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RENOVATION OF BUILDINGS USING STEEL TECHNOLOGIES (ROBUST)

RFSR CT 2007-0043

WP 1.5 / WP 5.1 Thermal Simulations of Office Building – Heating Energy Demand

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19 Seiten einschließlich Deckblatt

Content

1 Basics and Concept

Two building types are in the scope of this numerical study: A typical multi-storey office building (defined by VTT) and residential buildings in some variations. These building types are the “test specimen” for numerical investigations with the following objectives:

1) Benchmark for numerical tools
2) Identify the impact of various European climates
3) Work out the effect of various retrofit measures
4) Develop a simplified calculation method

The energy demand is a multidimensional function of the various components of the building (described by parameters x_i), the climate and the building use, whereas the function f is a result of a numerical calculation or a standardised calculation method. For the original state is valid:

$$Q_{p,orig} = f(x_{1,orig},....,x_{n,orig},\text{climate, use})$$

Furthermore a standard option (as “starting point”) for the retrofitted building can be defined:

$$Q_{p,retro} = f(x_{1,retro},....,x_{n,retro},\text{climate, use})$$

To identify the sensitivity or effectiveness of various measures x_i partial derivatives can be estimated:

$$Effectiveness\,(x_i) = \frac{\partial}{\partial x_i}(Q_{p,retro})$$

2 Office building

2.1 Design

2.1.1 Dimensions and use

Description:

- a typical office building with four floors
- inner dimensions 16 m x 55 m, floor height 3.6 m
- treat floor area 3 520 m², brutto area 3 664 m2
- window area 517 m² (25.3 % of the wall area)

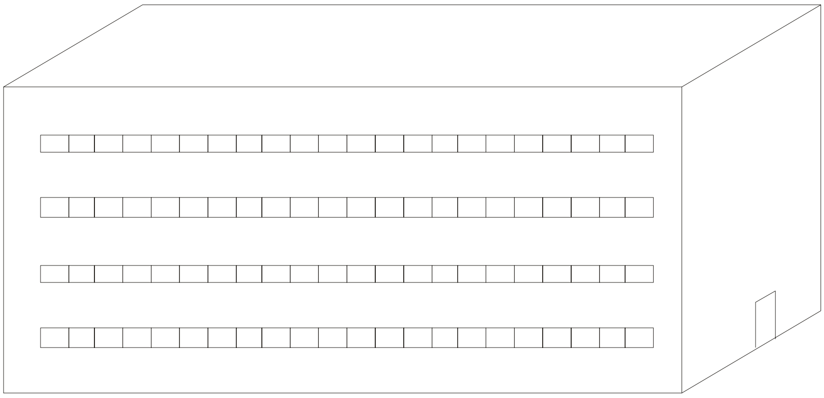

Fig. 1: Isometrie “Reference Office Building”

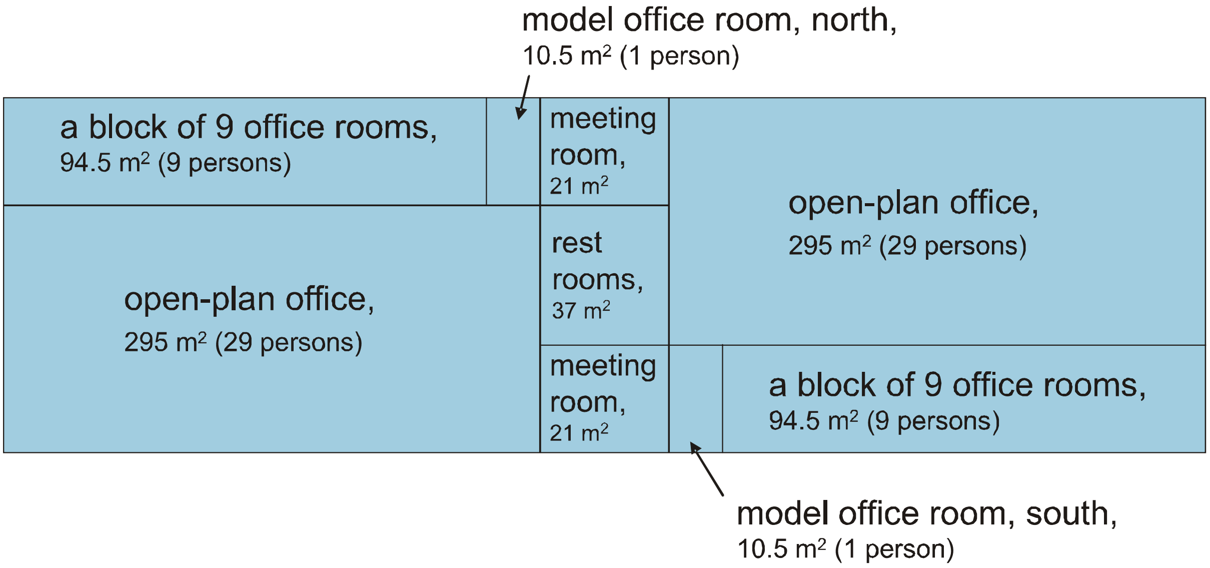

Fig. 2: Ground plan “Reference Office Building”

Thermal loads

Table 1: Thermal loads

Room	Person load	Device load	Lighting load (15 W/m²)
Model office room, A = 10.5 m²	(1): 113 W (work days 8-11 and 12-16)	200 W (work days 8-16)	157.5 W (work days 8-16)
Block of 9 office rooms, A = 94.5 m²	(9): 1 017 W (work days 8-11 and 12-16)	1 800 W (work days 8-16)	1 417.5 W (work days 8-16)
Open plan office, A = 295 m²	(29): 3 277 W (work days 8-11 and 12-16)	5 800 W (work days 8-16)	4 425 W (work days 8-16)
Meeting room, A = 21 m²	(5) 565 W (work days 9-11 and 13-16)	200 W (work days 9-11 and 13-16)	315 W (work days 8-16)
Rest room, A = 37 m²			555 W (work days 8-16)

Ventilation rates

Table 2: Ventilation rate

Room	Inlet Air (dm³/h)	Outlet Air (dm³/h)
Model office room, A = 10.5 m²	15,9	15,7
Block of 9 office rooms, A = 94.5 m²	134	133
Open plan office, A = 295 m²	439	436
Meeting room, A = 21 m²	79,2	78,6
Rest room, A = 37 m²	0	80
Whole Building	5350	5630

The air change rate (mechanical) was reduced to 1.21 h^{-1}. The infiltration air change rate can be estimated according DIN V 18599-2:

- without mechanical off:

$n_{inf} = n_{50} \cdot e_{wind}$

- with mechanical ventilation:

$n_{inf} = n_{50} \cdot e_{wind} \cdot f_{v,mech}$

whereas:

$$f_{\text{V,mech}} = 1 - \frac{1}{1 + \frac{f_{\text{wind}}}{e_{\text{wind}}} \left(\frac{n_{\text{ZUL}} - n_{\text{ABL}}}{n_{50}} \right)^2}$$

for the reference building:
n_{inf} (without mechanical ventilation): 0.21 h^{-1}

n_{inf} (with mechanical ventilation): 0.23 h^{-1}

Set Temperatures:
Heating: 21°C
Cooling: 24 °C

2.1.2 Parameters of original structure

Table 3 Performance data of original structure

	Original Structure (from outside)	**Thickness mm**	**U-value W/m²K**
Exterior Wall	Concrete 60 mm, insulating material 80 mm, concrete 160 mm	320	0.82
Roof	Concrete 60 mm, insulating material 80 mm, concrete 180 mm	340	0.81
Base floor	Filler 20 mm, concrete 60 mm, insulating material 100 mm, concrete 100 mm, gravel 200 mm	480	0.63
Floor slab	Filler 20 mm, cored slab 190 mm (concrete 79 mm, air gap 32 mm, concrete 79 mm), filler 20 mm	230	2.6
Partition wall	Plaster 20 mm, concrete 120 mm, plaster 20 mm	160	2.9
Window	2 glass panes (glass thickness = 4 mm), air gap 60 mm	68	2.4
Door	Wood 60 mm	60	1.6

Air-tightness	9.9 $m^3/(hm^2)$ or 3.0 1/h		

2.1.3 Parameters for retrofitted structures (starting point)

Table 4 Performance data retrofitted structure (starting point)

	Structure (from outside)	**Thickness mm**	**U-value W/m^2K**
Exterior Wall	Minerit 4 mm, wool 150/200/250 mm, wool/air (2/3 air) 50 mm, concrete 160 mm	364 (150) 414 (200) 464 (250)	0.258 0.211 0.182
Roof	Concrete 60 mm, insulating material 80 mm, concrete 180 mm	380	0.81 (Proposal: change to 0.2)
Base floor	Filler 20 mm, concrete 60 mm, insulating material 100 mm, concrete 100 mm, gravel 200 mm	480	0.63
Floor slab	Filler 20 mm, cored slab 190 mm (concrete 79 mm, air gap 32 mm, concrete 79 mm), filler 20 mm	230	2.6
Partition wall	Plaster 20 mm, concrete 120 mm, plaster 20 mm	160	2.9
Window	Passive house type windows, g-value 0.35 for the glass area		0.7
Door	Wood 60 mm	60	1.6

Air-tightness	3 $m^3/(hm^2)$ or 0.92 1/h		

2.1.4 Parameters retrofitted structure (matrix of parameters and range)

Table 5: Matrix for parametric study

Parameter	original	retrofit (starting point)	range min.	range max.
	W/m²K	W/m²K	W/m²K	W/m²K
U-Value exterior wall	0.82	0.265	0.15	0.3
U-Value roof	0.81	0.2	0.1	0.3
U-Value window (glazing and frame)	2.6	1.4 (U_g: 1.2, U_f: 2)	0.7	2.0
	W/mK	W/mK	W/mK	W/mK
ψ -Value base plate	?	?	0	1
	mm concrete	mm concrete	mm concrete	mm concrete
Thermal inertia	100 (each, floor and ceiling)	100 (each, floor and ceiling)	0	100 (each, floor and ceiling)
	%	%	%	%
Window area (in practise: mostly not variable)	25	25	20	60
Orientation (not relevant for refurbishment, only “academic”)	main facades: North and South	main facades: North and South	main facades: North and South	main facades: East and West

Climatic zones:

Helsinki, London, Berlin

2.2 Results office building

2.2.1 Original State

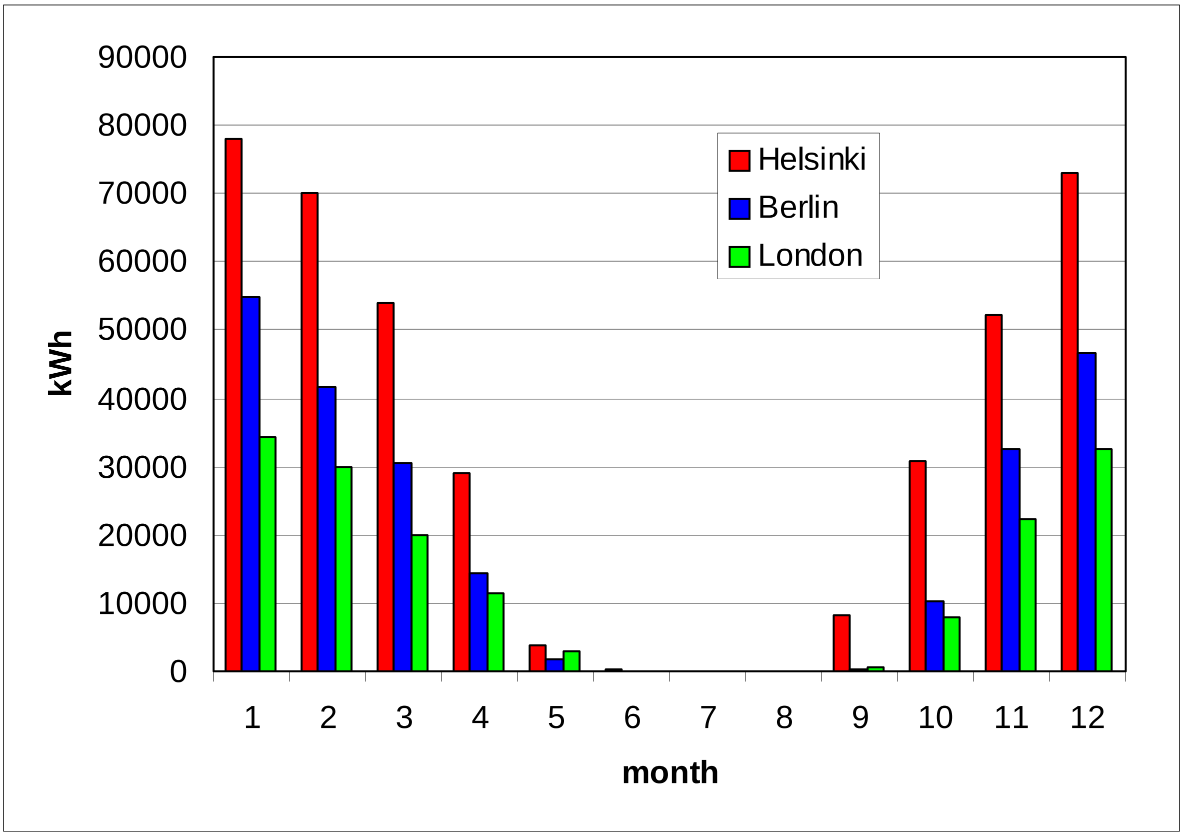

Fig. 3: Heating energy demand, whole building

Table 6: Heating energy demand (whole year, specific values)

	Helsinki	Berlin	London
kWh/m²a	108.2	64.5	43.6

2.2.2 Retrofit – Starting Point

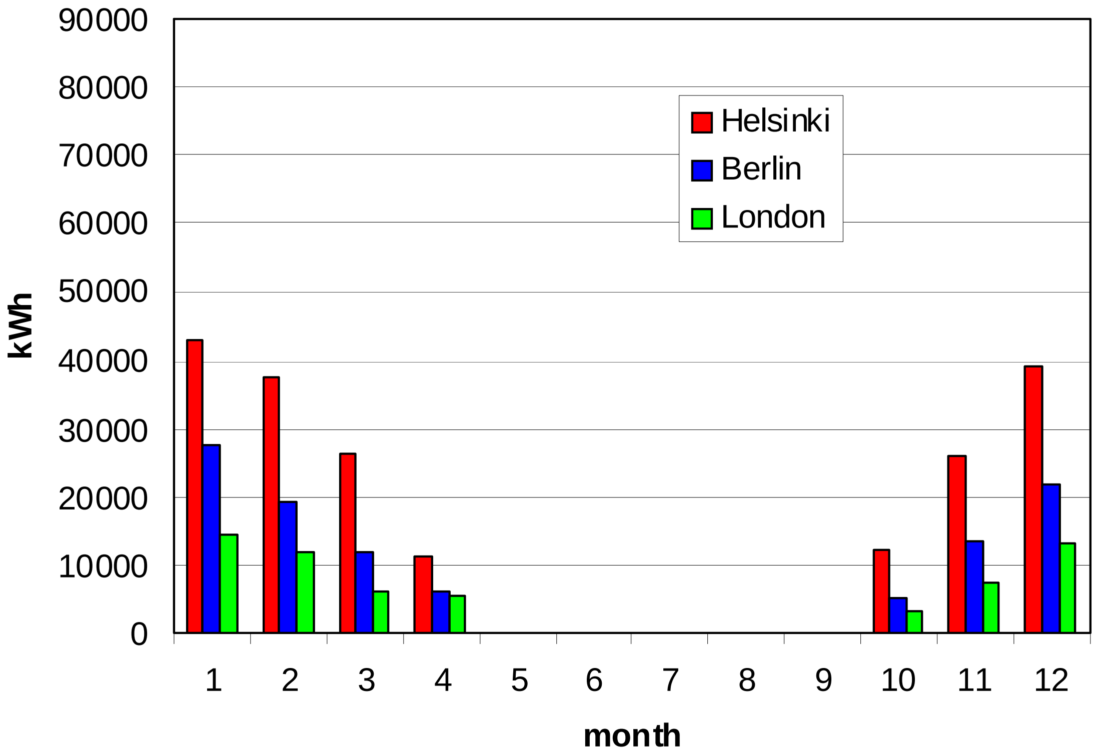

Fig. 4: Heating energy demand, whole building

Table 7: Heating energy demand (whole year, specific values)

	Helsinki	Berlin	London
kWh/m²a	55,5	30,0	17,6

2.2.3 Retrofit – Variation U-Value, exterior wall

Table 8: Heating energy demand (whole year, specific values, retrofit with variation of U-Value exterior wall, $\lambda_{\text{insulation}}$: 0.04 W/mK)

U-Value	Thickness insulation [cm]	Helsinki	Berlin	London
0.102	38	50.2	26.9	15.3
0.148	26	51.7	27.3	15.9
0.209	18	53.7	28.8	16.8
0.265	14	55.5	30.0	17.6
0.305	12	56.9	30.2	18.2
0.36	10	58.7	31.4	19.1
0.494	7.0	63.1	34.4	21.3
0.816	3.8	74.1	41.5	25.8

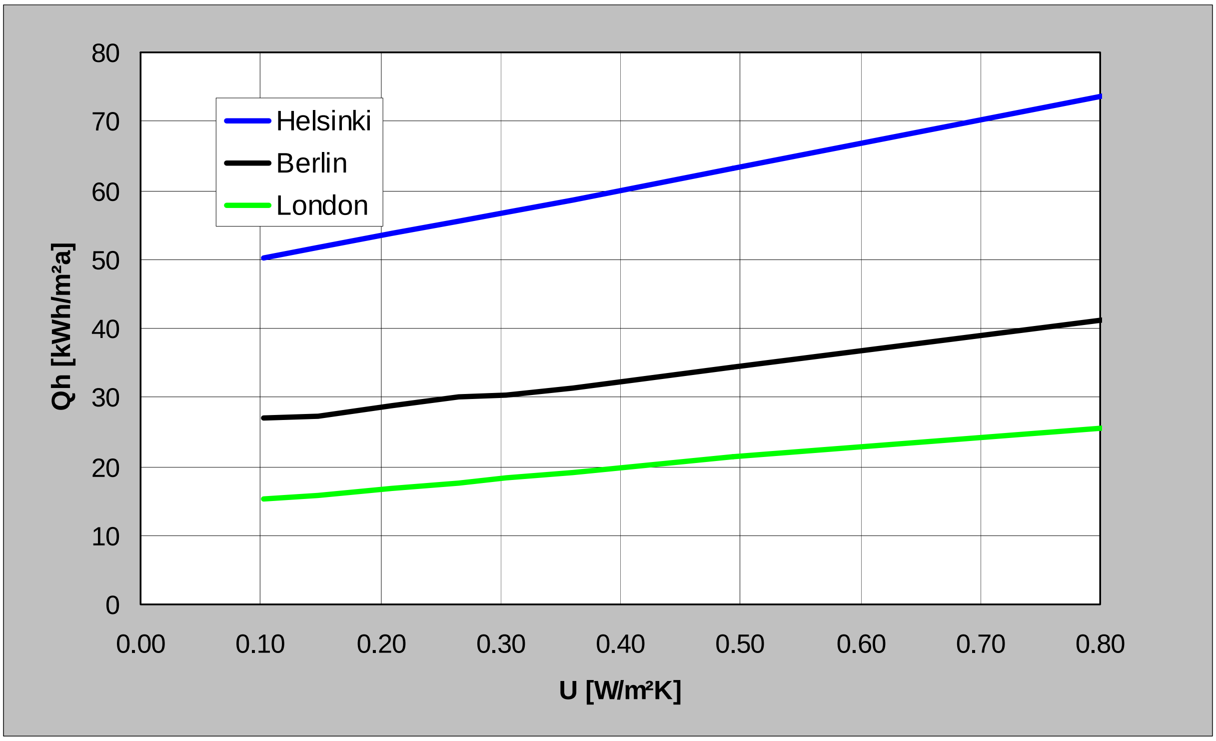

Fig. 5: Heating energy demand, whole building, specific values

$$Effectiveness\ (U_{Wall}) = \frac{\partial}{\partial U_{Wall}}(Q_{h,retro})$$

$$Effectiveness\ (d_{ins}) = \frac{\partial}{\partial d_{ins}}(Q_{h,retro})$$

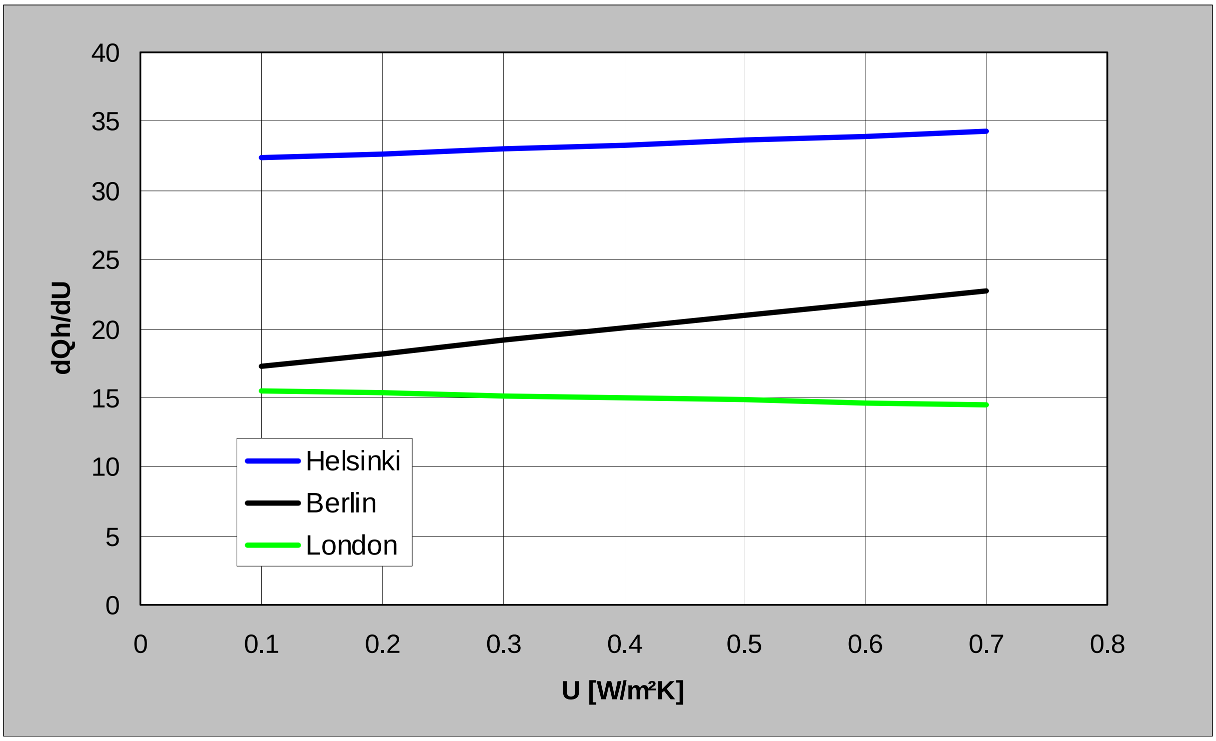

Fig. 6: Derivation energy demand/U-Value, whole building, specific values

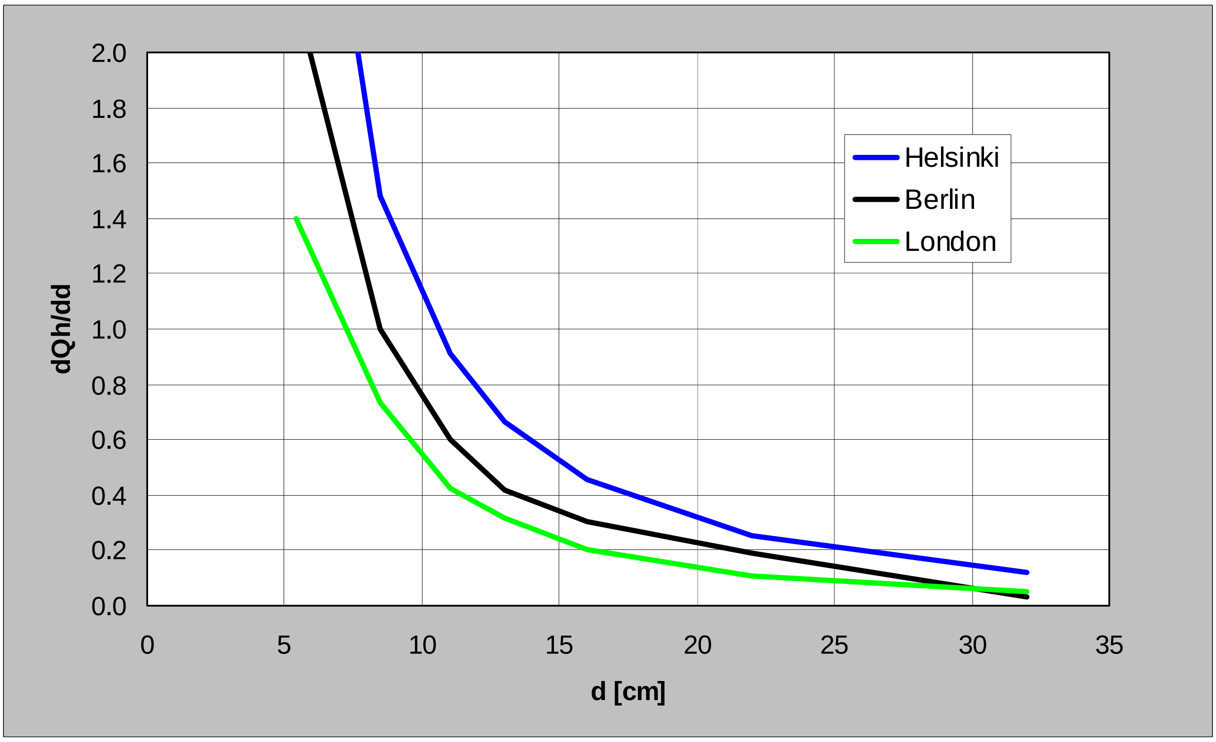

Fig. 7: Derivation energy demand/thickness insulation, whole building, specific values for $\lambda_{\text{insulation}}$: 0.04 W/mK

2.2.4 Retrofit – Variation U-Value, roof

Table 9: Heating energy demand (whole year, specific values, retrofit with variation of U-Value roof, $\lambda_{\text{insulation}}$: 0.05 W/mK)

		Heating energy demand [kWh/m²a]		
U-Value	Thickness insulation [cm]	Helsinki	Berlin	London
0.1	39	52.8	28.2	16.3
0.147	26	54.0	29.0	16.9
0.199	19	55.3	29.9	17.5
0.248	15	56.5	30.7	18.1
0.283	13	57.4	30.6	18.5
0.344	11	58.7	31.4	19.1
0.492	7.0	62.5	33.9	20.9
0.652	5.0	66.4	36.5	23.1
0.779	4.0	115.6	69.4	47.2

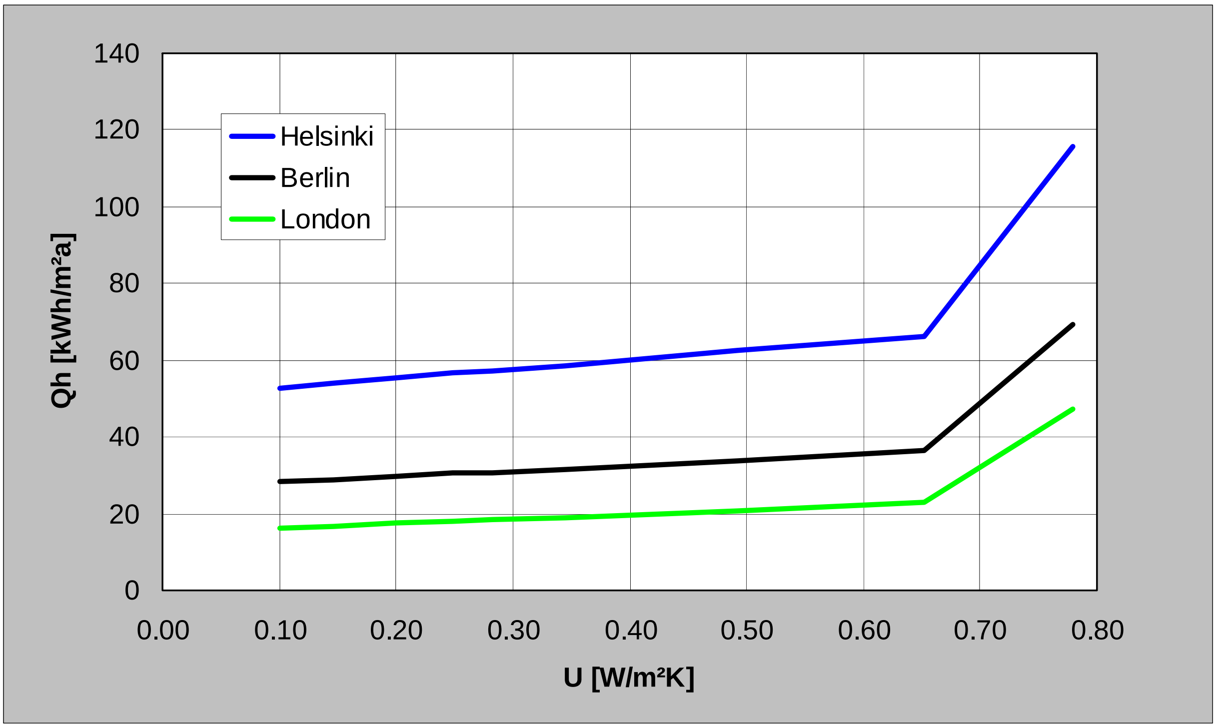

Fig. 8: Heating energy demand, whole building, specific values

2.2.5 Retrofit – Variation glazing

Table 10: Heating energy demand (whole year, specific values, retrofit with variation of glazing)

		Heating energy demand [kWh/m²a]		
U_g-Value		Helsinki	Berlin	London
0.4		49.9	26.9	16.2
0.7		48.9	26.9	15.9
1.2		55.5	30.0	17.6
1.4		58.7	31.2	18.8
2.8		77.0	43.4	27.0
5.8		169.4	107.3	77.5

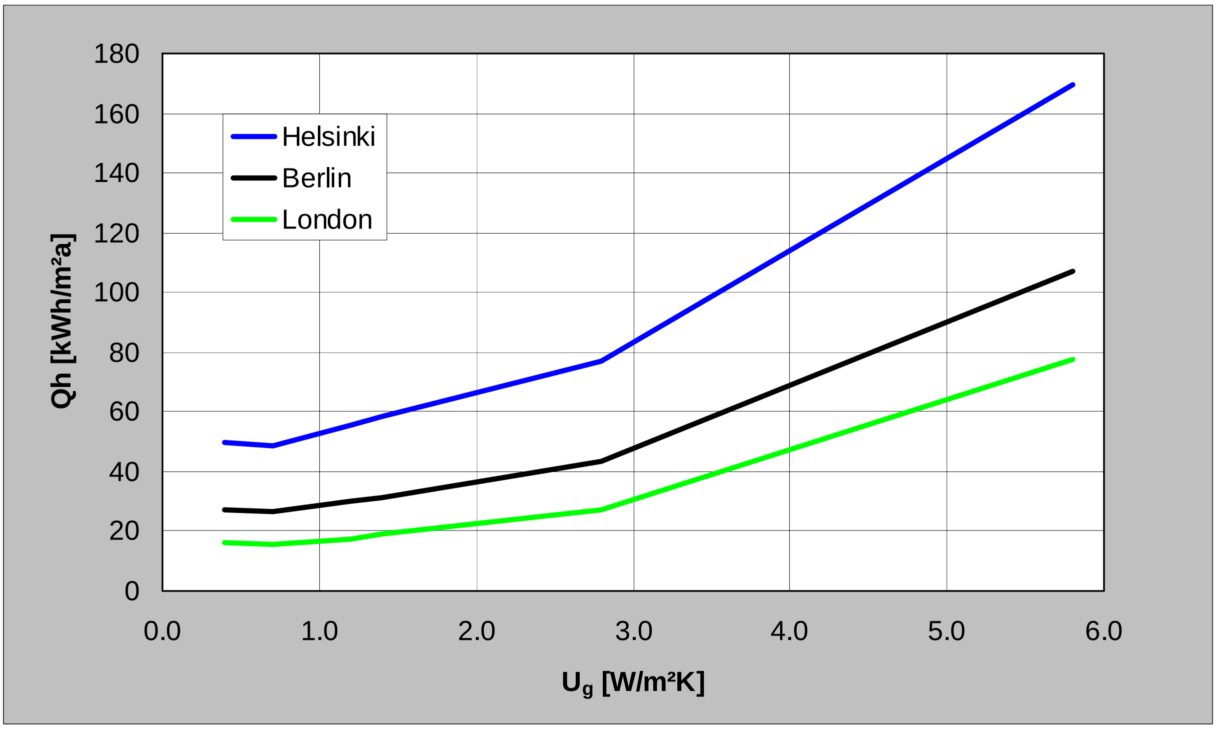

Fig. 9: Heating energy demand, whole building, specific values

2.2.6 Retrofit – Variation Thermal bridging, base plate

Table 11: Heating energy demand (whole year, specific values, retrofit with variation of thermal bridge effect base plate (“ψ-value”))

		Heating energy demand [kWh/m²a]		
Psi-Value		Helsinki	Berlin	London
0.1		55.89	29.14	16.81
0.2		56.26	29.40	17.01
0.3		56.63	29.65	17.21
0.4		56.99	29.90	17.40
0.5		57.34	30.14	17.58
0.6		57.68	30.32	17.77
0.7		58.01	30.55	17.94
0.8		58.33	30.77	18.12
0.9		58.65	30.99	18.29

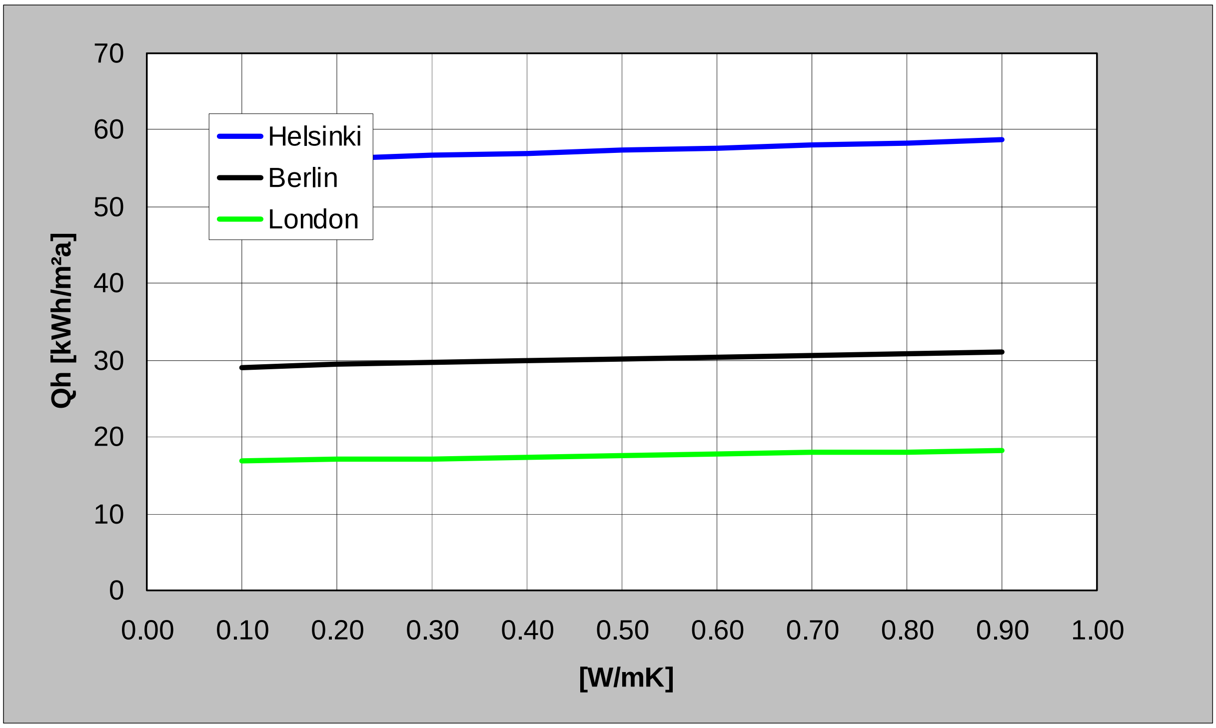

Fig. 10: Heating energy demand, whole building, specific values

2.2.7 Retrofit – Variation Thermal inertia

Table 12: Heating energy demand (whole year, specific values, retrofit with variation of thermal inertia: thickness of exposed concrete in internal floor plates)

		Heating energy demand [kWh/m²a]		
thermal mass (mm concrete)		Helsinki	Berlin	London
100		55.58	28.47	16.08
80		55.76	28.73	16.30
60		55.99	29.13	16.68
40		55.97	29.43	17.01
20		55.67	29.77	17.38
0		55.11	30.15	17.90

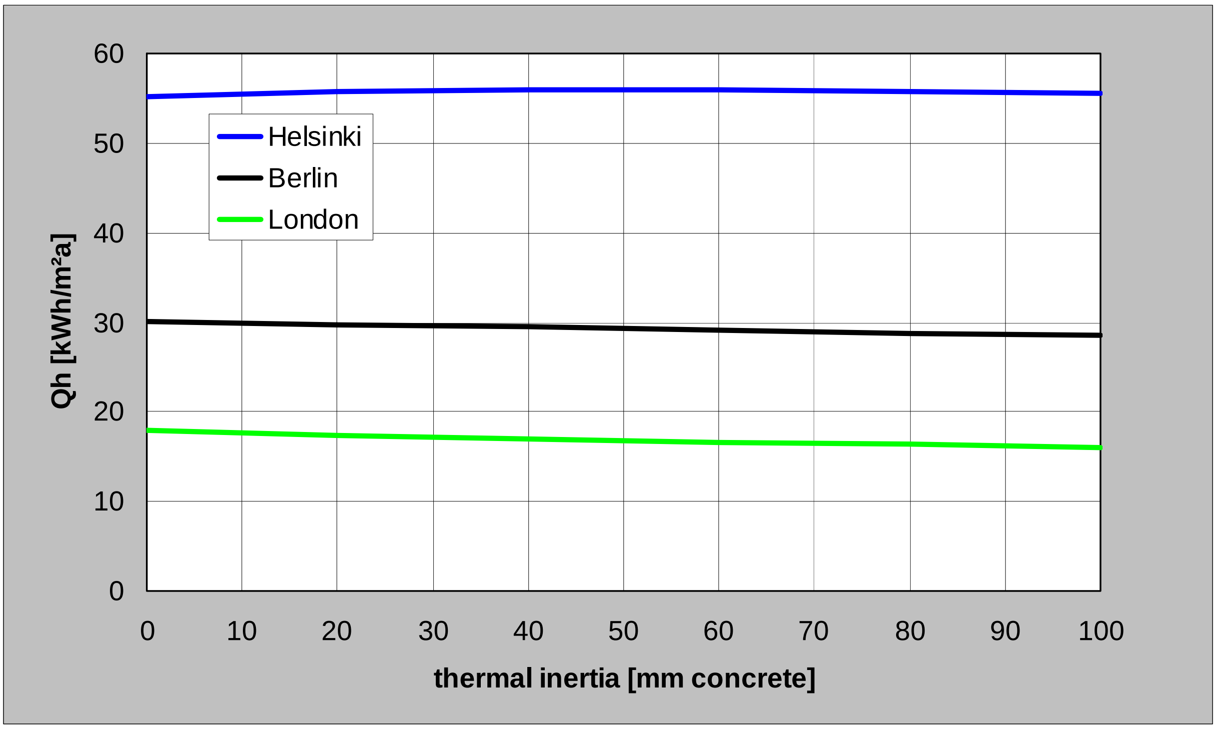

Fig. 11: Heating energy demand, whole building, specific values

2.2.8 Retrofit – Variation window area

Table 13: Heating energy demand (whole year, specific values, retrofit with variation of window area, in percentage of facade)

		Heating energy demand [kWh/m²a]		
Window-area		Helsinki	Berlin	London
20%		53.26	28.54	17.03
25%		55.54	30.04	17.61
30%		57.58	30.69	18.17
40%		62.09	33.53	19.82
50%		66.52	36.48	22.41
60%		71.14	39.09	24.41

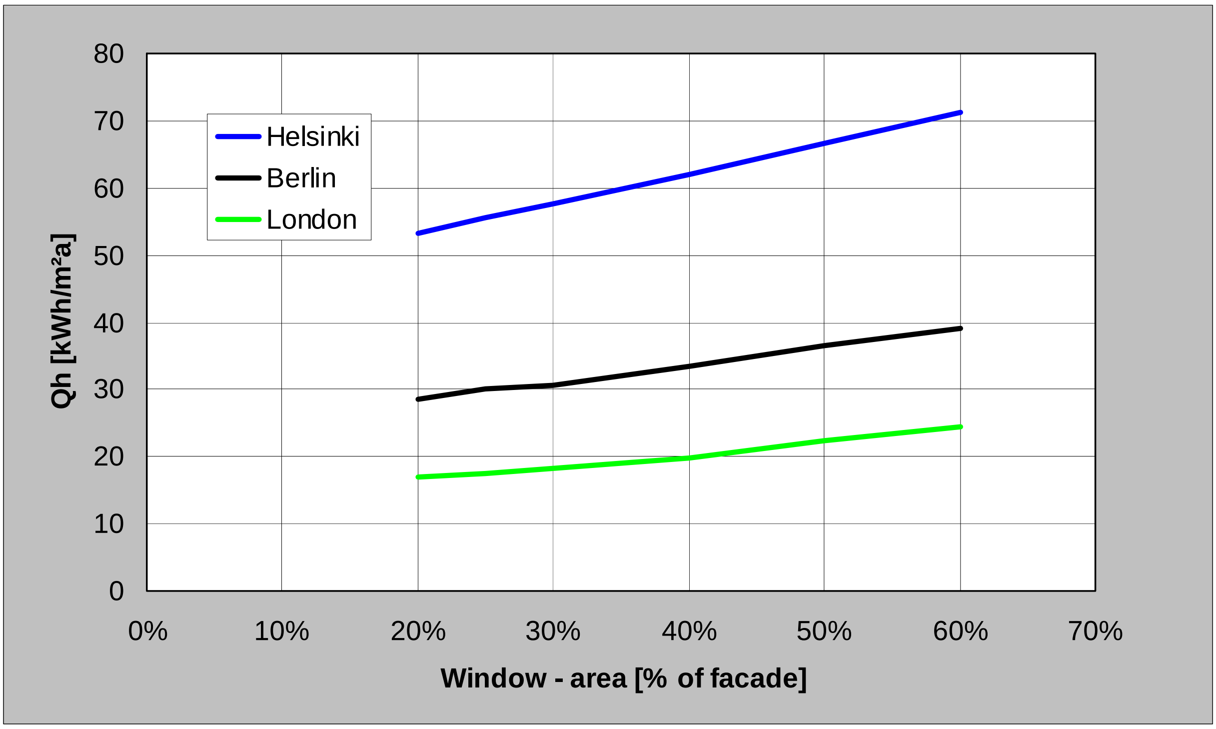

Fig. 12: Heating energy demand, whole building, specific values

2.3 Roof top extension

For testing the impact of a vertical extension on the energy performance one to three additional storeys were added on the existing building. In a first set of simulation runs the properties of the "original state" were taken for the whole building including the added storeys, then the "starting point" for the refurbishment (see chap. 0) were taken for second set of simulation runs.

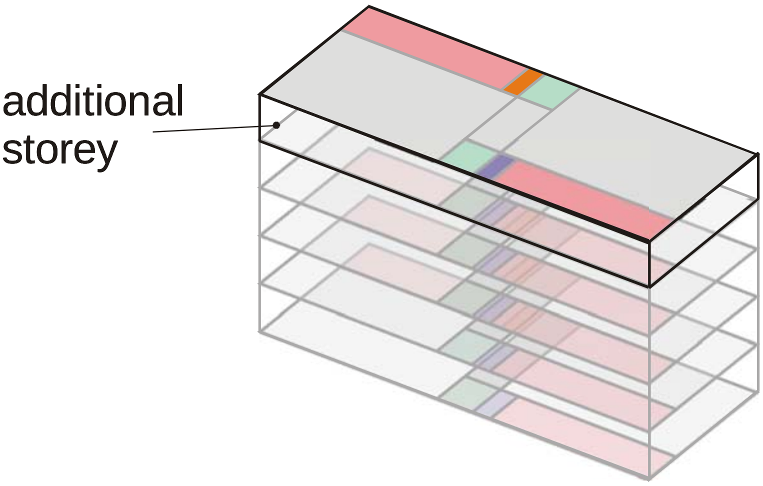

Fig. 13: sketch roof top extension office building

Table 14: Heating energy demand (whole year, specific values, original with vertical extension)

Number storeys	Helsinki	Berlin	London
4	108.18	64.51	43.58
5	102.92	60.80	40.56
6	99.96	58.42	38.42
7	97.85	56.72	36.89

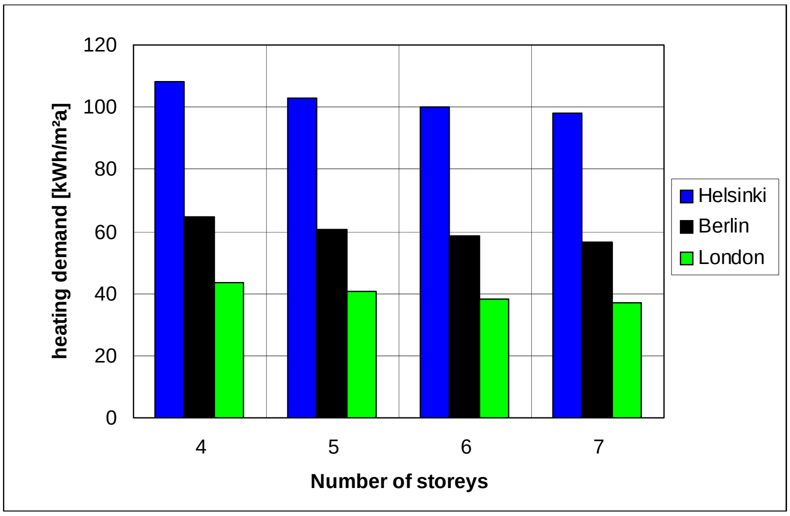

Fig. 14: Heating energy demand (whole year, specific values, original with vertical extension)

Table 15: Heating energy demand (whole year, specific values, “starting point retrofit” with vertical extension)

Number storeys	Helsinki	Berlin	London
4	55.54	30.04	17.61
5	53.25	28.10	16.18
6	51.82	26.96	15.22
7	50.79	26.15	14.53

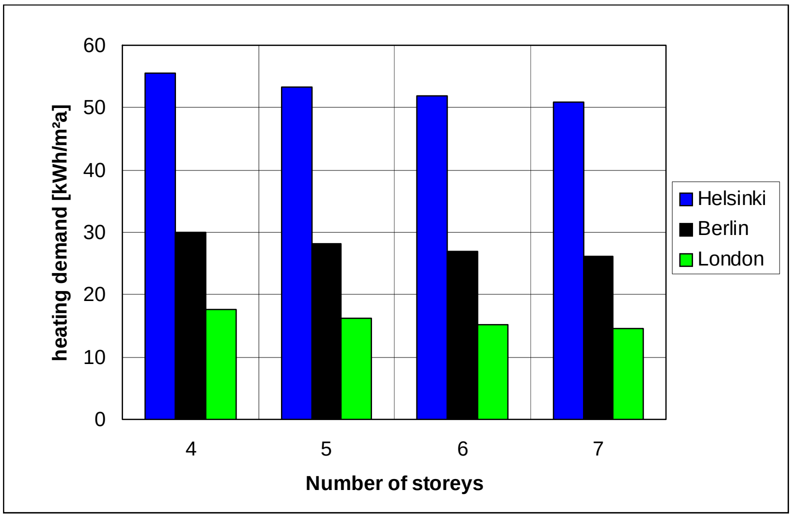

Fig. 15: Heating energy demand (whole year, specific values, original with vertical extension)

The benefit of the vertical extension is caused by the reduced A/V-ratio. The additional storeys do not enlarge the ground and roof areas, only the facades.