Comparison of 3-D and Equivalent Wall Models

A comparison between the three-dimensional and equivalent wall model response factors is shown in Figure 5.1, for a 2x4 wood stud wall. Equivalent wall z-transfer function coefficients for the same wall are listed in Table 5.1.

Although, in general, response factors for the equivalent wall look similar to those for the 3-D model, there are specific differences between them due to the fact, that the effect of parallel flow paths, of different conductance, may not be completely reproduced by the simple, one-dimensional model. A uniform plane wall produces high internal response during the time of duration of the triangular temperature excitation, which is represented by comparatively high values of X_0 and X_1. At the same time, heat transfer through the plane wall is delayed, as compared with the wall with thermal bridges, which is represented by a comparatively low value of Y_0. Consequently, for the equivalent wall, values of the z-transfer function coefficients c_n with lowest indices are high, whereas values of the first coefficients b_n are low, as compared to the 3-D model.

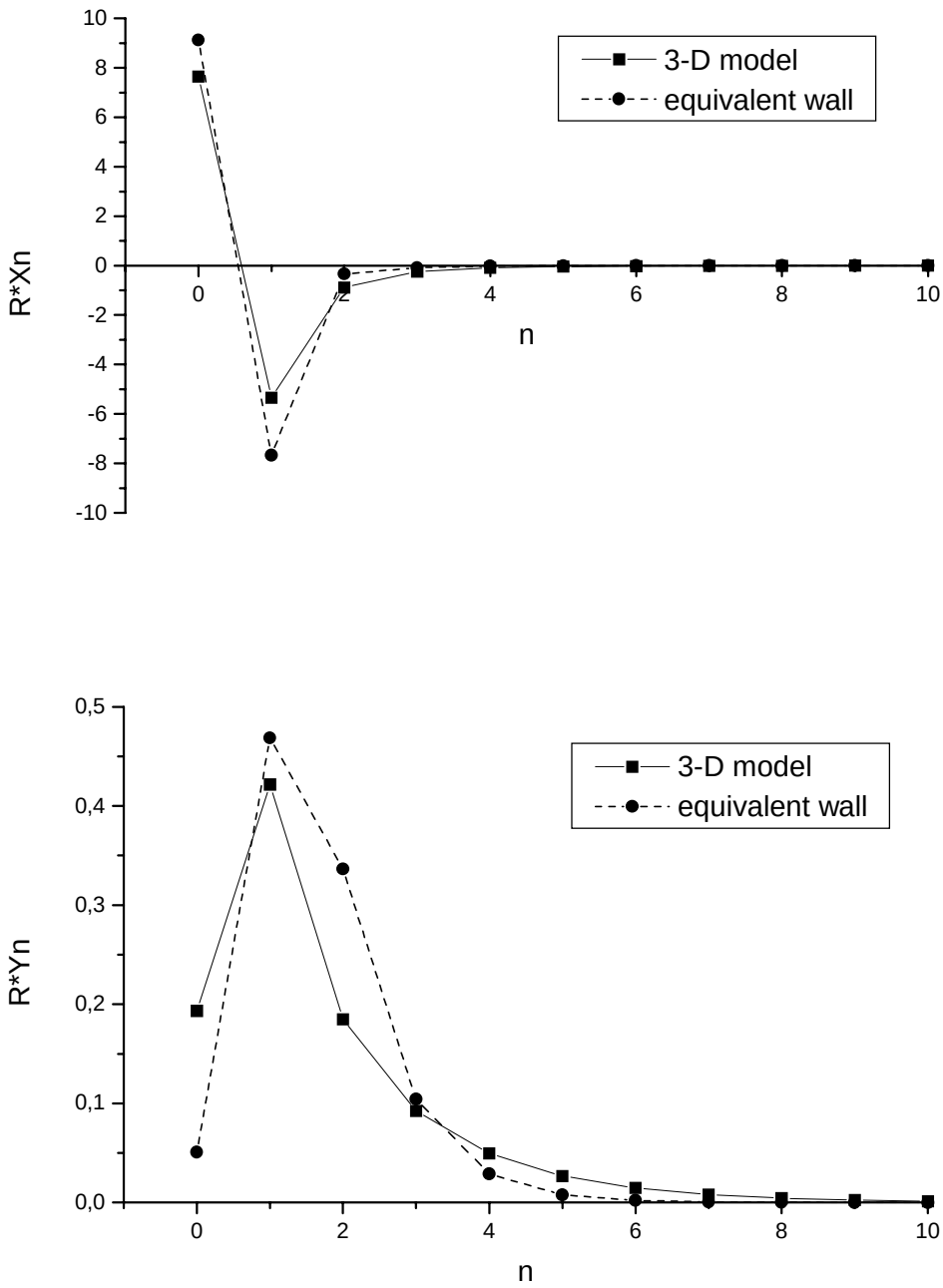

Figure 5.1 Comparison of the dimensionless response factors, $R{\cdot}X_n$ and $R{\cdot}Y_n$, for the 3-D model and equivalent wall; 2x4 wood stud wall

Table 5.1 Dimensionless Z-Transfer Function Coefficients for the Equivalent Wall

n	b_n	c_n	d_n
0	0.05080	9.12250	1.00000
1	0.45323	-10.47223	-0.30686
2	0.19302	2.10285	0.00942
3	0.00547	-0.05063	-0.00002
4	0.00001	0.00005	

$\Sigma\, c_n = 0.70254$

Frequency response for the 3-D model and equivalent wall was analyzed for temperature oscillations with the period of 48, 24, 12 and 6 hours. Values of the dimensionless amplitude and phase angle, for the transmittance and internal admittance, are collected in Part II: Tables n.9a, n.9b. Significant discrepancies appear only for the highest frequencies.

Amplitudes and time shifts for basic frequency 1/24 h^{-1} are listed in Table 5.2 below. (Dimensionless amplitude for the transmittance is the same as the decrement factor; absolute value of the negative time shift is the time lag). The equivalent wall model shows, in general, slightly higher amplitude and some delay of the heat flux variations transmitted through a wall, as compared with the 3-D model. At the same time, admittance amplitude is almost the same and a small time lead is observed for most cases.

Table 5.2 Frequency Response for the 3-D and Equivalent Wall Model; Dimensionless Amplitude and Time Shift for Frequency 1/24 h-1

No	Wall assembly	Transmittance				Internal admittance			
		3-D model		Equivalent wall		3-D model		Equivalent wall	
		Ampli-tude	Time shift [h]	Ampli-tude	Time shift [h]	Ampli-tude	Time shift [h]	Ampli-tude	Time shift [h]
1	2x4 wood stud; clear wall	0.92	-1.55	0.98	-1.62	2.63	3.68	2.54	4.18
2	2x6 wood stud; clear wall	0.83	-1.94	0.95	-2.30	3.68	3.98	3.69	4.53
3	2x4 wood stud; corner	0.88	-1.74	0.97	-1.91	2.52	3.36	2.46	4.07
4	2x4 wood; window header	0.88	-2.46	0.93	-2.63	2.15	3.03	2.12	3.37
5	2x4 wood stud; wall/floor	0.77	-2.92	0.89	-3.34	2.60	2.85	2.68	3.47
6	2x4 wood stud; wall/roof	0.77	-2.75	0.90	-3.25	3.63	3.17	3.84	4.01
7	Insul. concrete forms (ICF)	0.14	-7.14	0.10	-14.77	3.72	3.32	4.04	2.50

8	Sandwich wall, metal ties	0.93	-2.38	0.95	-2.39	12.87	4.75	12.93	5.12
9	Sandwich wall, plastic ties	0.93	-2.47	0.94	-2.48	18.42	4.85	18.40	5.06
10	2x4 steel stud; clear wall	0.98	-0.93	0.99	-0.93	1.82	3.13	1.72	3.50
11	2x4 steel stud; corner	0.95	-1.22	0.98	-1.25	1.42	2.21	1.35	2.48
12	2x4 steel; window header	0.98	-0.78	0.99	-0.78	1.10	1.09	1.07	1.15
13	2x4 steel stud; wall/floor	0.53	-2.52	0.61	-5.04	1.70	1.33	1.98	1.71
14	2x4 steel stud; wall/roof	0.98	-0.90	0.99	-0.91	1.21	1.66	1.16	1.78
15	2x4 steel stud+EPS+brick	0.88	-3.07	0.88	-3.04	2.14	3.50	2.05	3.86
16	2x6 steel stud clear wall	0.98	-1.10	0.99	-1.11	2.28	3.57	2.17	4.00
17	2x6 steel stud+EPS+stucco	0.93	-1.78	0.97	-1.82	2.40	3.74	2.34	3.99
18	2x6 steel stud+EPS+brick	0.89	-3.10	0.92	-3.14	2.46	3.76	2.40	3.98
19	Concrete blocks – empty	0.81	-2.10	0.94	-2.43	2.21	3.14	2.23	3.50
20	Concrete blocks – insulated	0.79	-3.35	0.88	-3.56	3.29	3.80	3.33	3.85

Test Computations Of The Heat Flux

The differences discussed above in dynamic thermal properties of composite wall assemblies (response factors, z-transfer function coefficients, and frequency responses) computed for three-dimensional and equivalent wall model do not significantly affect values of the heat flux calculated for continuously varying temperatures.

Test simulations were performed, using as exterior temperature excitation the sol-air temperature for 27 February 1981 in Warsaw. The outdoor temperature, was between 18°F and 32°F [-7.8°C - 0°C], maximum solar radiation was 154 Btu/h·ft^2 [1.75 MJ/h·m^2]; which gives sol-air temperature oscillations from 18°F to 63°F [-7.8°C - 17.2°C] (see Figure 5.2). Temperature of the inner surface of a wall assembly was held constant at 68°F [20°C].

Because temperature at the beginning and at the end of the chosen day was almost the same, consecutive identical days could be joined together to give a smooth curve. A five day period was used for simulations, to eliminate the effect of initial conditions.

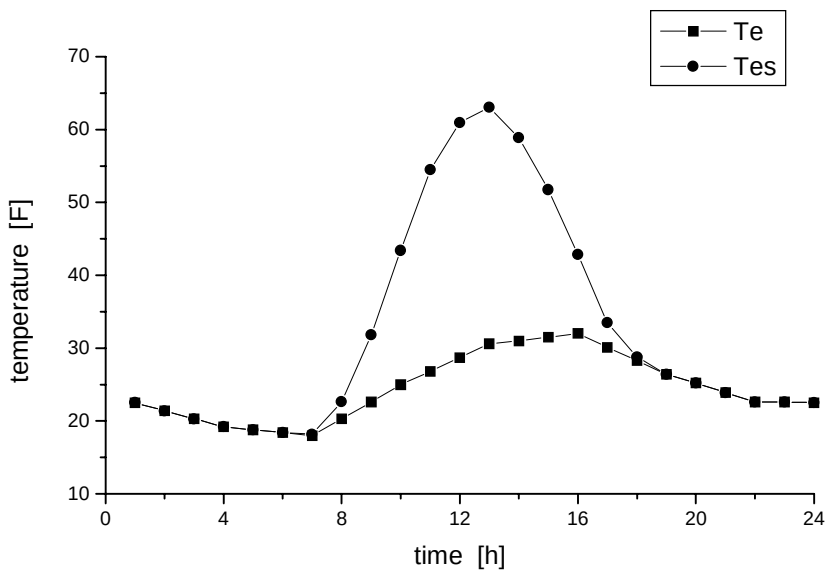

Figure 5.2 Daily course of the sol-air temperature T_{es}, used for test calculations of the heat flux; T_e the outdoor temperature

Heat flux at the interior surface of a wall assembly was simulated in three ways: (1) based on response factors for the 3-D model; (2) using z-transfer function coefficients for the 3-D model, derived from the response factors; and (3) using z-transfer function coefficients for the equivalent wall. Steady state (or massless wall) values were calculated to illustrate the effect of thermal mass.

Calculation results for the 2x4 wood-framed system clear wall are presented in Figure 5.3. Differences between the heat flux values calculated using the 3-D z-transfer function coefficients, the 3-D response factors and the equivalent wall model z-transfer function coefficients are very small. The equivalent wall shows a slightly “more dynamic” behavior.

The same results are observed for the corner shown in Figure 5.4. One should notice, however, that lightweight structures, such as the wood-framed walls, behave almost as “massless walls”, so minor differences between different models are not significant.

Figure 5.5 presents results of simulations for the 2x6 steel stud wall with 1-in EPS layer and brick, and Figure 5.4 for massive concrete blocks, filled with insulation. Compatibility of the 3-D model with the equivalent wall model is also very good.

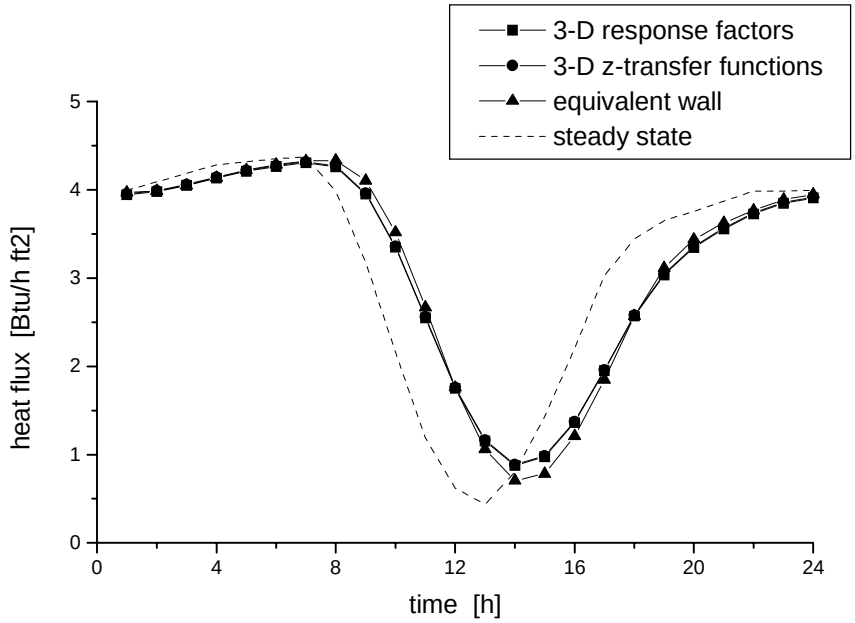

Figure 5.3 Comparison of the heat flux simulation results using three methods for the 2x4 wood-framed system clear wall

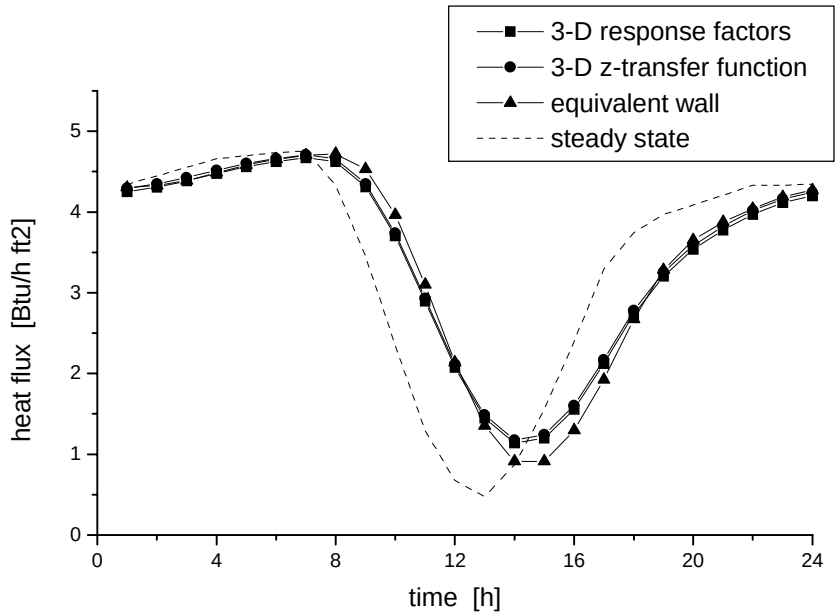

Figure 5.4 Comparison of the heat flux simulation results using three methods for the corner; 2x4 wood-framed wall system

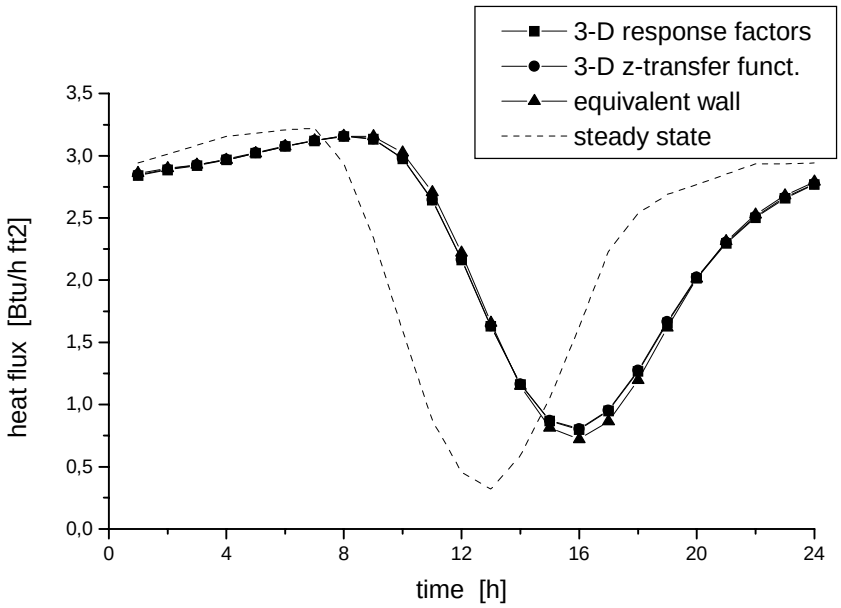

Figure 5.5 Comparison of the heat flux simulation results using three methods for the 2x6 steel-stud wall with 1-in EPS and brick

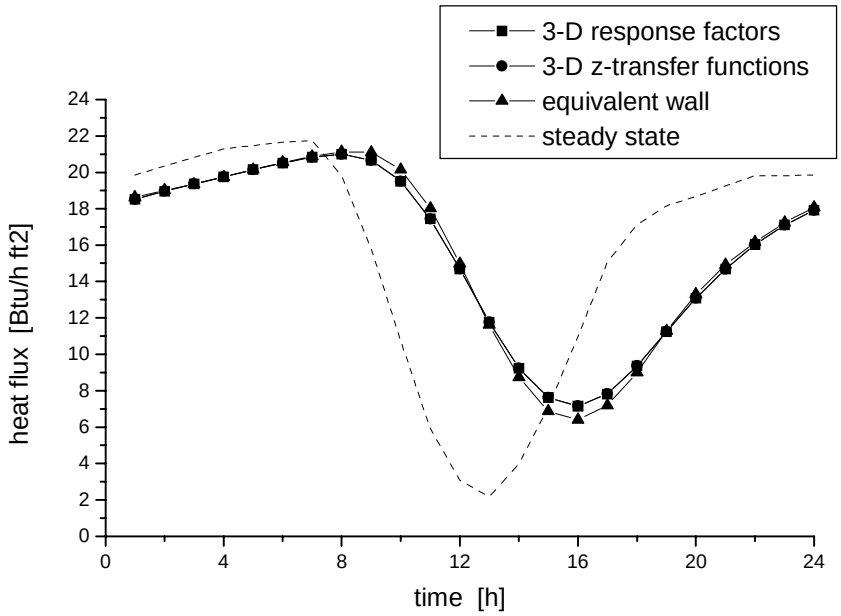

Figure 5.6 Comparison of the heat flux simulation results using three methods for the insulated concrete blocks