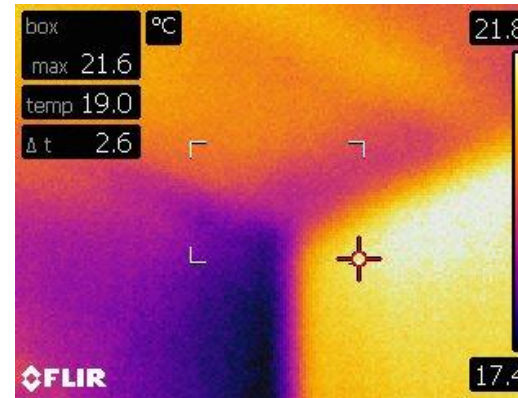
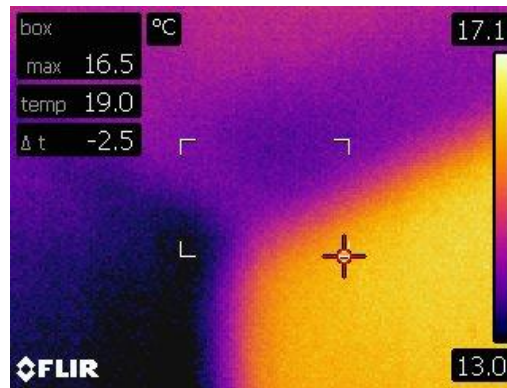
Pre-Installation



Post-Installation



cold



hot

U-Value Comparison



Pre-Installation U-Value

U-value analysis using average method (Section 7.1, ISO 9869-1:2014):

Analysis start time:	2022-12-12 19:14:00	U-value w/o last 24h (U24):	3.37 W/(m ² K)
Analysis end time:	2022-12-18 19:14:00	U-value first 2/3 (U2/3):	3.33 W/(m ² K)
Analysis period:	144 h	U-value last 2/3 (U2/3):	3.40 W/(m ² K)
U-value:	3.37 W/(m ² K)	dU24:	-0.1 %
		dU2/3:	-2.0 %
		dR24:	0.2 %
		dR2/3:	4.7 %

Measurement data fulfils requirements of ISO 9869-1:2014 section 7.1.

Post-Installation U-Value

U-value analysis using average method (Section 7.1, ISO 9869-1:2014):

Analysis start time:	2023-02-04 11:23:32	U-value w/o last 24h (U24):	2.26 W/(m ² K)
Analysis end time:	2023-02-07 11:23:32	U-value first 2/3 (U2/3):	2.26 W/(m ² K)
Analysis period:	72 h	U-value last 2/3 (U2/3):	2.22 W/(m ² K)
U-value:	2.27 W/(m ² K)	dU24:	0.2 %
		dU2/3:	1.9 %
		dR24:	-0.4 %
		dR2/3:	-3.0 %

Measurement data fulfils requirements of ISO 9869-1:2014 section 7.1.

Initial Recorded Improvement of
1.1 W/(m²K)

U-Value Validation



Post-Installation U-Value

U-Value analysis:

Total measurement duration	120.00 h	Average values:	
Analysis start time:	2023-03-12 21:10:00	Heat Flux (HF):	19.10 W/m ²
Analysis end time:	2023-03-15 21:10:00	Inner Ambient Temp. (Ti)	15.44 °C
Analysis period:	72 h	Inner Surface Temp. (Tsi)	12.79 °C
dR2/3:	2.20 %	Outer Ambient Temp. (Te)	7.58 °C
dR24:	-4.89 %	Outer Surface Temp. (Tse)	8.38 °C
U-Value (U):	2.041 W/(m²K)		
R-Value (R):	0.279 (m²K)/W		

U-Value analysis:

Total measurement duration	120.00 h	Average values:	
Analysis start time:	2023-03-12 21:10:00	Heat Flux (HF):	19.39 W/m ²
Analysis end time:	2023-03-15 21:10:00	Inner Ambient Temp. (Ti)	16.44 °C
Analysis period:	72 h	Inner Surface Temp. (Tsi)	12.65 °C
dR2/3:	2.64 %	Outer Ambient Temp. (Te)	7.58 °C
dR24:	-4.77 %	Outer Surface Temp. (Tse)	8.38 °C
U-Value (U):	1.862 W/(m²K)		
R-Value (R):	0.268 (m²K)/W		

U-Value analysis:

Total measurement duration	120.00 h	Average values:	
Analysis start time:	2023-03-12 21:50:00	Heat Flux (HF):	17.73 W/m ²
Analysis end time:	2023-03-15 21:50:00	Inner Ambient Temp. (Ti)	14.12 °C
Analysis period:	72 h	Inner Surface Temp. (Tsi)	12.48 °C
dR2/3:	2.41 %	Outer Ambient Temp. (Te)	7.58 °C
dR24:	-4.83 %	Outer Surface Temp. (Tse)	8.38 °C
U-Value (U):	2.255 W/(m²K)		
R-Value (R):	0.286 (m²K)/W		

U-Value analysis:

Total measurement duration	120.00 h	Average values:	
Analysis start time:	2023-03-12 21:30:00	Heat Flux (HF):	23.51 W/m ²
Analysis end time:	2023-03-15 21:30:00	Inner Ambient Temp. (Ti)	16.55 °C
Analysis period:	72 h	Inner Surface Temp. (Tsi)	13.26 °C
dR2/3:	2.67 %	Outer Ambient Temp. (Te)	7.58 °C
dR24:	-4.91 %	Outer Surface Temp. (Tse)	8.38 °C
U-Value (U):	2.217 W/(m²K)		
R-Value (R):	0.251 (m²K)/W		

U-Value analysis:

Total measurement duration	120.00 h	Average values:	
Analysis start time:	2023-03-12 21:00:00	Heat Flux (HF):	18.58 W/m ²
Analysis end time:	2023-03-15 21:00:00	Inner Ambient Temp. (Ti)	14.72 °C
Analysis period:	72 h	Inner Surface Temp. (Tsi)	12.40 °C
dR2/3:	3.98 %	Outer Ambient Temp. (Te)	7.58 °C
dR24:	-4.88 %	Outer Surface Temp. (Tse)	8.38 °C
U-Value (U):	2.136 W/(m²K)		
R-Value (R):	0.269 (m²K)/W		

U-value average: 2.1022 W/m²K

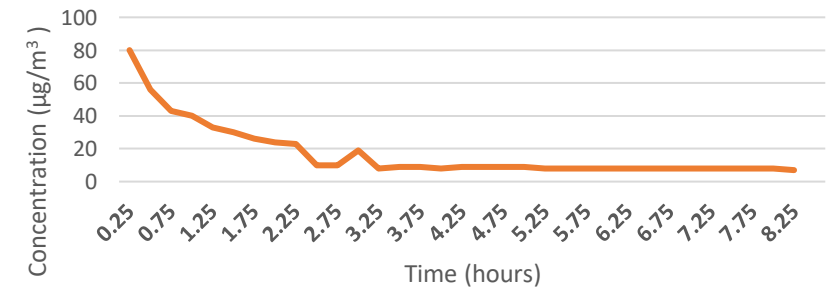
Improvement of **1.2678 W/(m²K)**

Air Quality Test Result

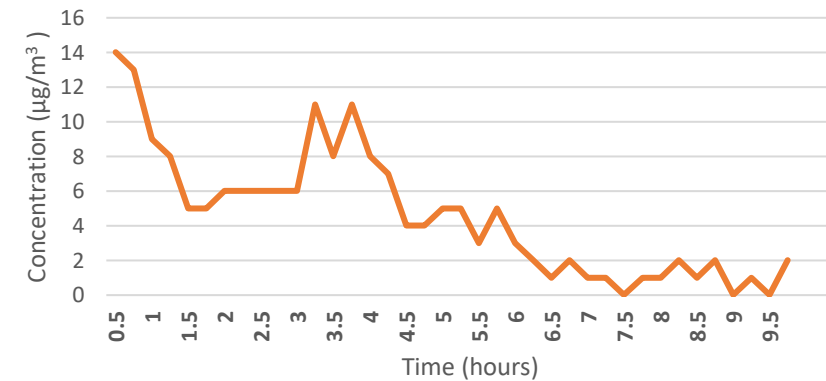


1. Before Painting: PM 2.5 = $2 \mu\text{g}/\text{m}^3$;
VOCs = $0 \text{ mg}/\text{m}^3$
2. After the base coat: PM 2.5 = $9 \mu\text{g}/\text{m}^3$;
VOCs = $0 \text{ mg}/\text{m}^3$
3. During the spray: PM 2.5 = $80 \mu\text{g}/\text{m}^3$;
VOCs = $43.72 \text{ mg}/\text{m}^3$

Indoor Air Quality (PM 2.5) After **Thick Spray**



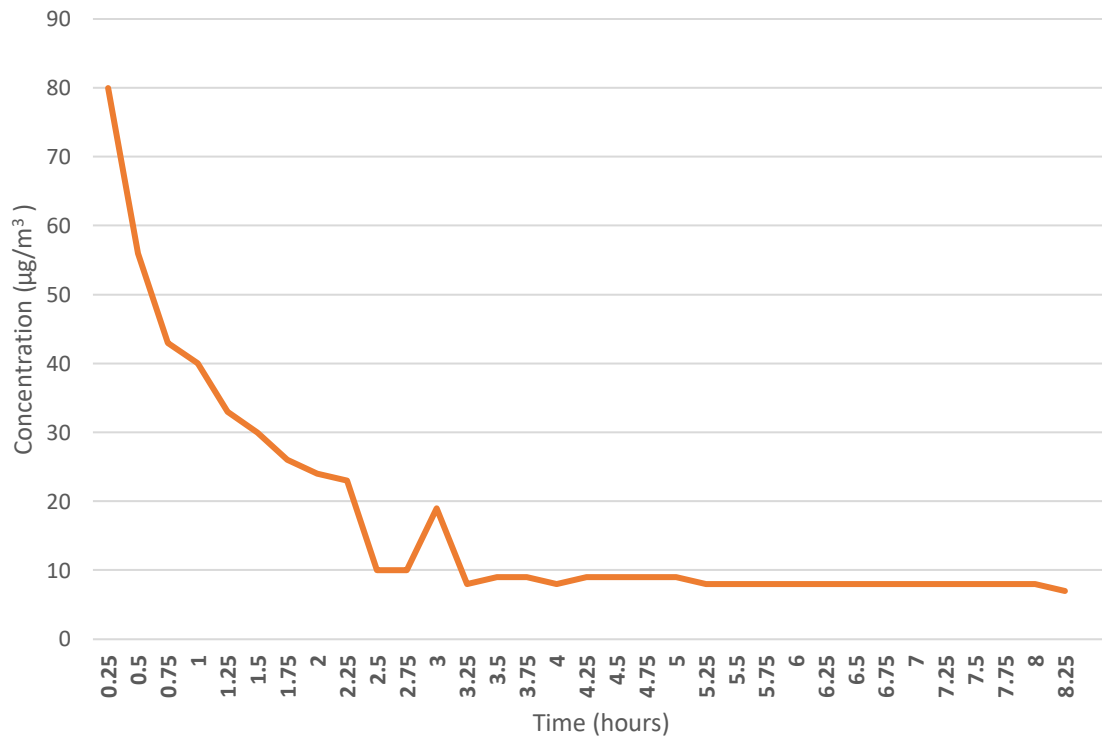
Indoor Air Quality (PM 2.5) After **Final Layer**



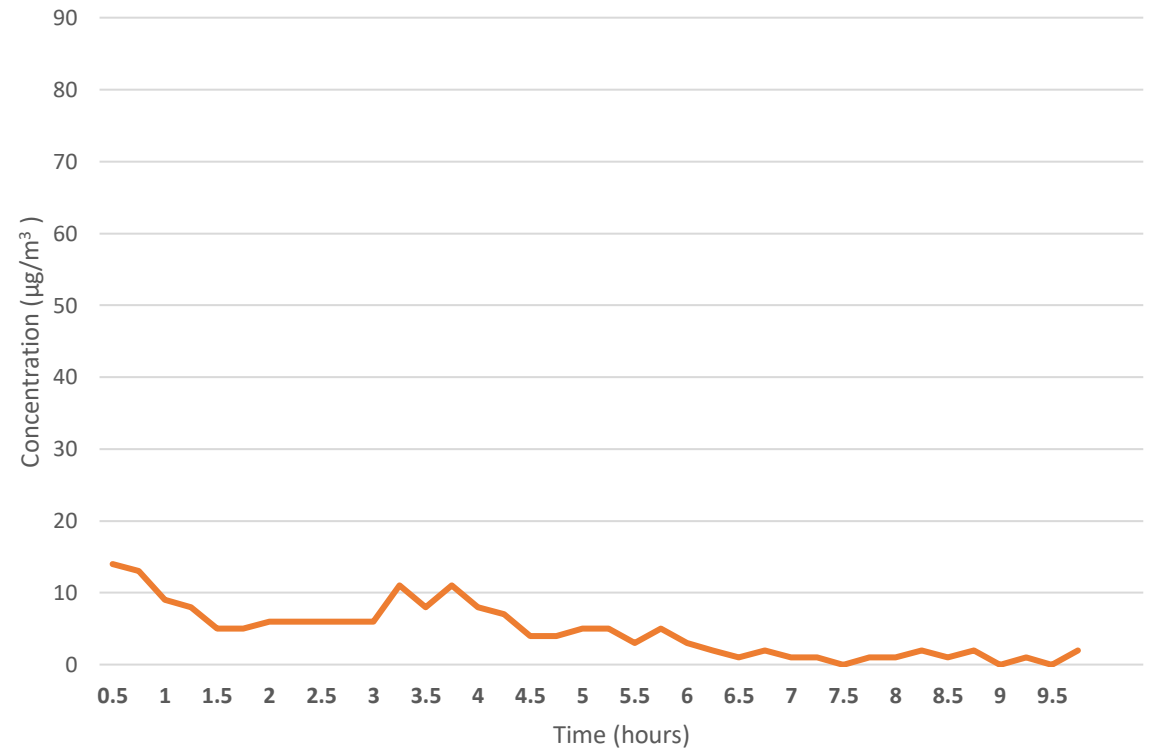
Air Quality Test Result



Indoor Air Quality (PM 2.5) After **Thick Spray**



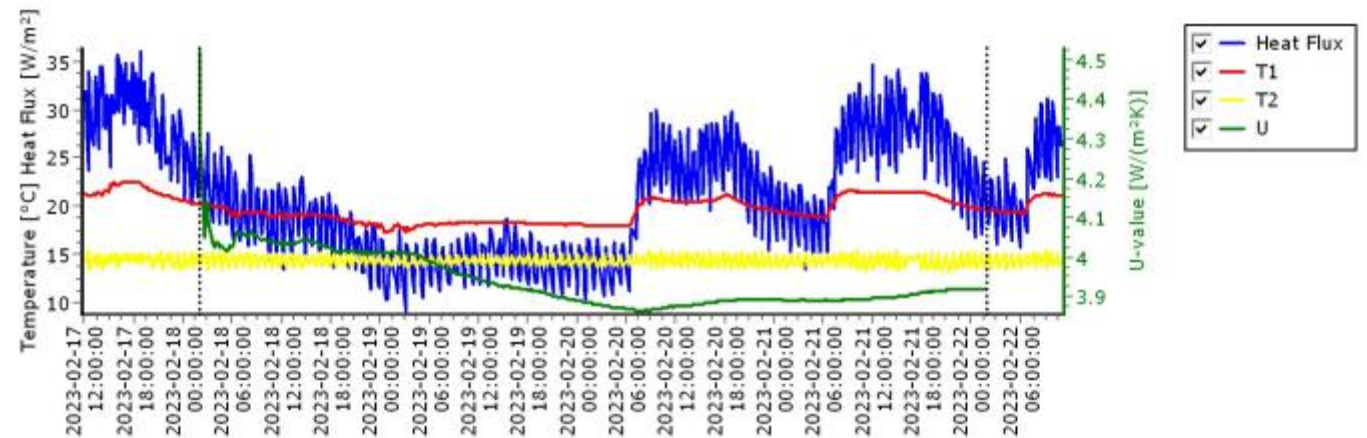
Indoor Air Quality (PM 2.5) After **Final Layer**



Material test Value

- The material test was done in the thermal chamber to simulate indoor and outdoor condition and was done with U-value test kit for at least 72 hours
- **1 mm thickness material:** U-value of **3.92 W/(m²K)**; thermal conductivity = 0.00392 W/mK

Measurement overview over t=118.83 h



U-value analysis using average method (Section 7.1, ISO 9869-1:2014):

Analysis start time:	2023-02-18 01:57:32	U-value w/o last 24h (U24):	3.89 W/(m ² K)
Analysis end time:	2023-02-22 01:57:32	U-value first 2/3 (U2/3):	3.88 W/(m ² K)
Analysis period:	96 h	U-value last 2/3 (U2/3):	3.94 W/(m ² K)
U-value:	3.92 W/(m²K)	dU24:	0.7 %
		dU2/3:	-1.6 %
		dR24:	-2.2 %
		dR2/3:	4.7 %

Measurement data fulfils requirements of ISO 9869-1:2014 section 7.1.

Uncertainties due to improper installation or environmental influences must be estimated by user (see section 6.1).

Thermal Conductivity

- **Background**

Different measurement results of thermal conductivity to be verified. The variety of results were due to the uneven sample composition, the dryness of the sample, and the sensor imprecision.

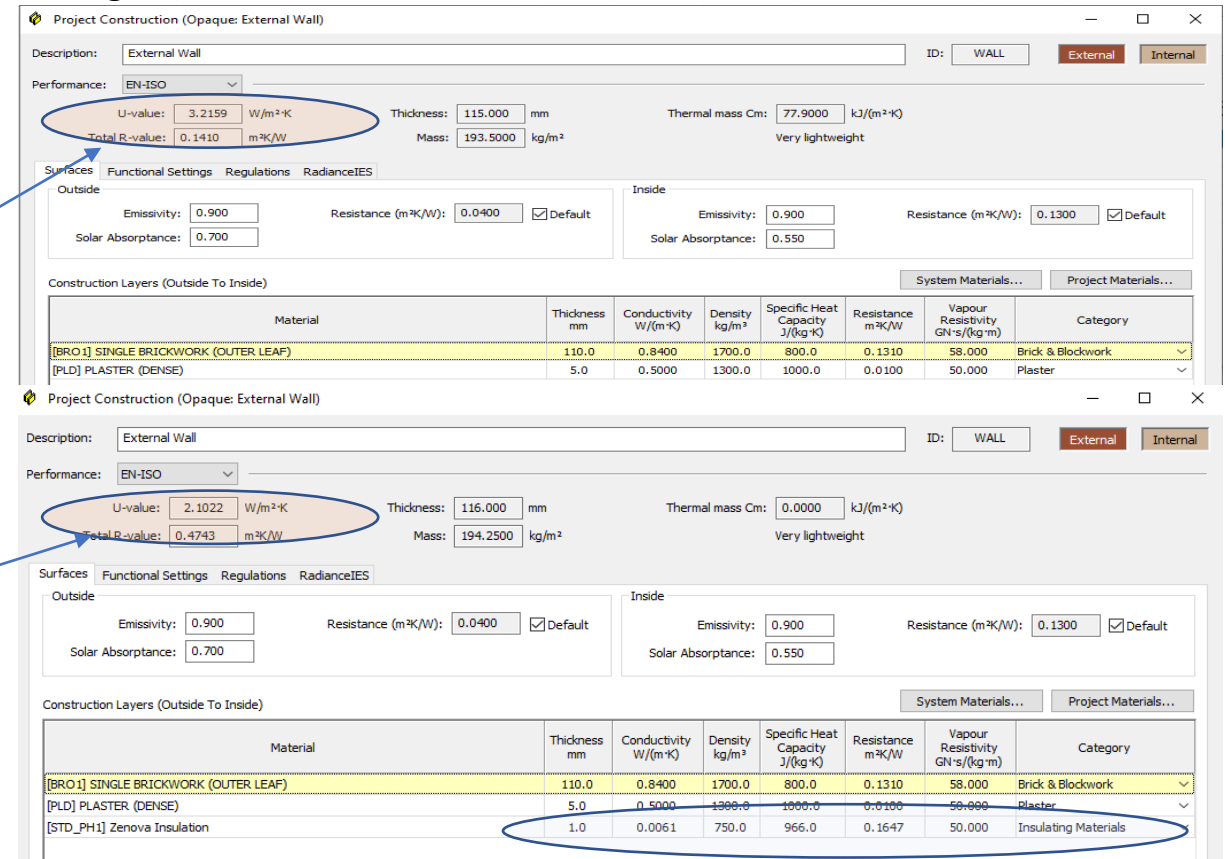
- **Methods**

The value was fed to the IES VE Software to obtain the software calculated results from the digital twin.

Parameters for the digital twin:

- U-value test for pre-refurbishment: $3.37 \text{ W}/(\text{m}^2\text{K}) \rightarrow$ in the digital twin, the materials composition generated U-value of $3.2159 \text{ W}/(\text{m}^2\text{K})$
- Average U-value test for post-refurbishment: $2.1022 \text{ W}/(\text{m}^2\text{K})$;
- Specific Heat Capacity: $966 \text{ J}/\text{kg} \cdot ^\circ\text{C}$
- Density $0.75 \text{ g}/\text{cm}^3 = 750 \text{ kg}/\text{m}^3$
- Vapour Resistivity: $50 \text{ GN}/\text{kg m}$

The Digital Twin:



Project Construction (Opaque: External Wall)

Description: External Wall ID: WALL External Internal

Performance: EN-ISO

U-value: 3.2159 W/m²K Thickness: 115.000 mm Thermal mass Cm: 77.9000 kJ/(m²·K)

Total R-value: 0.1410 m²K/W Mass: 193.5000 kg/m² Very lightweight

Surfaces: Functional Settings Regulations RadianceIES

Outside: Emissivity: 0.900 Resistance (m²K/W): 0.0400 Default Solar Absorptance: 0.700

Inside: Emissivity: 0.900 Resistance (m²K/W): 0.1300 Default Solar Absorptance: 0.550

Construction Layers (Outside To Inside)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRO.1] SINGLE BRICKWORK (OUTER LEAF)	110.0	0.8400	1700.0	800.0	0.1310	58.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster

Project Construction (Opaque: External Wall)

Description: External Wall ID: WALL External Internal

Performance: EN-ISO

U-value: 2.1022 W/m²K Thickness: 116.000 mm Thermal mass Cm: 0.0000 kJ/(m²·K)

Total R-value: 0.4743 m²K/W Mass: 194.2500 kg/m² Very lightweight

Surfaces: Functional Settings Regulations RadianceIES

Outside: Emissivity: 0.900 Resistance (m²K/W): 0.0400 Default Solar Absorptance: 0.700

Inside: Emissivity: 0.900 Resistance (m²K/W): 0.1300 Default Solar Absorptance: 0.550

Construction Layers (Outside To Inside)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRO.1] SINGLE BRICKWORK (OUTER LEAF)	110.0	0.8400	1700.0	800.0	0.1310	58.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster
[STD_PH1] Zenova Insulation	1.0	0.0061	750.0	966.0	0.1647	50.000	Insulating Materials

Result: the thermal conductivity value of **0.0061 W/(m. K)**

Similar Performing Materials (1)



Methods: Using the IES VE Software for the digital twin.

1. FELT & MEMBRANE - FELT - HF-E3 (31.3 mm thickness)

Project Construction (Opaque: External Wall)

Description: External Wall ID: WALL External Internal

Performance: EN-ISO

U-value: 2.1022 W/m²K Thickness: 225.000 mm Thermal mass Cm: 187.6554 kJ/(m²K)
 Total R-value: 0.7199 m²K/W Mass: 316.8100 kg/m² Mediumweight

Surfaces Functional Settings Regulations RadianceIES

Outside Emissivity: 0.900 Resistance (m²K/W): 0.0400 Default Solar Absorbance: 0.700
 Inside Emissivity: 0.900 Resistance (m²K/W): 0.1300 Default Solar Absorbance: 0.550

Construction Layers (Outside To Inside)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster
[USFM0000] FELT & MEMBRANE - FELT - HF-E3	31.3	0.1900	1121.0	1674.0	0.1647	15000.000	Insulating Materials

2. FELT & MEMBRANE - FINISH - HF-A6 (68.4 mm thickness)

Project Construction (Opaque: External Wall)

Description: External Wall ID: WALL External Internal

Performance: EN-ISO

U-value: 2.1022 W/m²K Thickness: 120.000 mm Thermal mass Cm: 81.2946 kJ/(m²K)
 Total R-value: 0.1530 m²K/W Mass: 199.7450 kg/m² Very lightweight

Surfaces Functional Settings Regulations RadianceIES

Outside Emissivity: 0.900 Resistance (m²K/W): 0.0400 Default Solar Absorbance: 0.700
 Inside Emissivity: 0.900 Resistance (m²K/W): 0.1300 Default Solar Absorbance: 0.550

Construction Layers (Outside To Inside)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster
[USFM0001] FELT & MEMBRANE - FINISH - HF-A6	68.4	0.4150	1249.0	1088.0	0.1647	15000.000	Insulating Materials

3. Expanded polystyrene (CIBSE) (5.8 mm thickness)

Project Construction (Opaque: External Wall)

Description: External Wall ID: WALL External Internal

Performance: EN-ISO

U-value: 2.1022 W/m²K Thickness: 120.000 mm Thermal mass Cm: 0.0000 kJ/(m²K)
 Total R-value: 0.2838 m²K/W Mass: 193.6250 kg/m² Very lightweight

Surfaces Functional Settings Regulations RadianceIES

Outside Emissivity: 0.900 Resistance (m²K/W): 0.0400 Default Solar Absorbance: 0.700
 Inside Emissivity: 0.900 Resistance (m²K/W): 0.1300 Default Solar Absorbance: 0.550

Construction Layers (Outside To Inside)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster
[EPSL] Expanded polystyrene (CIBSE)	5.8	0.0350	25.0	1400.0	0.1647	200.000	Insulating Materials

4. INSULATION BOARD - HF-B5 (7.2 mm thickness)

Project Construction (Opaque: External Wall)

Description: External Wall ID: WALL External Internal

Performance: EN-ISO

U-value: 2.1022 W/m²K Thickness: 120.000 mm Thermal mass Cm: 0.0000 kJ/(m²K)
 Total R-value: 0.2546 m²K/W Mass: 193.6000 kg/m² Very lightweight

Surfaces Functional Settings Regulations RadianceIES

Outside Emissivity: 0.900 Resistance (m²K/W): 0.0400 Default Solar Absorbance: 0.700
 Inside Emissivity: 0.900 Resistance (m²K/W): 0.1300 Default Solar Absorbance: 0.550

Construction Layers (Outside To Inside)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster
[USIN0001] INSULATION BOARD	7.2	0.0440	20.0	840.0	0.1647	5.000	Insulating Materials

Similar Performing Materials (2)



Methods: Using the IES VE Software for the digital twin.

5. POLYURETHANE BOARD (3.6 mm thickness)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster
[PUB] POLYURETHANE BOARD	3.6	0.0220	30.0	1400.0	0.1647	550.000	Insulating Materials

6. GLASSWOOL (6.6 mm thickness)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster
[GW] GLASSWOOL	6.6	0.0400	200.0	670.0	0.1647	6.000	Insulating Materials

7. THERMALITE "SHIELD"/"SMOOTH FACE" (28 mm thickness)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster
[THS] THERMALITE "SHIELD"/"SMOOTH FACE"	28.0	0.1700	650.0	1050.0	0.1647	83.000	Insulating Materials

8. SIPOREX (19.8 mm thickness)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.5000	1300.0	1000.0	0.0100	50.000	Plaster
[S] SIPOREX	19.8	0.1200	550.0	1004.0	0.1647	50.000	Insulating Materials

Similar Performing Materials (3)

Methods: Using the IES VE Software for the digital twin.

9. CRATHERM BOARD (8.2 mm thickness)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN-s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.3000	1300.0	1000.0	0.0100	50.000	Plaster
[CBA] CRATHERM BOARD	8.2	0.0500	176.0	837.0	0.1647	-	Insulating Materials

10. GLASS-FIBER - ORGANIC BONDED (ASHRAE) (5.9 mm thickness)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN-s/(kg·m)	Category
[BRCK0000] Single Brickwork (Outer Leaf)	110.0	0.8400	1700.0	800.0	0.1310	0.000	Brick & Blockwork
[PLD] PLASTER (DENSE)	5.0	0.3000	1300.0	1000.0	0.0100	50.000	Plaster
[LUSGF0000] GLASS-FIBER - ORGANIC BONDED (ASHRAE)	5.9	0.0360	100.0	1000.0	0.1647	10.000	Insulating Materials

Summary:

Zenova material has the advantage of the thickness against other insulation materials.

No	Materials	Thickness (in mm)
1	Zenova	1
2	FELT & MEMBRANE - FELT - HF-E3	31.3
3	FELT & MEMBRANE - FINISH - HF-A6	68.4
4	Expanded polystyrene (CIBSE)	5.8
5	INSULATION BOARD - HF-B5	7.2
6	POLYURETHANE BOARD	3.6
7	GLASSWOOL	6.6
8	THERMALITE "SHIELD"/"SMOOTH FACE"	28
9	SIPOREX	19.8
10	CRATHERM BOARD	8.2
11	GLASS-FIBER - ORGANIC BONDED (ASHRAE)	5.9

Thermal Modeling & Simulation of Exemplar 1920 House with Zenova Product

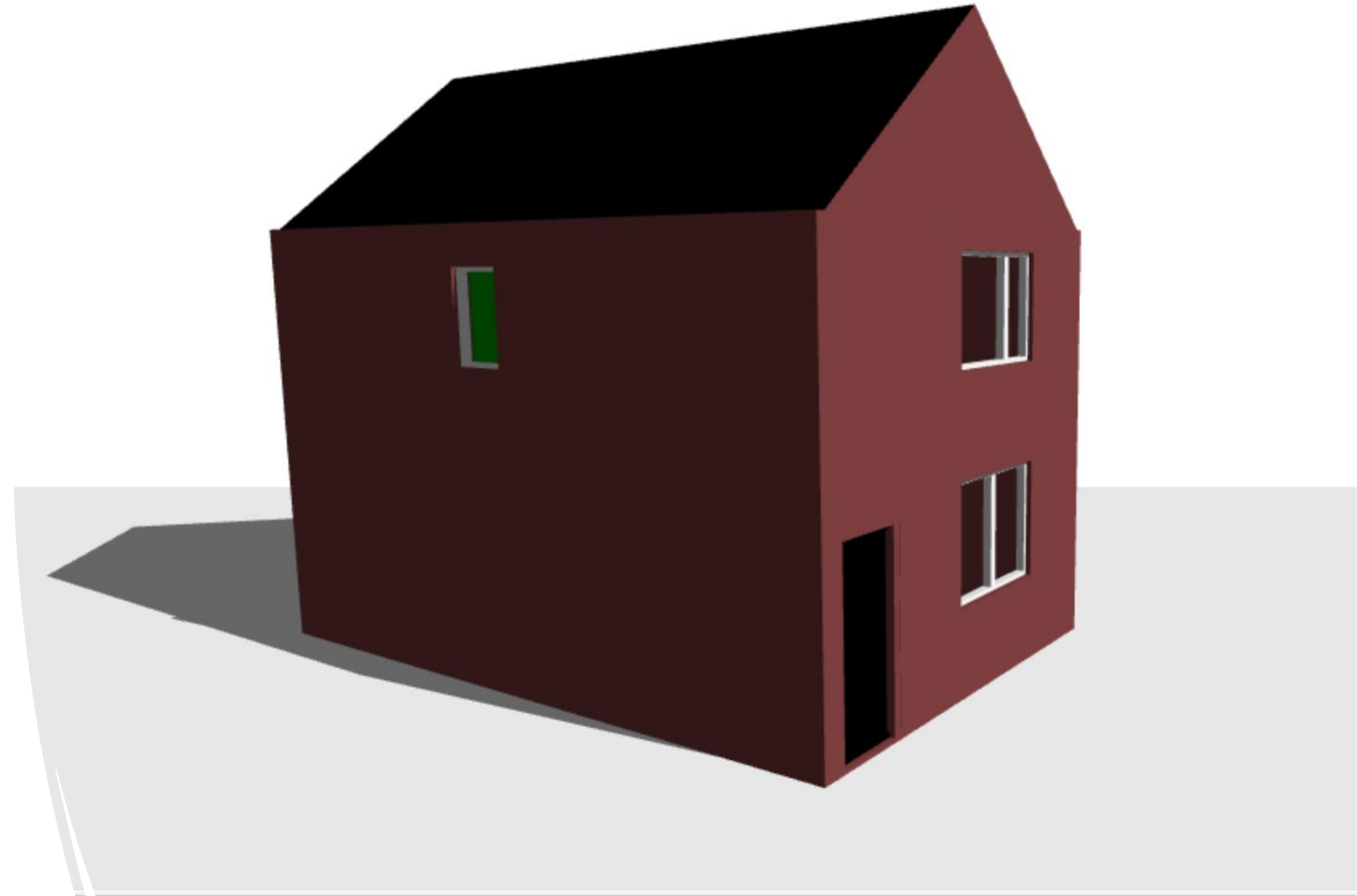
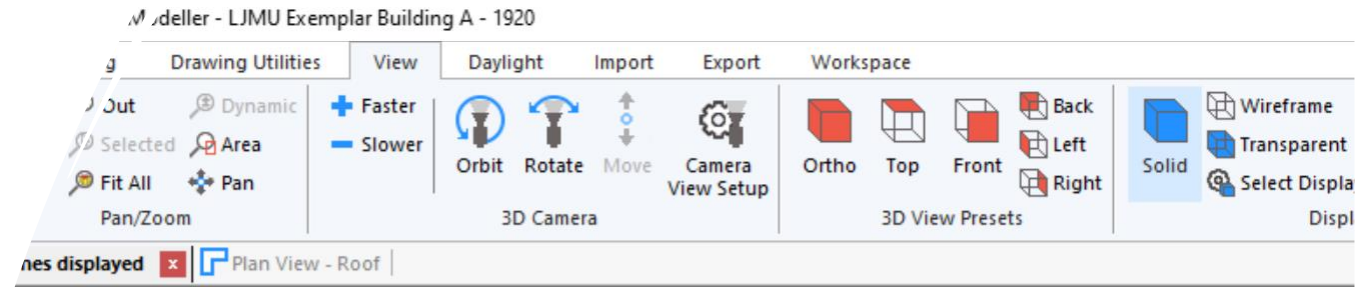
EDSL TAS software

Modeling & Simulation Assumptions

- Whole house modelled as detached
- Various Scenarios – Part L (SBEM Method)
- GHG Conversion Factors (Electricity – 0.519, Natural Gas – 0.216)
- Internal Condition – NCM v5.2.7

RESULTS – (BRUKL Output Document/EPC)

- U – values
- Energy Performance Certificate (EPC - Rating)
- Energy Consumption (Heating)
- CO₂ Emission Rate



Building Elements

1920 Existing External Wall

Opaque Construction Name: Solid brick wall, 115 Description: Existing solid wall, with no insulation added, as commonly found in pre-1915

Solar Absorbance		Emissivity		Conductance	Time Constant
Ext. Surf.	Int. Surf.	External	Internal	(W/m ² ·°C)	
0.700	0.700	0.900	0.900	7.095	0.638

Layer	M-Code	Thickness (mm)	Conductivity (W/m·°C)	Convection Coefficient (W/m ² ·°C)	Vapour Diff. Coefficient	Density (kg/m ³)	Specific Heat (J/kg·°C)	Description
Inner	Brick, 110 mm	110.0	0.84	0.001	9999.000	1700.0	800.0	110 mm layer of brick (ou...
2	Plaster, dense	5.0	0.5	0.001	9999.000	1300.0	1000.0	Dense plasterwork, 5 mm ...

*layer ignored in U-Value/R-Value Calculation

Flow Direction	Internal U Value (W/m ² ·°C)	External U Value (W/m ² ·°C)
Horizontal	2.494	3.216
Upward	2.933	3.559
Downward	2.079	2.849

Additional Heat Transfer: 0.0% F-Factor: 0.0 W/m²·°C

1920 Existing External Wall + 1mm Zenova Paint

Opaque Construction Name: 1920 External Wall - Description:

Solar Absorbance		Emissivity		Conductance	Time Constant
Ext. Surf.	Int. Surf.	External	Internal	(W/m ² ·°C)	
0.700	0.166	0.900	0.880	3.251	1.546

Layer	M-Code	Thickness (mm)	Conductivity (W/m·°C)	Convection Coefficient (W/m ² ·°C)	Vapour Diff. Coefficient	Density (kg/m ³)	Specific Heat (J/kg·°C)	Description
Inner	Zenova Paint, 1mm	1.0	0.006	0.001	50.000	750.0	966.0	
2	Plaster, dense	5.0	0.5	0.001	9999.000	1300.0	1000.0	Dense plasterwork, 5 mm ...
3	Brick, 110 mm	110.0	0.84	0.001	9999.000	1700.0	800.0	110 mm layer of brick (ou...

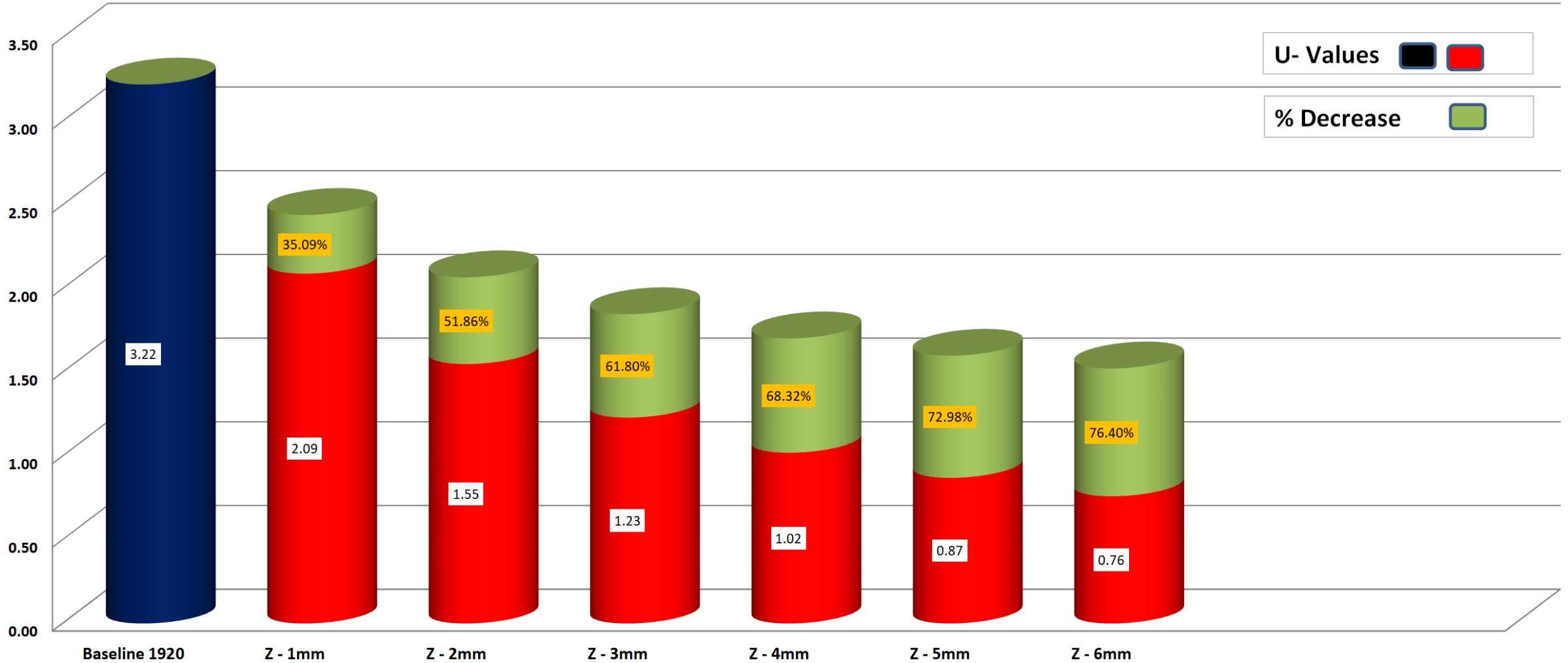
*layer ignored in U-Value/R-Value Calculation

Flow Direction	Internal U Value (W/m ² ·°C)	External U Value (W/m ² ·°C)
Horizontal	1.762	2.094
Upward	1.97	2.234
Downward	1.544	1.932

Additional Heat Transfer: 0.0% F-Factor: 0.0 W/m²·°C



Results – U-values (Walls) – W/(m²K)


U-values (Walls) – W/(m²K)

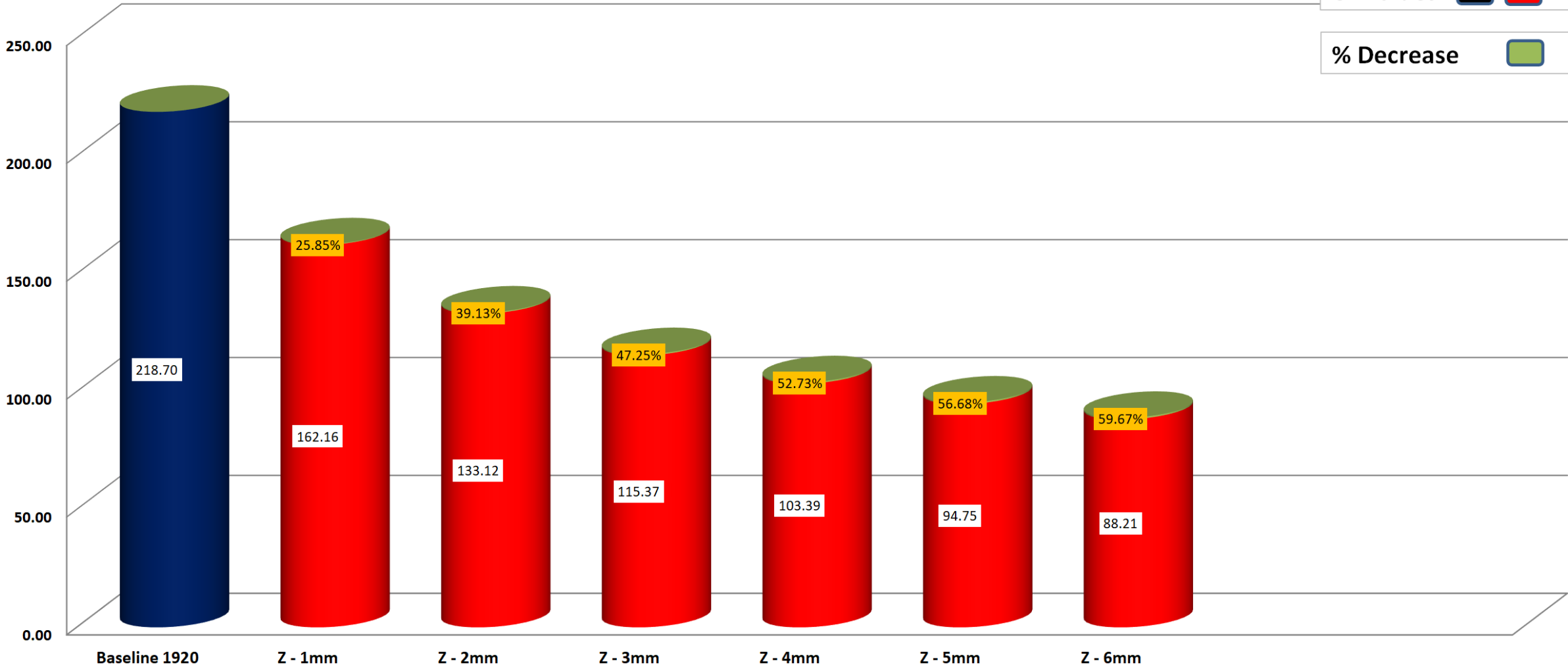


Energy Consumption (Heating) – kWh/m²

Energy Consumption (Heating) – kWh/m²

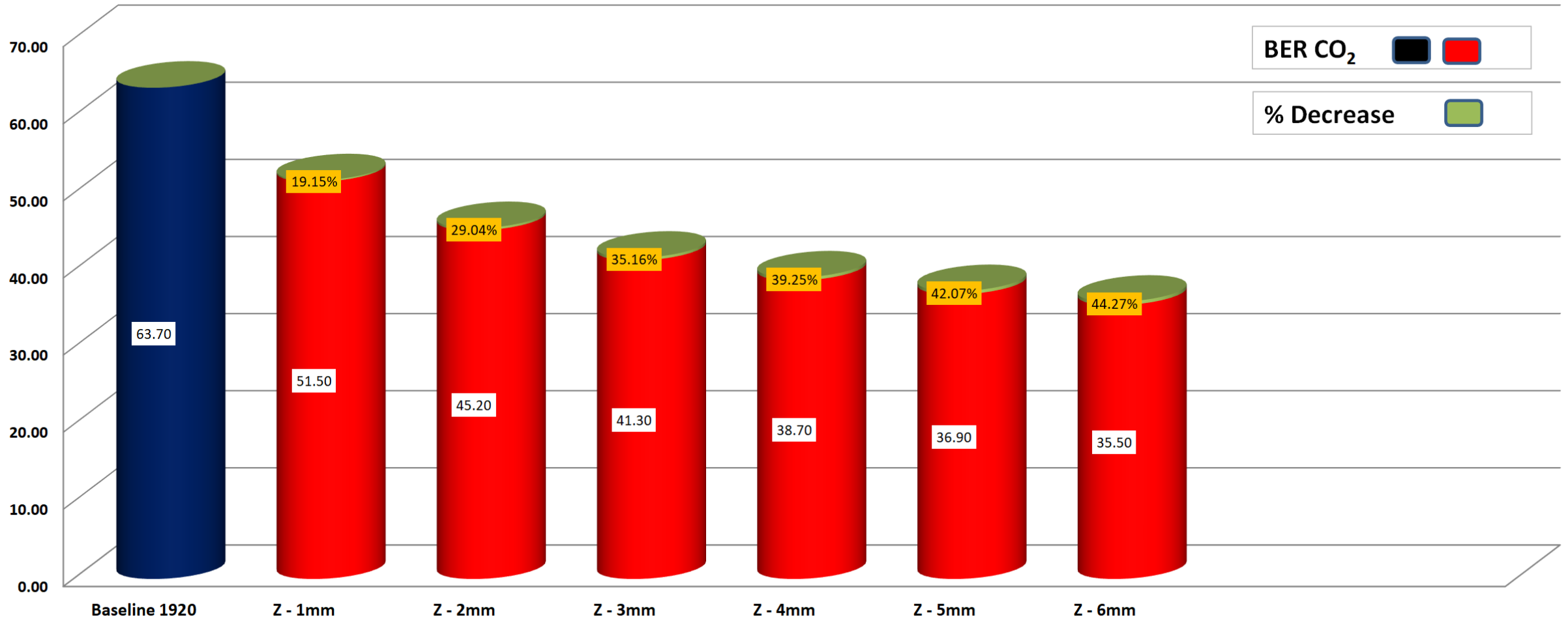
U- Values  

% Decrease 

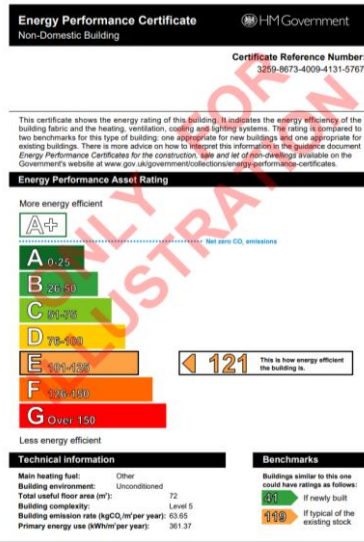


Building CO₂ Emission Rate (BER) – kgCO₂/m².annum

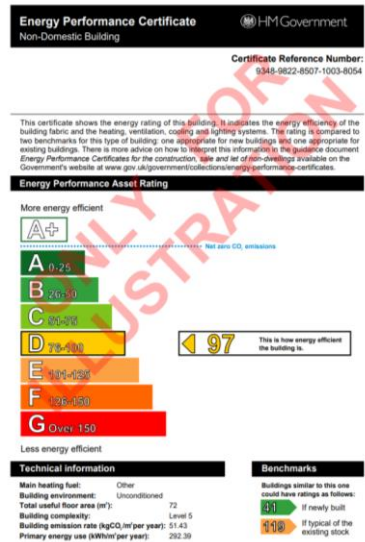
Building CO₂ Emission Rate (kgCO₂/m².annum)



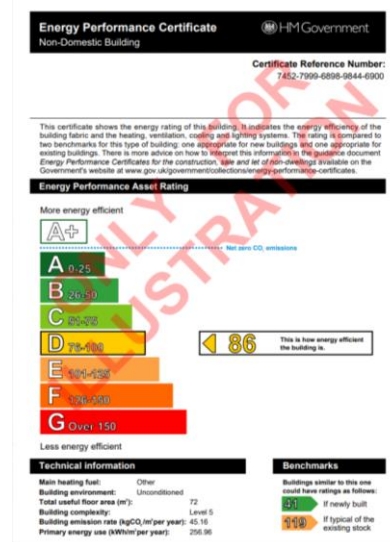
Energy Performance Asset Rating



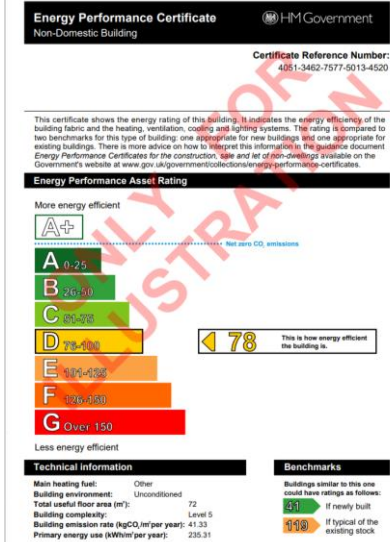
Base Line 1920



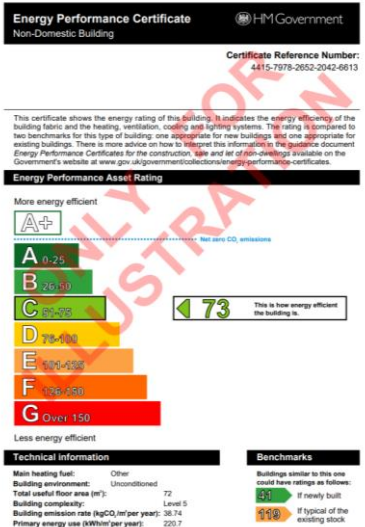
Zenova - 1mm



Zenova - 2mm



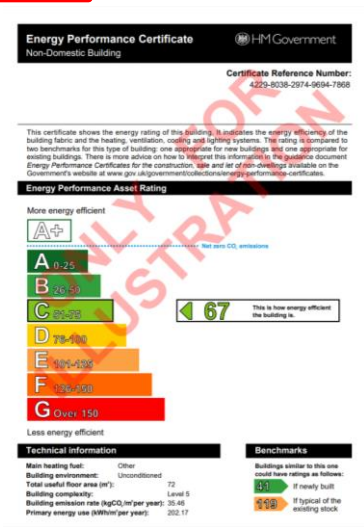
Zenova - 3mm



Zenova - 4mm



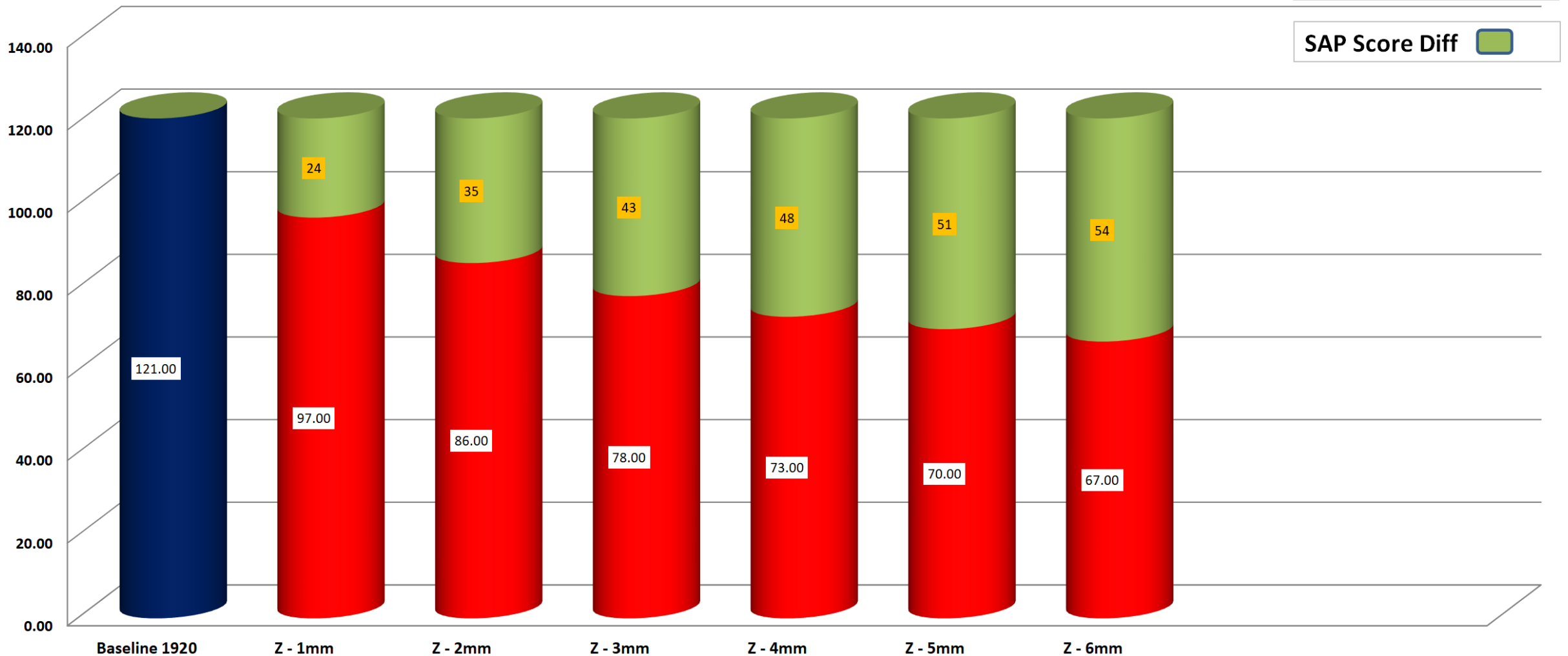
Zenova - 5mm



Zenova - 6mm

Energy Performance Asset Rating

EPC - Asset Rating



Conclusion



1. **The promising** result shown by the U-value Improvement which is 1.2678 $W/(m^2K)$.
2. Zenova material has the **advantage of the thickness** against other insulation materials.
3. Modeling and simulation of whole building results show evidence of **significant reduction** in U-values, Energy Consumption (Heating), Building Emission Rate and Asset Rating with progressive increase in thickness application of Zenova material.

Future Works/ Considerations



1. Performance with **Varying** coating thickness.
2. Run the test and measure the **heating energy (KWh)** before and after refurbishment with dedicated heater.
3. Testing other buildings (1950, 2010) and **2021 New Building regulation**
4. Future over heating analysis using **CIBSETM59 for 2050-2080**