Université de Liège

Faculté des Sciences Appliquées

Definition and Validation of a Simplified Multizone Dynamic Building Model Connected to Heating System and HVAC Unit

ANNEXES

Thèse présentée en vue de l'obtention du grade de
Docteur en Sciences de l'Ingénieur

Gabrielle Masy

Ingénieur Civil Architecte

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ANNEX 1: WALL TYPOLOGY

1.1. External walls

	Description from indoor to outdoor	Insulation thickness cm	U W/m²K	C J/m²K
1	hollow concrete block + insulation + air layer weakly ventilated + bricks	7	0.3922	290190
2	massive wood + insulation + air layer weakly ventilated + bricks	7.5	0.3049	235327
3	hollow concrete block + insulation + air layer strongly ventilated	5	0.5532	153493
4	hollow concrete block + insulation + air layer weakly ventilated + bricks	5	0.5054	289609
5	hollow concrete block + insulation + air layer strongly ventilated	7	0.4203	154074
6	hollow concrete block + insulation + air layer strongly ventilated	9	0.3389	154655
7	hollow concrete block + insulation + air layer weakly ventilated + bricks	9	0.3204	290771
8	clay block + insulation + air layer strongly ventilated	5	0.5006	153493
9	clay block + insulation + air layer weakly ventilated + bricks	5	0.4612	289609
10	clay block + insulation + air layer strongly ventilated	7	0.3893	154074
11	clay block + insulation + air layer weakly ventilated + bricks	7	0.365	290190
12	clay block + insulation + air layer strongly ventilated	9	0.3184	154655
13	clay block + insulation + air layer weakly ventilated + bricks	9	0.302	290771
14	plywood + insulation between rafters + plywood + air layer strongly ventilated	6	0.5856	16820
15	plywood + insulation between rafters + plywood + air layer weakly ventilated + bricks	6	0.5323	152936
16	massive wood + insulation + air layer strongly ventilated	7.5	0.3216	99187
17	insulation + multiplex + air layer weakly ventilated + bricks	7.5	0.3977	24379
18	insulation + multiplex + air layer weakly ventilated + bricks	7.5	0.3724	160495
19	cellular concrete block	-	0.4715	108360
20	cellular concrete block + insulation + air layer strongly ventilated	5	0.3373	76213
21	panel OSB + insulation + celit + air layer strongly ventilated	20	0.1497	67286
22	panel OSB + insulation + celit	20	0.1516	67286
23	fermacell wood + insulation + panel OSB + insulation + celit + air between battens + wood	18.6	0.1608	74545
24	air between battens + insulation + stone	9	0.3152	1.035E+06
25	insulation + panel OSB + insulation + concrete block	14	0.1732	225237

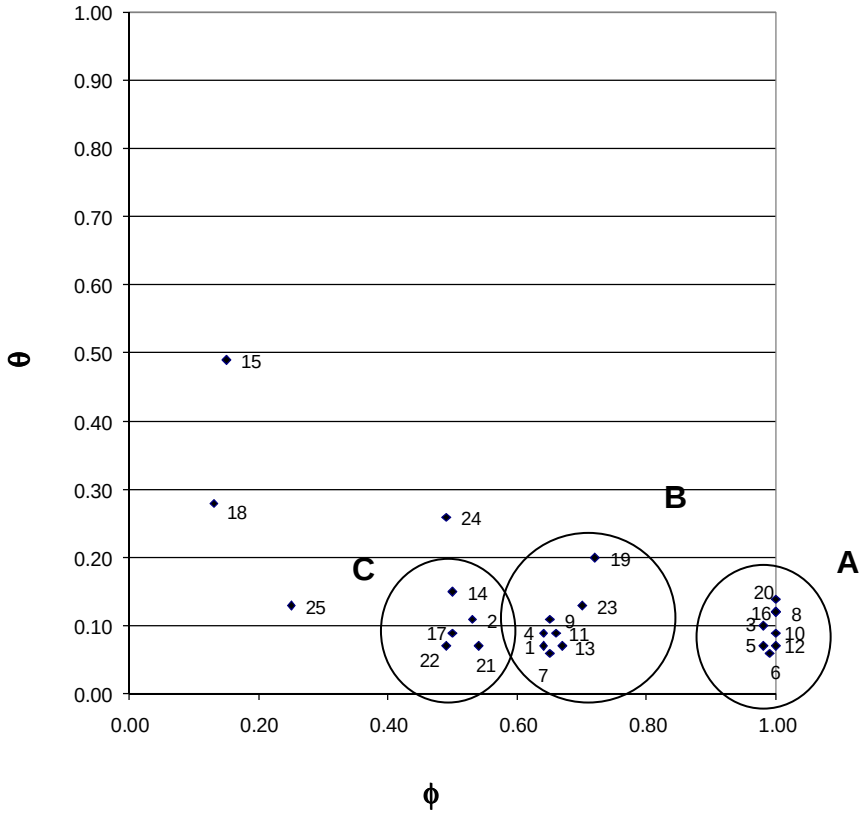

Fig A1.1: External walls ϕ and θ parameters

Category A includes:

- hollow concrete or clay blocs, insulation and strongly ventilated air layer
- massive wooden structure, insulation and strongly ventilated air layer
- cellular concrete with outdoor insulation

Mean values: θ = 0.10 ϕ = 0.99 Default values: θ = 0.10 ϕ = 1

Category B includes:

- hollow concrete or clay blocs, insulation and outside brick
- not insulated cellular concrete
- triple panel with two insulation layers

Mean values: θ = 0.10 ϕ = 0.67 Default values: θ = 0.10 ϕ = 0.70

Category C includes:

- massive wooden structure, insulation and weakly ventilated air layer
- light wooden structure
- sandwich panel

Mean values: θ = 0.10 ϕ = 0.51 Default values: θ = 0.10 ϕ = 0.50

1.2. Roofs

	Description from indoor to outdoor	Insulation thickness cm	U W/m²K	C J/m²K
1	light : insulation between purlins + air layer strongly ventilated	18	0.2775	21552
2	heavy : hollow concrete floor + concrete + insulation	8	0.3711	455924
3	light : air layer weakly ventilated + insulation	18	0.1828	16173
4	light : air layer weakly ventilated + insulation	6	0.4897	12687
5	light : air layer weakly ventilated + insulation	12	0.2662	14430
6	light : insulation between purlins + air layer strongly ventilated	6	0.5567	14612
7	light : insulation between purlins + air layer strongly ventilated	12	0.3525	18082
8	heavy : hollow concrete floor + concrete + insulation	12	0.2606	457086
9	heavy : hollow concrete floor + concrete + insulation	6	0.4709	455343
10	light : air layer weakly ventilated + agglomerates panel + insulation	6	0.4484	41795
11	light : air layer weakly ventilated + agglomerates panel + insulation	8	0.357	42376
12	light : air layer weakly ventilated + agglomerates panel + insulation	12	0.2535	43538
13	light : air between battens + insulation + celit + air layer strongly ventilated	17.5	0.173	50055
14	light : air between battens + insulation + air layer strongly ventilated	10	0.3111	18924
15	light : air between battens + insulation + tightness	10	0.2836	52046
16	heavy : insulation + hollow concrete floor + concrete	6	0.4359	455463
17	heavy : insulation + hollow concrete floor + concrete	8	0.3489	456044

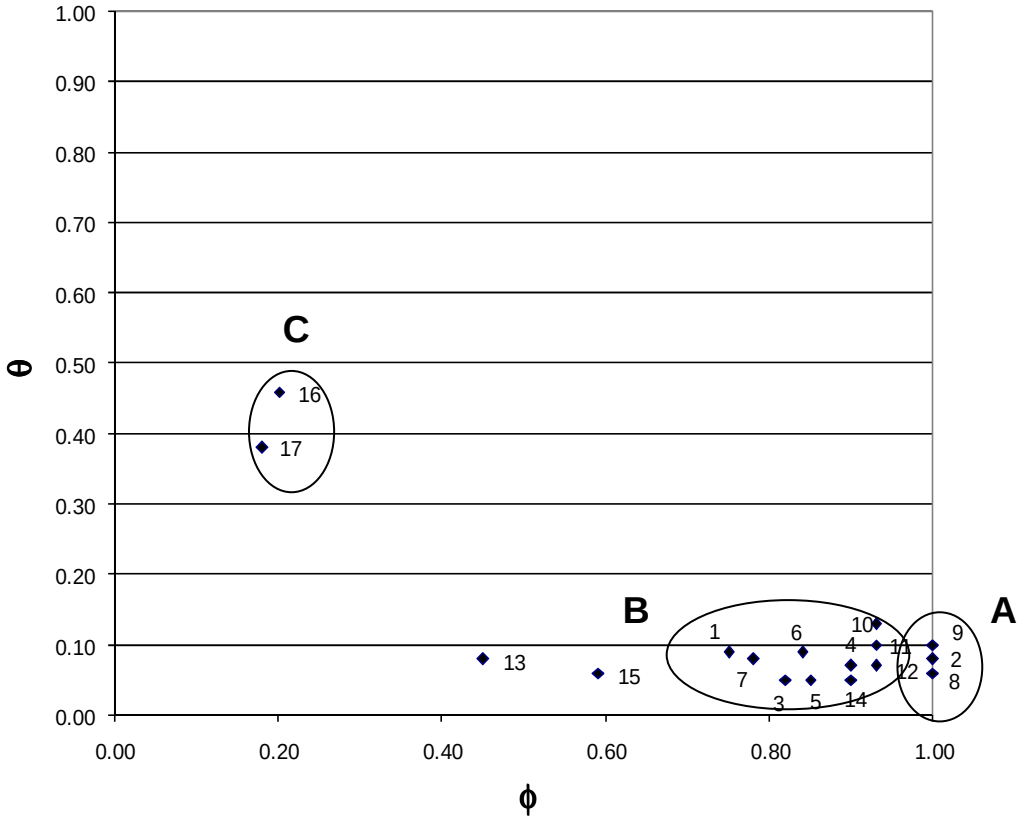

Fig A1.2: Roofs ϕ and θ parameters

Category A: includes precast concrete roofs with outdoor insulation

Mean values: θ = 0.08 ϕ = 1 Default values: θ = 0.10 ϕ = 1

Category B: includes wooden structure insulated roofs

Mean values: θ = 0.08 ϕ = 0.86 Default values: θ = 0.10 ϕ = 0.85

Category C: includes precast concrete roofs with indoor insulation

Mean values: θ = 0.42 ϕ = 0.19 Default values: θ = 0.40 ϕ = 0.20

1.3. Floors on outdoor environment

	Description from indoor to outdoor	Insulation thickness cm	U W/m²K	C J/m²K
1	heavy : tiled floor + mortar + insulation + concrete + hollow concrete floor	4	0.6393	364882
2	heavy : tiled floor + mortar + insulation + concrete + hollow concrete floor	6	0.4682	365463
3	heavy : tiled floor + mortar + insulation + concrete + hollow concrete floor	8	0.3694	366044
4	light : wood + insulation + panel OSB + insulation + air between battens + wood	15.7	0.1991	74031
5	heavy : tiled floor + mortar + concrete + hollow concrete floor + insulation	6	0.4682	365463
6	heavy : tiled floor + mortar + concrete + hollow concrete floor + insulation	8	0.3694	366044

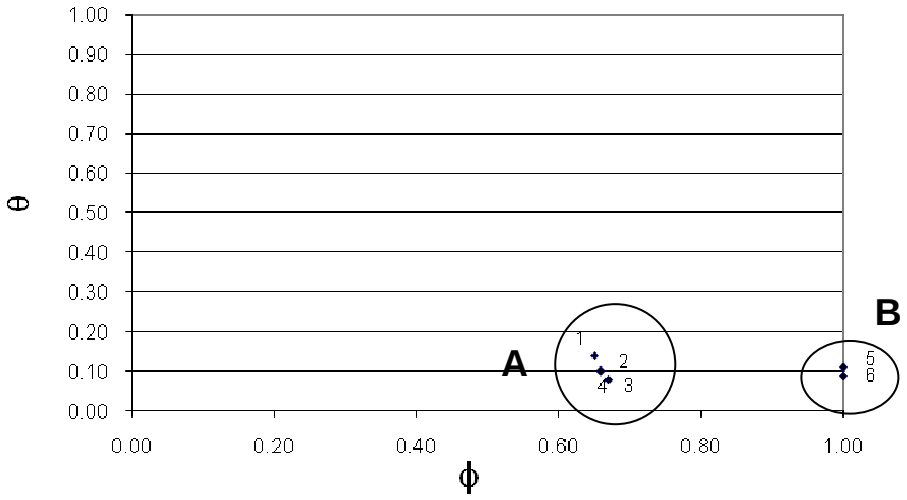

Fig A1.3: External floors ϕ and θ parameters

Category A: includes external floors with insulation above floor structure

Mean values: θ = 0.10 ϕ = 0.65 Default values: θ = 0.10 ϕ = 0.65

Category B: includes external floors with outdoor insulation

Mean values: θ = 0.10 ϕ = 1 Default values: θ = 0.10 ϕ = 1

1.4. Floors on crawled spaces

	Description from inside to outside of the zone	Insulation thickness cm	U W/m²K	C J/m²K
1	heavy : tiled floor + mortar + insulation + concrete + hollow concrete floor	4	0.5926	364882
2	heavy : tiled floor + mortar + concrete + hollow concrete floor + insulation	6	0.4427	365463
3	heavy : tiled floor + mortar + insulation + reinforced concrete slab	4	0.6111	391762
4	heavy : tiled floor + mortar + reinforced concrete slab + insulation	6	0.453	392343

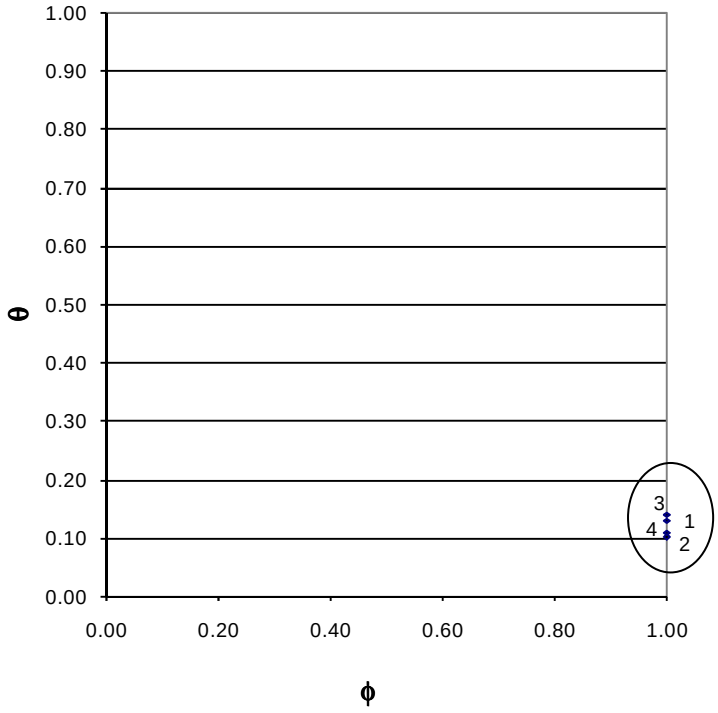

Fig A1.4: Floors on crawled space ϕ and θ parameters

One category:

Mean values: $\theta = 0.12$ $\phi = 1$ Default values: $\theta = 0.10$ $\phi = 1$

1.5. Floors on cellars

Those walls are considered as reinforced by a fictitious outdoor resistive layer modeling the cellar and ground insulation effect. Their U-value is weighted according to standards :

$$U_{weighted} = \frac{2}{3} U_{wall}$$

U_{wall} : U-value of the wall separating the zone under study from the cellar *W/m²-K*
$U_{weighted}$: U-value separating the zone under study from the outdoor *W/m²-K*
$U_{weighted}$ is multiplied by the wall area and by the indoor-outdoor temperature difference

	Description from inside to outside of the zone	Insulation thickness cm	U weighted W/m²K	C J/m²K
1	heavy : tiled floor + mortar + insulation + concrete + hollow concrete floor	4	0.3971	364882
2	heavy : tiled floor + mortar + concrete + hollow concrete floor + insulation	6	0.2966	365463
3	heavy : tiled floor + mortar + insulation + reinforced concrete slab	4	0.4095	391762
4	heavy : tiled floor + mortar + reinforced concrete slab + insulation	6	0.3035	392343

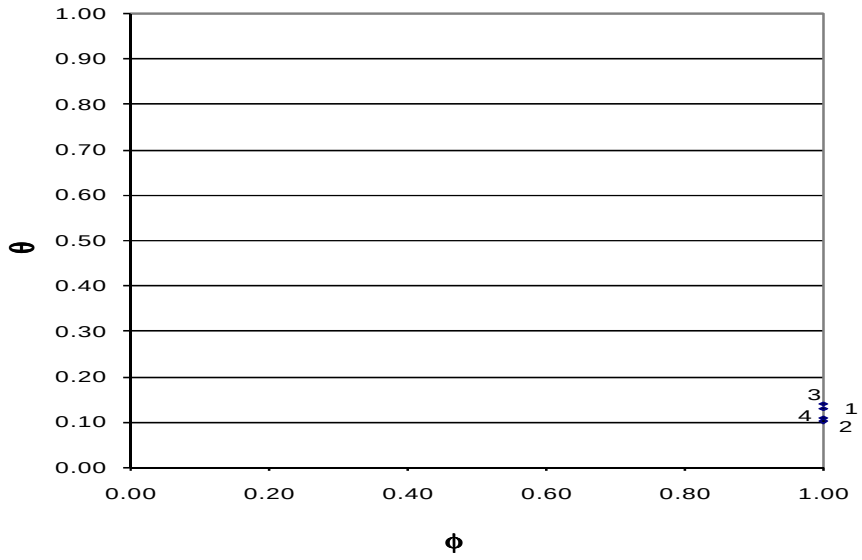

Fig A1.5: Floors on cellar ϕ and θ parameters

One category:

Mean values: θ = 0.08 ϕ = 1 Default values: θ = 0.10 ϕ = 1

1.6. Ground contact floors

Those walls are considered as reinforced by a fictitious outdoor resistive layer modeling the ground insulation effect. Their U-value is weighted according to standards:

$$U_{weighted} = \frac{1}{3} U_{wall}$$

U_{wall} : U-value of the wall separating the zone under study from the ground *W/m²-K*
$U_{weighted}$: U-value separating the zone under study from the outdoor *W/m²-K*
$U_{weighted}$ is multiplied by the wall area and by the indoor-outdoor temperature difference

	Description from inside to outside of the zone	Insulation thickness cm	U weighted W/m²K	C J/m²K
1	heavy : tiled floor + mortar + insulation + reinforced concrete slab	4	0.2246	391762
2	heavy : tiled floor + mortar + insulation + reinforced concrete slab	6	0.1617	392343
3	heavy : tiled floor + mortar + insulation + concrete (+ sand + ballast)	7	0.1411	432954
5	heavy : tiled floor + mortar + reinforced concrete slab + insulation	4	0.2228	432082

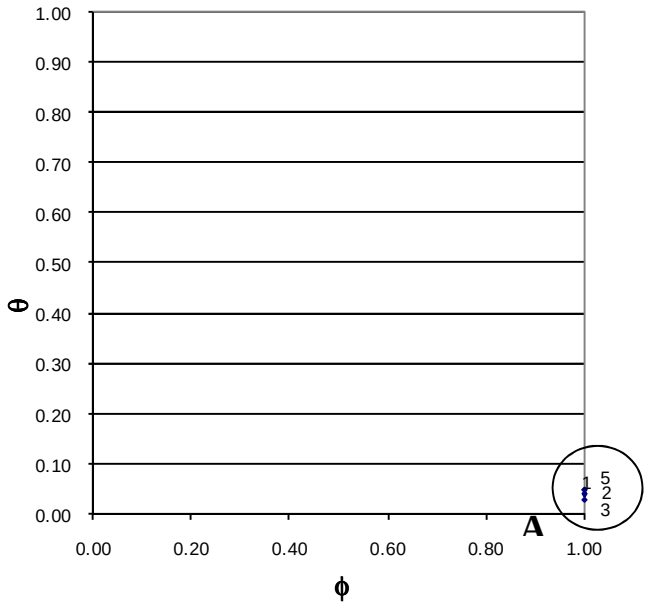

Fig A1.6: Ground contact foors ϕ and θ parameters

One category:

Mean values: θ = 0.04 ϕ = 1 Default values: θ = 0.05 ϕ = 1

1.7. Ground contact vertical walls

Those walls are considered as reinforced by a fictitious outdoor resistive layer modeling the ground insulation effect. Their U-value is weighted according to standards:

$$U_{weighted} = \frac{2}{3} U_{wall}$$

U_{wall} : U-value of the wall separating the zone under study from the ground *W/m²-K*
$U_{weighted}$: U-value separating the zone under study from the outdoor *W/m²-K*
$U_{weighted}$ is multiplied by the wall area and by the indoor-outdoor temperature difference

	Description from inside to outside of the zone	Insulation thickness cm	U weighted W/m²K	C J/m²K
1	hollow concrete block + mortar + insulation	5	0.3765	320653
2	hollow concrete block + mortar + insulation	3	0.5546	320072
3	hollow concrete block + mortar + insulation	7	0.285	321234

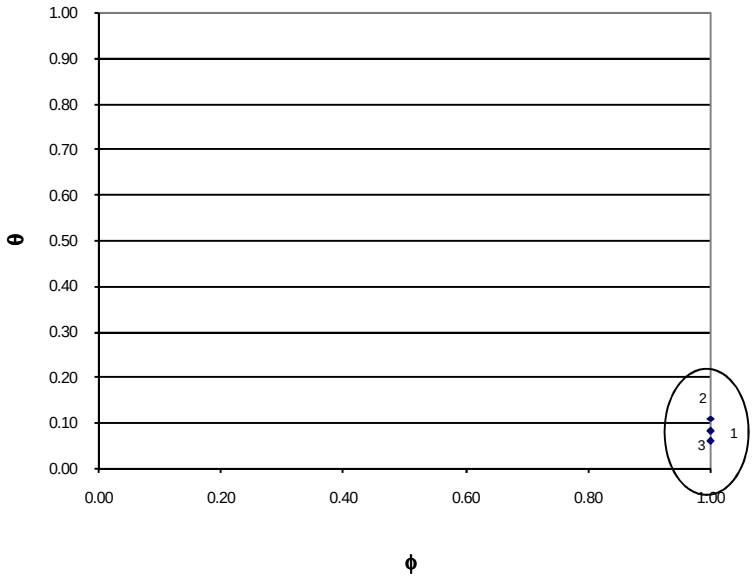

Fig A1.7: Ground contact vertical walls ϕ and θ parameters

One category:

Mean values: θ = 0.08 ϕ = 1 Default values: θ = 0.10 ϕ = 1

1.8. Cold partition walls with heat losses

Those walls are surrounding the zone under study. They separate it from another unheated zone, which is either included in the building under study or in an attached building. Thoses walls are responsible for heat losses but their U-value is weighted according to standards, to take into account the average temperature difference between both zones, which is less severe than indoor-outdoor temperature difference:

$$U_{weighted} = \frac{2}{3} U_{wall}$$

U_{wall} : U-value of the wall separating the zone under study from the unheated zone *W/m²-K*

$U_{weighted}$: U-value separating the zone under study from the outdoor *W/m²-K*

$U_{weighted}$ is multiplied by the wall area and by the indoor-outdoor temperature difference

Those walls are modelled as reinforced by a fictitious outdoor resistive layer.

	Description from inside to outside of the zone	Insulation thickness cm	U weighted W/m²K	C J/m²K
1	hollow concrete block + insulation + concrete block	2	0.9261	304661
2	clay block + insulation + clay block	2	0.6852	304661
3	cellular concrete block + insulation + cellular concrete block	2	0.2947	150101
4	hollow concrete block + insulation	6	0.4777	153783
5	clay block + insulation	6	0.438	153783
6	cellular concrete block + insulation	6	0.3077	76503

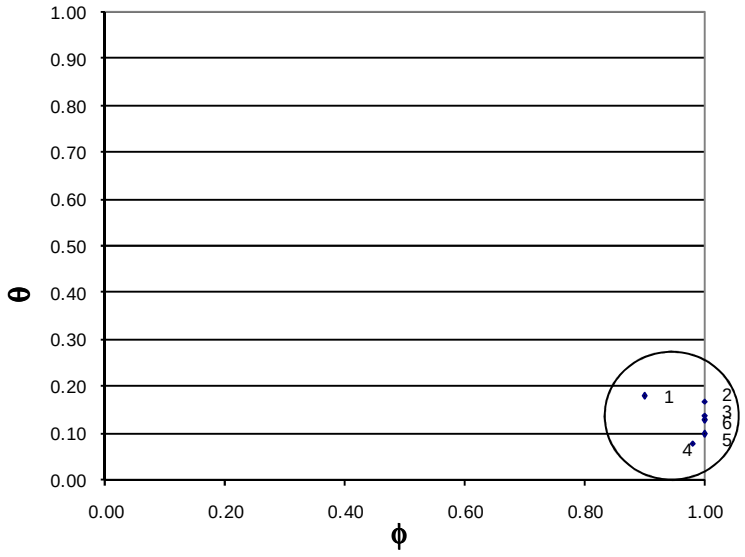

Fig A1.8: Cold partition walls ϕ and θ parameters

One category:

Mean values: θ = 0.13 ϕ = 0.98 Default values: θ = 0.15 ϕ = 1

1.9. Warm partition walls with heat losses

Those walls are surrounding the zone under study. They separate it from another heated zone, which is either included in the building under study or in an attached building. Anyway, thoses walls can be considered as responsible for heat losses with a U-value weighted according to standards, to take into account the average temperature difference between both zones, which is much less severe than indoor-outdoor temperature difference:

$$U_{weighted} = \frac{1}{3} U_{wall}$$

U_{wall} : U-value of the wall separating the zone under study from the heated zone *W/m²-K*
$U_{weighted}$: U-value separating the zone under study from the outdoor *W/m²-K*
$U_{weighted}$ is multiplied by the wall area and by the indoor-outdoor temperature difference

Those walls are modelled as reinforced by a fictitious outdoor resistive layer.

	Description from inside to outside of the zone	Insulation thickness cm	U weighted W/m²K	C J/m²K
1	hollow concrete block + insulation + hollow concrete block	2	0.6205	304661
2	clay block + insulation + clay block	2	0.4591	304661
3	cellular concrete block + insulation + cellular concrete block	2	0.1975	150101

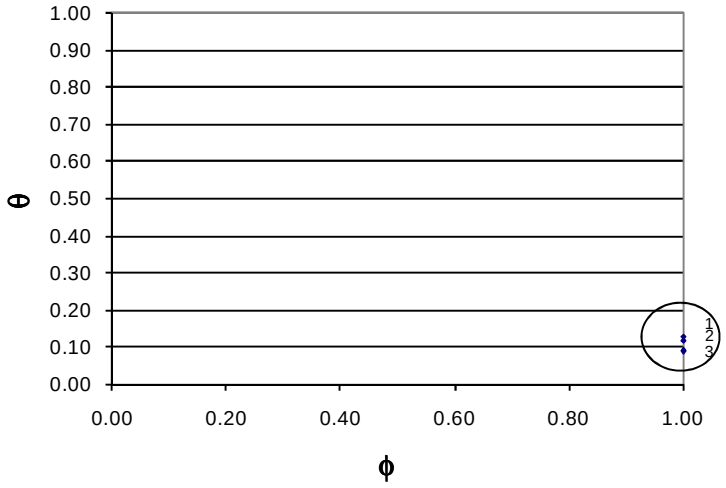

Fig A1.9: Warm partition walls ϕ and θ parameters

One category:

Mean values: θ = 0.11 ϕ = 1 Default values: θ = 0.10 ϕ = 1

1.10. Symmetrical internal walls without heat losses

Those walls are submitted to *adiabatic* boundary conditions and considered as crossed by a null heat flow plane, whose position is defined by parameter ζ. Parameter ζ is the portion of wall resistance comprised between one wall side and the null heat flow plane. For symmetrical or homogeneous walls $\zeta = 0.5$.
Parameters *U* and *C* are computed for the whole wall while θ and ϕ are related to half a wall, θ being defined from the wall external face to its inside null heat flow plane.

	Description from one side to the other side	Insulation thickness cm	U W/m²K	C J/m²K
1	hollow concrete block	-	2.51	162960
2	wood	-	1.03	97008
3	gypsum board + insulation + gypsum board	7	0.43	23874
4	gypsum board + air + gypsum board	-	1.92	21924

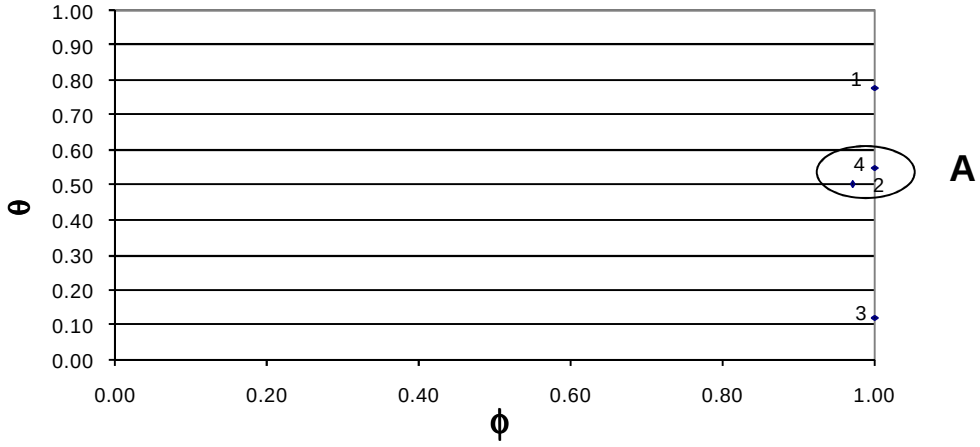

Fig A1.10: Half internal symetrical walls ϕ and θ parameters

Category A: includes light uninsulated indoor dividing walls

Mean values: $\theta = 0.53$ $\phi = 0.99$ Default values: $\theta = 0.50$ $\phi = 1$

Type (1): uninsulated internal hollow concrete wall, 14 cm thickness:

Mean values: $\theta = 0.78$ $\phi = 1$ Default values: $\theta = 0.80$ $\phi = 1$

Type (3): light insulated internal dividing wall:

Mean values: $\theta = 0.12$ $\phi = 1$ Default values: $\theta = 0.10$ $\phi = 1$

1.11. Symmetrical partition walls without heat losses

Those walls are separating the zone under study from an attached building. Contrary to §9 walls, they are considered here as submitted to *adiabatic* boundary conditions i.e. crossed by a null heat flow plane, whose position is defined by the parameter ζ. Parameter ζ is the portion of wall resistance comprised between one wall side and the null heat flow plane. For symmetrical or homogeneous walls, ζ= 0.5. Parameters *U* and *C* are computed for the whole wall while θ and ϕ are related to half a wall, θ being defined from the wall external face to its inside null heat flow plane.

	Description from inside to outside of the zone	Insulation thickness cm	U W/m²K	C J/m²K
1	hollow concrete block + insulation + hollow concrete block	2	0.93	304662
2	clay block + insulation + clay block	2	0.69	304660
3	cellular concrete block + insulation + cellular concrete block	2	0.29	150102

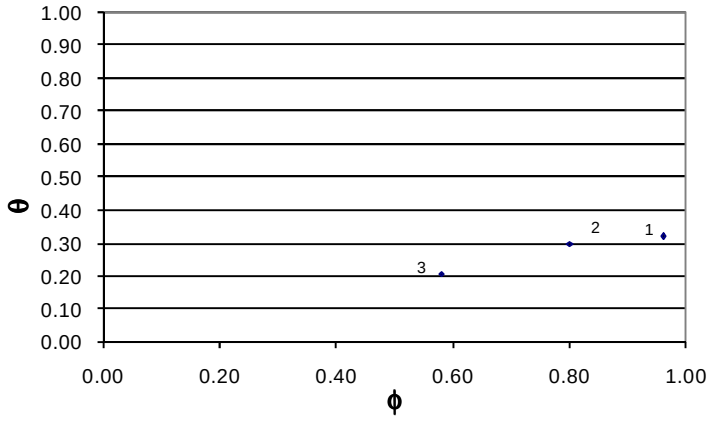

Fig A1.11: Internal partition walls ϕ and θ parameters

Mean value: $\theta = 0.28$ Default value: $\theta = 0.30$

ϕ is a function of the wall U-value: $U > 1.9 W/m^2K : \phi = 1$

$U \leq 1.9 W/m^2K : \phi = 0.302U + 0.4$

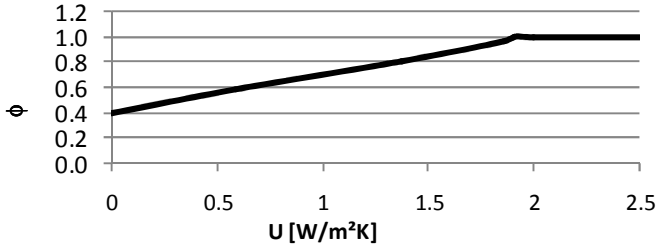

Fig A1.12: Parameter ϕ as function of U for internal partition walls

1.12. Internal floors without heat losses

Those walls are considered as submitted to *adiabatic* boundary conditions i.e. crossed by a null heat flow plane, whose position is defined by the parameter ζ. Parameter ζ is computed as the portion of the whole wall resistance comprised between one wall side and the null heat flow plane. Parameters *U,C* and ζ are computed for the whole wall, while parameters θ and ϕ are related to each wall part limited by the null heat flow plane, θ being defined from the wall external face to its inside null heat flow plane .

	Description from upside to downside	Insulation thickness cm	U W/m²K	C J/m²K	ζ
1 2	heavy : carpet + mortar + concrete + hollow concrete floor	-	1.945	359520	0.51 0.49
3 4	light : carpet + mortar + agglomerates panel	-	1.989	110432	0.43 0.57
5 6	heavy : finish flooring + mortar + concrete + hollow concrete floor	-	2.037	348460	0.5 0.5
7 8	light : finish flooring + mortar + agglomerates panel	-	2.085	99372	0.41 0.59
9 10	heavy : tiled floor + mortar + concrete + hollow concrete floor	-	2.129	358680	0.48 0.52
11 12	light : tiled floor + mortar + agglomerates panel	-	2.181	109592	0.39 0.61
13 14	heavy : tiled floor + mortar + concrete + hollow concrete floor	-	2.109	373800	0.48 0.52
15 16	heavy : finish flooring + mortar + concrete + hollow concrete floor	-	2.019	363580	0.5 0.5
17 18	heavy : carpet + mortar + concrete + hollow concrete floor	-	1.929	374640	0.51 0.49
19 20	heavy : tiled floor + screed + insulation + concrete + hollow concrete floor	5	0.529	401292	0.86 0.14
21 22	heavy : finish flooring + screed + insulation + concrete + hollow concrete floor	5	0.524	391072	0.87 0.13
23 24	heavy : carpet + screed + insulation + concrete + hollow concrete floor	5	0.517	402132	0.87 0.13
25 26	heavy : tiled floor + screed + insulation + concrete + hollow concrete floor	7	0.406	401873	0.89 0.11
27 28	heavy : finish flooring + screed + insulation + concrete + hollow concrete floor	7	0.403	391653	0.89 0.11
29 30	heavy : carpet + screed + insulation + concrete + hollow concrete floor	7	0.399	402713	0.89 0.11
31 32	heavy : tiled floor + screed + insulation + hollow concrete floor	3	0.773	330991	0.81 0.19
33 34	heavy : finish flooring + screed + insulation + hollow concrete floor	3	0.76	320772	0.81 0.19

	Description	Insulation thickness	U	C	ζ
	from upside to downside	cm	W/m²K	J/m²K	
35 36	heavy : carpet + screed + insulation + hollow concrete floor	3	0.747	331832	0.81 0.19
37 38	heavy : tiled floor + screed + insulation + hollow concrete floor	6	0.465	331863	0.88 0.12
39 40	heavy : finish flooring + screed + insulation + hollow concrete floor	6	0.46	321643	0.88 0.12
41 42	heavy : carpet + screed + insulation + hollow concrete floor	6	0.455	332703	0.88 0.12
43 44	heavy : tiled floor + mortar + concrete + interjoist moulded polystyrene	-	1.344	323400	0.42 0.58
45 46	heavy : finish flooring + mortar + concrete + interjoist moulded polystyrene	-	1.307	313180	0.43 0.57
47 48	heavy : carpet + mortar + concrete + interjoist moulded polystyrene	-	1.268	324240	0.43 0.57
49 50	light : finish flooring + mortar + insulation between joists + gypsum board	4.1	0.699	84041	0.21 0.79
51 52	light : finish flooring + mortar + insulation between joists + gypsum board	4.4	0.49	84218	0.25 0.75
53 54	light : finish flooring + mortar + insulation between joists + gypsum board	4.7	0.393	84414	0.28 0.72
55 56	heavy : tiled floor + screed + hollow concrete floor + insulation + plaque gypsum board	5	0.527	331573	0.12 0.88
57 58	heavy : finish flooring + screed + hollow concrete floor + insulation + plaque gypsum board	5	0.522	321353	0.13 0.87
59 60	heavy : carpet + screed + hollow concrete floor + insulation + plaque gypsum board	5	0.515	332412	0.14 0.86

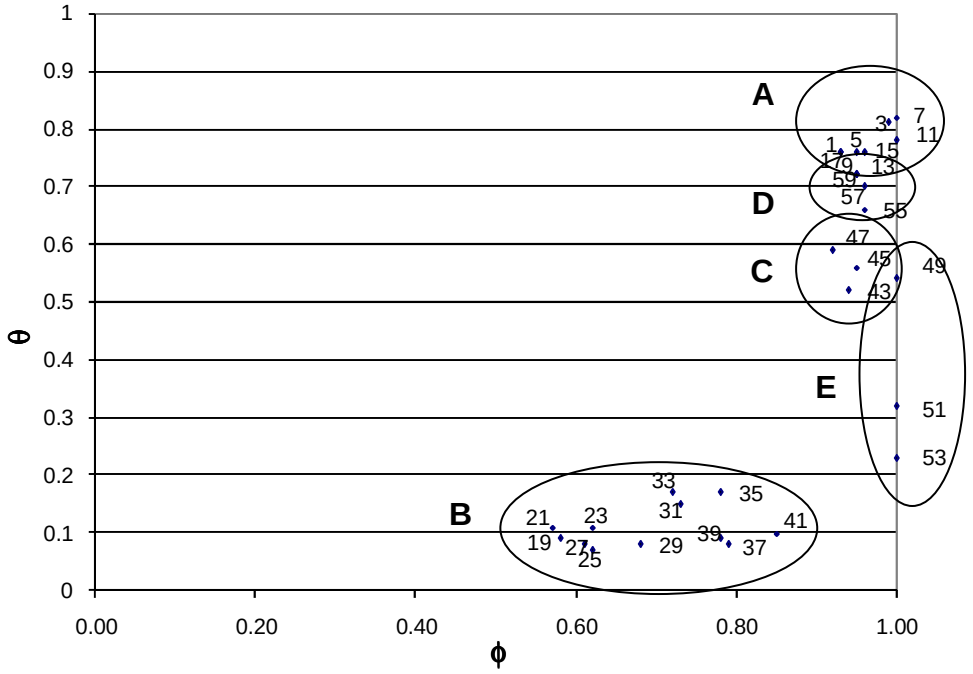

Fig A1.13: Upside internal floors ϕ and θ parameters

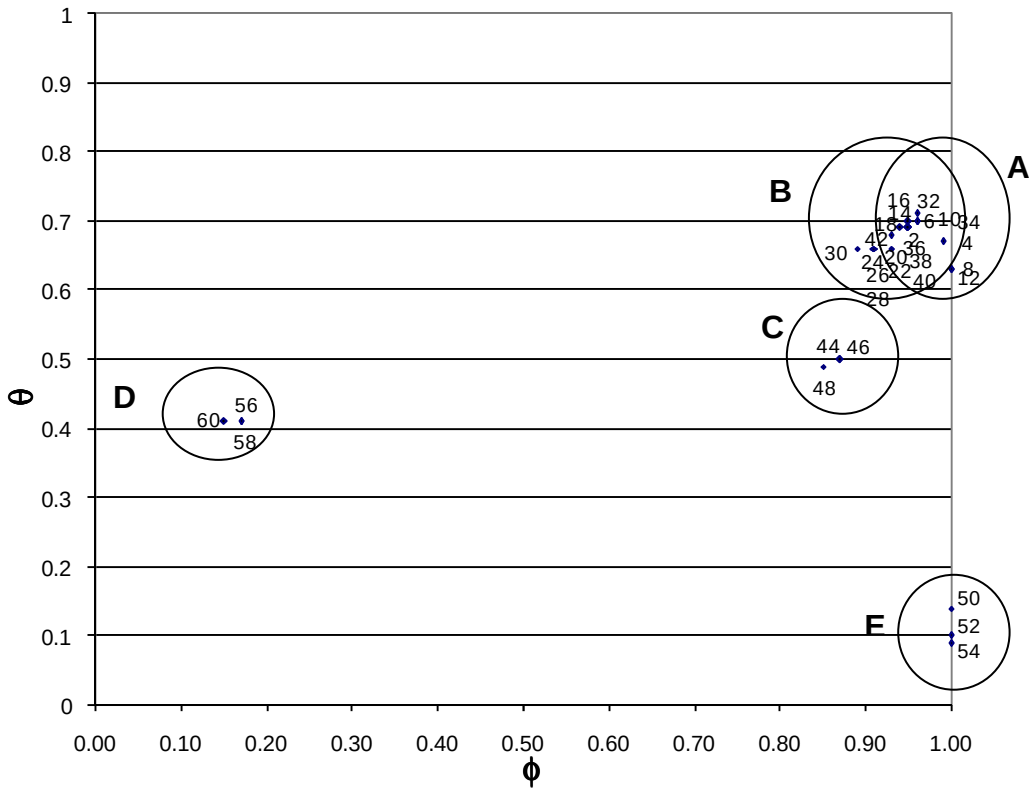

Fig A1.14: Downside internal floors ϕ and θ parameters

Category A: includes uninsulated internal floors

Upside mean values:	ζ =0.47	θ = 0.77	ϕ = 0.96
Downside mean values:	ζ =0.53	θ = 0.68	ϕ = 0.97
Upside default values:	ζ =0.50	θ = 0.75	ϕ = 0.95
Downside default values:	ζ =0.50	θ = 0.70	ϕ = 0.95

Category B: includes heavy internal floors with insulation layer under screed:

Upside mean values:	ζ =0.86	θ = 0.11	ϕ = 0.69
Downside mean values:	ζ =0.14	θ = 0.68	ϕ = 0.93
Upside default values:	ζ =0.85	θ = 0.10	ϕ = 0.70
Downside default values:	ζ =0.15	θ = 0.70	ϕ = 0.95

Category C: includes heavy internal floors with moulded polystyrene interjoists:

Upside mean values:	ζ =0.43	θ = 0.56	ϕ = 0.94
Downside mean values:	ζ =0.57	θ = 0.50	ϕ = 0.86
Upside default values:	ζ =0.45	θ = 0.55	ϕ = 0.95
Downside default values:	ζ =0.55	θ = 0.50	ϕ = 0.85

Category D: includes heavy internal floors with downside insulation layer:

Upside mean values:	ζ =0.13	θ = 0.69	ϕ = 0.96
Downside mean values:	ζ =0.87	θ = 0.41	ϕ = 0.16
Upside default values:	ζ =0.15	θ = 0.70	ϕ = 0.95
Downside default values:	ζ =0.85	θ = 0.40	ϕ = 0.15

Category E: includes light internal floors with insulation between wooden joists:

Upside mean values:	ζ =0.25	$\theta = 0.1612.U + 0.0036$	ϕ = 1
Downside mean values:	ζ =0.75	θ = 0.11	ϕ = 1
Upside default values:	ζ =0.25	$\theta = 0.1612.U + 0.0036$	ϕ = 1
Downside default values:	ζ =0.75	θ = 0.10	ϕ = 1