Annex II – Study of the University of Sevilla (Spain)

Internal space gains and CO_2 emissions savings in building renovations with Solstice® insulation technology

White Paper

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1. GOAL

The objective of this study is to determine the theoretical positioning of rigid foams for thermal insulation that incorporate Solstice blowing agent technology developed by Honeywell against traditional solutions for interior insulation in residential buildings.
This study includes:

a) The conditions in which rigid foam insulation made with Solstice blowing agents is advantageous against other insulation materials.
b) Quantify the above advantage (energy and/or economic savings):
   b.1.) At equal thickness of insulation, increase in energy performance.
   b.2.) At equal thermal resistance of insulation, increase of usable space.

The comparison between insulation solutions is performed under two scenarios:

– Compliance with current regulations in Spain (limit values of the Technical Building Code).
– Compliance with Passivhaus standard requirements.

2. PRIOR CONSIDERATIONS

The building's energy renovation requires in all cases a better insulating capacity of the façade regardless of climatic zone and type of building.

The renovation of the façade from the outside may not be an option in the event that there are some types of design or functional restrictions or it is an intervention in a building of a unique or protected nature.
At an urban level, insulating an outside wall means increasing the volume of the building, enlarging its footprint, reducing the separation to boundaries (front, side or rear) and/or invading adjoining party walls.
On the other hand, it is essential that buildings protected for their historical, architectural, artistic, cultural or aesthetic value are renovated so they do not become dilapidated or abandoned. In addition, many historical and protected buildings are used for housing.

Under these conditions, when renovating from the interior wall of the building is the only viable option, the reduction of insulation thickness plays an important role in reaching a compromise between comfort, the cost of the building and energy consumption during its lifetime (opposite factors for the estimation of the life cycle cost). In summary, the renovation of a façade from the interior of the building for energy efficiency improvement must consider the reduction of energy demand and consumption, the cost of the intervention considering its entire life cycle, and the reduction of usable interior space.

Since the cost per unit of thermal resistance €/(m^2K/W) is higher in Solstice-based rigid foams than in equivalent insulating materials, their competitive advantage should be based on the fact their implementation in a renovation project entails maximizing usable space as a result of their lower thermal conductivity. Usable floor area loss occurs only when insulating from the interior wall of the façade.

3. METHODOLOGY USED TO COMPARE INTERNAL WALL INSULATION

The search for scenarios in which Solstice-based insulation holds an advantage over alternative incumbent products and its quantification is based on an exhaustive parametric study underpinned by the following comparison framework:

- Basing the study in the Spanish construction market. Spain is a relevant player with over 22 million households.
- 3 single family homes and 2 multi-family buildings. Figure.11.
- 5 national climate zones linked to the wintertime period (A, B, C, D and E). Figure.2.
- Using the above-referenced heating and cooling equipment defined in table 4.5-HE0 of the Basic Document HE of the Spanish Technical Building Code.
- Using Life Cycle Cost (LCC) as a decision-making indicator.
- Using data generated from calculations using Lider-Calener Unified Tool (HULC).
- Filtering the combinations that comply with the Spanish building code CTE (Royal Decree 732/2019, of December 20).
- Identifying combinations that meet the Passivhaus standard.

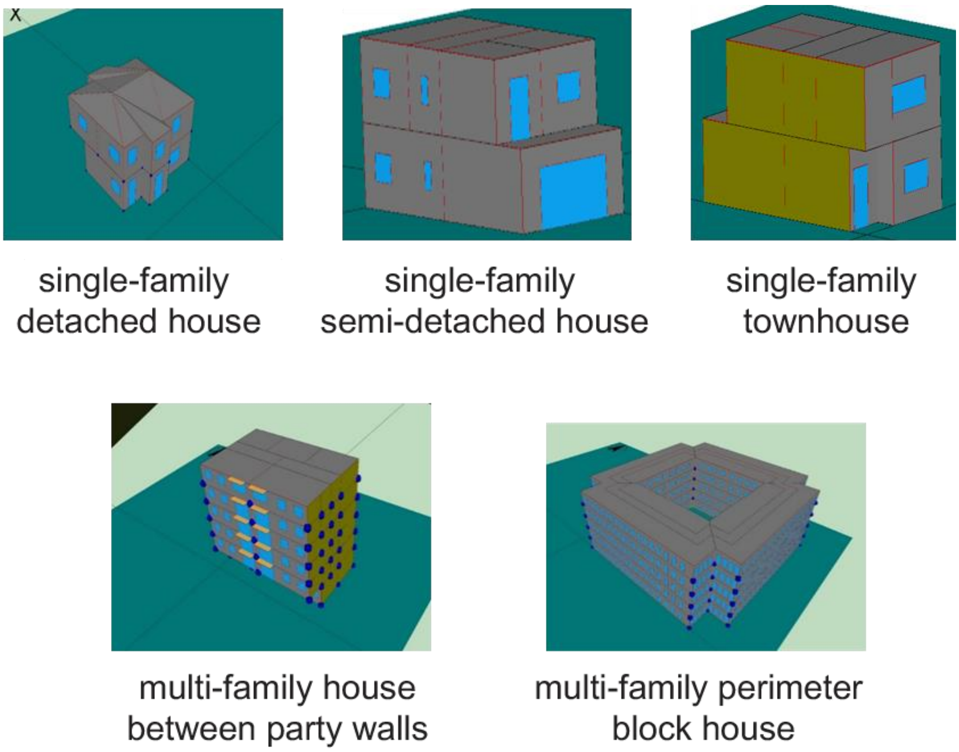


Figure.1. Housing considered in the parametric study.

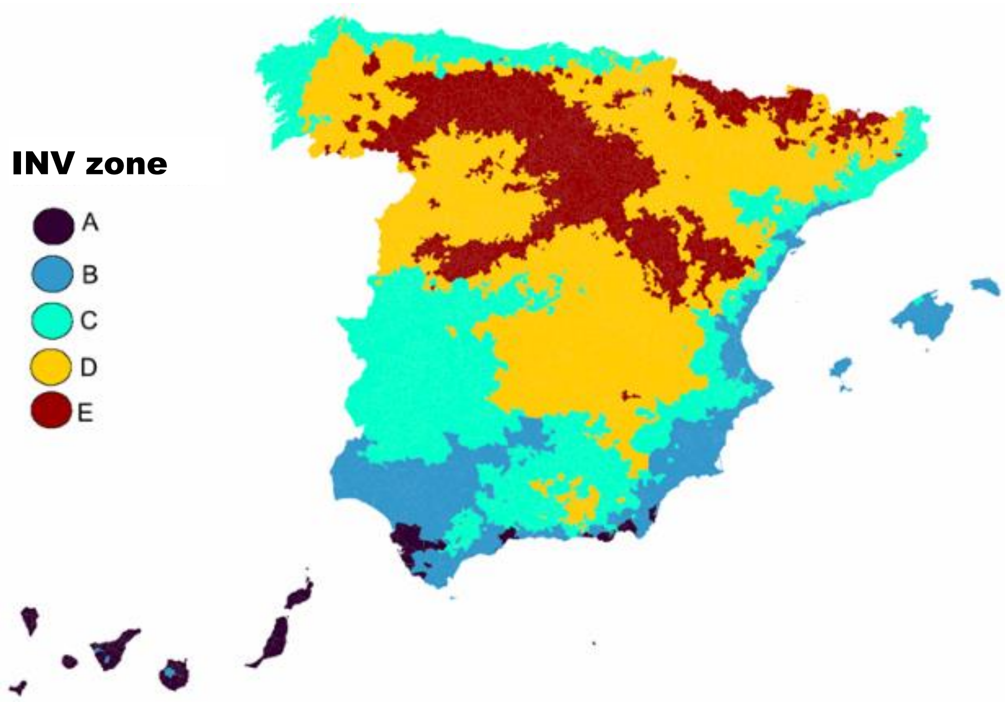


Figure.2. Spain climate zones by heating requirement

The following materials for interior wall insulation are compared to phenolic or PIR (polyisocyanurate) boards:

- mineral wool
- Graphite EPS (expanded polystyrene)

This table shows the thermal conductivities and estimated market prices of insulation materials as of October 2021, having neutralized the cost of the cladding wall for all solutions. It is assumed that the difference in prices among insulation materials remains constant independently of the market evolution.

Table 1. Conductivity and estimated cost of insulation materials via the study.

Product	Conductivity (W/m·K)	Insulation price €/m^2 per cm of insulation	Insulation price €/m^2 per thermal resistance unit	Labor and ancillary cost per m^2
Mineral wool	0.035	0.80	2.78	2.13
EPS Graphite	0.032	0.69	2.20	5.00
PIR HC	0.022	2.10	4.62	5.00
Solstice-based Phenolic/PIR	0.019	3.15	5.67	5.00

4. CONCLUSIONS

4.1. Compliance with the Spanish Technical Building Code (CTE) and Passivhaus standard

All the buildings evaluated in this study met the performance requirements of the Spanish technical building code CTE (total primary energy consumption and non-renewable primary energy consumption) by using prescriptive requirements and the required level of performance of the buildings' envelope at the optimal cost combination.

It is not necessary to consider higher performing equipment (heating and cooling, lightning, windows, etc.) than that used in the study.

Figure 3 shows the heating demand for optimal cost combinations to meet the CTE's prescriptive requirements.

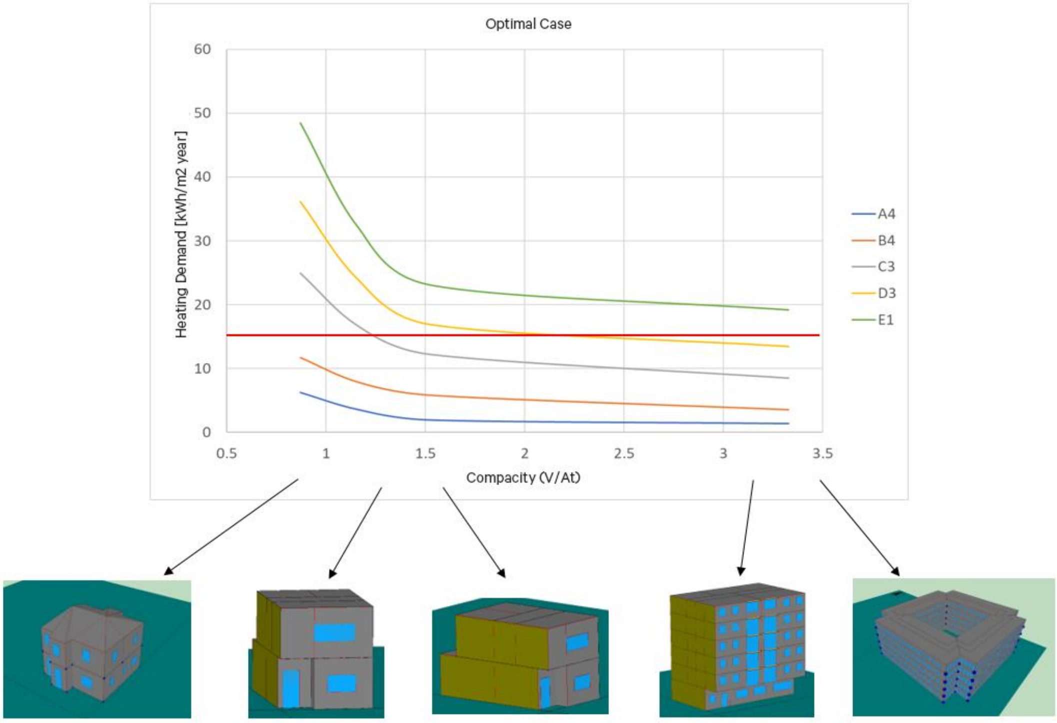


Figure 3. Heating demand for the combinations of constructive solutions and equipment of the envelope that originate the optimal cost combination

In the case of the performance requirements for the Passivhaus standard, the situation is similar. The cooling demand limit value (15 kWh/m^2·year) loosely meets the CTE's prescriptive requirements, with cases where night ventilation might be required.

The limit value of the heating demand (15 kWh/m^2·year), on the contrary, requires additional improvements to those specified by the CTE. As per Figure 3, only in climatic zones A and B, buildings that comply with the CTE would meet the requirement of the maximum heating demand value of the Passivhaus standard. For climatic zone C, the detached single-family house falls outside the standard. For D, all single-family homes fall outside; and for E, buildings that comply with CTE don't comply with the Passivhaus standard.

If the Passivhaus airtightness requirement (n_{50} =0.6 h^{-1}) is added to CTE requirements and a double air flow system with recuperator is incorporated, the situation changes significantly. If the level of insulation of the façades is improved beyond the cost-optimal value, the only case that would not meet the standard would be the single-family detached house in climate zones D and E. In the latter case, the performance of other building components would have to be improved, which is the reason it has not been considered in this study.

4.2. Net floor area loss when insulating the interior wall

The loss of useful floor space depends largely on the performance of the insulation material used.

A study has been conducted of 10 random houses in Spain. Figure 4 shows a schematic of 3 of the homes analyzed.

Figure 4. Floor area of 3 of the 10 homes evaluated

Table 1 shows the difference of m² saved (m² lost using Solstice minus m² lost using alternative insulation material) assuming the homes required a thermal insulation resistance of R 5 m² K/W.

Table 1. Useable floor area following renovation

€/m² built	House	Original situation		After renovation m² useful floor saved		
		Built Area m²	Net Floor Area m²	Solstice vs. MW	Solstice vs. EPS	Solstice vs. PIR HC
3,807	1	36.00	31.24	0.60	0.49	0.14
1,881	2	75.00	65.09	1.47	1.21	0.35
3,024	3	60.00	51.86	3.55	2.92	0.83
2,322	4	123.00	106.90	3.75	3.09	0.88
2,009	5	106.00	92.13	2.06	1.70	0.49
1,120	6	72.50	63.06	1.89	1.56	0.45
995	7	50.50	44.03	2.24	1.84	0.53
1,561	8	66.00	57.66	2.42	1.99	0.57
1,085	9	56.00	48.93	2.02	1.67	0.48
1,783	10	72.50	63.16	1.74	1.44	0.41

4.3. Price threshold values of the usable floor area that makes the Solstice solution competitive with equal thermal resistance

Comparisons have been made of the total cost of an investment in the renovation of façade walls, taking into account the cost of insulation, labor and ancillary - on the one hand - and the cost of the usable area lost by installing worse performing and thicker insulation in the interior wall, on the other. In these studies, a threshold value of the price of the usable area of the house was calculated to determine scenarios in which investment in Solstice-based insulation was lower than alternatives.

Table 3 shows the threshold values of useable area for all buildings for each of the two comparisons:

Table 2. Threshold values of the price of the soil surface preserved for the buildings under study (€/m²).

Solstice vs.	Single-Family Detached House	Single-Family Semi-Detached House	Single-Family House between Party Walls	Multi-Family House between Party Walls	Multi-Family Perimeter House
Mineral wool	452 a 798	494 a 927	441 a 802	413 a 587	442 a 829
Graphite EPS	555	608	542	508	544
PIR HC	728	797	711	666	713

It can be easily demonstrated that the threshold values are significantly lower than the market prices per m² of usable floor area in all the Spanish regions and provinces. Therefore, the Solstice solution is more competitive based on the threshold prices detailed in Table 3.

The map below shows average property prices by region as of May 2022.

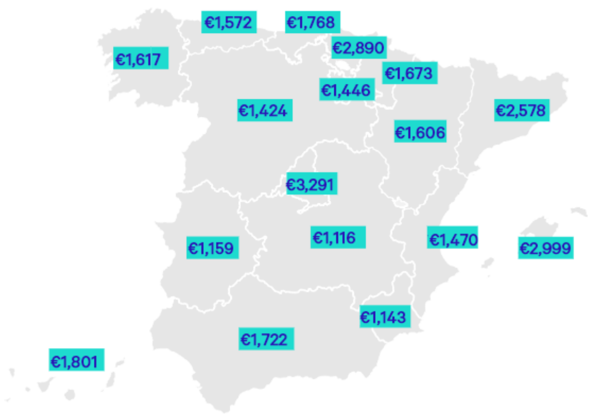


Figure 4. Usable floor area price as of May 2022 (€/m²).
Source: Fotocasa Real Estate Index

4.4 Economic value of the usable floor area saved at equal thermal resistance The initial investment required with the Solstice solution is higher than that which would be required with any of the alternative insulation materials as indicated in Table 1. This investment would be more than offset by the economic value of the usable floor saved thanks to the use of thinner insulation.

Figure 6 shows the economic value difference of the usable floor area saved considering the initial investment required (per total m^2 of usable floor area of the house) between mineral wool insulation and Solstice-based foam to meet the requirements of the CTE in climatic zones D (R = 3 m^{2}K/W) and E (R = 3.5 m^{2}K/W) and assuming property price scenarios of €1,000, €2,000 and €3,000/m^2, respectively

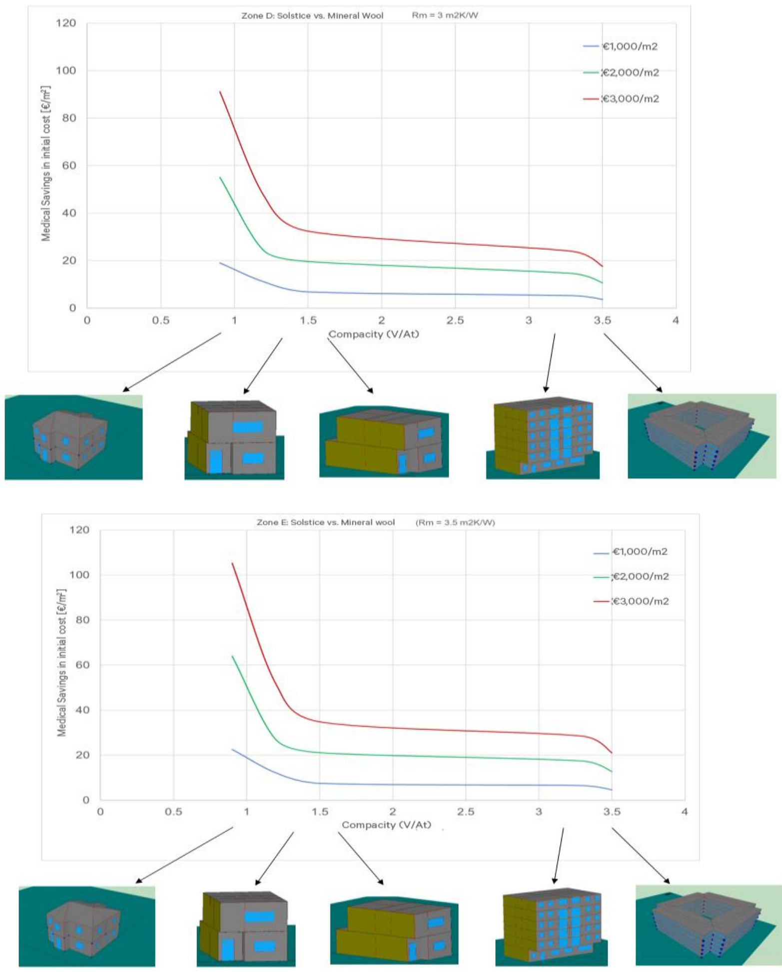


Figure 6. Economic value difference of the usable floor area saved considering the initial investment required between mineral wool and Solstice-based foam in climate zones D (top graph) and E (bottom graph).

4.5. Compliance with CTE and Passivhaus standards at the same thickness with Solstice-based foam and insulation alternatives.

As expected, for the same insulation thickness, Solstice-based foams can satisfy regulatory requirements or meet Passivhaus standards, while a greater thickness is required for alternative insulation materials.

Table 4.34 shows results for a single-family detached house in zone C. The red cells mean that no insulation solution at the specified thickness met the standard. The green cells mean that the only two insulation solutions met the standard. Finally, the yellow cells show that Solstice-based foam met the standard at the specified thicknesses, while the alternatives did not.

Table 4.3. Example of application of CTE and Passivhaus standard at equal thickness for a single-family detached house home in zone C.

Thickness [cm]	Solstice	Mineral Wool
	CTE (Código Técnico de la Edificación [Technical Building Code]) compliant	**CTE (Código Técnico de la Edificación [Technical Building Code]) compliant**
2	No	No
4	Yes	No
6	Yes	Yes
8	Yes	Yes
10	Yes	Yes

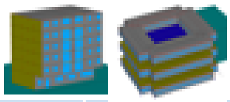
Thickness [cm]	Solstice	Mineral Wool
	Passivhaus compliant	**Passivhaus compliant**
2	No	No
4	No	No
6	No	No
8	Yes	No
10	Yes	No

4.6. Economic and CO2 emissions saving comparison of Solstice's solution vs. insulation alternatives

SINGLE FAMILY

Solstice vs. Mineral Wool	Thickness (cm)	Climatic region A3	B4	C3	D3	E1
Additional cost (€/m²)	5	7.1-20.0	7.1-20.0	7.1-20.0	7.1-20.0	7.1-20.0
Heating demand reduction (%)	5	14.0-22.5	11.4-20.4	10.0-17.4	11.3-16.5	11.1-15.7
CO2 emissions avoided (kg/m2/year)	5	0.1-0.4	0.2-0.7	0.4-1.4	0.6-2.0	0.8-2.6
Additional payback time for extra-investment (years)	5	7.5-13.9	5.1-7.6	3.2-3.9	2.3-2.7	1.9-2.1
Solstice vs. XPS/EPS Graphite	**Thickness (cm)**	**Climatic region A3**	**B4**	**C3**	**D3**	**E1**
Additional cost (€/m²)	5	5.9-16.6	5.9-16.6	5.9-16.6	5.9-16.6	5.9-16.6
Heating demand reduction (%)	5	11.9-19.4	9.6-17.5	8.5-14.9	9.6-14.1	9.4-13.4
CO2 emissions avoided (kg/m2/year)	5	0.1-0.4	0.1-0.6	0.3-1.2	0.5-1.7	0.7-2.1
Additional payback time for extra-investment (years)	5	6.2-11.5	4.3-6.3	2.7-3.2	1.9-2.3	1.6-1.8
Solstice vs. PIR HC	**Thickness (cm)**	**Climatic region A3**	**B4**	**C3**	**D3**	**E1**
Additional cost (€/m²)	5	2.3-6.4	2.3-6.4	2.3-6.4	2.3-6.4	2.3-6.4
Heating demand reduction (%)	5	3.2-5.6	2.6-5.0	2.3-4.2	2.6-4.0	2.6-3.8
CO2 emissions avoided (kg/m2/year)	5	0.0-0.1	0.0-0.2	0.1-0.3	0.1-0.4	0.2-0.5
Additional payback time for extra-investment (years)	5	2.4-4.4	1.6-2.4	1.0-1.2	0.7-0.9	0.6-0.7

MULTI-FAMILY



Solstice vs. Mineral Wool	Thickness (cm)	Climatic region A3	B4	C3	D3	E1
Additional cost (€/m²)	5	3.9-5.2	3.9-4.9	3.9-4.9	3.9-4.9	3.9-4.9
Heating demand reduction (%)	5	10.6-16.7	9.3-13.7	9.7-12.2	10.0-11.2	9.3-11.0
CO2 emissions avoided (kg/m2/year)	5	0.1-0.1	0.1-0.2	0.3-0.4	0.5-0.6	0.7-0.7
Additional payback time for extra-investment (years)	5	5.8-12.5	3.7-6.6	2.2-3.2	1.6-2.2	1.2-1.7
Solstice vs. XPS/EPS Graphite	**Thickness (cm)**	**Climatic region A3**	**B4**	**C3**	**D3**	**E1**
Additional cost (€/m²)	5	3.2-4.0	3.2-4.0	3.2-4.0	3.2-4.0	3.2-4.0
Heating demand reduction (%)	5	9.0-13.3	7.9-11.6	8.2-10.4	8.4-9.5	7.9-9.3
CO2 emissions avoided (kg/m2/year)	5	0.0-0.1	0.1-0.2	0.3-0.3	0.4-0.5	0.6-0.6
Additional payback time for extra-investment (years)	5	4.8-9.9	3.1-5.4	1.9-2.7	1.3-1.8	1.0-1.4
Solstice vs. PIR HC	**Thickness (cm)**	**Climatic region A3**	**B4**	**C3**	**D3**	**E1**
Additional cost (€/m²)	5	1.2-1.6	1.2-1.6	1.2-1.6	1.2-1.6	1.2-1.6
Heating demand reduction (%)	5	2.4-3.6	2.1-3.2	2.2-2.8	2.3-2.6	2.1-2.5
CO2 emissions avoided (kg/m2/year)	5	0.0-0.0	0.0-0.0	0.1-0.1	0.1-0.1	0.1-0.2
Additional payback time for extra-investment (years)	5	1.8-3.8	1.2-2.1	0.7-1.0	0.5-0.7	0.4-0.5

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Table 4. Summary of the 5 cm equal thickness analysis for multi-family homes.