Background to the Equivalent Wall Model

A simplified model involves creating a fictitious multi-layer wall lacking thermal bridges and with properties selected so that its dynamic response to the transient conditions is the same as the complex wall assembly. For example, a homogenous wall material could be defined with a specific conductivity, density, specific heat, etc., to give the same dynamic (and steady-state) response as a steel-framed wall with gypsum wallboard sheathing.

A general approach is the equivalent wall method [Kosny and Kossecka 1997, Kosny et al. 1998]. This procedure is based upon formal relationships describing the effect of structure on the dynamic thermal behavior of walls that have been developed from the integral formulae for heat flow across wall surfaces in a finite time interval [Kossecka 1992]. The distribution of thermal resistance and thermal mass through the thickness of the wall is characterized by thermal structure factors. Thermal structure factors play a key role in development of the equivalent wall model. These dimensionless quantities appear in expressions for the asymptotic heat flow across the surfaces of a wall, for boundary conditions independent of time. Correlations between thermal structure factors, response factors and z-transfer function coefficients have been derived and analyzed [Kossecka 1996, Kossecka 1998, Kossecka and Kosny 1997].

The equivalent wall method has been used by ORNL for dynamic evaluations of several complex wall technologies. During these projects a detailed three-dimensional computer model was developed for each wall. Dynamic measurements of these wall systems were carried out by hot-box testing. A full-scale representative (8 x 8 ft) cross-section of the clear wall area of the wall system was used to determine its dynamic thermal performance. A clear wall represents the exterior wall area containing only insulation and necessary framing materials for a clear section with no fenestrations, corners, or connections between other envelope elements such as roofs, foundations, and other walls. A dynamic test typically consists of three basic stages:

- steady-state stage (constant temperatures on both sides of the wall);
- thermal ramp (rapid change of the temperature on the one side of the wall); and
- stabilizing stage (the wall is maintained at constant boundary temperatures until steady-state heat transfer occurs).

Computer models were then used to generate equivalent walls. An equivalent wall has a simple one-dimensional multi-layer structure and the same thermal properties as the actual wall (total resistance and thermal capacitance). Its dynamic thermal behavior is

identical to the actual wall. The thermal structure factors, together with total resistance and capacity, provide the basic thermal characteristics of the structure. Even for a complex thermal bridge configuration, response factors, steady-state R-values and thermal structure factors have the same values for both walls (the “complex” wall and the equivalent wall) [Kossecka and Kosny 1996, Kossecka and Kosny 1997, Kosny et al. 1998].

A validation of the equivalent wall theory was performed using dynamic test and finite-difference computer modeling results [Kosny et al. 1998]. A dynamic thermal performance of the EPS Form Wall System was analyzed based on dynamic hot-box testing. The Oak Ridge National Laboratory’s Buildings Technology Center guarded hot-box facility served for this test that took about 240 hours to complete. The same wall configuration was modeled for dynamically changing boundary conditions. The finite-difference computer code HEATING 7.2 was used for dynamic modeling (HEATING 7.2 was previously calibrated during steady-state tests). Thermal mass validation of the model was made using the dynamic boundary conditions monitored during the hot-box test. Computer-generated results were compared with the results of the dynamic test. Also, a series of response factors, heat capacity, and R-value were computed using finite-difference computer modeling. They were compared with response factors generated for the equivalent wall. Very good agreement was found between test and computer modeling results. The response factors for the equivalent wall were almost identical to those for the equivalent wall.

The equivalent wall technique is a relatively simple way to use whole-building energy simulations (e.g., DOE-2.1 or BLAST) for buildings containing complex assemblies. The traditional method used by DOE-2.1 modelers is to generate a series of response factors or transfer functions for the complex wall and modify DOE-2.1 or BLAST source codes to permit this type of wall data input. The equivalent wall method represents all the thermal information about the wall using only five numbers (R, C, and three thermal structure factors). This is much simpler than the alternate use, ascribed to a three-dimensional model, where a long series of response factors or Z-transfer function coefficients (for massive walls, 60 to as many as 150 numbers, multiplied by 3) must be accompanied by the troublesome modification of the program source code to enable this type of wall data input.

In this project detailed multi-dimensional (two- and three-dimensional in space, and time-dependent) heat transfer modeling of 20 common building envelope details is performed. These results are analyzed and equivalent wall models are developed for each assembly. The equivalent wall models are validated by comparing them to the detailed models.