BRE Report :

Thermal performance of swimming pools

Project report number 15959

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August 2004

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Executive Summary

BRE has been commissioned by Nigel Rose, with backing from Polypools Ltd, Perfect Pools Ltd, SPATA and the British Swimming Pool Federation to undertake a thermal performance assessment of swimming pools.

The effects of the following are assessed:

1) the size of the swimming pool;
2) the type of soil in which the swimming pool is located;
3) the wetness of the soil in which the swimming pool is located;
4) the level of insulation used in order to achieve a U-value of 0.25 W/m²K;
5) whether the pool is indoor or outdoor.

Calculations were carried out using Physibel Trisco software in order to assess the effects of the above parameters. Results of the calculations are presented in this report.

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1 Introduction

BRE has been commissioned by Nigel Rose, with backing from Polypools Ltd, Perfect Pools Ltd, SPATA and the British Swimming Pool Federation to examine the thermal performance of swimming pools and heat losses. The assessments include three sizes of swimming pools ('public', 'commercial' and 'private'), various soil types ('clay', 'sandy' and 'rock' etc) and different levels of moisture in the soil.

This study has also set out to examine the effects of thermal insulation on the sides and bottom of a pool, and whether the position of the insulation can affect heat loss. This report, therefore, explores the effect of applying insulation either to the inside or to the outside of the 200 mm concrete shell of the pool.

Additional calculations are given in Appendix B to show the thicknesses of insulation needed in order to achieve a U-value of 0.20 W/m²K.

2 Thermal performance calculations

2.1 The swimming pool sizes and dimensions

The client supplied three swimming pool sizes, considered to be typical sizes for the purposes of this work. The sizes are given in Table 2.1A.

Pool size designation	Dimensions
'public'	50 m long, 25 m wide, 2 m deep perimeter = 150 m, area = 1250 m²
'commercial'	25 m long, 13 m wide, 2 m deep perimeter = 76 m, area = 325 m²
'privately owned'	10 m long, 5 m wide, 1.5 m deep perimeter = 30 m, area = 50 m²

Table 2.1A

For the purposes of thermal modelling, the calculation time was reduced by modelling just one quarter of each pool instead of the whole pool. Given the lengths and breadths of the pools, the dimensions in table 2.1B are applicable.

Pool size	length (m)	breadth (m)	Surface area of quarter of pool (m²)	Quarter of surface area of walls (m²)	Quarter of surface area of sides and base (m²)
public	50	25	312.5	75	387.5
commercial	25	13	81.25	38	119.25
private	10	5	12.5	11.25	23.75

Table 2.1B

In most swimming pools the tiling or coping stones are above the water surface. A gap of approximately 4" (ie approx 100 mm) between the water surface and the top of the coping stones or tiles is considered to be typical.

For the purposes of this project, a typical pool will be considered to consist of a 200 mm concrete shell. The shell may be left uninsulated, or insulation can be applied either internally (between the concrete shell and the water) or externally (between the concrete shell and the surrounding soil).

2.2 Temperatures and surface resistances

For calculating heat loss, the internal and external temperatures were selected so as to be typical of heated swimming pools in the UK. The external temperature influences heat loss from pools and the external temperature used in the calculations was based upon the average annual external temperature for the UK, and was set at 10°C. For indoor pools, an air temperature of 22°C was assumed above the pool.

It is considered appropriate to use the annual average external temperature (at least for indoor pools) since heating will normally be required for 12 months of the year.

The appropriate temperatures for modelling the swimming pool are as follows:

Temperature of water in pool	29°C
Temperature of external air	10°C
Temperature of air above indoor pool	22°C

The surface resistances for the thermal calculations are as follows:

Surface resistance of water-air interface	0.04 m²K/W
Surface resistance of water-solid interface	0.00 m²K/W
Surface resistance of soil-air interface	0.04 m²K/W

2.3 The soil types to be tested

The soils tested involve a variety of types and moisture levels. Table 2.3A below gives typical thermal conductivities for various soil types.

Type of soil	Thermal conductivity of soil	Source of data
typical clay soil or silt	1.5 W/m·K (dry)	ISO 13370
high conductivity clay/silt	2.0 W/m·K	ISO 13370 Annex G
typical sand or sandy soil	2.0 W/m·K	ISO 13370
typical gravel	2.0 W/m·K	ISO 13370
rock	2.5 to 4.5 W/m·K	ISO 13370 Annex G
typical dry sand	1.6 W/m·K	ISO 13370 Annex G
typical wet sand	2.1 W/m²K	ISO 13370 Annex G
loam	1.2 W/m²K	CIBSE Guide A3 (1980)

Table 2.3A

A conductivity of 1.5 W/m·K is considered to be typical of soils in the UK. It is clear from the above table that soil conductivities vary widely, but generally speaking the conductivity of soil tends to be in the range 1.0 W/m·K to 4.5 W/m·K.

2.4 The insulation around the swimming pool

In the calculations, thermal insulation was applied to the sides and bottom of the pool. The insulation was either applied internally (ie adjacent to the water in the pool) or externally (between the 200 mm concrete shell and the surrounding soil). In all of the calculations that follow, the 200 mm concrete shell is considered to be dense with a thermal conductivity of 1.93 W/m·K.

Depending upon the porosity of the concrete and/or tiling, liquid water may seep from the pool causing the insulation material to be wetted. Depending upon the suitability of the insulation for this purpose, the thermal conductivity of the insulation could be adversely affected by the presence of water.

In addition, some insulation materials can be affected by the ambient moisture content of soil, even in the absence of any leakage from the pool.

The effect of liquid water cannot be determined by thermal modelling calculations, however wetting of insulation could increase its thermal conductivity, thereby reducing its effectiveness.

2.5 The base case

The base case, against which other variations have been based, was chosen to be a private pool (this being the most common), set in clay soil (typical of UK), outdoors, with sides and bottom uninsulated. The calculations were designed to show the effects of altering various parameters in relation to the base case.

For illustration, the following shows data used in a typical calculation:

Name	lambda [W/mK]	eps [-]	t [°C]	h [W/m²K]
Soil	1.500			
Water in pool			29.0	1000.00
External air			10.0	25.00
Concrete	2.000			
Cover sheet	1.000			
Air above pool			22.0	25.00

The symbol "lambda" above stands for thermal conductivity, "t" above stands for temperature, "h" stands for heat transfer coefficient.

2.6 Carbon emissions

The carbon emissions attributable to swimming pools will depend upon the heat loss from the pool and the efficiency of the heating system. The carbon emission will also depend very much upon the fuel used and the efficiency of the boiler.

2.6.1 Gas heating

For the purposes of the present calculations, it is assumed that the pool is heated using mains gas and that the boiler efficiency is 78%. The carbon emissions factor for mains gas is assumed to be 0.053 kgC/kWh, based upon figures published in Approved Document L2.

The carbon emissions will therefore amount to (0.053 / 0.78) kgC/kWh. This factor is used for conversion of heat loss in watts to kg of carbon emitted per annum.

In the case of gas, therefore, a heat loss of 1 watt corresponds to 0.5956 kg of carbon per year.

2.6.2 Oil heating

In the case of oil heating, the carbon emissions factor is higher, and the appropriate carbon emissions, taking account of typical boiler efficiency, will be (0.074 / 0.85) kgC/kWh.

In the case of oil, therefore, a heat loss of 1 watt corresponds to 0.7632 kg of carbon per year.

2.7 Results of the calculations

2.7.1 Private (domestic) outdoor swimming pool

No.	Insulation (100 mm thick) (internal or external)	Soil type	Average U-value of sides and bottom ISO10211, W/m²K	Heat loss through sides and bottom, for a temperature difference of 19 K, in watts and kg carbon per annum
1	none	clay(1)	1.5	2696.8 W; 1606 kgC/yr
2	0.04 W/m·K int.	clay	0.30	537.6 W; 320.2 kgC/yr
3	0.02 W/m·K int.	clay	0.17	312.2 W, 185.9 kgC/yr
4	0.04 W/m·K ext.(2)	clay	0.89	1604 W; 955.3 kgC/yr
5	0.02 W/m·K ext.(2)	clay	0.81	1460.8 W; 870.1 kgC/yr
6	none	sandy(3)	1.7	3088 W; 1839 kgC/yr
7	0.04 W/m·K int.	sandy	0.31	568.4 W; 339 kgC/yr
8	0.04 W/m·K ext.(2)	sandy	0.94	1695 W; 1010 kgC/yr
9	none	rock	1.9	3436 W; 2046 kgC/yr
10	0.04 W/m·K int.	rock	0.33	590.8 W; 351.9 kgC/yr
11	0.04 W/m·K ext.(2)	rock	0.98	1765 W; 1051 kgC/yr

Table 2.7A

(1) Also applies to loam, silt and dry sandy soil
(2) Allowing for 200 mm wide trench foundations bridging the insulating layer at the perimeter
(3) Also applies to wet sand and to gravel

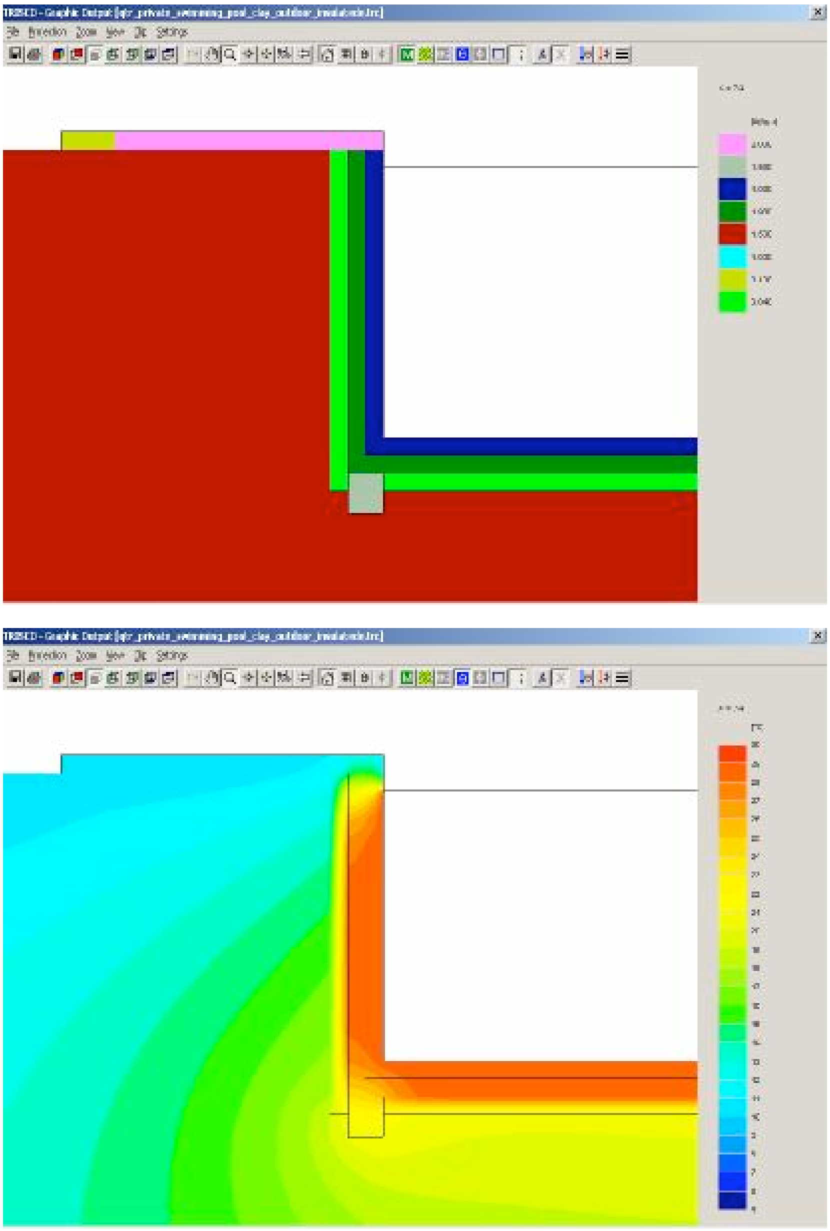

Figure 2.7 Thermal conductivities and temperature distribution for the externally insulated case (0.04 W/m·K) with clay soil.

2.7.2 Private (domestic) indoor swimming pool

No.	Insulation (100 mm thick) (internal or external)	Soil type	Average U-value of sides and bottom ISO10211, W/m^2K	Heat loss through sides and bottom, for a temperature difference of 19 K, in watts and kg carbon per annum
12	none	clay(1)	0.88	1596 W; 951 kgC/yr
13	0.04 W/m·K int.	clay	0.21	378 W; 225 kgC/yr
14	0.04 W/m·K ext.(2)	clay	0.50	899 W; 536 kgC/yr

(1) Also applies to loam, silt and dry sandy soil
(2) Allowing for 200 mm wide trench foundations bridging the insulating layer
(3) Also applies to wet sand and to gravel

Table 2.7B

2.7.3 Public outdoor swimming pool

No.	Insulation (100 mm thick) (internal or external)	Soil type	Average U-value of sides and bottom ISO10211, W/m²K	Heat loss through sides and bottom, for a temperature difference of 19 K, in watts and kg carbon per annum
15	none	clay	0.51	15028 W; 8951 kgC/yr
16	0.04 W/m·K int.	clay	0.13	3940 W; 2347 kgC/yr
17	0.04 W/m·K ext.	clay	0.27	8960 W; 5337 kgC/yr

Table 2.7C

2.7.4 Public indoor swimming pool

No.	Insulation (100 mm thick) (internal or external)	Soil type	Average U-value of sides and bottom ISO10211, W/m²K	Heat loss through sides and bottom, for a temperature difference of 19 K, in watts and kg carbon per annum
18	none	clay	0.32	9424 W; 5613 kgC/yr
19	0.04 W/m·K int.	clay	0.12	3610 W; 2150 kgC/yr
20	0.04 W/m·K ext.	clay	0.19	5653 W; 3367 kgC/yr
21	none	rock	0.44	13064 W; 7781 kgC/yr
22	0.04 W/m·K int.	rock	0.16	4701 W; 2800 kgC/yr
23	0.04 W/m·K ext.	rock	0.24	7128 W; 4245 kgC/yr

Table 2.7D

2.7.5 Commercial outdoor swimming pool

No.	Insulation (100 mm thick) (internal or external)	Soil type	Average U-value of sides and bottom ISO10211, W/m²K	Heat loss through sides and bottom, for a temperature difference of 19 K, in watts and kg carbon per annum
24	none	clay	0.94	8560 W; 5099 kgC/yr
25	0.04 W/m·K int.	clay	0.19	1728 W; 1029 kgC/yr
26	0.04 W/m·K ext.	clay	0.67	6040 W; 3598 kgC/yr

Table 2.7E

2.7.6 Commercial indoor swimming pool

No.	Insulation (100 mm thick) (internal or external)	Soil type	Average U-value of sides and bottom ISO10211, W/m²K	Heat loss through sides and bottom, for a temperature difference of 19 K, in watts and kg carbon per annum
27	none	clay	0.50	4552 W; 2711 kgC/yr
28	0.04 W/m·K int.	clay	0.16	1484 W; 884 kgC/yr
29	0.04 W/m·K ext.	clay	0.24	2172 W; 1294 kgC/yr

Table 2.7F

Table 2.7G summarises some of the information that was used in the calculations.

Pool size	Area of pool sides	Area of pool bottom	Total area of sides and bottom	Ratio of heat transfer (W) to average U-value (W/m²K), for a temperature difference of 19 K
private / dom.	45	50	95	1805
commercial	152	325	477	9063
public	300	1250	1550	29450

Table 2.7G

The effects of varying the parameters upon heat loss through the sides and bottom of the pool are summarised in Tables 2.7H and 2.7I, expressed in terms of the percentage change in heat loss through the sides and bottom:

Uninsulated pool	Private	Commercial	Public
Using sandy soil instead of clay soil	+14%	-	-
Using rock instead of clay soil	+27%	-	+36%
Using loam instead of clay soil	+0%	-	-
Using gravel instead of clay soil	+27%	-	-
Silt instead of clay soil	+0%	-	-
Wet sand instead of dry sand	+14%	-	-
Application of 100 mm insulation (0.04 W/m·K) internally	-80%	-80%	-63%
Application of 100 mm insulation (0.04 W/m·K) externally	-41%	-29%	-40%

Table 2.7H

Pool insulated internally (0.04 W/m·K)	**Private**
Using sandy soil instead of clay soil	+6%
Using rock instead of clay soil	+10%
Using loam instead of clay soil	+0%
Using gravel instead of clay soil	+6%
Silt instead of clay soil	+0%
Wet sand instead of dry sand	+6%

Table 2.7l

2.8 Dependence of heat loss on insulation level

Figure 2.8 shows the dependence of heat loss (expressed as average U-value in W/m^2K) on insulation level (expressed in terms of thermal resistance in m^2K/W).

The horizontal axes give the thermal resistance of the insulation. This is a measure of the amount of insulation used and it is equal to the thickness of insulation divided by its conductivity.

The vertical axes give the U-value (or thermal transmittance). The U-value is a measure of the amount of heat lost allowing for the area and allowing for the difference in temperature between inside and outside. The U-value is equal to the heat loss in watts per square metre of area divided by the difference between the internal temperature and the external temperature (in K).

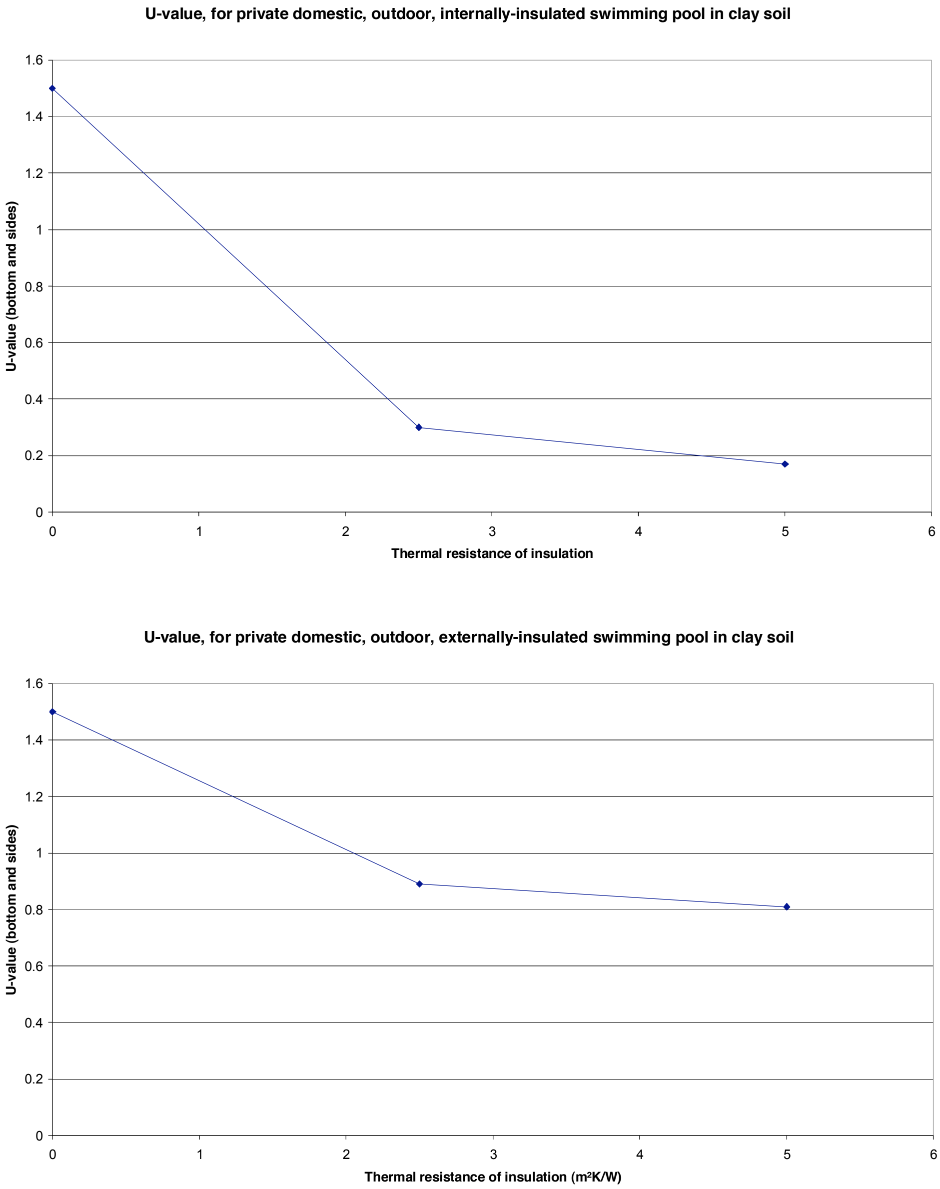
U-value, for private domestic, outdoor, internally-insulated swimming pool in clay soil
U-value (bottom and sides)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 1 2 3 4 5 6
Thermal resistance of insulation
U-value, for private domestic, outdoor, externally-insulated swimming pool in clay soil
U-value (bottom and sides)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 1 2 3 4 5 6
Thermal resistance of insulation (m²K/W)

Figure 2.8

2.9 Thermal capacitance

The thermal capacitance of a pool filled with water will be much higher than that of an air-filled basement room of the same size and dimensions. Table 2.9 gives typical values for these.

	Water	Air
Specific heat capacity (J/kgK)	4184	1000
Density (kg/m³)	1000	1.25
Thermal capacity per m³ (J/K)	4200000	1250

Table 2.9

Due to the large thermal capacity of water, a swimming pool will require a significant heat input to heat up when cold. The heating requirement, therefore, will be influenced by the need to replace old water with new water or to warm up the pool after periods of not being used.

3 Conclusions

Results are presented in this report for various swimming pool configurations. U-values tend to be higher for smaller pools, such as the 'private' pool, and smaller for larger pools, such as 'public' pools. Heat losses are lower if the pool is insulated, in many cases achieving a U-value of 0.25 W/m^2K or less.

The location of the insulation, whether to the inside or to the outside of the concrete shell, was found in some cases to have a substantial effect upon the heat loss. The effect of location of the insulation appeared to be most marked for small outdoor pools. The results suggest that, in the case of externally-insulated pools, it could be beneficial to place insulation between the concrete shell and the coping stones above the shell.

Heat losses, under the design conditions specified, are presented in this report, in conjunction with the estimated carbon emissions attributable to heat loss through the sides and bottom of the pool. Some analysis of the figures is given in the report, indicating that insulation in many cases leads to a significant reduction in carbon emissions.

The soil type has a noticeable effect, particularly when the pool is uninsulated. The effect is often considerably lessened, however, when the pool is insulated, particularly if the insulation layer is positioned to the inner side of the concrete shell.

If we can neglect the risk of insulation degrading, placing the insulation to the inner side of the concrete shell appears to be more beneficial than placing it to the outer side of the shell.

The calculations are carried out on the basis that the insulation does not degrade as a result of the presence of water. Some insulation materials could deteriorate if there are leaks in the swimming pool and for such materials it is advisable to provide adequate waterproofing to ensure that the insulation does not degrade.

Some insulation materials are placed below soil level in building works to form floor edge insulation, and this approach is usually considered acceptable for building regulatory purposes for most types of buildings. While there may be debate about whether such materials can deteriorate with time as a result of being placed under the soil, there is relatively little research in this area, and it would be difficult to arrive at firm conclusions about which insulation materials, if any, can be used beneath swimming pools without any deterioration in their performance.

4 References

[1] The Building Regulations 2000, Approved Document L2: Conservation of fuel and power in buildings other than dwellings, 2002 Edition. London, The Stationery Office, 2001.

[2] BS EN ISO 10211-1, Thermal bridges in building constructions - Heat flows and surface temperatures, British Standards Institute, 1996

Appendix A : An example of a U-value calculation using the simplified procedure in BS EN ISO 13370 for comparison with the results given in this report

The following examples serve as a check on some of the results presented elsewhere in this report. The following are some calculations of swimming pool designs based upon the method in BS EN ISO 13370. Strictly speaking, BS EN ISO 13370 applies to basements rather than swimming pools and should not be used for assessing swimming pools, however the results of the following calculations can serve as a rough check on the calculations given in the main body of this report. While the calculations in this appendix are reasonably similar to the results for internally-applied insulation, they are found to be significantly different from the results for externally-applied insulation.

U-value calculation
by BRE U-value Calculator version 1.08d
Printed on 10 Aug 2004 at 13:37

Element type: Heated basement
Calculation Method: BS EN ISO 6946, BS EN ISO 13370

Base case without insulation - private pool, outdoor, clay soil

Thermal resistance of basement floor construction:

Layer	d (mm)	λ layer	λ bridge	Fraction	R layer	R bridge	Description
					0.000		Rsi
1	200	1.930			0.104		concrete
	200				0.104		

Total resistance: Upper limit: 0.104 Lower limit: 0.104 Average: 0.104 m²K/W

Thermal resistance of basement wall construction:

Layer	d (mm)	λ layer	λ bridge	Fraction	R layer	R bridge	Description
					0.000		Rsi
1	200	1.930			0.104		concrete
	200				0.104		

Total resistance: Upper limit: 0.104 Lower limit: 0.104 Average: 0.104 m²K/W

Ground parameters:
Perimeter P: 30.00 m, Area A: 50.00 m², Wall thickness: 300 mm
P/A = 0.60, Ground type: Clay/silt λ = 1.5 W/m·K, Rse = 0.04 m²K/W
Average basement depth: 1.500 m, Area of basement walls: 45.00 m²

	Floor	Walls	Overall (area-weighted average)
U-value	0.569	1.404	0.965
U-value (rounded)	**0.57**	**1.40**	**0.96 W/m²K**

Calculated by:
Sean Doran
BRE Ltd

U-value calculation
by BRE U-value Calculator version 1.08d
Printed on 10 Aug 2004 at 13:38

Element type: Heated basement
Calculation Method: BS EN ISO 6946, BS EN ISO 13370

Base case with insulation (0.04 W/m·K) - private pool, outdoor, clay soil

Thermal resistance of basement floor construction:

Layer	d (mm)	λ layer	λ bridge	Fraction	R layer	R bridge	Description
					0.000		Rsi
1	200	1.930			0.104		concrete
2	100	0.040			2.500		insulation
	300				2.604		

Total resistance: Upper limit: 2.604 Lower limit: 2.604 Average: 2.604 m²K/W

Thermal resistance of basement wall construction:

Layer	d (mm)	λ layer	λ bridge	Fraction	R layer	R bridge	Description
					0.000		Rsi
1	200	1.930			0.104		concrete
2	100	0.040			2.500		insulation
	300				2.604		

Total resistance: Upper limit: 2.604 Lower limit: 2.604 Average: 2.604 m²K/W

Ground parameters:
Perimeter P: 30.00 m, Area A: 50.00 m², Wall thickness: 300 mm
P/A = 0.60, Ground type: Clay/silt λ = 1.5 W/m·K, Rse = 0.04 m²K/W
Average basement depth: 1.500 m, Area of basement walls: 45.00 m²

	Floor	Walls	Overall (area-weighted average)
U-value	0.229	0.278	0.253
U-value (rounded)	**0.23**	**0.28**	**0.25 W/m²K**

Calculated by:
Sean Doran
BRE Ltd

U-value calculation
by BRE U-value Calculator version 1.08d
Printed on 10 Aug 2004 at 13:37

Element type: Heated basement
Calculation Method: BS EN ISO 6946, BS EN ISO 13370

Base case with insulation (0.04 W/m·K) - private pool, outdoor, rock

Thermal resistance of basement floor construction:

Layer	d (mm)	λ layer	λ bridge	Fraction	R layer	R bridge	Description
					0.000		Rsi
1	200	1.930			0.104		concrete
2	100	0.040			2.500		insulation
	300				2.604		

Total resistance: Upper limit: 2.604 Lower limit: 2.604 Average: 2.604 m²K/W

Thermal resistance of basement wall construction:

Layer	d (mm)	λ layer	λ bridge	Fraction	R layer	R bridge	Description
					0.000		Rsi
1	200	1.930			0.104		concrete
2	100	0.040			2.500		insulation
	300				2.604		

Total resistance: Upper limit: 2.604 Lower limit: 2.604 Average: 2.604 m²K/W

Ground parameters:
Perimeter P: 30.00 m, Area A: 50.00 m², Wall thickness: 300 mm
P/A = 0.60, Ground type: User-defined λ = 2.5 W/m·K, Rse = 0.04 m²K/W
Average basement depth: 1.500 m, Area of basement walls: 45.00 m²

	Floor	Walls	Overall (area-weighted average)
U-value	0.272	0.305	0.288
U-value (rounded)	**0.27**	**0.31**	**0.29 W/m²K**

Calculated by:
Sean Doran
BRE Ltd

Appendix B Thickness required to achieve a U-value of 0.20 W/m²K

Table B.1 shows the thicknesses of insulation needed in order to achieve a U-value of 0.20 W/m²K.

No.	Pool type	Soil type	Insulation location	Thermal resistance needed (m²K/W)	Thickness of insulation needed if conductivity is 0.040 W/m·K
1	Private outdoor	Clay	Internal	4.2	**170**
2	Private indoor	Clay	Internal	2.7	**110**
3	Commercial indoor	Clay	Internal	1.7	**70**
4	Public indoor	Clay	Internal	0.6	**20**
5	Private outdoor	Rock	Internal	4.5	**180**
6	Private indoor	Rock	Internal	3.1	**130**
7	Commercial indoor	Rock	Internal	2.5	**100**
8	Public indoor	Rock	Internal	1.0	**40**
9	Private outdoor	Clay	External	-	*
10	Private indoor	Clay	External	-	*
11	Commercial indoor	Clay	External	4.0	**160**
12	Public indoor	Clay	External	2.5	**100**
13	Private outdoor	Rock	External	-	*
14	Private indoor	Rock	External	-	*
15	Commercial indoor	Rock	External	5.0	**200**
16	Public indoor	Rock	External	2.6	**110**

In some cases, the heat loss through the sides of the pool is very large, and it is not possible to achieve a U-value of 0.20 W/m²K. These cases are indicated by an asterisk(*)