HIGH-PERFORMANCE BUILDING CONSTRUCTION ASSEMBLIES AND DETAILS:

THE IEA TASK 13 EXPERIENCE

Working Document of the International Energy Agency Task 13 of the Solar Heating and Cooling Program Final Report

PREPARED FOR:

The CANMET Energy Technology Centre (CETC)
Energy Technology Branch, Energy Sector
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PREPARED BY:

Enermodal Engineering Limited
650 Riverbend Drive
Kitchener, Ontario, N2K 3S2
Tel: (519) 743-8777, Fax: (519) 743-8778
Email: office@enermodal.com

SCIENTIFIC AUTHORITY:

Dr. Roger Henry
The CANMET Energy Technology Centre (CETC)
Energy Technology Branch, Energy Sector
Department of Natural Resources Canada
580 Booth Street
Ottawa, Ontario, K1A 0E4

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NOTE

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High-Performance Building Construction Assemblies And Details: The IEA Task 13 Experience

Summary

Task 13 of the International Energy Agency Solar Heating and Cooling Program involved designing, building and monitoring low-rise residential buildings with extremely low total purchased energy requirements. Envelopes were built with high levels of insulation, minimized thermal bridging, high-performance windows and air-tight design.

This report goes beyond the final report of the Task to document and quantify the energy-impact of the energy-efficient construction assemblies and details used in twelve of the buildings. This was done to encourage and facilitate implementation by the construction industry.

In general the building assembly u-values for the houses studied, wood frame, steel frame and masonry, were twice as good as for conventional housing. Windows too demonstrated exceptionally high efficiency. Weaknesses were window/wall interfaces and below grade wall/basement junctions.

Preparation of this report was undertaken as part of Canada's contribution to the Task 13 project.

Éléments fonctionnels et détails de la construction de bâtiments à haut rendement :l'expérience *Task 13* de l'AIE

Résumé

Task 13, un élément du Programme de chauffage et de climatisation par énergie solaire de l'Agence internationale de l'énergie, prévoit la conception, la construction et la surveillance de bâtiments résidentiels dont les exigences globales en énergie achetée sont minimales. Les enveloppes des bâtiments ont été conçues pour présenter des niveaux élevés d'isolation, des possibilités réduites de ponts thermiques, des fenêtres à haut rendement énergétique et des caractéristiques d'étanchéité à l'air.

Ce rapport s'ajoute au rapport définitif de *Task 13* puisqu'il vient étayer et quantifier les conséquences énergétiques des éléments fonctionnels et des détails de construction favorisant l'efficacité énergétique, tels que l'on retrouve dans douze bâtiments. En fait, le rapport vise à inciter et à favoriser la mise en application par l'industrie de la construction des techniques, des systèmes et des dispositifs utilisés.

En général, les coefficients de transmission de la chaleur dans les éléments fonctionnels de construction à l'intérieur des maisons étudiées, soit les charpentes en bois, les charpentes en acier et les bâtisses, s'avéraient deux fois meilleurs que dans le cas d'une maison classique. De même, les fenêtres ont présenté un rendement exceptionnel. Les seuls points faibles sont apparus à l'interface des fenêtres et dès murs, ainsi qu'au raccordement des murs souterrains et des sous-sols.

On a entrepris la rédaction de ce rapport à titre de contribution du Canada à la réalisation du projet *Task 13.*

ACKNOWLEDGEMENTS

This project was undertaken by IEA Task 13 to document the design and performance of the Task 13 houses. All Task 13 members assisted in collecting and reviewing the information. This report was written by Stephen Carpenter of Enermodal Engineering, Canada. The drawings were prepared by Heike Kluttig and Hans Erhorn of the Fraunhofer Institute for Building Physics, Germany. Guofeng Mao and Gudni Johanneson of KTH, Sweden performed the U-value calculations. Bart Poel of Damen Consultants, The Netherlands analysed the performance of the entire house.

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1.0 INTRODUCTION

1.1 Purpose

In 1989 Task 13 of the International Energy Agency Solar Heating and Cooling Program was established. The goal of the task is to design, build and monitor low-rise residential buildings that have extremely low total purchased energy requirements. Fourteen countries from Europe, North America and Japan are participating in this program. Fifteen buildings have been or are in the process of construction. The average (predicted) energy use in these houses is only 45kWh/m^2 of floor area of which approximately fifty percent is required for space heating.

To achieve the low energy budgets, the designers had to incorporate the latest technologies in energy conservation, energy efficiency, active solar, passive solar and photovoltaics. The final report of the Task (Solar Low Energy Houses of IEA Task 13, published by James and James of London, U.K.) documents the design process, the building designs and monitoring results and presents an overview of the technologies used in the buildings.

To reduce the demand for space heating, most of the buildings were constructed with an extremely low heat loss building shell. This was achieved through high levels of insulation, minimization of thermal bridging, high-performance windows and air-tight building construction. The purpose of this report is to document and quantify the energy impact of the energy-efficient construction assemblies and details used in Task 13 buildings. This report supplements the task final report by providing more detailed information on the building assemblies so that they can be implemented by the construction industry.

1.2 The Case for High-Performance Building Assemblies and Details

The purpose of the building envelope is to protect the occupants from the extremes in outdoor weather. A well-designed building envelope will allow very little heat transfer, minimize air leakage and drafts and protect building materials from moisture damage. Unfortunately, many conventional building assemblies do not meet these requirements. Low insulation levels contribute to high heating and cooling bills. Thermal bridging through building framing and window edges cause condensation. Air leakage through building components and junctions causes occupant discomfort. Accumulation of moisture in walls (either from diffusion of occupant-generated moisture or transport of rain) reduces the effectiveness of insulation and ultimately causes irreparable damage to the structure.

The thermal performance of conventional building assemblies is often over-stated. In many cases the quoted U-values for components are nominal values instead of total values. The nominal values are usually for the centre of the wall ignoring the additional heat loss of the framing around window and doors, at the sill and header plates, and between floors. The same situation often applies to windows with the U-value based on centre-of-glazing performance ignoring the higher heat loss regions at the edge-of-glass and frame. These thermal discontinuities (also referred to as thermal bridges and thermal anomalies) can increase heat loss by over 20%. The use of nominal U-values instead of total U-values results in a false sense of performance and an under-prediction of space heating energy use.

Simply adding more insulation does not turn a conventional assembly into a high-performance assembly. As more insulation is added, the thermal discontinuities and junctions between building assemblies become more important. For example, in a standard wood framed double-glazed window, the total U-value is only 13% higher than the centre-glazing value, whereas if the same window were triple-glazed with low-e and argon, the total U-value is almost twice the centre-glazing value.

The building assemblies presented in this document have been carefully designed to achieve maximum total performance and occupant comfort. Section 2, describes conventional wood frame and masonry building construction as used in most of North America and Europe. These construction systems can be contrasted with the high performance assemblies and details of Task 13 as presented in Section 3.

1.3 Evaluating the Thermal Performance of Building Assemblies and Details

The thermal performance of the construction assemblies and details in this report were carefully evaluated to give an accurate assessment of the heat transfer (i.e., U-value). For the purposes of evaluation, the building shell was divided into building assemblies (walls, windows, floors and ceilings) and details (junctions at the wall/floor, wall/ceiling, and wall/window).

In most cases the thermal performance of building assemblies can be assumed to have one-dimensional heat flow. The U-value of the assembly was calculated as the reciprocal of the sum of the thermal resistances of each layer in the assembly. If more than one material is used in a layer (e.g., wood framing with insulation in between), the calculation process was modified. Separate calculations were made for each different path through the assembly (parallel path method) and the U-values area weighted. This approach gives reasonable results provided the thermal conductivity of the two materials does not differ by more than a factor of ten.

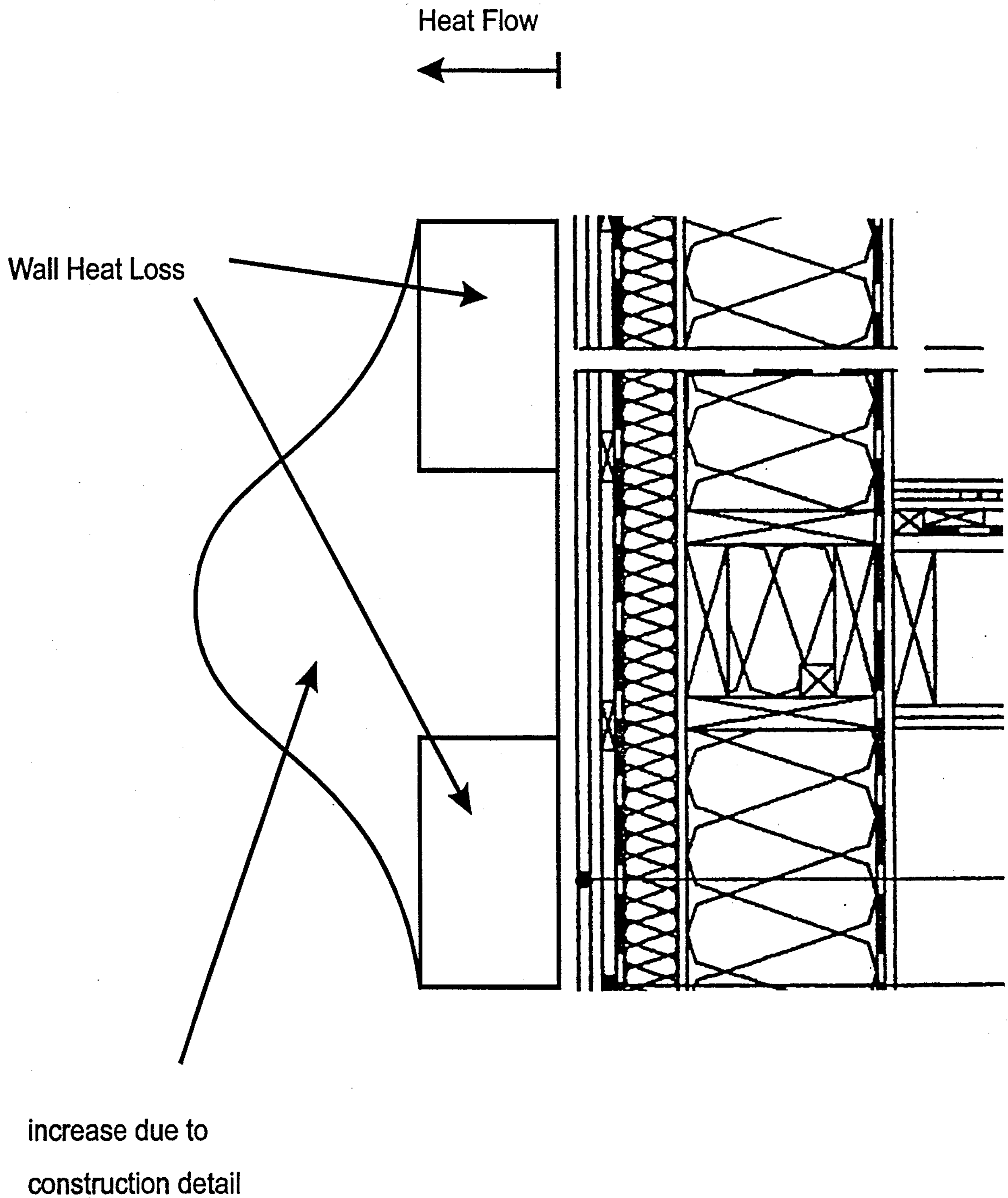
Heat flow at building junctions is more complicated and requires two-dimensional heat transfer analysis. Two ISO standards, prEN ISO 13789 "Thermal Performance of Buildings - Transmission Heat Loss Coefficient - Calculation Method" and prEN ISO 10211-1 "Thermal Bridges in Building Construction - Heat Flows and Surface Temperatures - Part 1: General Calculation Methods" and several computer programs [FRAME, 1995; EuroKOBRU, 1995; GF2DIM, 1990] have been written to help perform this analysis. The heat transfer through these details is characterized by a linear thermal transmittance. It is defined as the increase in heat transfer through the junction and adjacent walls due to the junction on a per unit length and temperature difference basis. Figure 1.1 shows a junction between a wall and an intermediate floor and the corresponding heat flow. An increase in heat flow due to thermal bridging through the support framing can be clearly seen.

According to the ISO standards, the increase in heat flow can be based on either inside or outside dimensions. Both approaches are correct provided they are applied consistently. In this report, all calculations are based on inside dimensions and were performed with a 2-D heat transfer program. Mao, 1996 gives a more detailed description of the process.

There are many junctions or details in a house. Time and budget limited this study to the five details that typically have the largest impact: wall/roof, wall/intermediate floor, wall/window, wall/grade level floor, and below-grade wall/basement floor. Other details such as corners, pipe penetrations and the wall/foundation wall were not examined.

The U-values for the assemblies and details are presented in Sections 2 and 3 for each of the buildings studied. The U-values are compared in Section 4. Section 5 examines the impact that building details can have on total building performance.

Figure 1.1: Heat Flow Through a Typical Wall/ Intermediate Floor Junction



2.0 CONVENTIONAL BUILDING ASSEMBLIES

The two most common wall construction systems in Europe and North America are wood-frame and masonry (sometimes referred to as brick). Wood-frame construction is used in North America and northern Europe. Masonry construction is used in central and southern Europe. The two construction systems are described in this section.

2.1 Typical Wood Frame Construction

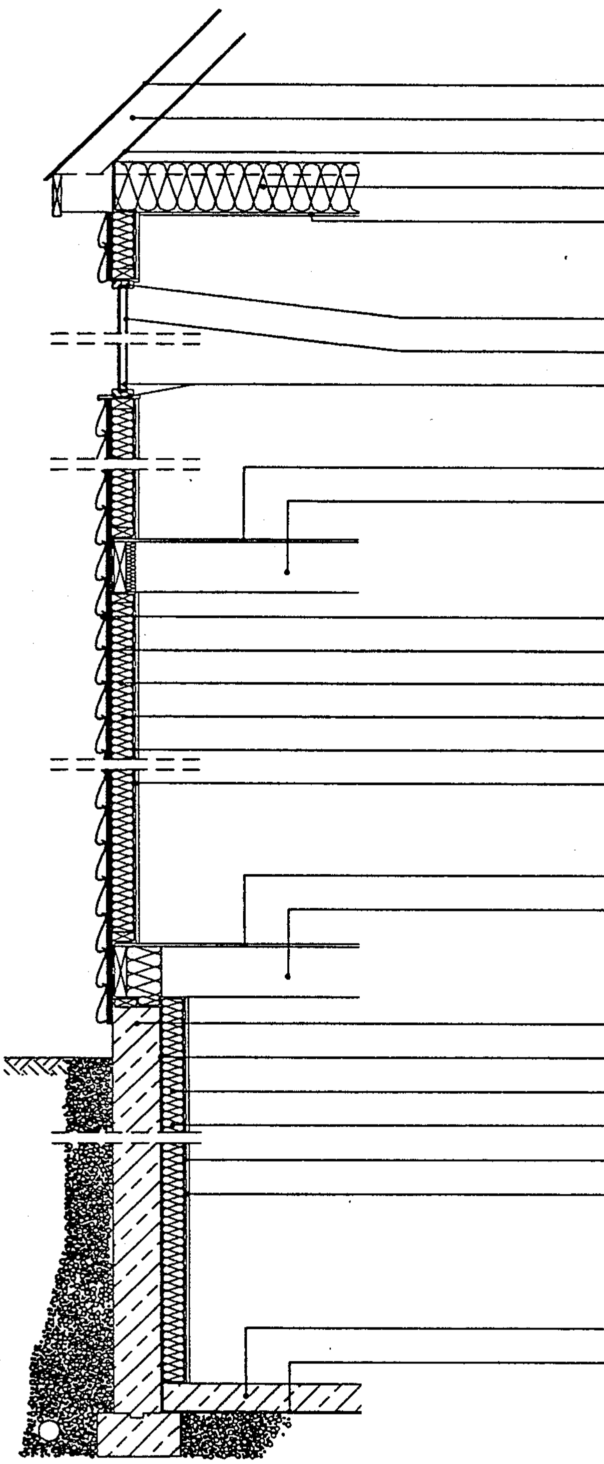
Although there are many variations in wood frame construction, the most common approach is to use 38 X 89 mm studs (nominal 2" X 4") spaced at 400 mm centres. In the colder climates, 25 to 50 mm of insulated sheathing is added to the outside to reduce heat loss. Figure 2.1 shows the cross-section of a typical wood-frame building. The wall system is insulated with 89 mm of fibreglass batt insulation between the wood frame studs and 25 mm of exterior polystyrene sheathing. The U-value of the wall (including the effects of the wood studs) is 0.33 W/m^2K.

The below grade wall can be insulated on either the interior or exterior. Figure 2.1 shows a typical interior wall insulation system: wood studs on 400 mm centres with fibreglass batts in between. The basement floor slab is uninsulated. In warm climates, the basement walls are not insulated or the building is built slab-on-grade. The U-values for the below-grade components are to the exterior of the assembly and exclude any insulating effects of the ground.

Four details or junctions were examined for this building: wall/roof, wall/intermediate floor, wall/window and below-grade wall/basement floor. The detail for the wall/window junction is shown in Figure 2.2. The linear U-values for the four junctions are also included with this figure. The linear U-value for the below-grade wall/basement floor is significantly higher than the other details, however, the inside-to-outside temperature difference will be much lower because of the adjacent ground.

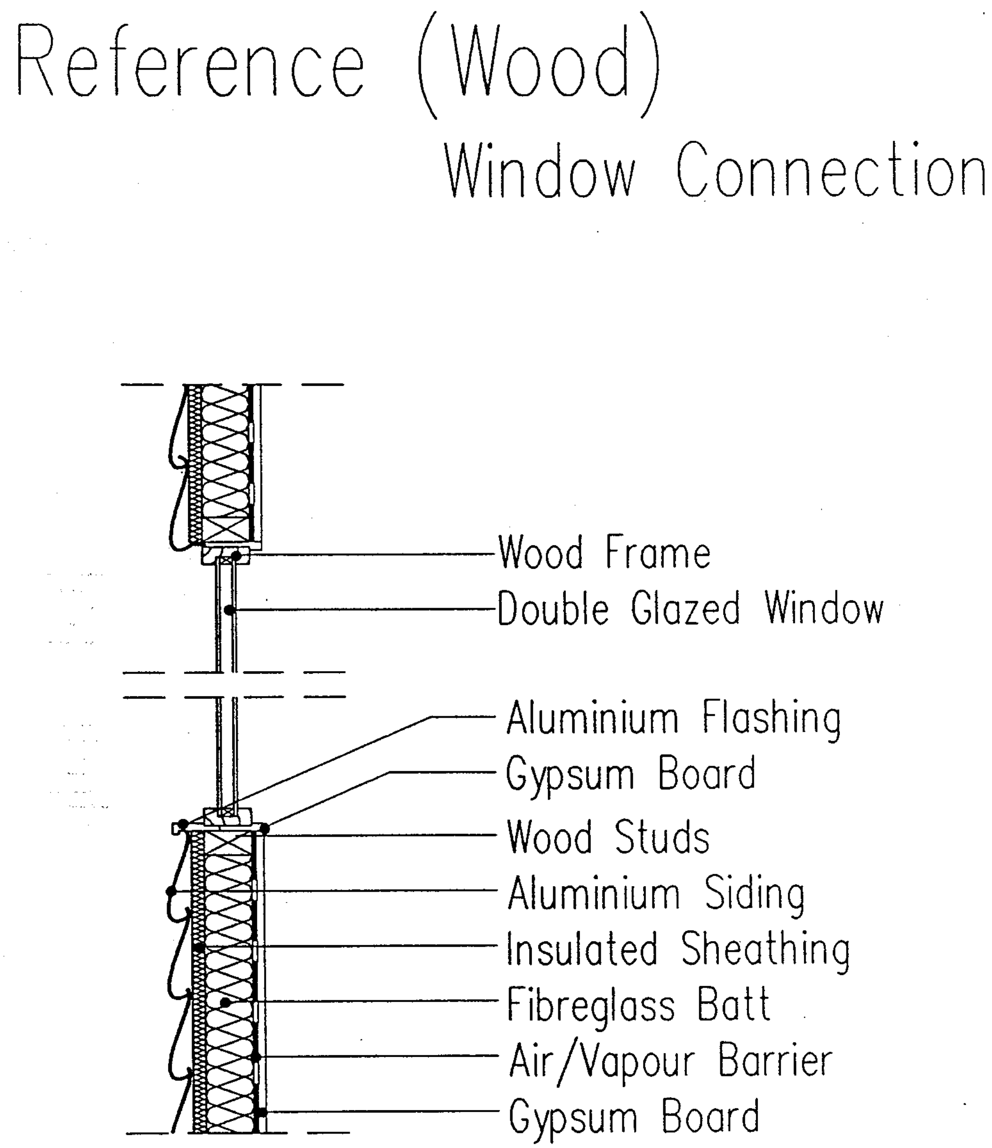
Figure 2.1

Reference (Wood)



Layer	Description	Width cm	Thermal Conduct. W/mK	U-Value W/m²K
Roof				
1	Asphalt Shingles	-	-	0.19
2	Wood on 400 mm Centres	14.0	0.14	
3	Air/Vapour Barrier	-	-	
4	Cellulose Insulation	22.0	0.04	
5	Gypsum Board	1.3	0.21	
Window				
6	Wood Frame			2.80
7	Glazing			2.80
8	Glazing and Frame			2.80
Ceiling				
9	Wood Subfloor	1.9	0.14	-
10	Wood Joist	22.0	0.14	
Exterior Wall				
11	Aluminium/Vinyl Siding	-	-	0.33
12	Extruded Insulating Sheating	2.5	0.029	
13	Wood Studs	8.9	0.14	
14	Fibreglass	8.9	0.04	
15	Air/Vapour Barrier	-	-	
16	Gypsum Board	1.3	0.21	
Basement Ceiling				
17	Wood Subfloor	1.9	0.14	-
18	Wood Joist	22.0	0.14	
Below Grade Wall				
19	Concrete	20.0	2.0	0.46
20	Moisture Barrier	-	-	
21	Wood Studs on 400mm Centres	8.9	0.14	
22	Fibreglass	8.9	0.04	
23	Air/Vapour Barrier	-	-	
24	Gypsum Board	1.3	0.21	
Basement Slab				
25	Concrete	12.0	2.0	4.35
26	Water Proofing	-	-	

Figure 2.2



Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.067
wall/intermediate floor	0.112
wall/window	0.023
below-grade wall/basement floor	1.076

2.2 Typical Masonry (Brick) Construction

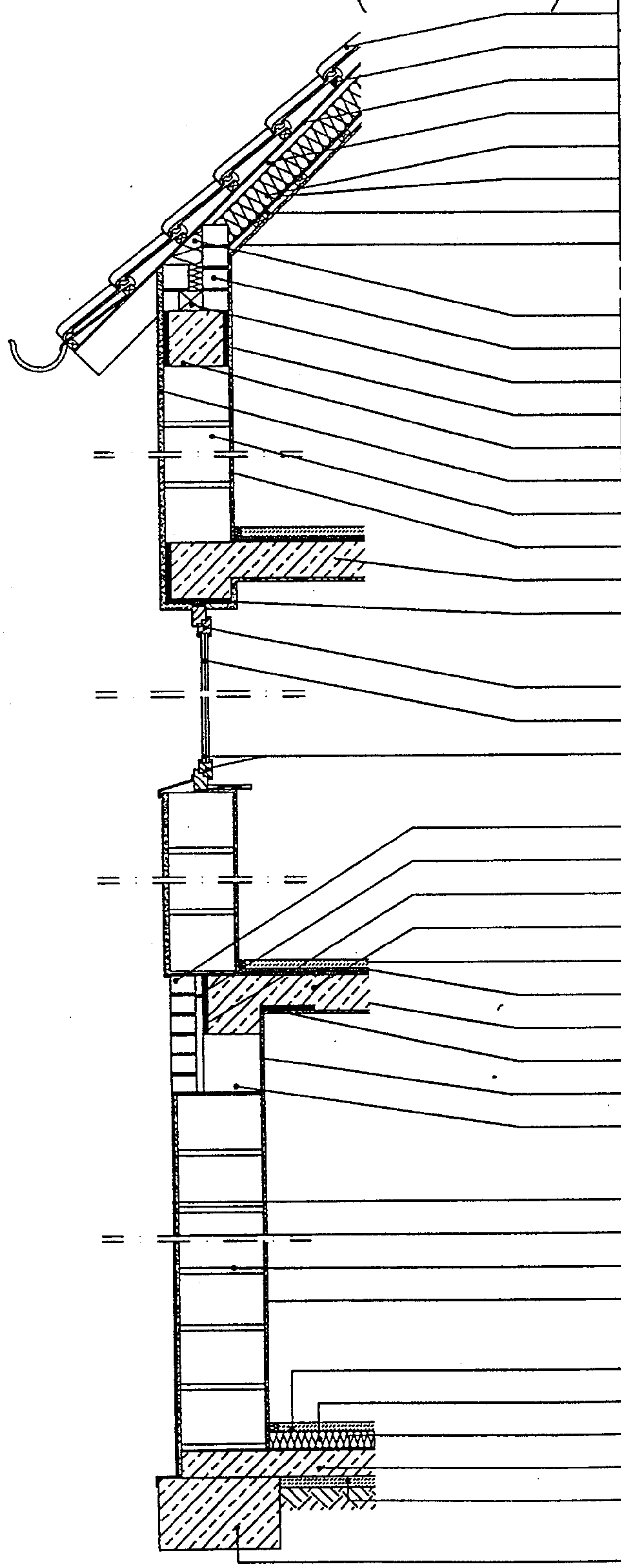
In conventional masonry construction, concrete blocks provide the structural support for the building. The inside and outside surfaces are often finished by adding a layer of plaster. The heat flow through the assembly is reduced by either using rigid insulation on the exterior of the block or by using a porous or aerated concrete block. In either case, the wall U-value is approximately 0.47 W/m^2K.

Figure 2.3 shows a typical masonry or brick building system. The walls are constructed with low-conductivity brick. For structural reasons the floors need to be constructed of medium density concrete. To reduce heat loss at wall floor junctions, 25 mm of polyurethane foam insulation is used. The roof is a wood frame assembly with 120 mm of mineral wool insulation.

Three details were examined for this building system: wall/intermediate floor, wall/window and below-grade wall/basement floor. The linear U-value for the wall/intermediate floor detail includes the effect of the window header.

Figure 2.3

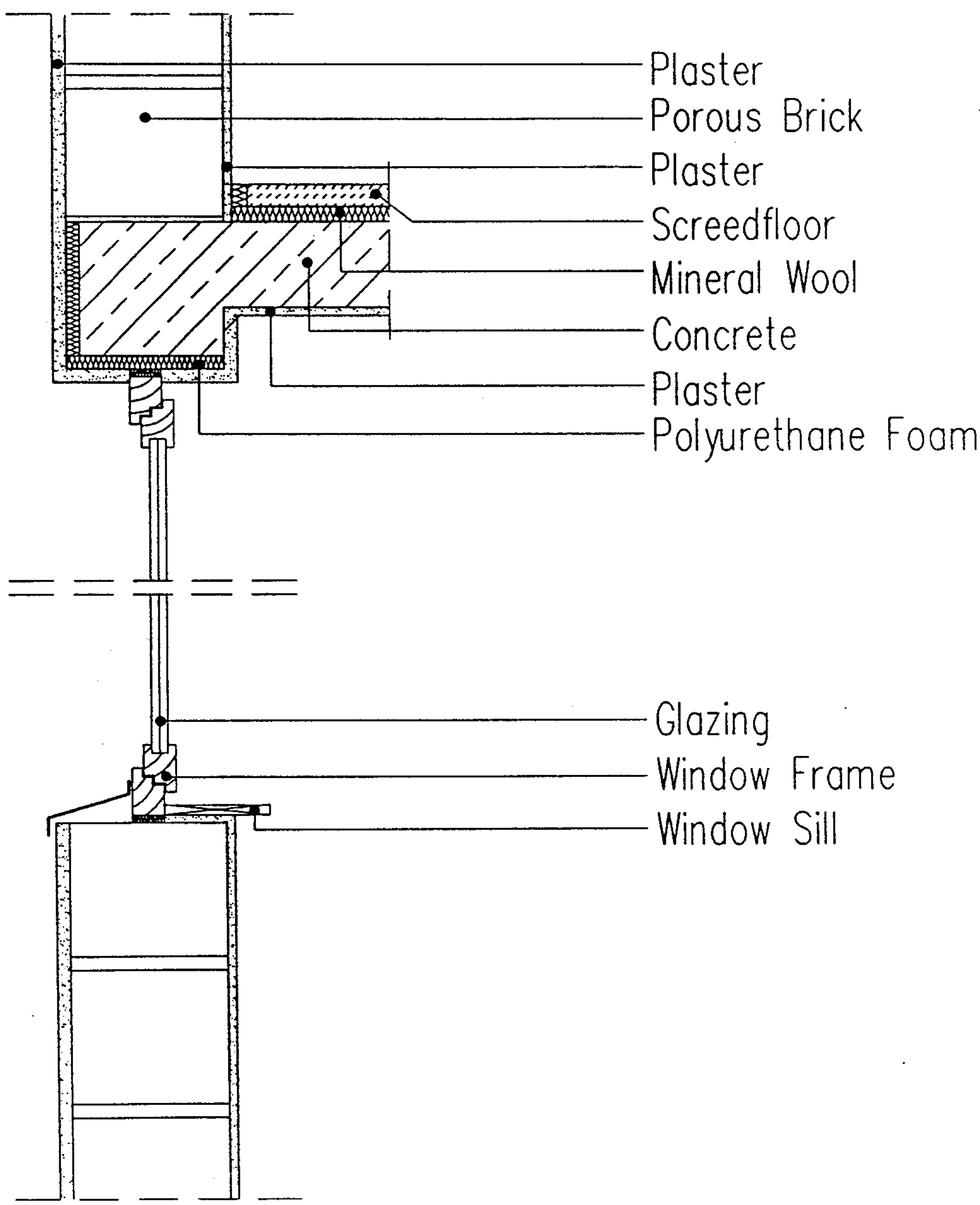
Reference (Brick)



Layer	Description	Width cm	Thermal Conduct. W/mK	U-Value W/m²K
Roof				
1	Roofing Tile	-	-	
2	Lattice	2.4	-	
3	Water Barrier	-	-	
4	Wood (15%)	16.0	0.14	0.33
5	Mineral Wool (85%)	12.0	0.04	
6	Vapour Barrier	-	-	
7	Lattice/Air Space	2.4	R=0.17m²K/W	
8	Gypsum Board	1.3	0.23	
Exterior Wall				
9	Mineral Wool	7.0	0.04	
10	Brick	11.5	0.7	-
11	Wood	12.0	0.14	
12	Polyurethane Foam	2.5	0.025	-
13	Concrete	25.0	2.1	
14	Plaster	2.5	0.87	
15	Porous Brick	30.0	0.16	0.47
16	Plaster	1.5	0.35	
17	Concrete	27.5	2.1	-
18	Polyurethane Foam	2.5	0.025	
Window				
19	Wood Frame			2.80
20	Glazing			2.80
21	Glazing and Frame			2.80
Basement Ceiling (Connection)				
22	Brick	11.5	0.7	
23	Air Space	3.0	R=0.17m²K/W	
24	Polyurethane Foam	2.5	0.025	-
25	Concrete	21.5	2.1	
26	Screedfloor	4.0	1.4	
27	Mineral Wool	3.0	0.04	
28	Concrete	16.0	2.1	
29	Polyurethane Foam	2.5	0.025	0.86
30	Plaster	1.5	0.35	
31	Porous Brick	24.0	0.21	-
Below Grade Wall				
32	Asphalt Bitumen	-	-	
33	Plaster	2.5	0.87	0.52
34	Porous Brick	36.5	0.21	
35	Plaster	1.5	0.35	
Basement Slab				
36	Screedfloor	4.0	1.40	
37	Polystyrene	8.0	0.04	
38	Water Proofing	0.2	-	0.44
39	Concrete	12.0	2.1	
40	Concrete	5.0	2.1	
Foundation				
41	Concrete	50.0	2.1	-

Figure 2.4 Reference(Brick)

Window Connection



Detail	Linear U-value W/m/K (interior dimensions)
wall/intermediate floor	0.304
wall/window	0.041
below-grade wall/basement floor	0.455

3.0 THE TASK 13 BUILDING ASSEMBLIES

In most cases the designers of the Task 13 houses had to redesign the conventional building assemblies to achieve the desired energy efficiency and performance. Typically the key modification was to widen the building wall assembly to accommodate additional insulation. In addition, special details were designed to minimize thermal bridging and minimize air leakage at the details. The following sections describe the building assemblies used in the Task 13 buildings. Each section contains a description and schematic drawings of the construction assemblies and details for each building. The thermal performance of each assembly and detail is computed using the methods described in Section 1.3. The values given are for the total assembly account for any thermal discontinuities. Not all of the Task 13 houses are included in this document. The examples contained in this report illustrate the range of high-performance building assemblies investigated among the participating countries.

3.1 BELGIUM - PLEIADE ROW HOUSE (LOUVAIN-LA-NEUVE)

The Pleiade House in Louvain-la-Neuve, Belgium features a light-weight, well-insulated building envelope. The walls and roof feature a triple layer of insulation. The middle layer in the wall assembly is a 14-cm-thick insulated, prefabricated wood structure. Each side of the panel is coated with 5 cm of cement fibre. The inside layer of the wall consists of 50 mm of mineral wool and plaster. The outside layer contains 6 cm of mineral wool and a brick veneer. The total U-value of the assembly is 0.15 W/m^2K.

The middle layer of the roof consists of 19 cm wood rafters filled with mineral wool insulation. A further 5 cm of mineral wool is used for the inner layer. The outer layer consists of 9 cm of polyurethane insulation covered with slate shingles. The U-value of this assembly is 0.11 W/m^2K.

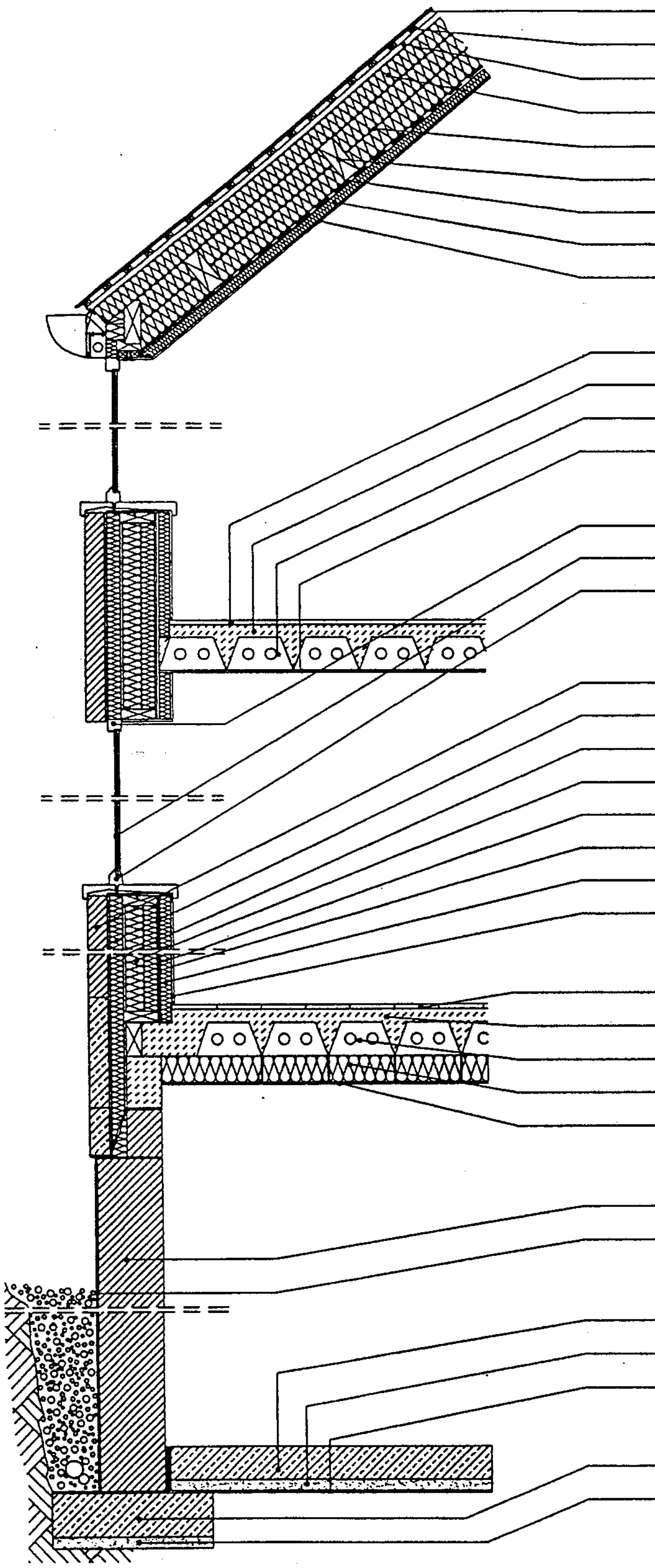
The basement is unconditioned space. The floor between the basement and the main floor is insulated with 12 cm of polyurethane insulation. The outer layer of wall insulation covers the basement ceiling/wall junction to reduce heat loss at this detail.

The windows are double glazed with low-e glass and argon gas fill. The south-facing windows have one low-e coating whereas the north-facing windows have two low-e coatings.

Four details were studied for this house: wall/roof, wall/intermediate floor, wall/window and the wall/grade level floor. The triple layer wall and roof system helps to minimize the thermal bridging at these locations. The linear U-values for the wall/roof and wall/intermediate floor include the effect of the window.

Figure 3.1

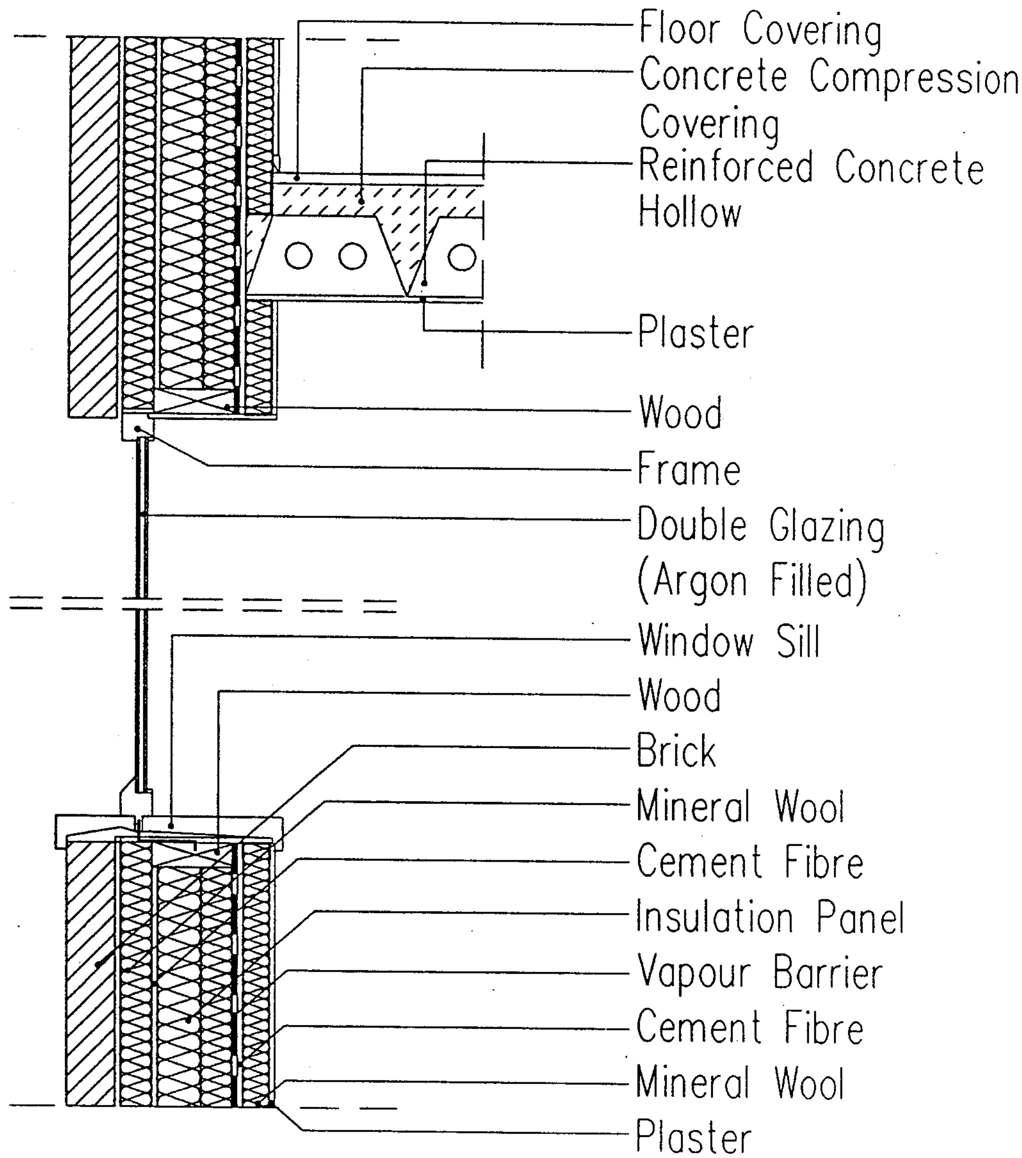
Louvain-la-Neuve



Layer	Description	Width	Thermal Conduct.	U-Value
		cm	W/mK	W/m²K
Roof				
1	Slate	1.0	-	0.11
2	Lattice/Air Space	2.5	-	
3	Lattice/Air Space	2.5	-	
4	Polyurethane Insulation	9.0	0.029	
5	Mineral Wool	19.0	0.04	
6	Wood	19.0	0.13	
7	Vapour Barrier	0.5	-	
8	Mineral Wool	5.0	0.04	
9	Plaster	1.0	0.2	
Ceiling				
10	Floor Covering	2.0	-	-
11	Concrete Compression Covering	6.0	1.3	
12	Reinforced Concrete Hollow	15.0	1.23	
13	Plaster	1.0	0.2	
Window				
14	Frame			1.80
15	Double Glazing			1.14
16	Glazing and Frame			1.37
Exterior Wall				
17	Brick	9.0	1.1	0.15
18	Mineral Wool	6.0	0.04	
19	Cement Fibre	0.5	-	
20	Insulation Pannel	14.0	0.04	
21	Vapour Barrier	0.5	-	
22	Cement Fibre	0.5	-	
23	Mineral Wool	5.0	0.04	
24	Plaster	1.0	0.2	
Basement Ceiling				
25	Tiling	2.0	3.5	0.22
26	Concrete Compression Covering	6.0	1.3	
27	Reinforced Concrete Hollow	15.0	1.23	
28	Polyurethane Insulation	12.0	0.029	
29	Plaster	1.0	0.2	
Below Grade Wall				
30	Calcareous and Silica Blocks	29.0	0.49	-
31	Vertical Draining	-	-	
Basement Slab				
32	Concrete	15.0	2.1	-
33	Sand	5.0	0.7	
34	Visqueen	-	-	
Foundation				
35	Concrete	20.0	2.1	-
36	Sand	5.0	0.7	

Figure 3.2 Louvain-la-Neuve

Window Connection



Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.029
wall/intermediate floor	0.087
wall/window	0.057
wall/grade level floor	0.132

3.2 CANADA - BRAMPTON ADVANCED HOUSE

The Brampton Advanced House uses a double-stud wall system. In this system, two frame walls are constructed and connected by head and sill plates. Spacing the two framed walls far apart and filling with insulation (in this case, cellulose) results in a highly resistive building assembly with little thermal bridging through the framing members. The air/vapour barrier is placed behind the gypsum board and all seams are sealed air-tight with acoustical caulking.

The below-grade walls are built in a similar manner, with the exterior wall being concrete instead of wood. Cellulose insulation is used to insulate these walls. 50 mm of rigid fibreglass is placed under the concrete floor slab to reduce heat loss to the ground.

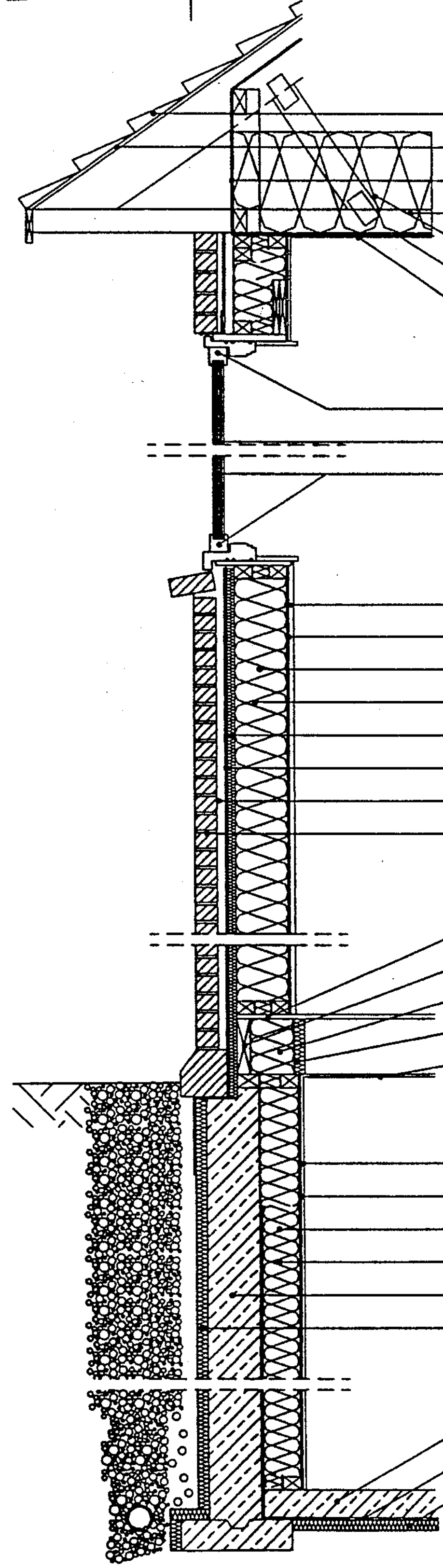
The ceiling is made of wood trusses and filled with 45 cm of cellulose insulation. The truss is constructed with a high heel to accommodate the thick insulation right out to the eaves.

The windows used in the Brampton House are triple-glazed in a wood frame. The glazing unit is triple-glazed with low-emissivity coatings on surfaces 2 and 5 (e=0.10). The 12 mm glazing cavities are filled with argon gas. The edge spacer is butyl rubber with an aluminum strip inserted.

Three details were studied for this house: wall/roof, wall/window and below-grade wall/basement floor. There is very little thermal bridging at the wall/intermediate floor junction because of the high insulation levels between the floor joists.

Figure 3.3

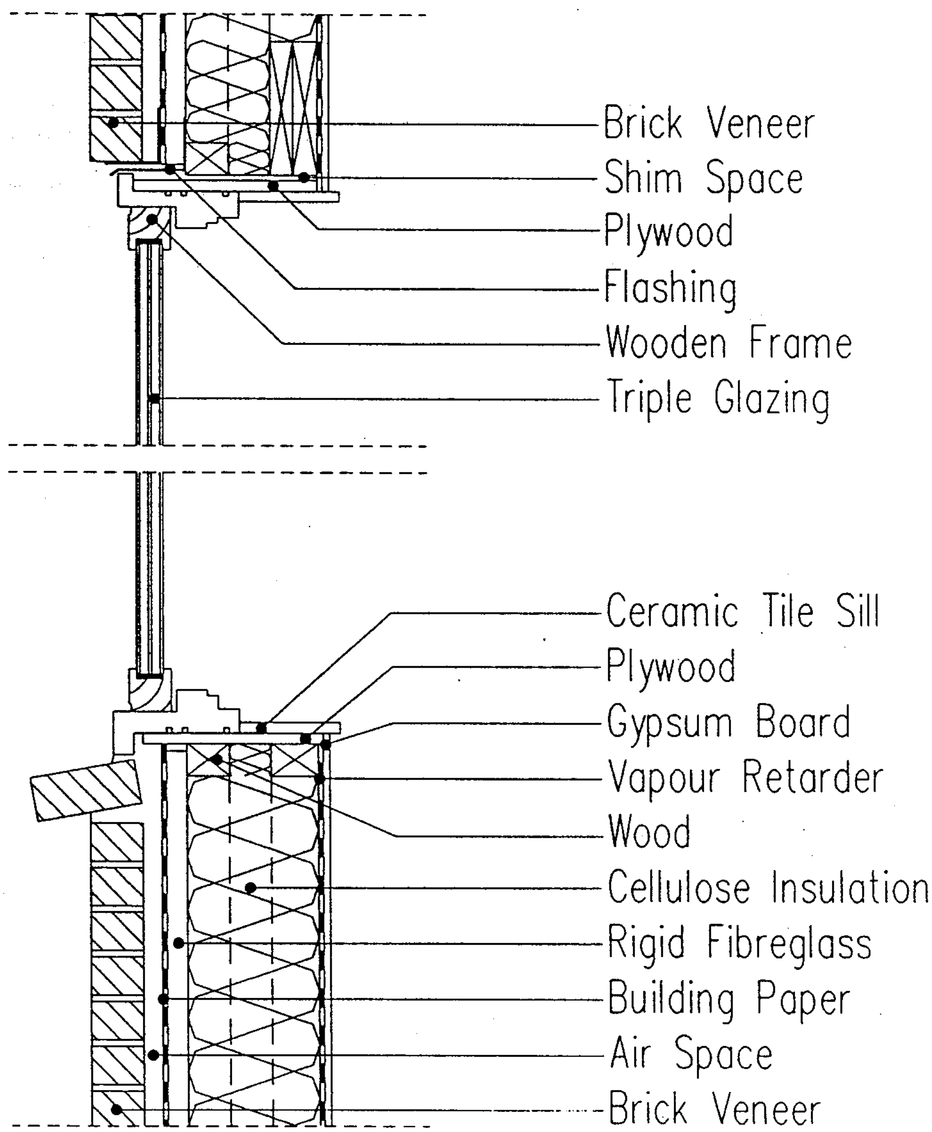
Brampton



Layer	Description	Width (cm)	Thermal Conduct. (W/mK)	U-Value (W/m²K)
Roof				
1	Asphalt Shingles	–	–	0.09
2	Plywood Sheathing	1.5	–	
3	Cardboard Insulation Retainer	–	–	
4	Wood Training on 600 Centres	14.0	0.14	
5	Cellulose Insulation	46.0	0.04	
6	Vapour Retarder	–	–	
7	Gypsum Board	1.3	0.21	
Window				
8	Wood Frame			1.58
9	Triple Glazing			0.83
10	Glazing and Frame			1.10
Exterior Wall				
11	Gypsum Board	1.3	0.21	0.15
12	Vapour Retarder	–	–	
13	Double Stud Wall on 400 Centres	8.9	0.14	
14	Cellulose	24.0	0.04	
15	Rigid Fibreglass	3.8	0.04	
16	Building Paper	–	–	
17	Air Space	2.5	–	
18	Brick Veneer	10.0	–	
Ceiling				
19	Wood Subfloor	1.9	0.14	–
20	Wood Joists on 400 Centres	25.0	0.14	
21	Cellulose Insulation	18.0	0.04	
22	Extruded Polystyrene Blocking	5.0	0.025	
23	Gypsum Board	1.3	0.21	
Below Grade Wall				
24	Gypsum Board	1.3	0.21	0.18
25	Vapour Retarder	–	–	
26	Wood Frame on 400 Centres	3.8	0.14	
27	Cellulose Insulation	17.8	0.04	
28	Concrete	25.4	2.0	
29	Rigid Fibreglass	5.0	0.04	
Below Grade Floor				
30	Concrete Slab	12.7	2.1	0.63
31	Poly Damproof Membrane	–	–	
32	Rigid Fibreglass	5.8	0.04	

Figure 3.4

Brampton Window Connection



Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.034
wall/window	0.046
below-grade wall/basement floor	0.410

3.3 CANADA - WATERLOO REGION GREEN HOME

The above-grade walls for the Green Home are constructed using engineered wood I-beams spaced 60 cm apart. This assembly allows for 24 cm of cellulose insulation with 1.9 cm of rigid insulation on the exterior for a thermal conductance of 0.16 W/m^2K. The engineered wood product is made up of two load bearing members separated by a thin sheet of waferboard that resembles an I-beam. Thermal bridging is minimized over conventional wood stud framing by spacing the I-beams far apart (60 cm as opposed to 40 cm) and using a 1.1 cm thick wood waferboard to separate the wood support members instead of 3.8 cm dimensional lumber. A polyethylene vapour barrier is placed behind the interior drywall and all joints are sealed with a non-drying sheathing tape. This wall systems requires 30% less wood than conventional wood framing and does not require any large dimensional lumber.

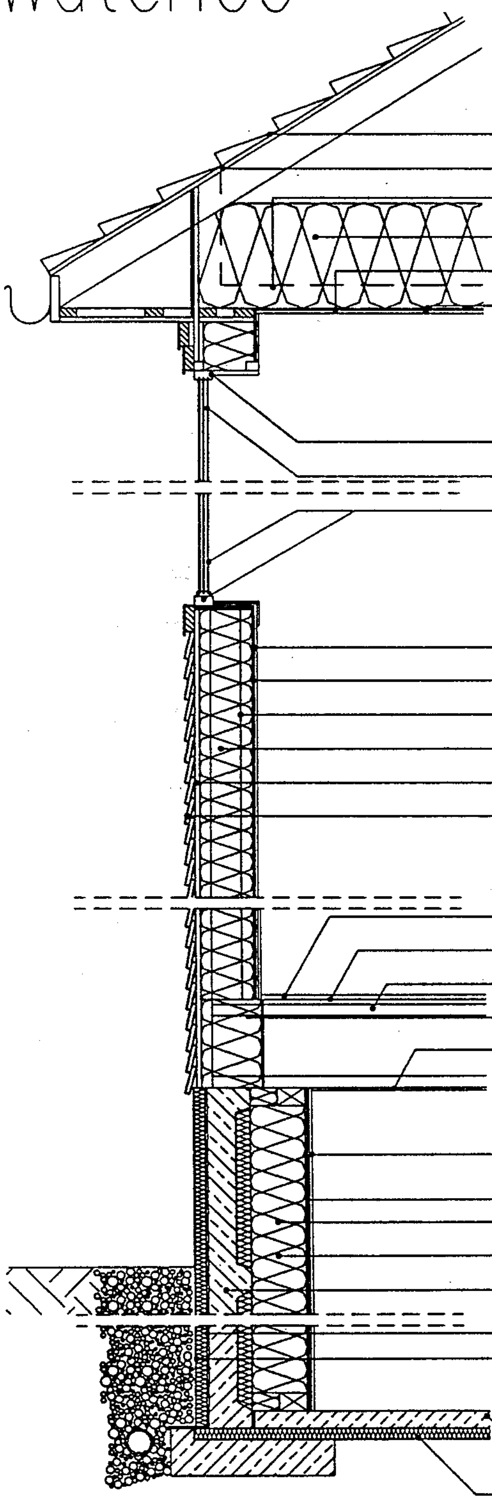
The foundation system has low heat loss and requires only half the concrete of conventional poured basements. The below-grade walls are precast concrete panels that are flat on the exterior side but waffle shaped on the interior side. Five centimetres of rigid fibreglass is used on the exterior and the waffle cavities are filled with cellulose insulation. Wood stud walls are placed 6.3 cm inside of the concrete wall and another layer of cellulose insulation fills the entire cavity. Five centimetres of expanded polystyrene is placed under the floor slab.

The windows used in the Waterloo Region Green Home are triple-glazed with low-emissivity coatings on surfaces 2 and 5. The 12 mm glazing cavities are filled with argon gas. The edge spacer is a silicone foam. The framing system is made from pultruded fibreglass. The cavities within the frame are filled with polystyrene insulation to further reduce window heat loss.

Three details were studied for this house: wall/roof, wall/window and below-grade wall/basement floor. There is very little thermal bridging at the wall/intermediate floor junction because of the high insulation levels between the floor joists.

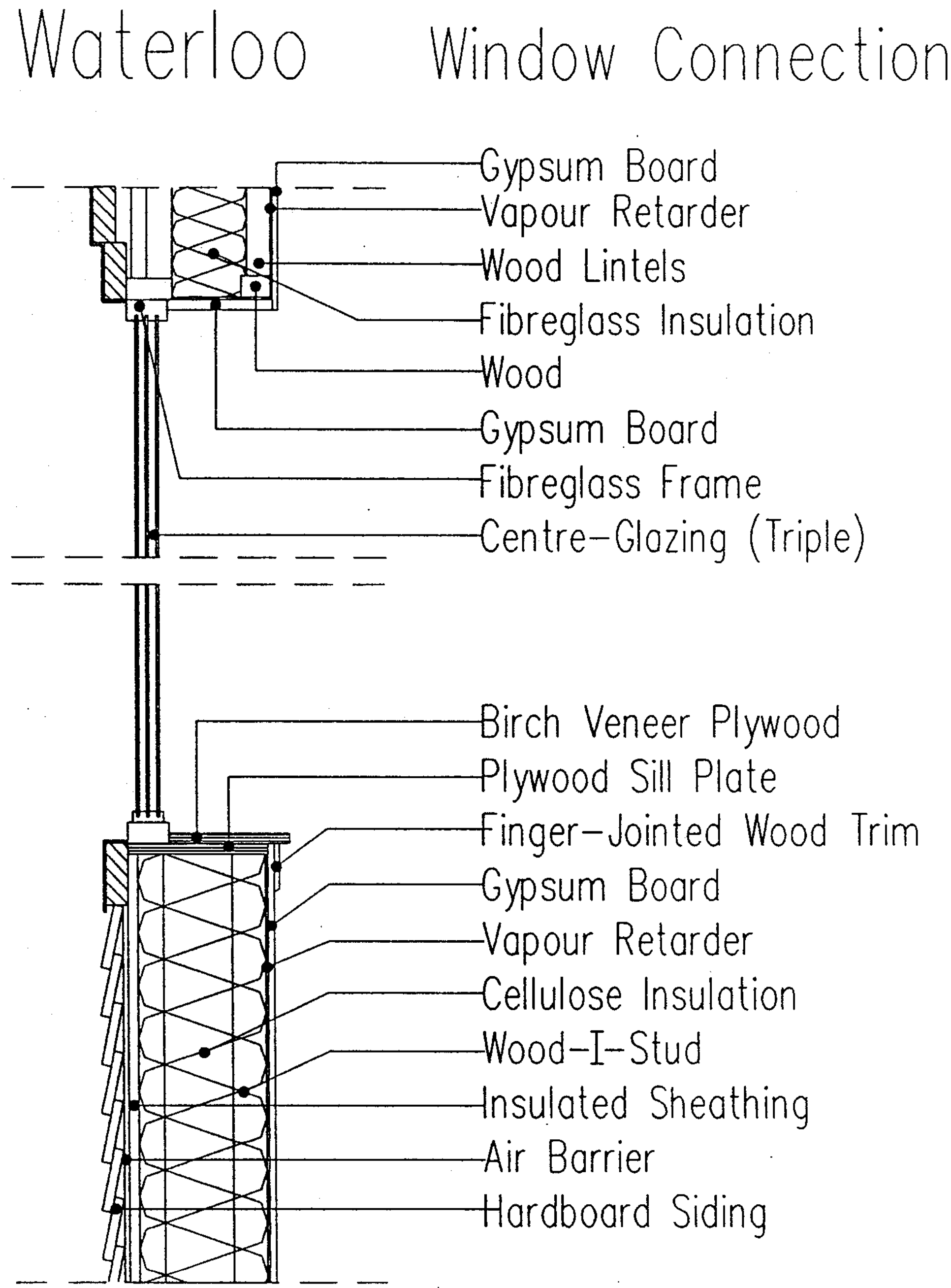
Figure 3.5

Waterloo



Layer	Description	Width (cm)	Thermal Conduct. (W/mK)	U-Value (W/m²K)
Roof				
1	Steel Roofing	-	-	0.094
2	Wood Waferboard	1.6	0.14	
3	Wood I-Beam On 600 Centres	8.9	0.14	
4	Cellulose Insulation	46.0	0.04	
5	Vapour Retarder	-	-	
6	Gypsum Board	1.2	0.21	
Window				
7	Fibreglass Frame			1.07
8	(Triple) Centre-Glazing			0.95
9	Glazing and Frame			1.02
Exterior Wall				
10	Gypsum Board	1.2	0.21	0.16
11	Vapour Retarder	-	-	
12	Cellulose Insulation	24.0	0.04	
13	Wood I-Beam On 600 Centres	24.0	0.14	
14	Insulated Sheathing	1.9	0.06	
15	Wood Siding	1.9	0.14	
Ceiling				
16	Hardwood Flooring	1.9	0.14	-
17	Waterboard Subfloor	2.2	0.14	
18	Wood I-Beam On 600 Centres	36.6	0.14	
19	Polyurethane Foam	15.0	0.025	
20	Gypsum Board	1.2	0.21	
Below Grade Wall				
21	Gypsum Board	1.2	0.21	0.20
22	Vapour Retarder	-	-	
23	Cellulose Insulation	24.0	0.04	
24	Wood Studs On 600 Centres	6.4	0.14	
25	Reinforced Precast Concrete	5-20	2.0	
26	Moisture Barrier	-	-	
27	Semi-Rigid Fibreglass	5.0	0.04	
Below Grade Floor				
28	Concrete	7.6	2.0	0.61
29	Polystyrene Insulation	5.0	0.035	

Figure 3.6



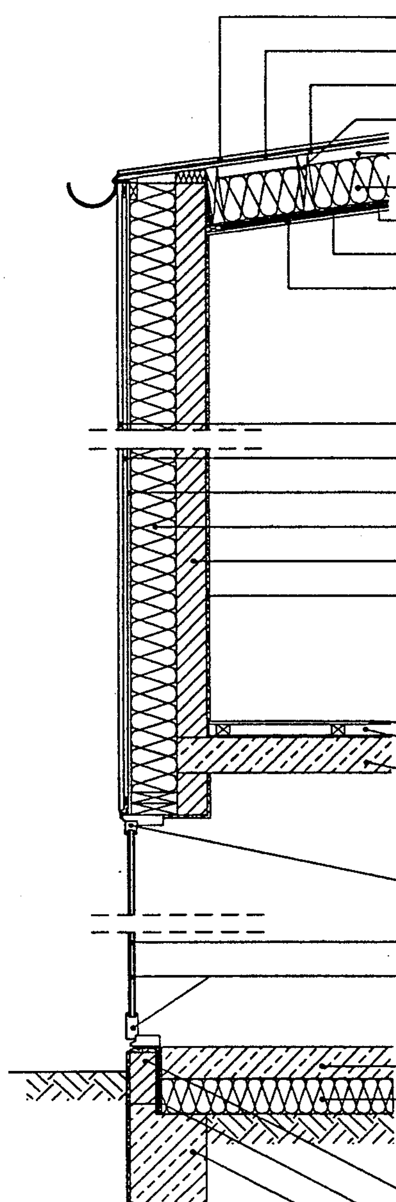
Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.044
wall/window	0.029
below-grade wall/basement floor	0.398

3.4 DENMARK - KOLDING ROW HOUSE

The Danish row houses are super-insulated slab-on-grade structures. Part of the row house is one story and part two stories. The building walls are low-density concrete with 20 cm of mineral wool and wood siding on the outside. The roof is constructed of 25 cm wood rafters with 20 cm of mineral wool in between. The slab-on-grade floor is insulated on the underside with 16 cm of expanded polystyrene. Four details were examined for this building.

Figure 3.7

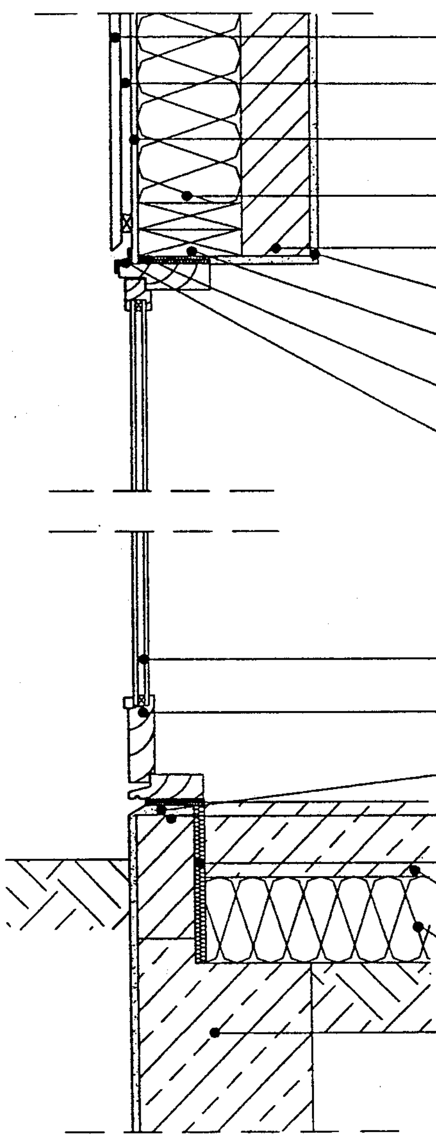
Kolding



Layer	Description	Width (cm)	Thermal Conduct. (W/mK)	U-Value (W/m²K)
Roof				
1	Sheet Metal	–	–	0.15
2	Water Barrier	–	–	
3	Shuttering	4.0	0.12	
4	Wood	25.0	0.12	
5	Air Space	5.0	$1/\Lambda = 0.17\ m^2K/W$	
6	Mineral Wool	20.0	0.036	
7	Polyethylene Foil	–	–	
8	Lattice/Mineral Wool	2.4	0.036	
9	Gypsum Board	1.3	0.21	
Exterior Wall				
10	Timber Shuttering	2.0	–	0.17
11	Lattice/Air Space	2.0	–	
12	Plywood	1.2	0.12	
13	Mineral Wool	20.0	0.036	
14	Expanded Clay Concrete	13.0	0.55	
15	Plaster	1.5	0.7	
Ceiling				
16	Plywood	1.2	0.12	–
17	Air Space	5.0	$1/\Lambda = 0.17\ m^2K/W$	
18	Concrete	16.0	2.1	
Window				
19	Wood Frame			1.60
20	Glazing			0.70
21	Glazing and Frame			0.80
Basement Slab				
22	Concrete	14.0	2.1	0.17
23	Expanded Polystyrene	16.0	0.039	
Foundation				
24	Expanded Clay Concrete	11.0	0.55	–
25	Expanded Polystyrene	1.0	0.039	
26	Concrete	33.0	2.1	

Figure 3.8

Kolding Window Connection



Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.132
wall/intermediate floor	0.138
wall/window	0.057
wall/grade level floor	0.404

3.5 FINLAND - IEA 5 HOUSE (PIETARSAARI)

The savings in heating energy in the Finnish Task 13 house in Pietarsaari are based on minimizing heat losses through the building envelope with the use of effective thermal insulation. The insulation thickness is twice that in normal Finnish houses. Special attention was paid to the airtightness of the structure and to the quality of installation of the air-permeable thermal insulation.

The two-story wooden house is built of prefabricated wooden units. In the wall units, 24 cm of rock wool is between two layers of gypsum board. On top of the outer gypsum board, rigid rock wool coated with a plastic fibre wind proofing is installed using point type fasteners. The additional insulation improves the U-value of the structure and increases the temperature of the outer gypsum board to decrease the possibility of temperature-based natural convection inside the insulation cavity. The extra rock wool layer goes continuously from the concrete footings to the top of the wall forming also an air barrier for the wall. It also performs as a thermal break for the wooden parts in the wall and upper floor structure.

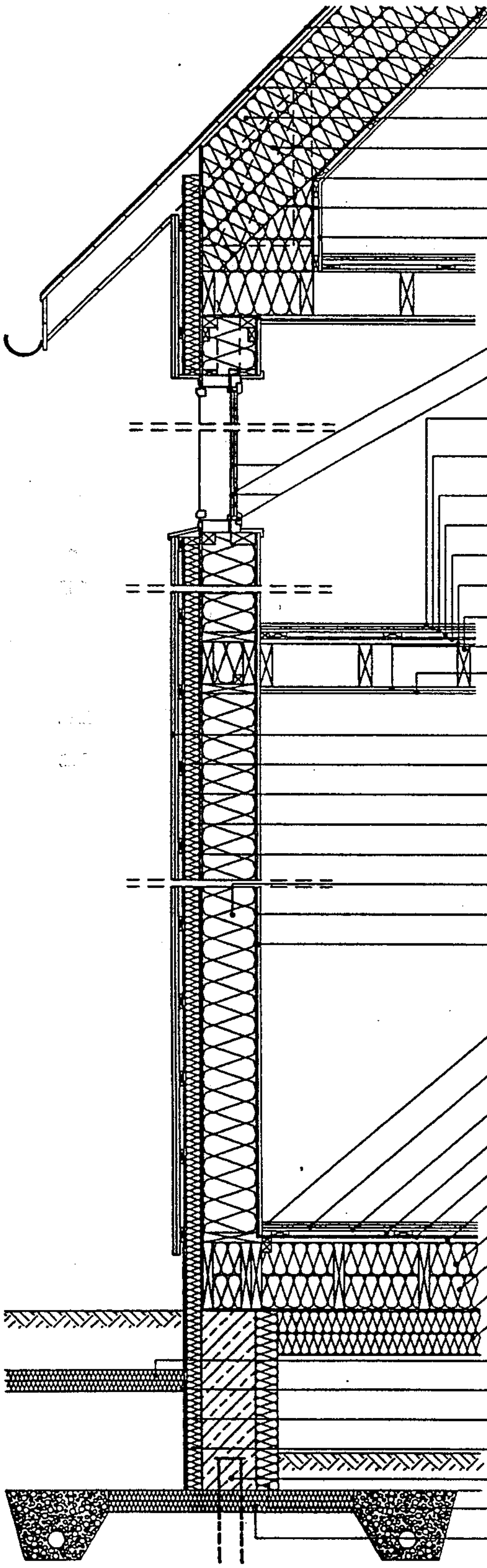
The structure has three air barriers: inner gypsum board together with vapour barrier (with sealed joints), outer gypsum board and the windproofing membrane on external surface of the rigid rock wool.

The same procedure of several air barriers has also been used in the floor construction. The floor is built of prefabricated units with 30 cm rock wool insulation. The total insulation thickness of the floor is 50 cm since 20 cm of rigid rock wool is fixed underneath the floor on site (crawl space foundation ventilated with outdoor air). The extra insulation is made of two layers with a plastic fibre fabric wind proofing underneath each layer. The floor construction is a specially designed light-weight structure for a floor heating system. The water pipings are embedded in a construction consisting of three layers of gypsum boards with overlapping joints and sealing with a cementitious material in the middle layer and a plastic film vapour barrier underneath the gypsum board floor.

The roof of the house is insulated with 50 cm of rock wool. Roof insulation is installed at site. Three details were examined for the Finnish house: wall/intermediate floor, wall/window and wall/grade level floor. The high insulation levels and wide window system result in very low linear U-values for this project.

Figure 3.9

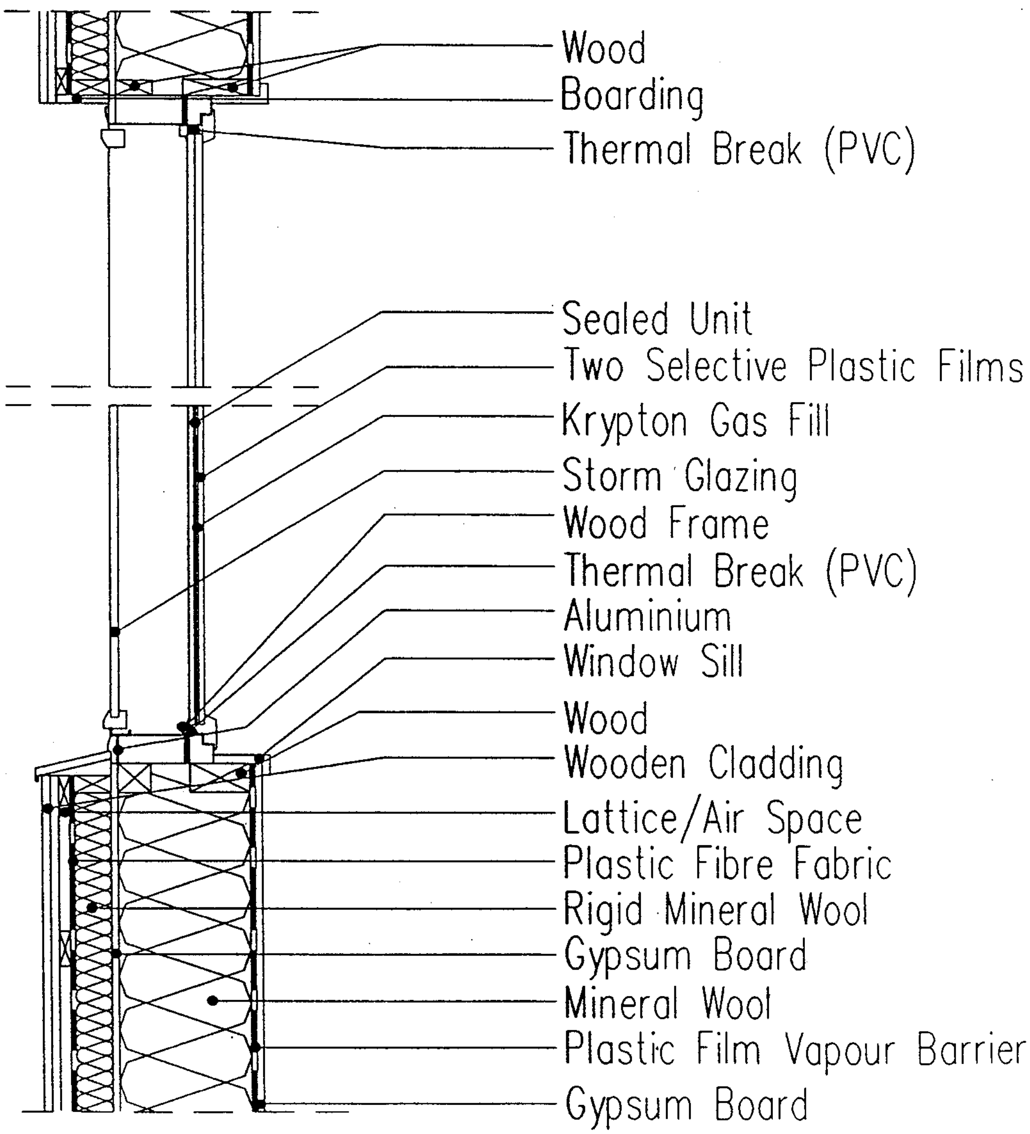
Pietarsaari



Layer	Description	Width	Thermal Conduct	U-Value
		cm	W/mK	W/m²K
Roof				
1	Sheet Steel Waterproofing	–	–	0.09
2	Boarding	1.9	–	
3	Ventilation Gap	5.0	–	
4	Wood	10.0	0.12	
5	Mineral Wool	45.0	0.035	
6	Vapour Barrier	–	–	
7	Lattice	2.2	0.12	
8	Gypsum Board	1.3	0.23	
Window				
9	Frame Aluminium/Wood			0.70
10	Glazing			0.70
11	Glazing and Frame			0.70
Ceiling				
12	Gypsum Board	1.3	0.23	–
13	Gypsum Board Stripes/ Plastic Piping	1.3	0.23	
14	Gypsum Board	1.3	0.23	
15	Boarding/Air Space	2.2	0.12	
16	Plastic Film Vapour Barrier	–	–	
17	Wood Frame Structure	2.2	0.12	
18	Wood Composite Beams	20.0	0.014	
19	Wood Frame Structure	2.0	0.12	
20	Gypsum Board	1.3	0.23	
Exterior Wall				
21	Wooden Cladding	3.0	–	0.12
22	Lattice/Air Space	2.0	–	
23	Plastic Fibre Fabric	–	–	
24	Rigid Mineral Wool	7.0	0.035	
25	Gypsum Board	0.9	0.21	
26	Mineral Wool	24.5	0.035	
27	Plastic Film Vapour Barrier	–	–	
28	Gypsum Board	1.3	0.23	
Floor				
29	Gypsum Board	1.3	0.23	0.11
30	Gypsum Board Stripes/ Plastic Piping	1.3	0.23	
31	Gypsum Board	1.3	0.23	
32	Boarding/Air Space	2.2	0.12	
33	Plastic Film Vapour Barrier	–	–	
34	Wood Frame Structure	2.0	0.12	
35	Mineral Wool	30.0	0.035	
36	Wood Composite Beams	30.5	0.014	
37	Plastic Fibre Fabric	–	–	
38	Rigid Mineral Wool	20.0	0.035	
Foundation				
39	Extruded Polystyrene	10.0	0.03	–
40	Rendering	0.5	–	
41	Plastic Fibre Fabric	–	–	
42	Rigid Mineral Wool	7.0	0.035	
43	Concrete	25.0	1.5	
44	Rigid Mineral Wool	10.0	0.035	
45	Extruded Polystyrene	10.0	0.03	
46	Steel Columns	11.0	60.0	

Figure 3.10 Pietarsaari

Window Connection



Detail	Linear U-value W/m/K (interior dimensions)
wall/intermediate floor	0.057
wall/window	0.014
wall/grade level floor	0.087

3.6 GERMANY - ULTRAHOUSE (ROTTWEIL)

The exterior walls of the Ultra House are constructed with 17.5 cm limestone blocks and 40 cm rockwool insulation on the outer side with the surface sealed with plaster. The rockwool is glued to the blocks. For the foundation area above the ground, the insulation layer is 10 cm thinner.

All exterior windows are triple glazed with a xenon gas filling. The inner glazing (i.e., conservatory to living area) is double glazed. The framing is pine wood and accounts for approximately twenty-eight percent of the window area. The glazing has a U-value of 0.5 W/m^2K while the total window has a U-value of 0.75 W/m^2K.

The roof is constructed using rafters. With 25 cm of mineral wool in between. Above the rafters is a layer of wood boards which support an unbroken layer or 10 cm thick insulation. On the inner side is 12.5 mm gypsum board screwed to a lattice. Under the rafters is an aluminum vapour barrier. The outer layer of the roof is finished off with vegetation.

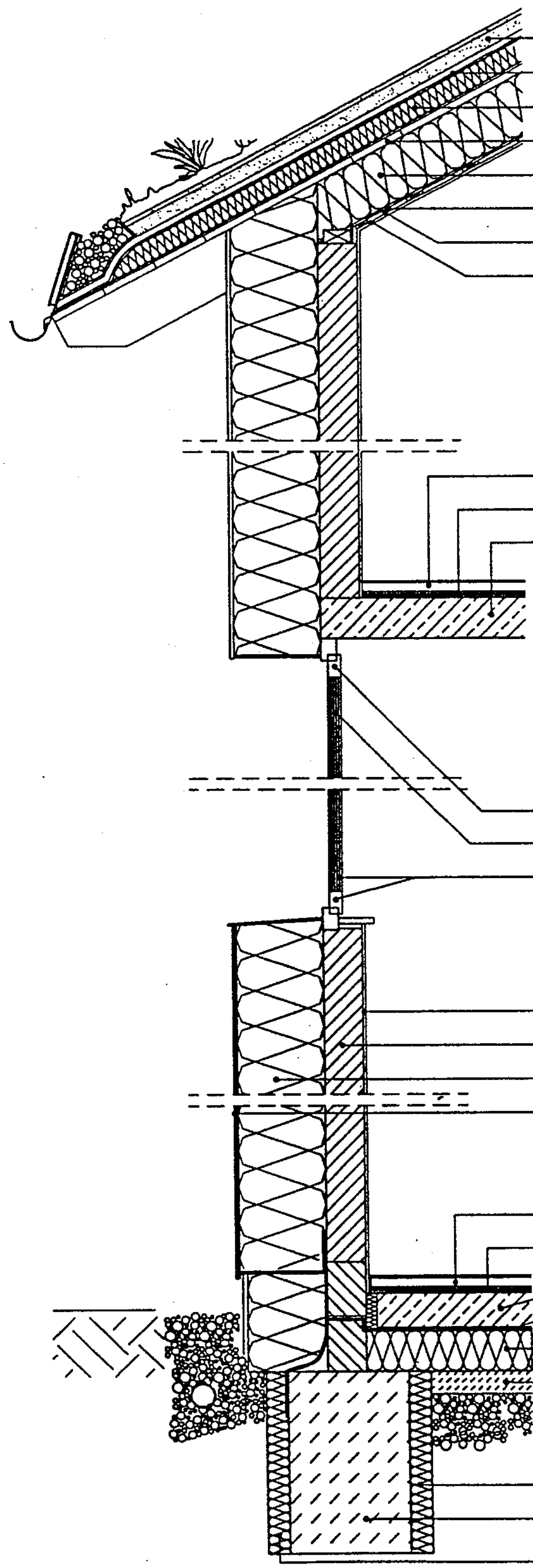
The basement ceiling is insulated with 10 cm of polystyrene. The floor slab is of standard german construction except for the additional insulation (20 cm expanded polystyrene).

The basement outer wall is constructed from 36.5 cm aerated concrete with an outer layer of 10 cm extruded polystyrene. Over the polystyrene is a drainage mat.

The thermal performance of three details were examined: wall/intermediate floor, wall/window and wall/grade level floor. The wall/intermediate floor detail includes the effect of the window header.

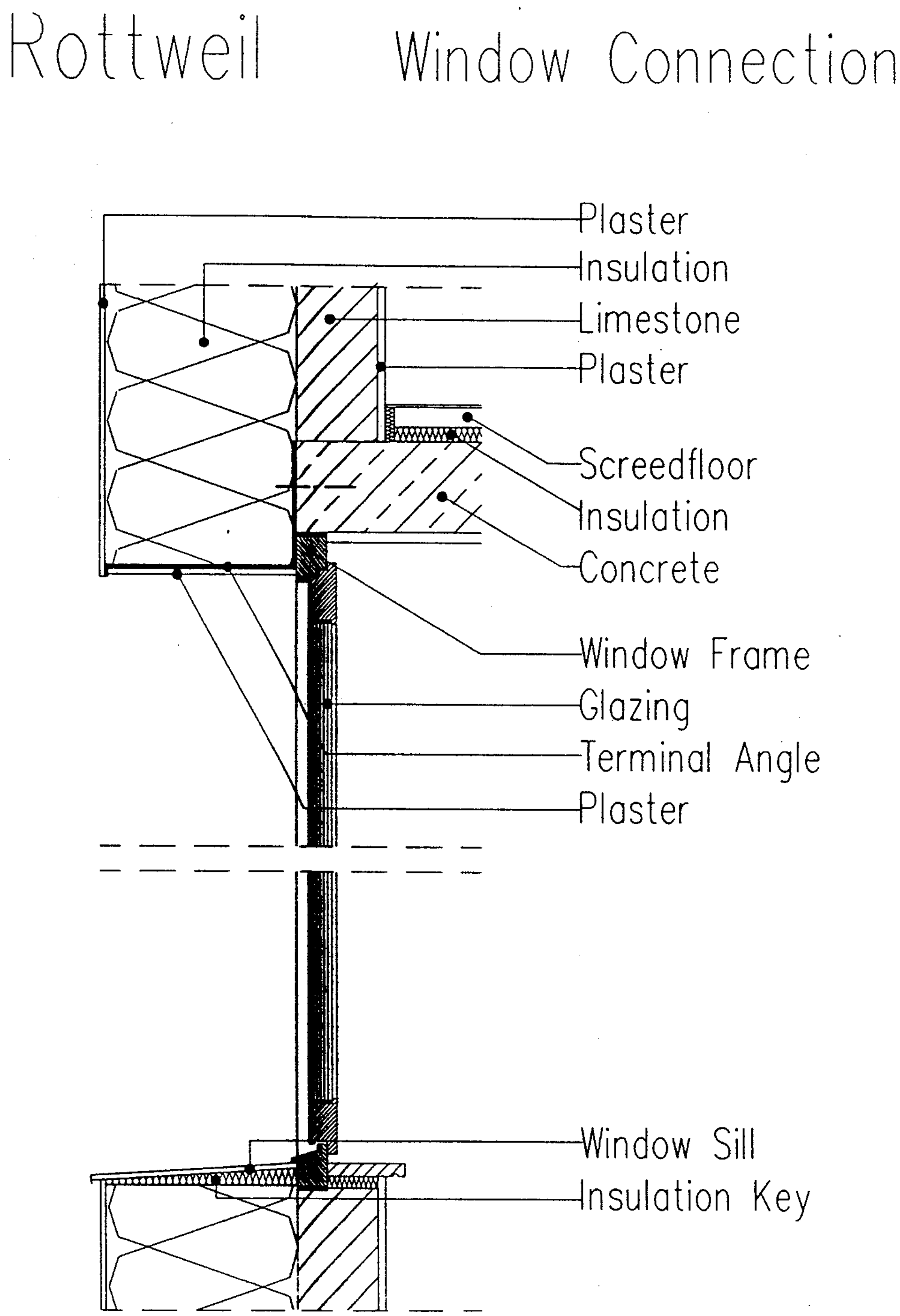
Figure 3.11

Rottweil



Layer	Description	Width (cm)	Thermal Conduct. (W/mK)	U-Value (W/m²K)
Roof				
1	Earth + Vegetation	11.5	-	0.12
2	Water Proofing	–	–	
3	Insulation	10.0	0.035	
4	Wood	2.0	0.130	
5	Insulation + Wood	24.0	0.049	
6	Vapour Barrier	–	–	
7	Lattice	2.4	–	
8	Gypsum Board	1.5	0.7	
Ceiling				
9	Screedfloor	4.0	1.4	0.83
10	Insulation	3.0	0.04	
11	Concrete	18.0	2.1	
Window				
12	Sealed Frame			1.40
13	Glazing			0.50
14	Glazing and Frame			0.75
Exterior Wall				
15	Plaster	1.5	0.7	0.11
16	Limestone	17.5	0.99	
17	Insulation	40.0	0.045	
18	Plaster	2.0	0.87	
Basment Slab				
19	Screedfloor	4.0	1.4	0.13
20	Insulation	3.0	0.04	
21	Concrete	18.0	2.1	
22	Water Proofing	–	–	
23	Insulation	20.0	0.03	
24	Concrete	10.0	2.1	
Foundation				
25	Insulation	10.0	0.035	–
26	Concrete	60.0	2.1	
27	Insulation	10.0	0.035	

Figure 3.12



Detail	Linear U-value W/m/K (interior dimensions)
wall/intermediate floor	0.057
wall/window	0.038
wall/grade level floor	0.222

3.7 GERMANY - ZERO HEATING ENERGY HOUSE (BERLIN)

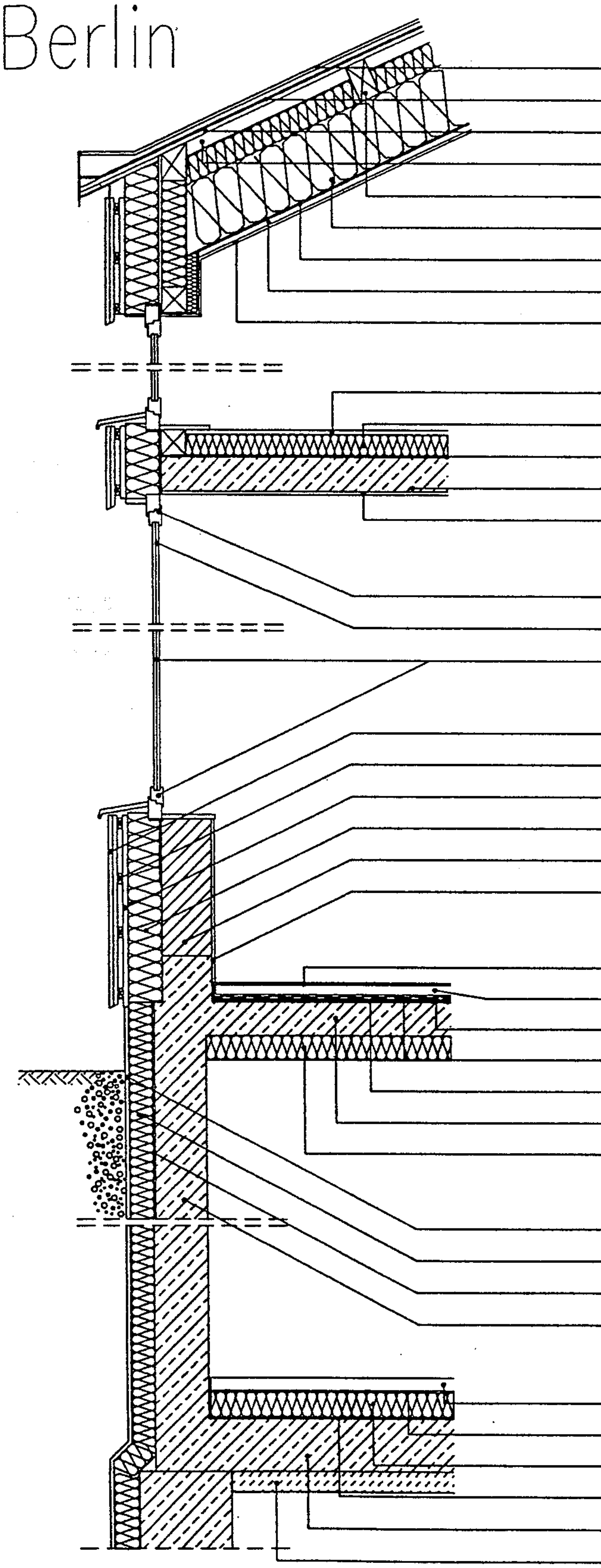
The Berlin house was designed to require no auxiliary space heating. The space heating was reduced to zero by constructing a well-insulated building envelope and using an active solar heating system with seasonal storage. The walls consist of low-conductivity brick insulated on the outside with 16 cm of mineral wool. The wood frame roof is insulated with 30 cm of mineral wool. The basement is insulated with 12 cm of polyurethane insulation on the outside of the walls and on the top side of the basement floor.

The windows are triple glazed with two low-e coatings and filled with the low conductivity xenon. The U-value of the glazing is only 0.40 and the total window U-value (including the wood frame) is 0.68.

Four details were examined for this house: wall/roof, wall/intermediate floor, wall/window and below-grade wall/basement floor. The wall intermediate floor junction includes the effects of the wall/window detail.

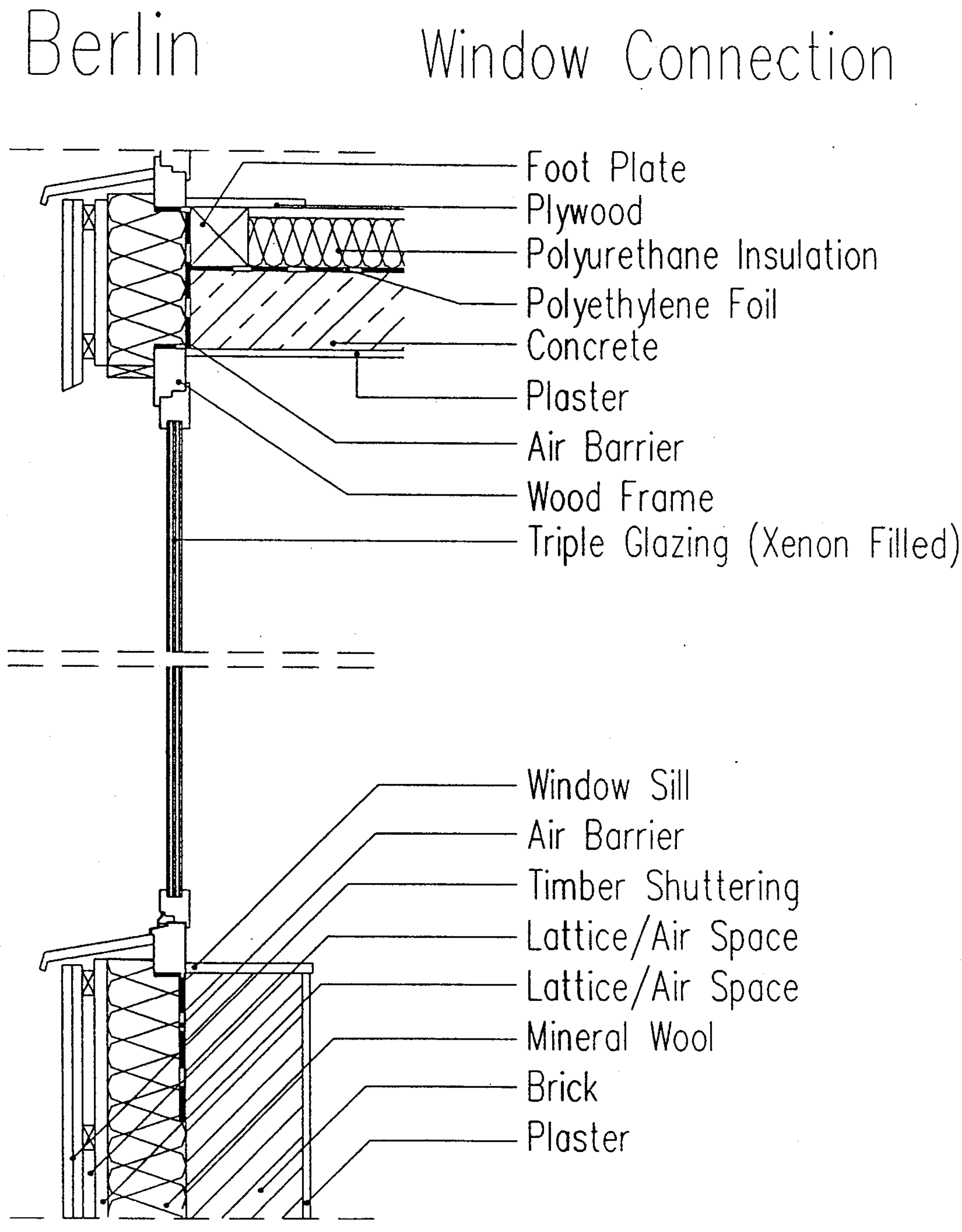
Figure 3.13

Berlin



Layer	Description	Width (cm)	Thermal Conduct. (W/mK)	U-Value (W/m²K)
Roof				
1	Zinc Metal Sheet	-	-	
2	Asphalt Bitumen	-	-	
3	Shuttering	-	-	
4	Air Space	6.0	-	
5	Wood	18.0	0.13	0.12
6	Mineral Wool	30.0	0.035	
7	Polyethylene Foil	-	-	
8	Lattice/Air Space	2.4	$R=0.17\ m^2K/W$	
9	Gypsum Board	1.3	0.21	
Ceiling				
10	Plywood	2.0	0.13	
11	Insulation	10.0	0.035	
12	Polyethylene Foil	-	-	0.30
13	Concrete	16.0	2.1	
14	Plaster	1.5	0.7	
Window				
15	Wood Frame			1.80
16	Triple Glazing			0.40
17	Glazing and Frame			0.68
Exterior Wall				
18	Timber Shuttering	4.0	-	
19	Lattice/Air Space	2.0	-	
20	Lattice/Air Space	2.5	-	
21	Mineral Wool	16.0	0.04	0.19
22	Brick	24.0	0.21	
23	Plaster	1.5	0.7	
Basement Ceiling				
24	Tiling	1.0	1.0	
25	Screedfloor	4.5	1.40	
26	Polyethylene Foil	-	-	
27	Water Proofing	-	-	0.23
28	Insulation	2.0	0.04	
29	Concrete	16.0	2.1	
30	Insulation	12.0	0.035	
Below Grade Wall				
31	Plaster	2.0	0.87	
32	Insulation	12.0	0.035	0.27
33	Asphalt Bitumen	-	-	
34	Watertight Concrete	24.0	2.1	
Basement Slab				
35	Screedfloor	6.0	1.4	
36	Polyethylene Foil	-	-	
37	Polyurethane Insulation	12.0	0.035	
38	Water Proofing	-	-	0.26
39	Watertight Concrete	25.0	2.1	
40	Concrete	10.0	2.1	

Figure 3.14



Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.037
wall/intermediate floor	0.080
wall/window	0.035
below-grade wall/basement floor	0.459

3.8 JAPAN - WISH HOUSE (IWAKI)

The WISH house is a 150 m^2 detached residence in Iwaki, Japan. The innovative features in this house are a hybrid PV array and air-based solar collector. Heat from the solar collector is stored in phase change material panels. This heat is the source for the space heating heat pump.

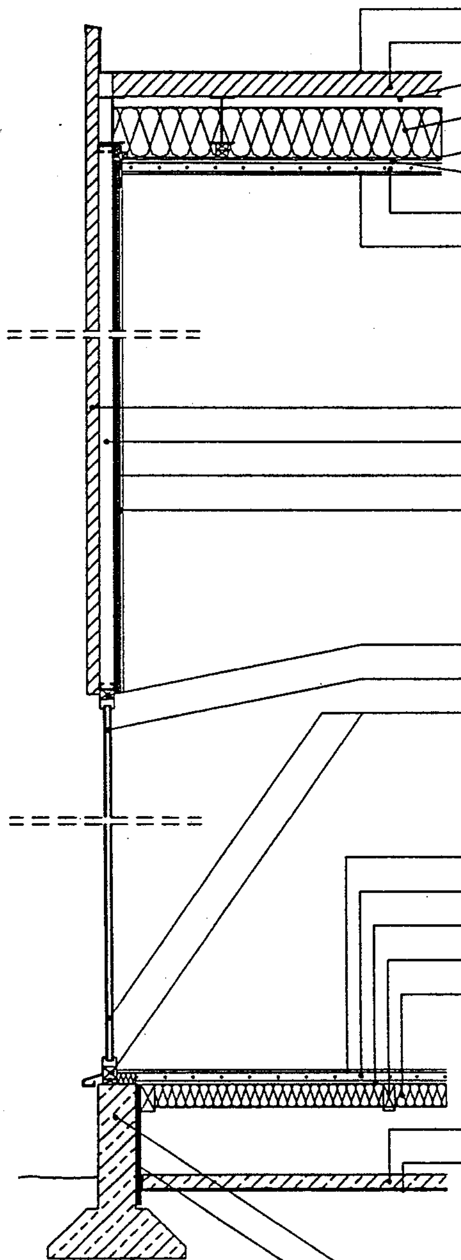
The building envelope is insulated to above Japanese standards, although the U-values are close to standard practice in the other IEA countries. The house is built using an industrialized construction method popular in Japan. The factory-built steel-frame panels are fitted with an exterior layer of lightweight concrete for fire protection. Five centimetres of urethane insulation is used on the inside to reduce heat transfer. The wall U-value is 0.43 W/m^2K. The wood-frame floor is insulated with 10 cm of polystyrene. The steel frame roof has 22 cm of blown mineral wool and an outer layer of lightweight concrete for a U-value of 0.19 W/m^2K.

The windows are double-glazed with a low-e coating and argon gas fill. The window frames are constructed from vinyl.

Three details were examined for this house: wall/roof, wall/window, and wall/grade level floor.

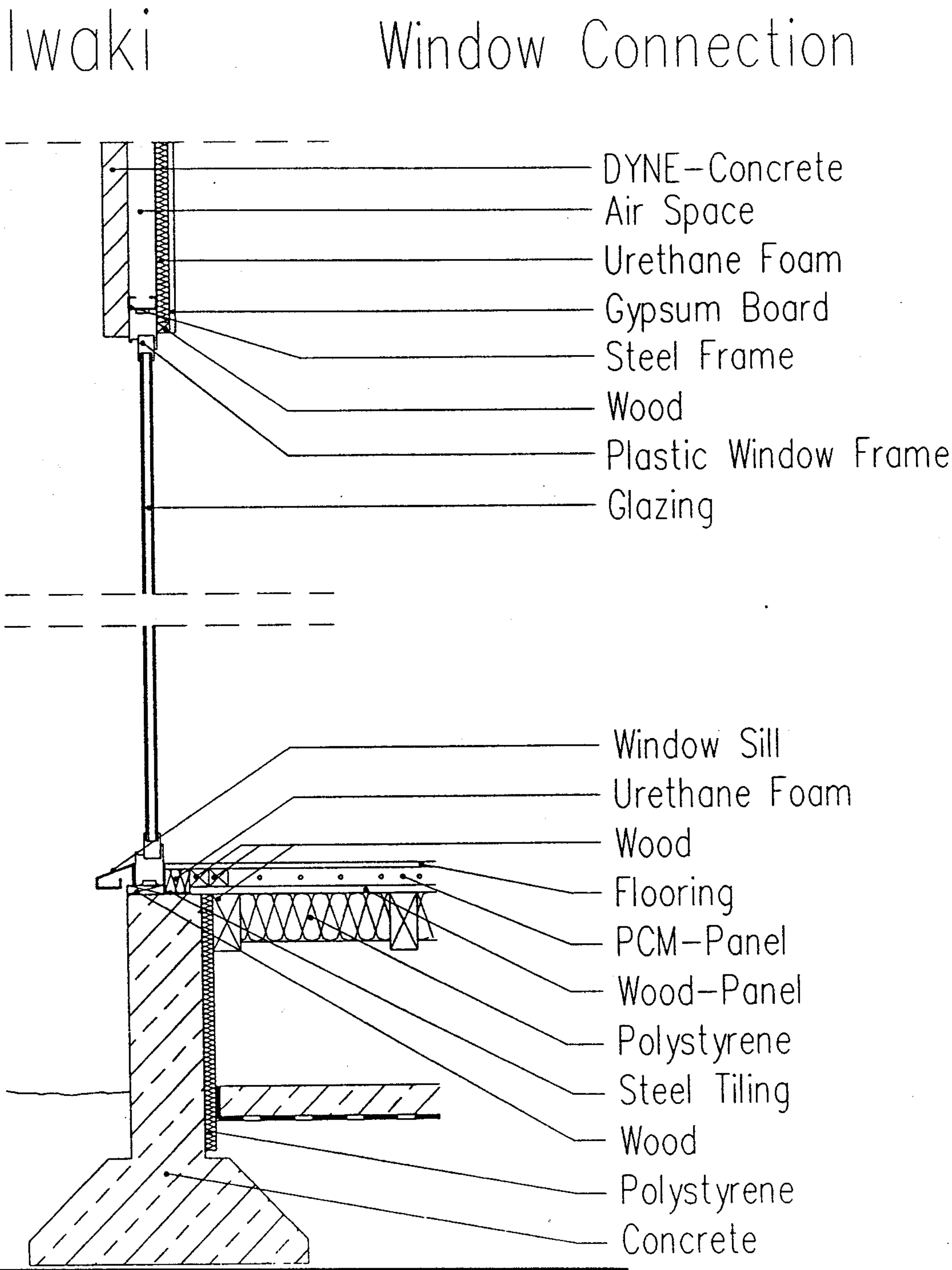
Figure 3.15

Iwaki



Layer	Description	Width	Thermal Conduct.	U-Value
		cm	W/mK	W/m²K
Roof				
1	Water Proofing	0.3	-	0.19
2	Autoclav. Lightw. Concrete	10.0	0.175	
3	Air Space	5.0	$1/\Lambda=0.1\ m^2K/W$	
4	Blown Mineral Wool	22.0	0.052	
5	Vapour Barrier	-	-	
6	Wood Panel	1.5	0.15	
7	PCM-Panel	3.7	0.7	
8	Gypsum Board	1.2	0.14	
Exterior Wall				
9	DYNE-Concrete	5.5	0.26	0.43
10	Air Space	6.0	$1/\Lambda=0.1\ m^2K/W$	
11	Urethane Foam	5.0	0.026	
12	Gypsum Board	1.2	0.14	
Window				
13	Plastic Frame			3.48
14	Glazing			1.38
15	Glazing and Frame			1.80
Ceiling				
16	Flooring	1.2	0.15	0.27
17	PCM-Panel	3.7	0.7	
18	Wood Panel	1.5	0.15	
19	Wood	11.7	0.15	
20	Polystyrene	10.0	0.035	
Basement Slab				
21	Concrete	16.0	1.63	-
22	Vapour Barrier	-	-	
Below Grade Wall				
23	Concrete	16.0	1.63	-
24	Polystyrene	2.5	0.035	

Figure 3.16



Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.024
wall/window	0.028
wall/grade level floor	0.216

3.9 NETHERLANDS - URBAN VILLA (AMSTELVEEN)

The Netherlands project is a 42-unit apartment building in Amstelveen. It consists of two four-story buildings connected to a five-story building by a large atrium. The atrium serves to preheat ventilation air and reduce wall heat loss. The prefabricated south facade was specifically designed to incorporate direct gain windows, passive cooling/venting system, shading devices and auxiliary heating systems.

The remainder of the walls are highly insulating (see Figure 3.17). The walls consist of 14 cm wood studs with the cavities filled with mineral wool. An additional 5 cm of mineral wool is added to the inside and outside of this assembly. The wall U-value is 0.17 W/m^2K. The flat roof is insulated with up to 30 cm of polystyrene. The slab-on-grade floor is insulated with 17 cm of polystyrene on the underside.

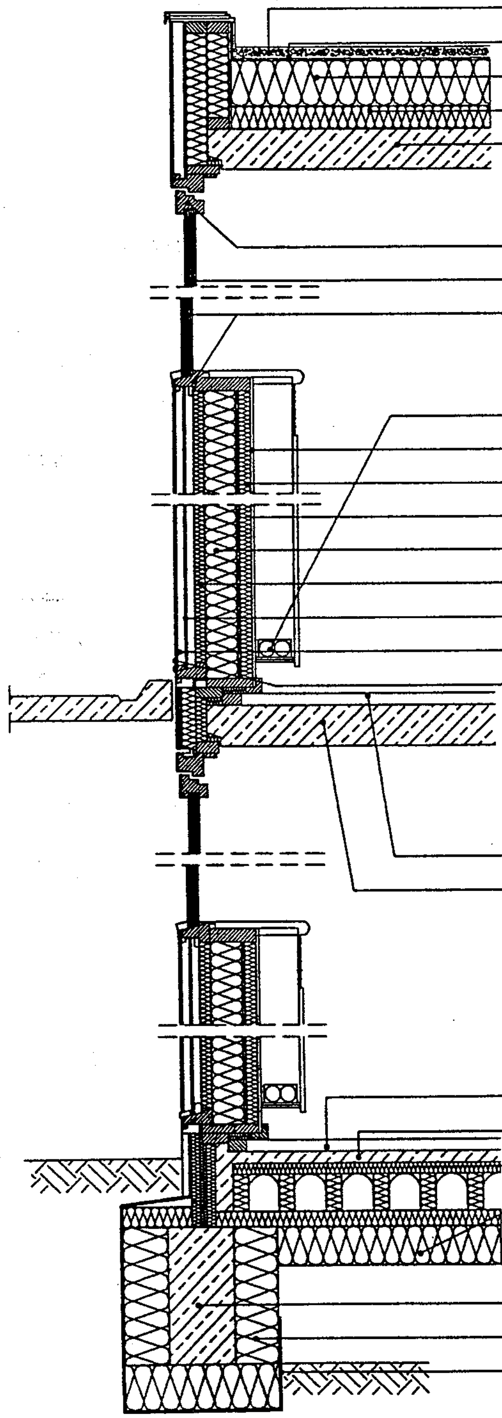
The windows are triple glazed with low-e and argon gas fill in a wood frame. The total window U-value is 1.35 W/m^2K.

Special attention was paid to minimizing thermal bridging in the assemblies and details. Of particular interest are the concrete balconies. The balcony structure is self-supporting with only minimal connections to the building. This technique avoids the large thermal bridge caused when concrete floors are extended beyond the building envelope to provide a balcony.

Four details were studied: wall/roof, wall/intermediate floor, wall/window and wall/grade level floor. Because the window frame overlaps the wall, the linear U-value for this detail is very low.

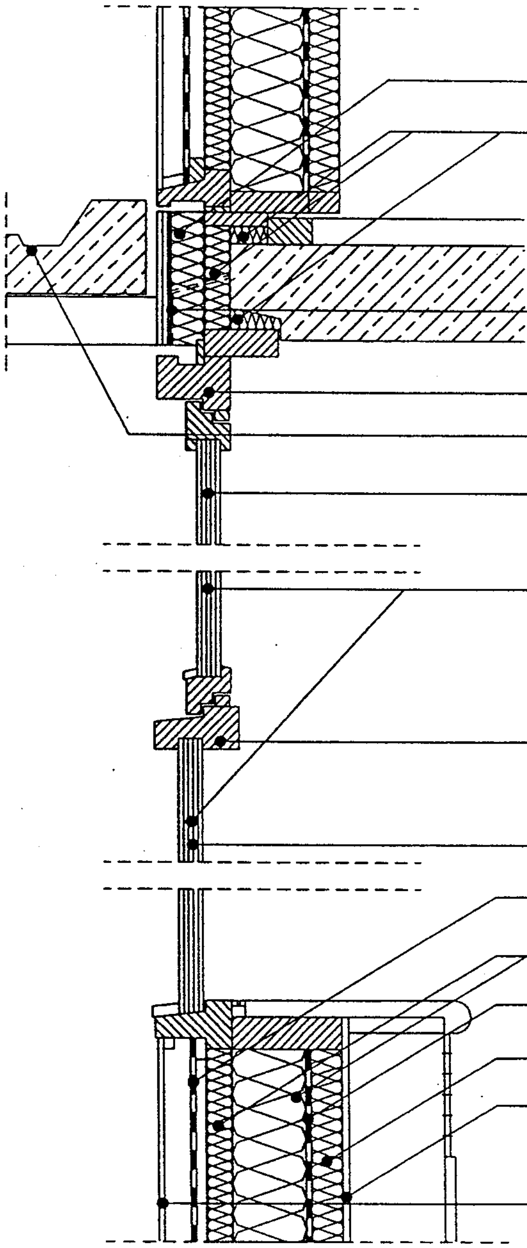
Figure 3.17

Amstelveen



Layer	Description	Width	Thermal Conduct.	U-Value
		cm	W/mK	W/m²K
Roof				
1	Ballast	4.0	-	
2	Bituminous Cover	-	-	
3	Expanded Polystyrene	20.0	0.035	0.14
4	Expanded Polystyrene	4.0 to 10.0	0.035	
5	Concrete	18.0	2.0	
Window				
6	Wood Frame			2.27
7	Triple Glazing			0.69
8	Glazing and Frame			1.35
Wall				
9	Heating Elements (Convectors)	-	-	
10	Gypsum Board	1.3	0.25	
11	Glass Wool	5.0	0.037	
12	Airtight Vapour Barrier	-	-	
13	Mineral Wool	14.0	0.037	0.17
14	Mineral Wool	5.0	0.037	
15	Wind Barrier	-	-	
16	Air Space (vented)	-	-	
17	Plywood Sheathing	-	-	
Ceiling				
18	Finishing Floor (Cement)	5.0	1.0	-
19	Concrete	18.0	2.0	
Floor				
20	Finishing Floor (Cement)	5.0	1.0	
21	Ribbed Concrete Slab	5.0	2.0	0.17
22	Hollow Core Exp. Polystyrene	28.0	0.035	
23	Expanded Polystyrene	17.0	0.035	
Foundation				
24	Concrete	30.0	2.0	
25	Expanded Polystyrene	20.0	0.035	-
26	Polyethylene Foil	-	-	

Figure 3.18 Amstelveen Window Connection



Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.101
wall/intermediate floor	0.095
wall/window	0.006
wall/grade level floor	0.195

3.10 NORWAY - IEA TASK 13 HOUSE (HAMAR)

The Norwegian row house energy consumption is minimized by using a lightweight well-insulated structure and a solar-assisted heat pump. The building envelope is insulated to over twice the levels required by the 1987 national building code. The walls and roof are wood frame with wood I-beams serving as the structural members. Mineral wool insulation fills the cavities between the wood members: 25 cm thick for the walls and 35 cm thick for the roof. To minimize thermal bridging through the wood I-beams, a 5 cm layer of mineral wool is added on the inside. The wall U-value is 0.14 and the roof U-value is 0.11 W/m^2K.

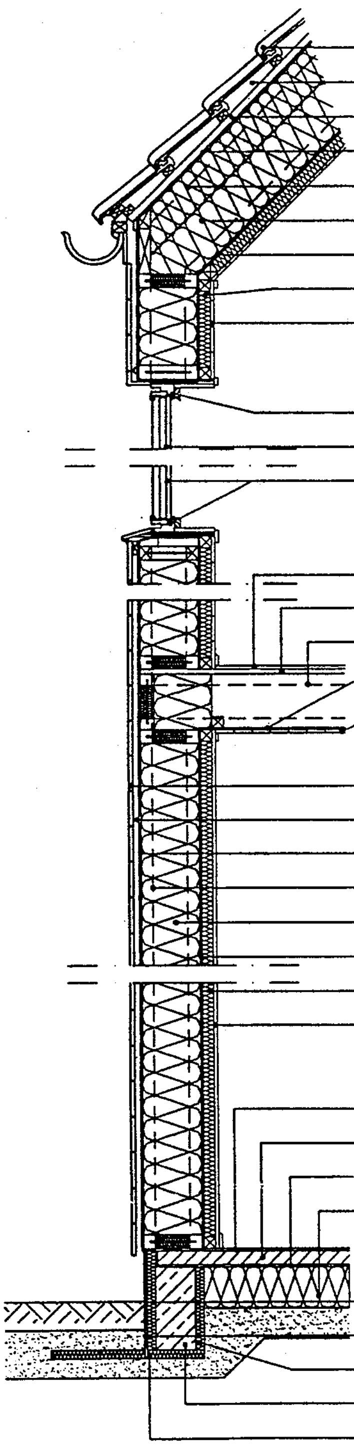
The building is slab-on-grade with 18 cm of extruded polystyrene under the concrete floor. The footings are also insulated on the inside and outside to minimize thermal bridging.

The windows are quadruple glazed: a triple-glazed sealed unit with an additional storm glazing on the outside. The sealed unit has two low-e coatings and argon gas fills. The total window U-value is 0.80 W/m^2K.

Three details are examined: wall/intermediate floor, wall/window and wall/grade level floor. The high insulation levels, wide window assembly and attention to detail keeps the linear U-values very low.

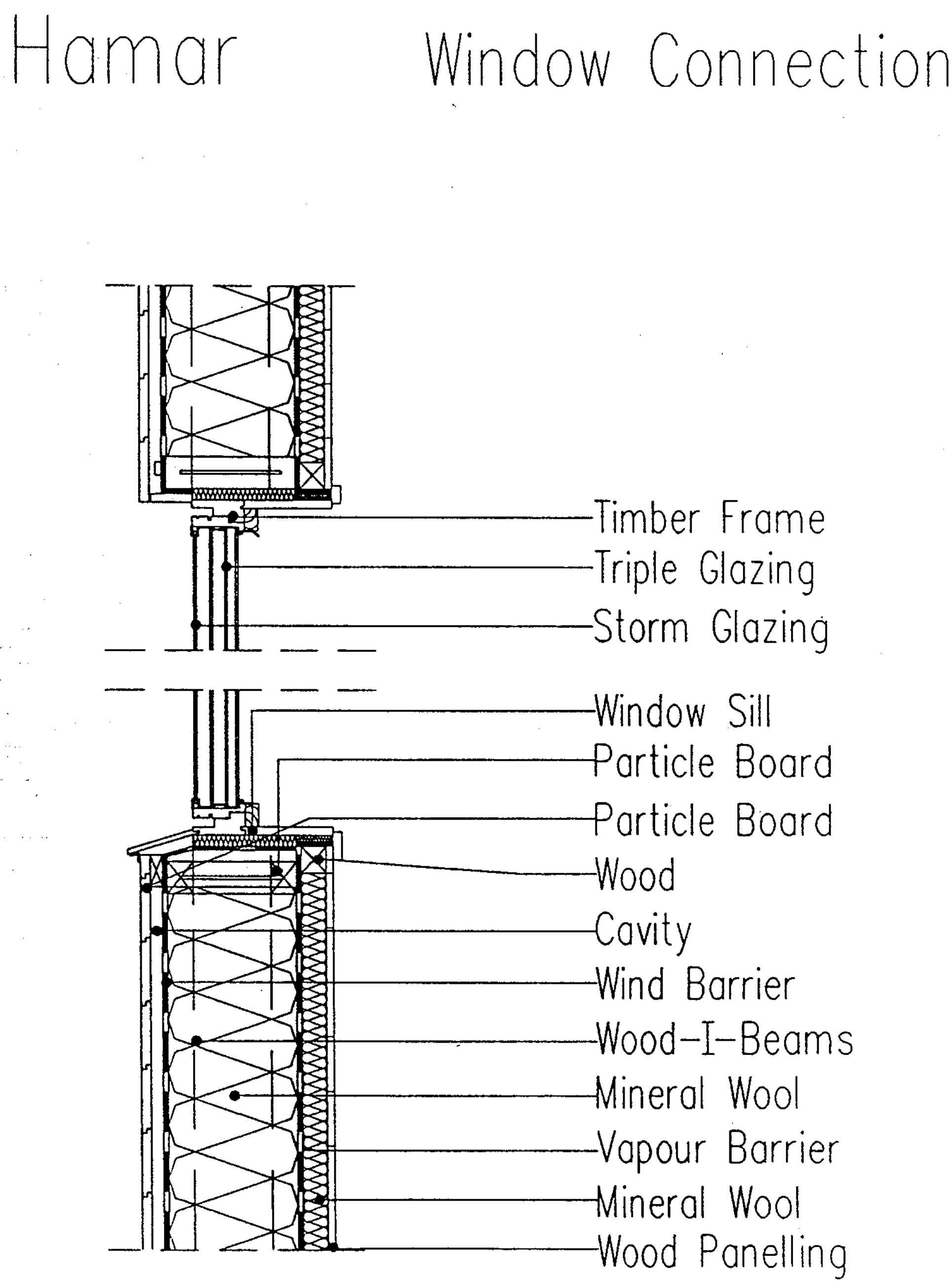
Figure 3.19

Hamar



Layer	Description	Width (cm)	Thermal Conduct. (W/mK)	U-Value (W/m²K)
Roof				
1	Concrete Roof Tiles	-	-	0.11
2	Lattice/Air Space	3.5	-	
3	Lattice/Air Space	3.5	-	
4	Wind Barrier	-	-	
5	Wood I-Beams	35.0	0.12	
6	Mineral Wool	35.0	0.036	
7	Vapour Barrier	-	-	-
8	Mineral Wool	5.0	0.036	
9	Wood Panelling	1.5	0.12	
Window				
10	Timber Frame			1.20
11	Glazing			0.52
12	Glazing and Frame			0.80
Ceiling				
13	Floor Cover	-	-	-
14	Particle Board	2.2	0.12	
15	Wood I-Beams	25.0	0.12	
16	Vapour Barrier	-	-	
17	Wood Panelling	1.5	0.12	
Exterior Wall				
18	Wood Panelling	1.9	-	0.14
19	Cavity	2.3	-	
20	Wind Barrier	-	-	
21	Wood I-Beams	25.0	0.12	
22	Mineral Wool	25.0	0.036	
23	Vapour Barrier	-	-	
24	Mineral Wool	5.0	0.036	
25	Wood Panelling	1.5	0.12	
Floor				
26	Floor Cover	-	-	0.13
27	Concrete	6.0	2.1	
28	Polyethylene Foil	-	-	
29	Extruded Polystyrene	18.0	0.03	
Foundation				
30	Extruded Polystyrene	4.0	0.03	-
31	Cement Plaster	1.0	1.2	
32	Extruded Polystyrene	4.0	0.03	
33	Concrete	17.0	2.1	
34	Extruded Polystyrene	4.0	0.03	

Figure 3.20



Detail	Linear U-value W/m/K (interior dimensions)
wall/intermediate floor	0.060
wall/window	0.021
wall/grade level floor	0.241

3.11 SWEDEN - ROSKAR LOW ENERGY HOUSE

The Swedish house is a prototype building to demonstrate the feasibility of several advanced building systems. The building is a rectangular bungalow with a floor area of 54 square metres. The building envelope is made of expanded polystyrene blocks and thin-walled steel C-channels. The steel profiles, rather than spanning the insulation, are used to clip the polystyrene blocks together on the inside and outside. The flange of the C-channel inserts into the polystyrene block 5 cm from each side. This leaves a thermal break of 8 cm of polystyrene insulation. The top and bottom of the wall are locked together with perforated thin-walled steel rails. The U-values of the wall and roof are 0.14 and 0.13 W/m^2K respectively.

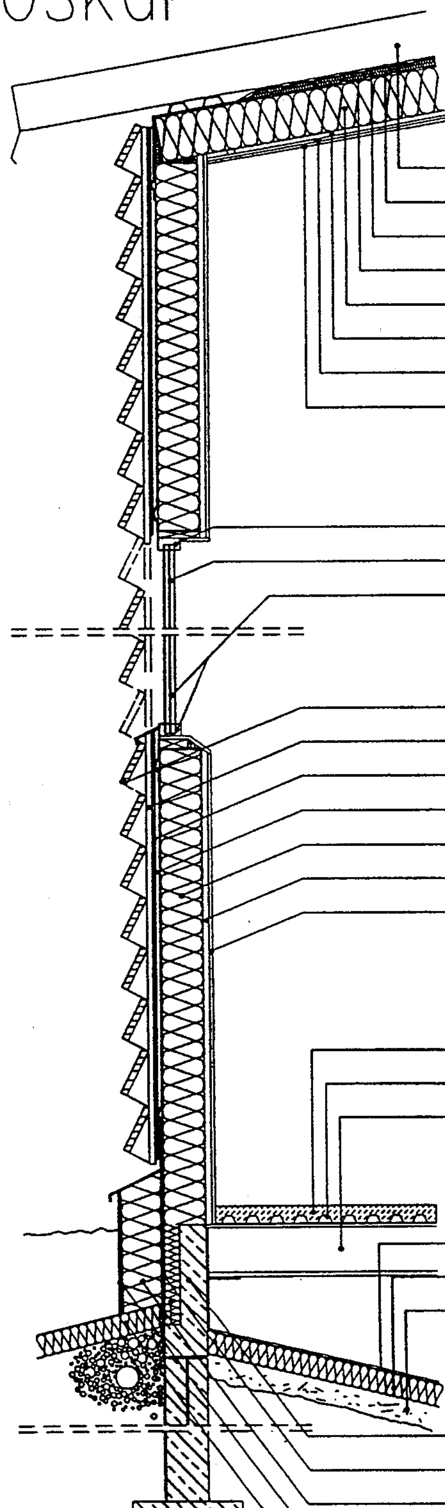
A crawl-space foundation system is used. The main floor is concrete over a fluted sheet metal pan. The air cavities caused by the metal pan are used to carry ventilation air. The walls and floor of the crawl-space are insulated with 10 cm of polystyrene.

The window system in the Swedish house consists of clear doubling glazing with an insulating shutter system. The shutter is open during the day and acts to reflect more light in through the window. At nighttime the shutter is closed to reduce night heat loss. The average U-value of the window is 1.20 W/m^2K.

Three details were examined for this house: wall/roof, wall/window and wall/grade level floor.

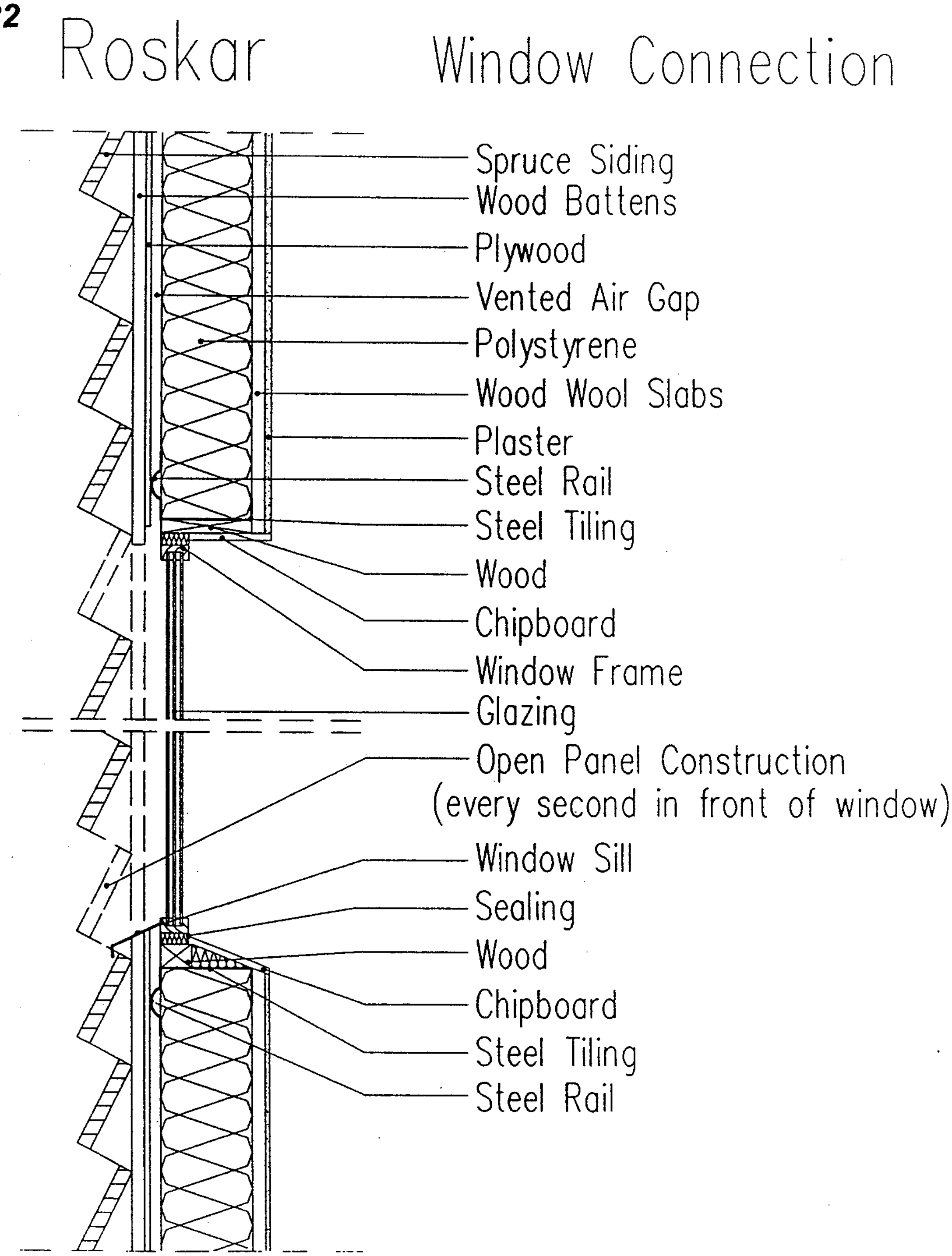
Figure 3.21

Roskar



Layer	Description	Width	Thermal Conduct.	U-Value
		cm	W/mK	W/m²K
Roof				
1	Vent. Sheet Metal	1.0	-	
2	Bitumen	0.3	-	
3	Mineral Wool	5.0	0.04	
4	Vapour Barrier	-	-	0.13
5	Polystyrene	19.5	0.032	
6	Air Gap	2.5	-	
7	Plywood	1.2	0.13	
8	Gypsum Board	1.3	0.22	
Window				
9	Sealed Frame			1.20
10	Glazing			0.80
11	Glazing and Frame			1.20
Exterior Wall				
12	Spruce Siding	2.2	-	
13	Wood Battens	2.8	-	
14	Plywood	1.2	-	
15	Ventilated Air Gap	2.5	-	0.14
16	Polystyrene	19.5	0.032	
17	Wood Wool Slabs	2.8	0.1	
18	Plaster	1.0	1.0	
Floor				
19	Concrete	8.0	1.7	
20	Fluted Sheet Metal	1.0	-	-
21	Steel Profile	20.0	60.0	
Basement Slab				
22	Polyethylene Film	-	-	
23	Polystyrene	10.0	0.032	0.16
24	Gravel	10.0	2.0	
Below Grade Wall				
25	Concrete	12.0	1.7	
26	Polyethylene Film	-	-	
27	Polystyrene	19.5	0.032	-
28	Plaster	2.0	1.0	
29	Extruded Polystyrene	10.0	0.032	-
30	Concrete Slab	50.0	1.7	-

Figure 3.22



Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.051
wall/window	0.122
wall/grade level floor	0.361

3.12 SWITZERLAND - DUPLEX IN GELTERKINDEN

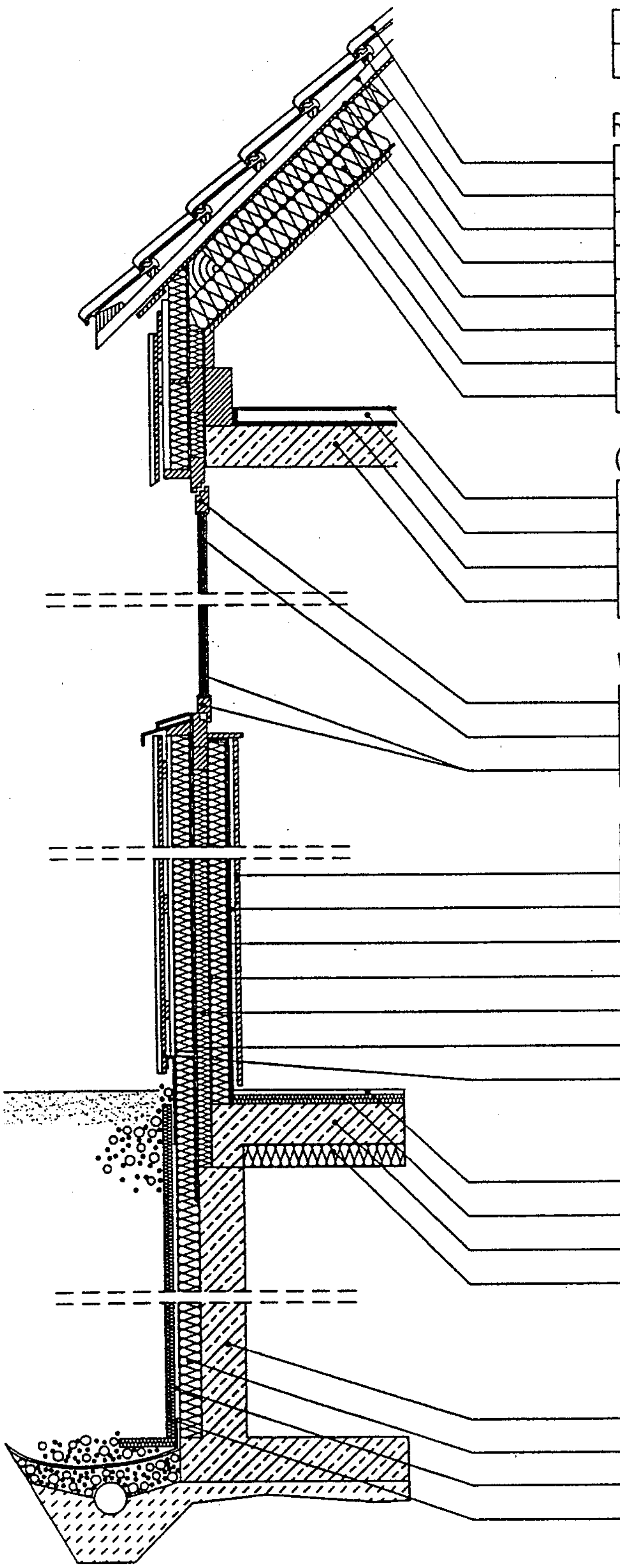
The Gelterkinden duplex has 180 square metres of floor area spread over three floors. The south facade features floor-to-ceiling windows (36% of the south wall area in windows). The building was constructed as a wood frame structure instead of conventional Swiss practice of masonry housing. The designers found that a wood frame system was cheaper to build and easier to super-insulate. The wood frame walls and roof contain 26 cm of mineral wool insulation and have U-values of 0.15 and 0.16 W/m^2K respectively. The floors, however, were made of concrete for extra thermal mass to avoid overheating.

The basement is an unconditioned space. The basement ceiling is insulated with 13 cm of insulation to reduce heat loss from the living space to the basement. The basement walls are insulated on the outside with 10 cm of foamglass.

The performance of three details were simulated: wall/roof, wall/window, and below-grade wall/basement floor. The basement is a semi-heated space so that the temperature difference at the wall/basement floor detail would be very small.

Figure 3.23

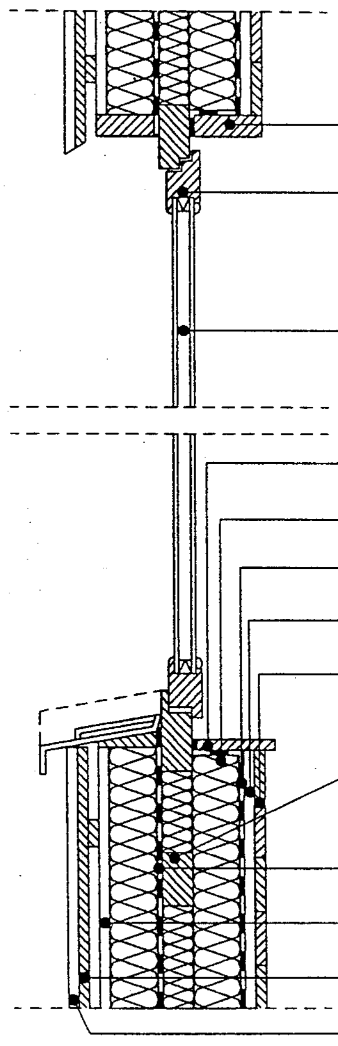
Gelterkinden



Layer	Description	Width	Thermal Conduct.	U-Value
		cm	W/mK	W/m²K
Roof				
1	Roofing Tile	-	-	0.16
2	Lattice	2.4	-	
3	Lattice	5.0	-	
4	Hardboard	1.5	-	
5	Insulation (90%)	26.0	0.04	
6	Wood (10%)	26.0	0.14	
7	Vapour Barrier	-	-	
8	Lattice	2.0	0.14	
Ceiling				
9	Parquet	1.0	0.21	1.54
10	Lower Floor	5.0	1.8	
9	Insulation	2.0	0.04	
10	Concrete	18.0	2.4	
Window				
13	Wood Frame			1.4
14	Glazing			1.1
15	Glazing and Frame			1.2
Exterior Wall				
16	Lattice	-	0.14	0.15
17	Air Space	-	0.12	
18	Vapour Retarder	-	-	
19	Insulation (90%)	26.0	0.04	
20	Wood (10%)	26.0	1.4	
21	Wind Proofing	-	-	
22	Lattice	-	-	
Basement Ceiling				
23	Strand Board Subfloor	3.0	0.21	0.27
24	Insulation	3.0	0.04	
25	Concrete	18.0	2.4	
26	Insulation	10.0	0.04	
Below Grade Floor				
27	Concrete	20.0	2.4	0.33
28	Foamglass	10.0	0.036	
29	Air Space	-	-	
30	Polystyrene Insulation	-	-	

Figure 3.24

Gelterkinden Window Connection



Detail	Linear U-value W/m/K (interior dimensions)
wall/roof	0.053
wall/window	0.029
below-grade wall/basement floor	0.954

4.0 COMPARISON OF BUILDING ASSEMBLIES

4.1 Wall Systems

Above-grade walls have the largest exterior surface area in a house. If the walls are poorly insulated (as is the case with many conventional buildings), they can represent the largest heat loss component in a house. The IEA Task 13 houses contain a variety of approaches to achieve high-performance wall systems.

Table 4.1 compares the IEA Task 13 wall U-values to conventional practice for the two types of construction (wood frame and masonry). Excluding the Japanese house, the Task 13 houses have an average wall U-value of 0.15 W/m^2K – less than half the value of conventional construction. Nine of the twelve IEA Task 13 houses had wood- or steel-frame wall systems. Although masonry wall systems were less popular, the three masonry houses have similar U-values to those of the wood frame houses. The construction technique chosen was dependent on climate, availability of resources and cultural traditions

The reduced U-value in masonry wall systems was achieved by adding extra insulation on the exterior of the brick wall. For example, in the Rottweil, D project, 20 cm of mineral wool is placed on the exterior of the masonry wall and then the wall is coated with stucco.

Additional insulation was also used in the wood (and steel) frame houses. Several approaches were used in the IEA Houses to achieve the higher insulation levels. Two of the houses (Pietarsaari, FIN and Brampton, CDN) have a double wall system to achieve insulation thickness of up to 30 cm. In this system two framed walls (typically made from 38 x 89 mm framing) are joined together top and bottom but separated by approximately 100 mm. Each of the framed walls and the intermediate cavity are filled with insulation. The second technique uses recently developed wood I-beams or engineered wood products as the framing member (as found in the Waterloo, CDN and Hamar,N projects). These framing members provide an insulation cavity approximately 25 cm deep and the thin web in the I-beam reduces the impact of thermal bridging. Several houses used wood framing with interior and exterior layers of insulation to minimize thermal bridging through the wood members. Perhaps the most innovative wall system among the Task 13 houses is the steel channel and polystyrene block system used in the Swedish house.

Table 4.1: Task 13 Wall Systems

House	Wall Type	Wall U-value
Typical Wood Frame	Wood Frame	0.33
Typical Masonry	Masonry	0.47
Louvain, B	Wood Frame	0.15
Brampton, CDN	Wood Frame	0.15
Waterloo, CDN	Wood Frame	0.16
Kolding, DK	Masonry	0.17
Pietarsaari, FIN	Wood Frame	0.12
Rottweil, D	Masonry	0.11
Berlin, D	Masonry	0.19
Iwaki, J	Steel Frame	0.43
Amstelveen, NL	Wood Frame	0.17
Hamar, N	Wood Frame	0.14
Roskar, S	Steel Frame	0.14
Gelterkinden, CH	Wood Frame	0.15

4.2 Foundation Systems

Foundation assemblies (floors and walls) in conventional housing are often uninsulated. The thinking is that over the heating season the ground is warmer than the outdoor air, and thus the heat loss to the ground is a small percentage of the total heat loss. In an advanced or super-insulated house, however, the percent heat loss through uninsulated below-grade assemblies would represent a major heating requirement. As a result, all of the Task 13 houses use insulated foundations to decrease heat loss to the ground.

Foundations provide the structural support for the building. In cold climates, it is necessary to place the house footings below the frost line to prevent building shifts caused by ground freeze thaw cycles. Three types of foundation systems have evolved based on the need for frost protection: slab-on-grade, unheated crawlspace or basement and full-height heated basement. In warm climates, a slab-on-grade foundation is typically used. In cold climates, shallow excavations are necessary to prevent frost heave and unheated crawlspaces are often used. The crawlspaces made range in height from 30 cm to over 2 metres depending on building design and how the space is to be used. The deeper crawlspaces often contain mechanical equipment (space and water heaters) and seasonal items. In North America, it is common for the basements to be fully heated. This space is typically used for locating mechanical equipment, seasonal storage of items and, when finished, as a family/play room.

Table 4.2 lists the details of the foundation systems used in the Task 13 Houses. The houses are grouped by foundation type for easy comparison of the different systems. The U-values are nominal values for the assembly excluding any insulating effects of the ground. The floor U-values are for the floor separating the heated space from the unheated space. For crawlspaces this is the main living floor, for basements and slab-on-grade it is the floor in contact with the ground. Wall U-values are included for the basements since they separate heated spaces from the ground.

The U-values for the floor systems are only a fraction of those of conventional construction. Task 13 designers recognized the importance of reducing foundation heat loss. Slab-on-grade and crawlspace floors have more insulation than do full-basement floors since they get less benefit from the insulating effects of the ground.

Some innovative approaches to insulating foundation systems can be found in the Task 13 Houses. Although polyurethane and polystyrene are the common floor insulating material, the Finnish house used 50 cm of mineral wool to achieve the lowest floor U-value. The designers of the Waterloo Green Home developed a foundation system that has low heat loss and requires only half the concrete of conventional poured basements. The below-grade walls are precast concrete panels that are flat on the exterior side but waffle shaped on the interior side. Fifty mm of rigid fibreglass is used on the exterior and the waffle cavities are filled with cellulose insulation. Wood stud walls are attached to the interior of the concrete wall and another layer of cellulose insulation is placed between the studs.

4.3 Task 13 Roof Systems

Roof systems are often the easiest (and cheapest) building component to superinsulate. Roof trusses create a large cavity between the sloped roof and flat ceiling. Low ceiling U-values can be achieved by blowing or laying in a thick layer of insulation into this cavity. The principle is the same for flat roofs or cathedral ceilings, but the insulation is slightly more difficult to install (and therefore more costly).

Table 4.2: Task 13 Foundation Systems

House	Foundation Type	Floor U-value	Below-Grade Wall U-value
Typical Wood	Basement	4.35	0.46
Canada -Brampton	Basement	0.63	0.18
Canada - Waterloo	Basement	0.61	0.20
Berlin, D	Basement	0.26	0.27
Typical Masonry	Crawlspace	0.86	
Pietarsaari, FIN	Crawlspace	0.11	
Iwaki, J	Crawlspace	0.27	
Amstelveen,NL	Crawlspace	0.17	
Roskar, S	Crawlspace	0.16	
Belgium	Unheated Basement	0.22	
Gelterkinden, CH	Unheated Basement	0.27	
Kolding, DK	Slab-on-Grade	0.17	
Rottweil, D	Slab-on-Grade	0.13	
Hamar, N	Slab-on-Grade	0.13	

Table 4.3 presents the roofing system U-values used in the Task 13 buildings. The two Canadian houses use a truss-type roof with the insulation placed above the ceiling. It was necessary to modify the truss design to accommodate the high levels of insulation. The Brampton (Canada) house uses "high-heel" trusses to raise the level of the roof so that the full thickness of insulation can fit at the eaves. Most of the houses used cathedral-type roofing systems. The roofing systems are either made up of wooden rafters or prefabricated insulated panels. Two buildings (The Netherlands and Japan) have a flat built-up roofing system.

Table 4.3 also lists the roofing U-values for the 25 houses. The super-insulated houses have roof U-values between 0.09 and 0.19 W/m^2K with the lowest values in the coldest regions. These values are typically half the U-value of conventional construction for the respective region. Truss roofs have lower U-values than cathedral roofs reflecting the ease of installation and cost effectiveness of insulation in this system.

Table 4.3 Task 13 Roof Systems

House	Roof Type	Roof U-value
Typical Wood Frame	Truss	0.19
Typical Masonry	Cathedral	0.33
Louvain, B	Cathedral	0.11
Brampton, CDN	Truss	0.09
Waterloo, CDN	Truss	0.09
Kolding, DK	Cathedral	0.15
Pietarsaari, FIN	Cathedral	0.09
Rottweil, D	Cathedral	0.12
Berlin, D	Cathedral	0.12
Iwaki, J	Flat	0.19
Amstelveen, NL	Flat	0.14
Hamar, N	Cathedral	0.11
Roskar, S	Cathedral	0.13
Gelterkinden, CH	Cathedral	0.16

4.4 Task 13 Window Systems

High-performance windows are an integral part of an energy-efficient building envelope. Advanced window technologies are used in all of the projects. High-performance windows can be defined as any window system that has a U-value of 1.5 W/m^2K or lower, which is half the value of conventional double-glazed windows. These low heat-loss values are achieved through a combination of multiple glazings, low-emissivity coatings, inert gas fills, insulating edge spacers, low-conductivity frames and insulating shutters. The glazing systems and coatings were carefully selected to ensure adequate passive solar gains and natural daylight.

The types of window used in the Task 13 buildings are summarized in Table 4.4. The buildings generally opted for triple- and quadruple-glazed windows with inter-pane gas fills of argon or krypton and two low-emissivity (low-e) coatings.

There are many window innovations in the Task 13 buildings. Although most of the houses have wood frames, two projects feature "insulated "framing systems. The window frames in the Pietarsaari, FIN house are constructed with interior sections of foam insulation. The Waterloo, CDN house has pultruded fibreglass frames with the interior cavities filled with polystyrene insulation. Several houses use low-conductivity edge spacers made from butyl rubber or silicone foam in order to reduce edge-of-glass heat loss.

Two innovative systems are used to reduce heat transfer in the glazing cavity. The windows in the German houses have a gas fill of low-conductivity xenon gas to achieve the lowest centre-glazing U-value. The Norwegian house features transparent insulation in some of the windows. The Swedish house uses an automated shuttering system to reduce nighttime heat loss.

Table 4.4: Task 13 Window Systems

House	Window Type (Frame/Glass)	Centre Glazing U-value	Total U-value
Typical Wood Frame	wood/double	2.80	2.80
Typical Masonry	wood/double	2.80	2.80
Louvain, B	wood/double/low-e/argon	1.14	1.37
Brampton, CDN	wood/triple/low-e/argon	0.83	1.10
Waterloo, CDN	fibre/triple/low-e/argon	0.95	1.02
Kolding, DK	wood/triple/low-e/argon	0.70	0.80
Pietarsaari, FIN	wood/quad/low-e/argon	0.70	0.70
Rottweil, D	wood/triple/low-e/xenon	0.50	0.75
Berlin, D	wood/triple/low-e/xenon	0.40	0.68
Iwaki, J	vinyl/double/low-e/argon	1.38	1.80
Amstelveen, NL	wood/triple/low-e/argon	0.69	1.35
Hamar, N	wood/quad/low-e/argon	0.52	0.80
Roskar, S	double plus ins. shutter	0.80	1.20
Gelterkinden, CH	wood/triple/low-e/argon	1.10	1.20

5.0 COMPARISON OF BUILDING DETAILS

5.1 Comparison of U-values

Traditionally building practitioners have concentrated on the design of the building assemblies: walls, roofs, foundations, and windows. However, as the thermal performance of the building assemblies improve, the construction details used to connect assemblies to one another become more important. These details are often a weak link in the thermal integrity of the building envelope. Recognizing this problem, the Task 13 house designers developed low-heat-loss construction details.

Five details were examined in this report: wall/roof, wall/intermediate floor, wall/window, wall/grade level floor and below-grade wall/basement floor. Because of the different construction techniques, not all of the details are found in each house. Table 5.1 lists the linear U-values for these five details.

With the exception of the wall/window detail, the linear U-values for the Task 13 houses are significantly less than those of conventional housing. The higher levels of insulation and good thermal design reduce the heat loss in the Task 13 details by up to 60%.

It is interesting to note, however, that the wall/window heat loss for the Task 13 houses is often equal to or higher than that for conventional housing. The high heat loss is attributed to the junction between a narrow window and a deep wall assembly. The heat loss through the wall is increased because the heat can flow through the sill bypassing much of the wall insulation. Nevertheless, two of the IEA houses were able to provide a design solution. The Finnish house has triple glazed windows with an exterior storm window. This wide window minimizes the amount of thermal short-circuiting through the wall. The Dutch project provides an even more effective solution. The window system overlaps the wall system on the outside. By covering the window frame with some of the insulated wall, the heat loss out the window frame is reduced.

Table 5.1: Linear U-values of the Construction Details (in W/mK)

House	Wall/Roof	Wall/Int. Floor	Wall/Window	Wall/ Floor (Grade Level)	Basement Wall/Floor
Typical Wood Frame	0.067	0.112	0.023	-	1.076
Typical Masonry	-	0.304	0.041	-	0.455
Louvain, B	0.029	0.087	0.057	0.132	-
Brampton, CDN	0.034	-	0.046	-	0.410
Waterloo, CDN	0.044	-	0.029	-	0.398
Kolding, DK	0.132	0.138	0.057	0.404	-
Pietarsaari, FIN	-	0.057	0.014	0.087	-
Rottweil, D	-	0.057	0.038	0.222	-
Berlin, D	0.037	0.080	0.035	-	0.459
Iwaki, J	0.024	-	0.028	0.216	-
Amstelveen, NL	0.101	0.095	0.006	0.195	-
Hamar, N	-	0.060	0.021	0.241	-
Roskar, S	0.051	-	0.122	0.361	-
Gelterkinden, CH	0.053	-	0.029	-	0.954
Task 13 Average	0.056	0.082	0.040	0.232	0.555

5.2 Impact of Details on House Performance

In this section, whole house performance is calculated to better understand the significance of heat flow through the construction details. The heating season heat loss was evaluated for two Task 13 houses: Waterloo, CDN representative of wood frame construction and Rottweil, D representative of masonry construction. The performance of these houses were compared with that of the conventional wood frame and masonry houses described in Section 2.

The heat balance for the four houses were calculated with the aid of the TCM-HEAT4.1 computer program. The model that this program is based on was developed by TNO Institute of Applied Physics TPD in Deflt, The Netherlands, under the framework of the IEA Energy Conservation in Buildings and Community Systems Programme (Annex XII - Windows and Fenestration).

It should be noted that it is not the goal of this evaluation to calculate the exact heat balance of the houses, but rather to illustrate the relative impact of construction details on house performance. Some simplifications of the buildings were made and not all construction details were included.

The heat balance was calculated for the period October 1 to March 31 with a constant interior temperature of 20 C and monthly average weather conditions. The houses were modelled as a single zone. The typical wood and masonry houses have the same floor plans and building dimensions as the Waterloo and Rottweil houses respectively. Thus, the differences between the houses are due to the U-values of the assemblies and details.

Two sets of calculations were performed for the four houses. The first set is the heating season heat balance ignoring the effects of the construction details, as is often done by building designers. The second set of calculations is a heat balance on the entire house including the details. The difference between these two sets of data is the increased heat loss and auxiliary energy supply due to the details. The auxiliary energy supply does not include the effect of heating system efficiency.

Table 5.2 summarizes the results of the analysis for the Rottweil and typical masonry houses. Table 5.3 presents the results for the Waterloo and wood frame houses. The heat loss associated with the details increases the house heat loss by between 6 and 22%. The increase in net heating load or auxiliary heat supply is approximately the same in absolute energy terms, but significantly higher in percentage terms. The auxiliary heat supply is increased by 21 to 47%. This effect is greatest in the two IEA houses. The construction details increased heat loss by a modest 6 and 10%. In these two houses, however, internal and solar gains offset approximately 75% of the heat loss. Thus, this modest increase in heat loss increases auxiliary supply by 26 and 47%.

The situation could have been more severe had the two IEA houses not improved the design of the construction details. Had the IEA houses used the construction details in the conventional houses, the total heat loss would have increased by 20 and 27%. The increase in auxiliary heating would have been 72 and 101%. Thus, in energy-efficient housing, if the design and performance of the construction details is ignored, the auxiliary heating requirement could be twice the expected value.

The wall/window and below-grade wall/basement floor are the two most significant thermal bridges. In the masonry houses, the wall/window connection accounts for 40% of the heat loss for all the details. In the wood frame houses, the basement wall and floor junction accounts for approximately 75% of the heat loss from all the details.

Table 5.2: Heat Balance for Rottweil and Typical Masonry Houses (in MJ)

ROTTWEIL	Heat Balance (no details) Gains	Losses	Heat Balance (with details) Gains	Losses	% Difference
- int. gains	6761		6761		
- solar gains	25709		25435 (-300)		
- aux. supply	11650		14652 (+3000)		26
- heat losses		44121		46848 (+2700)	6
MASONRY	Heat Balance (no details) Gains	Losses	Heat Balance (with details) Gains	Losses	% Difference
- int. gains	6761		6761		
- solar gains	35823		38888 (+3000)		
- aux. supply	43182		52391 (+9000)		21
- heat losses		85765		95820 (+10000)	12

Table 5.3: Heat Balance for Waterloo and Typical Wood Frame Houses (in MJ)

WATERLOO	Heat Balance (no details) Gains	Losses	Heat Balance (with details) Gains	Losses	% Difference
- int. gains	16338		16338		
- solar gains	19447		16899 (-2500)		
- aux. supply	16475		24227 (+8000)		47
- heat losses		52260		57464 (+5200)	10
WOOD FRAME	Heat Balance (no details) Gains	Losses	Heat Balance (with details) Gains	Losses	% Difference
- int. gains	16338		16338		
- solar gains	22240		22841 (+600)		
- aux. supply	43674		61385 (+18000)		40
- heat losses		82252		100564 (18000)	22

6.0 CONCLUSIONS

The Task 13 houses are significantly more energy efficient than conventional houses. On average, the U-values for the building assemblies were less than half those of conventional housing. These reductions were achieved in all construction types: wood frame, steel frame and masonry. The lowest U-values are 0.09 for roofs, 0.11 for walls and 0.70 W/m^{2}K for windows.

The Task 13 houses also have more energy-efficient construction details than conventional housing. The linear U-values for the wall/roof, wall/intermediate floor and foundation junctions are typically less than half that of conventional housing. The one exception is the wall/window detail, where the linear U-value is similar to that of conventional housing. This appears to be because of the thermal short circuit caused by a narrow window in a wide (highly insulated) wall.

The heat loss associated with the construction details increases house heat loss by between 6 and 22%. The increase in net heating load or auxiliary heat supply is approximately the same in absolute energy, but significantly higher in percentage terms. The auxiliary heat supply is increased by 21 to 47%. The wall/window and below-grade wall/basement floor junctions are the greatest contributors to the increased heat loss from construction details.

7.0 REFERENCES

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