# Interactive Internet-Based Building Envelope Materials Database for Whole-Building Energy Simulation Programs

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## ABSTRACT

*The concept of an interactive envelope materials database for whole-building energy simulation programs is presented in this paper. This database was developed to reinforce an accurate, fast, and simple energy analysis of building energy consumption in shell-dominated buildings. The main purpose of this database is to serve architects, system designers, and energy modelers by enabling detailed envelope analysis during whole-building energy simulations. However, it can also be utilized for performance comparisons between different envelope technologies. The user simply selects the material configuration and sets dimensions. Later, the Internet program calculates whole wall/roof or floor R-values, generates three-dimensional dynamic thermal characteristics, and calculates detailed air leakage for the selected building envelope system. This information is then converted into the format required by programs such as BLAST, DOE-2, or ENERGY PLUS.*

## INTRODUCTION

In existing residential and small commercial buildings, over 50% of the energy loss is associated with heat transfer and air leakage through building envelope components. Today, thermal bridging is the best-known factor affecting thermal performance of building envelopes. However, there are many other physical characteristics, such as airtightness, dynamic response, surface physical properties, etc., that may also control the overall energy performance of the building shell. Thus, it is essential to accurately represent the full complexity of building envelopes in energy analysis.

With the rapid development of energy-efficient building materials and systems, numerous novel wall technologies have been introduced to the marketplace. Some of them represent complex three-dimensional internal structure. Also, building designs are getting so advanced that in the near future a single change in a building envelope configuration may no longer be able to significantly improve energy consumption. Only an optimized combination of subsystems may cause notable changes in energy use.

At the same time, many building designers and energy modelers only understand basic heat transfer principles and merely operate in a one-dimensional environment. Requesting three-dimensional transient heat transfer analysis for each envelope component seems unrealistic. Therefore, a simple computational tool supporting thermal analysis of the building envelope in shell-dominated buildings would be very helpful in the design process.

The concept of an interactive envelope materials database for whole-building energy simulation programs was developed to reinforce an accurate, fast, and simple energy analysis of building energy consumption in shell-dominated buildings. This database uses several already existing subroutines, experimental results, and calculation techniques. The main purpose of this database is to serve architects, system designers, and energy modelers by enabling detailed envelope analysis during whole-building energy simulations. However, it can also be utilized for performance comparisons between different envelope technologies. The user simply selects the material configuration and sets dimensions. Later, the Internet program calculates whole wall/roof/ or floor R-values, generates three-

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dimensional dynamic thermal characteristics, and calculates detailed air leakage for the selected building envelope system. This information is then converted into the format required by programs such as BLAST, DOE-2, or ENERGY PLUS.

This paper summarizes the theoretical foundations for this new approach and presents some examples of component analysis for residential buildings.

## DESIGN OF LOW-ENERGY BUILDINGS AND THE NEED FOR PARAMETRIC ANALYSIS

Since the 1970s, several zero-energy buildings have been constructed in different countries and in a wide variety of climatic conditions. The main lesson learned from these exercises was that, while it is possible to design and construct a million-dollar zero-energy house, the real engineering challenge is to build such a house for a low-income family.

A proper balance between the cost of high-tech materials and equipment and the reduction of whole-building energy consumption is critical for designing affordable low-energy buildings. The most effective way to optimize the building envelope is parametric analysis of all components. The following architectural and material components and building characteristics are usually considered during this process:

- geometry and orientation of the building
- overall thermal characteristics of the building shell (three-dimensional steady-state and transient performance of all envelope components)
- application and configuration of thermal mass
- application of cool surfaces and radiant barriers
- optimization of the attic/roof design
- foundation type and foundation insulation
- size and location of glazing
- solar gain control systems
- inherent air leakage characteristics of main building envelope systems and interface connections
- location of air ducts, etc.

To illustrate the importance of this parametric analysis during the design of low-energy buildings, Figure 1 shows potential energy savings calculated for four different configurations of massive walls with the same R-value. These configurations can be utilized to represent existing building envelope technologies, for example:

- the *ICI* configuration may represent insulated concrete forms,
- *Ext. mass* may represent a concrete block wall insulated from the interior side with foam sheathing, etc.

Energy savings are computed by comparisons of energy consumption in a single-story ranch with massive walls against a similar house built with traditional wood-framed walls.

As shown in Figure 1, potential energy savings are the function of wall material configuration. Most efficient are configurations with thermal mass located on the interior side of the wall.

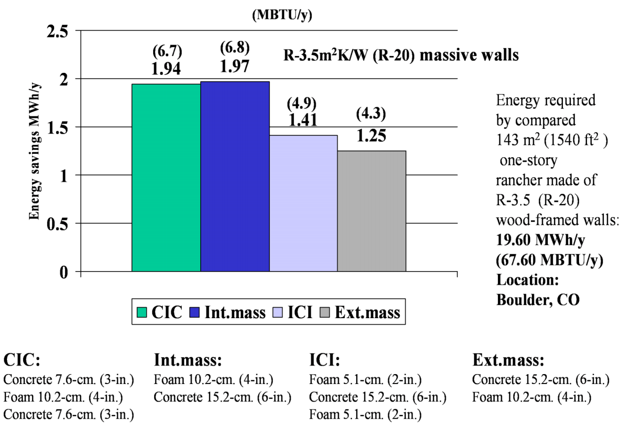



***Figure 1*** *Energy savings estimates computed for one-story ranch with R-3.5 (R-20) massive walls for Boulder, Colo.*

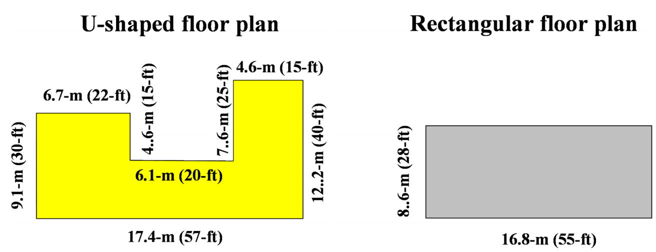



***Figure 2*** *Schematics of two floor plans used in comparisons.*

Simple changes in configuration of the same wall materials (insulation and concrete) may bring energy savings in the range ±30% from each other. The scale of differences in energy savings is close to 0.7 MWh/y (2.4 MBtu/y). This is equivalent to the energy effect generated by adding 5 cm (2 in.) of rigid foam sheathing. This example demonstrates that sometimes it might be wise to optimize a configuration of building envelope materials before making recommendations for a costly addition of thermal insulation.

Another example shows how relatively small changes in building envelope configuration (floor plan, addition of window, addition of door, and application of different wall structural components) may notably modify building thermal characteristics. As shown in Figure 2, two floor plans were considered for a one-story 144 $m^2$ (1540 $ft^2$) house. A list of basic building components that are different in each house is given in Table 1. It is assumed that in both houses traditional 2-by-4 wood-framed walls insulated with R-1.9 (R-11) fiberglass batts and exterior wood siding are used. Relations between in-cavity, clear wall, and whole wall R-values are presented in Figure 3.

**Table 1. List of Basic Building Components That Are Different in the Houses**

| | | |
|---|---|---|
| Foundation plan | U-shaped | Rectangular |
| Number of corners | 8 | 4 |
| Wall openings | Windows: 7-1.2×1.5 m. (4×5 ft),<br>2-1.2×0.9 m (4×3 ft), 1-1.2×1.8 m. (4×6 ft)<br>Doors: 2-2.1×1.2 m. (7×4 ft) | Windows: 7-1.2×1.5 m.<br>(4×5 ft), 1-1.2×0.9 m. (4×3 ft)<br>Doors: 1-2.1×1.2 m. (7×4 ft) |
| Elevation area | 167 $m^2$ (1800 $ft^2$) | 124 $m^2$(1320 $ft^2$) |
| Windows + Doors | 22 $m^2$ (237 $ft^2$) | 16 $m^2$(172 $ft^2$) |
| Opaque wall area | 145 $m^2$ (1560 $ft^2$) | 108 $m^2$(1160 $ft^2$) |

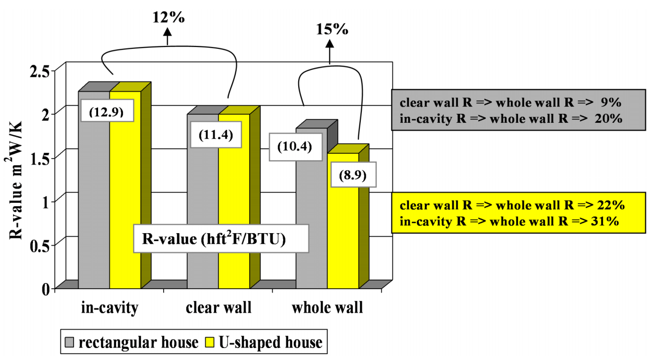



***Figure 3*** *Relations between in-cavity, clear wall, and whole wall R-values for both compared houses (traditional 2 × 4 wood framing).*

In both houses clear wall R-values are 12% lower from in-cavity R-values (in-series R-value for the center of cavity). However, differences in building envelope configuration generated differences in whole wall thermal performance for both houses.

In this exercise, the whole wall thermal resistance of the wall system ($R_{ww}$) was computed by combining in an area weighted method the thermal resistance of the subsystems, wall intersections, and clear wall area.

$$R_{ww} = 1/\left[A_{cw}/R_{cw} + \sum_{i=1}^{n} A_i/R_i\right] \quad (1)$$

where $A_{cw}$ is the clear wall area expressed as a percentage of the overall wall area, $R_{cw}$ is the clear wall thermal resistance, $A_i$ is the area of the $i$th wall detail expressed as a percentage of the overall wall area, $R_i$ is the thermal resistance of the $i$th wall detail, and $n$ is the number of wall details.

The whole wall R-value (with all wall architectural details and intersections included [Kosny and Desjarlais 1994]) for the house placed on the U-shaped floor plan is R-1.6 $m^2$ W/K (8.9 h $ft^2$ °F/Btu). The whole wall R-value for the house with a rectangular floor plan is R-1.8 $m^2$ W/K (10.4 h $ft^2$ °F/Btu). The difference is about 15%. Also, the opaque wall area of the U-shaped house is about 25% larger than the opaque wall area of the other house. This yields about 35% difference in wall heat transfer rates for both houses. It is important to realize that all these closely related differences would not be fully accounted for if conventional techniques for energy analysis were utilized.

## PROBLEMS OF ACCURACY IN DYNAMIC WHOLE-BUILDING ENERGY SIMULATIONS

Most whole-building energy simulation programs require one-dimensional descriptions of building envelope components. Unfortunately, proper analysis of complex thermal envelope systems sometimes requires application of advanced analytical tools for three-dimensional transient heat transfer. This situation may create problems of accuracy in whole-building energy modeling. It may also generate uncertainties in sizing HVAC equipment because of inaccuracies in building load calculations. To reduce the cost of the process and minimize the potential for inaccuracies, a method of developing architectural component descriptions in simulation programs has to be as simple as selecting the specific material configuration, setting dimensions, and determining building orientation.

### Inaccuracies in Approximation of Thermal Bridges Generated by Common Architectural Details and Envelope Intersections

For decades, exterior building envelopes have been represented in whole building energy simulation programs by simple one-dimensional approximations. For example, in the case of wood-framed walls, clear wall area used to be simulated using two material paths: in-cavity path and framing path. However, numerous novel wall technologies have been introduced to the building marketplace. Some of them represent complex two- and three-dimensional networks of structural and insulating materials. Therefore, the simple case description acceptable for wood-framed structures does not work for steel or concrete technologies. The simple one-dimensional “in-cavity and framing path approach” cannot be applied to more complex assemblies.

In addition, currently built houses are becoming progressively larger and their architecture is becoming progressively more complex. As a result, the number of structural components is increasing. A study performed for the California Energy Commission (Carpenter and Schkumacher 2003) demonstrated that the framing factor (fraction of the opaque wall area represented by solid wood used for framing) for residential walls is close to 27%. The relevance of this finding is overwhelming:

- The actual R-value for 2-by-4 walls insulated with R-2.3 (R-13) fiberglass batts (nominal R-value of R-2.6 $m^2$ W/K [R-14.5]) is in the range between R-1.5 and R-1.6 $m^2$ W/K (R-8.5-9.0 h $ft^2$ °F/Btu).
- This is a 35%-40% *reduction* of nominal wall R-value.
- This is equivalent to an R-value of an *additional* 3.8 cm. (1.5 in.) of EPS.
- This means that houses built in this way would require approximately 10-12% *more energy* than is predicted by currently used energy calculation tools.

Finally, it is important to state that in the whole-country scale, this difference of 10%-12% is equivalent to about *0.23-0.29 petawatthour (0.8-1.0 quad) of energy* consumed by residential buildings (according to DOE's 2003 Building Energy Databook (http://buildingsdatabook.eren.doe.gov/).

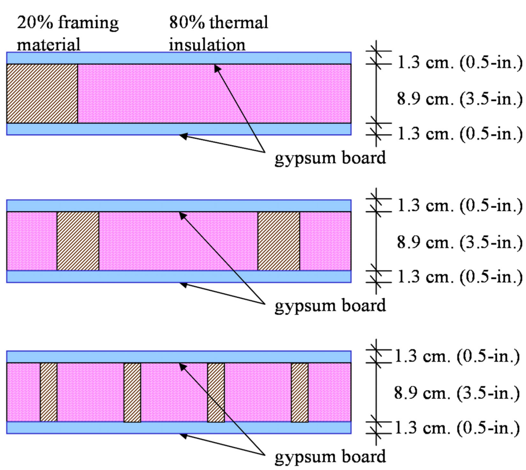
The scale of this problem is even larger considering that wood framing is the dominant, but not the only, building envelope technology available in the U.S. In other technologies, thermal bridges created by highly conductive structural materials can significantly reduce local R-values and change the transient response for building envelope details.

A simple thermal modeling exercise, presented in Figure 4, illustrates the differences between heat flow calculated using a simplified parallel-path method (top case) and using a more-complicated (closer to reality) two-dimensional simulation model. Three theoretical wall sections with 20% framing were simulated. Three different framing materials were assumed for thermal modeling: wood, 0.116 Wm/K (0.8 Btu·in./h $ft^2$ °F); concrete, 1.40 Wm/K (9.7 Btu·in./h $ft^2$ °F); and steel, 46.20 Wm/K (320 Btu·in./h $ft^2$ °F). Expanded polystyrene (EPS) foam, 0.035 W m/K (0.24 Btu·in./h $ft^2$ °F) served as a cavity insulation. Figure 4 shows that differences in R-value estimations depend on the thermal conductivity ratios between structural and insulation materials and the number of the framing material inserts. For the simplified in-series calculation (similar to the traditional method of describing a wall in whole-building modeling input files), errors in R-value calculations may exceed 44% for steel framing and 27% for concrete framing, while less than 2% for wood framing. Unfortunately, real life situations are much more complex than the simple example above. In real buildings, the scale of errors can be different since proportions between wall area, amount of structural framing, and number of penetrations through the thermal insulation may be different from those strictly theoretical numbers analyzed in Figure 4.

Steel framing is considered more difficult to analyze. Assume that a one-story 8.5 × 16.8 m. (55 × 28 ft) building has 2 × 4 steel stud walls insulated with fiberglass batts. Steel studs are installed at 40.6 cm (16-in.) o.c. On the exterior, the wall is finished with a 1.2 cm (0.5 in.) layer of plywood and wood siding. Some energy modelers probably will make the following assumptions:

*Exterior walls materials*:

1. Gypsum board — thickness, 1.2 cm (0.5)
   thermal conductivity, 0.16 W/m·K (1.1 Btu·in./h·$ft^2$·°F).
2. Insulation — thickness, 8.9 cm (3.5)
   thermal conductivity, 0.041 W/m·K (0.28 Btu·in./h·$ft^2$·°F).




| Framing material | Ratio between thermal cond. Insul./Fram. | R-value differences Base case 1 insert | |
|---|---|---|---|
| | | 2 inserts | 4 inserts |
| Wood | 3 | 1.4 % | 1.8 % |
| Concrete | 40 | 17.8 % | 27.5 % |
| Steel | 1330 | 28.1 % | 44.4 % |

**Difference in R-value calculations are computed using comparison of the configuration case containing a single one framing material insert against cases with two or four framing material inserts.**

***Figure 4*** *Results of comparisons between R-value estimations for three walls of the same framing factors.*

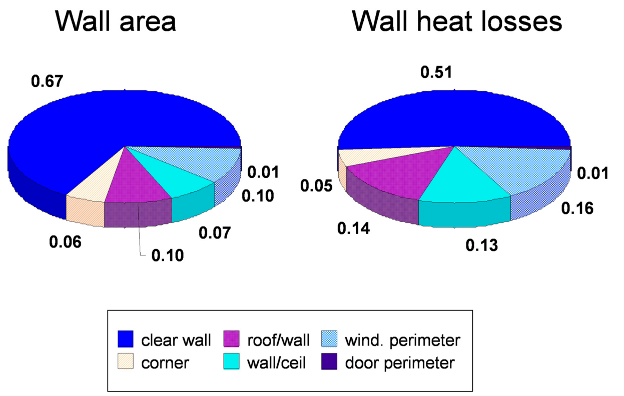



***Figure 5*** *Comparison of wall area distribution and wall heat losses distribution in 8.9-cm (3.5-in.) steel stud wall.*

| | | |
|---|---|---|
| 3. | Steel studs | web depth, 8.9 cm (0.5)<br>thermal conductivity, 46 W/m·K (320 Btu·in./h·ft$^2$·°F). |
| 4. | Plywood | thickness, 1.2 cm (3.5)<br>thermal conductivity, 0.115 W/m·K (0.8 Btu·in./h·ft$^2$·°F) |
| 5. | Wood siding | R- 0.17 m$^2$·W/K (R-1 h·ft$^2$·°F/Btu) |

Clear wall R-value calculated using the modified zone method (ASHRAE 2001a) is R-1.16 m$^2$ W/K (R-6.6). As shown in Figure 5, the clear wall represents only 67% of the whole opaque area of the elevation for a considered building. Because wall details generate about 50% of the total heat transfer, the whole-wall R-value is much closer to reality than the clear wall R-value. In our example, the whole-wall R-value is R-0.94 m$^2$ W/K (R-5.3) (about 18% less than the clear wall R-value). Two DOE 2.1E simulations were performed for the Atlanta climate, with both clear-wall and whole-wall R-value inputs for a steel stud wall. These computations yielded a 4.5% difference in predicted total energy consumption.

In both simulation exercises, miscalculations of energy consumption were below 5%. However, similar miscalculations for other components could easily result in a total combined error exceeding 10%.

**Example:** Assume that in the same steel stud wall, fiberglass insulation was replaced by polyurethane foam (conductivity 0.024 W/m K or 0.17 Btu·in./h ft$^2$ °F). As a result, clear wall R-value and whole wall R-value were changed to R-2.1 (R-11.7) and R-1.7 (R-9.4), respectively. For Atlanta climatic conditions, this change yielded a 5.6% reduction in whole-house HVAC energy consumption. Installation of an extra layer of gypsum board (application considered in the past for thermal mass effect) will bring an additional 2.7% of energy savings. In total we are relatively close to 10% saving without performing any changes in attic or floor insulation levels, glazing area, window quality, whole house air leakage characteristics, etc. In that light, chances for other (relatively small) energy savings are significant.

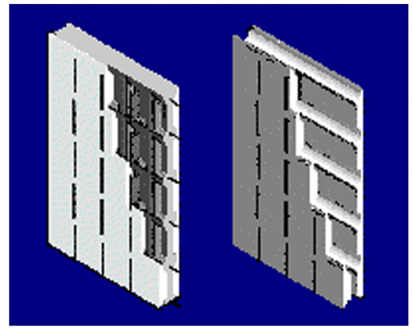


***Figure 6*** *Insulated concrete form wall made of EPS.*

Note that in the above case where envelope configuration was relatively simple, it took well over two hours to perform all necessary simulations and computations. It is unlikely that similar complex and time-consuming calculations will be made for residential buildings.

Very often, material configurations are more complex than those in the above examples. They require application of computer simulation tools for R-value estimations. It is probable that the modeler would prefer to use approximate values instead of performing complex and time-consuming calculations. Thus, it is important to offer a simple Internet-based tool for this type of calculation.

## Potential Errors in Transient Heat Transfer Analysis Generated by Inaccuracies in One-Dimensional Simplifications of Complex Building Envelope Assemblies

Since most of the whole-building energy simulation programs use one-dimensional thermal calculation procedures; one-dimensional simplified descriptions of envelope components are used by the majority of energy modelers. For simple lightweight wood-framed envelopes (conventional 2×4 wood framing), these simplifications cause insignificant errors in energy calculations. However, in the case of more complex building envelopes incorporating highly conducting members and massive components, these errors can be more significant. Unfortunately, proper analysis of complex thermal envelope systems is time-consuming and requires application of advanced three-dimensional transient heat transfer analytical tools. It is good to realize that, in most cases, because of economic reasons, this kind of analysis is performed using only inaccurate one-dimensional approximations.

To illustrate the scale of this problem, an insulated concrete form (ICF) wall was analyzed using several heat transfer analytical procedures. The ICF wall is made of two EPS shells and a solid concrete core as shown in Figure 6. Inside this wall, there is a three-dimensional network of vertical and horizontal channels that are filled with concrete and steel reinforcement during construction of the wall.

For accurate representation of the complex three-dimensional internal structure of the ICF wall, the “equivalent wall” concept was utilized. Equivalent theory is based on an advanced heat transfer analytical procedure that was developed by Kossecka and Kosny in 1996. Equivalent wall has a simple one-dimensional multilayer structure. Its dynamic thermal behavior is identical to that of the actual wall (Kossecka and Kosny 1997). ASHRAE Research Project RP-1145 demonstrated that physical properties of equivalent wall could be used in whole-building energy simulation programs (ASHRAE 2001b).

At first, a finite difference computer model was developed for the ICF wall. Figure 7 depicts a complex temperature field on the interior surface of the ICF wall. A series of response factors, heat capacity, and R-value were computed using this model. They enabled generation of a series of one-dimensional equivalent wall.

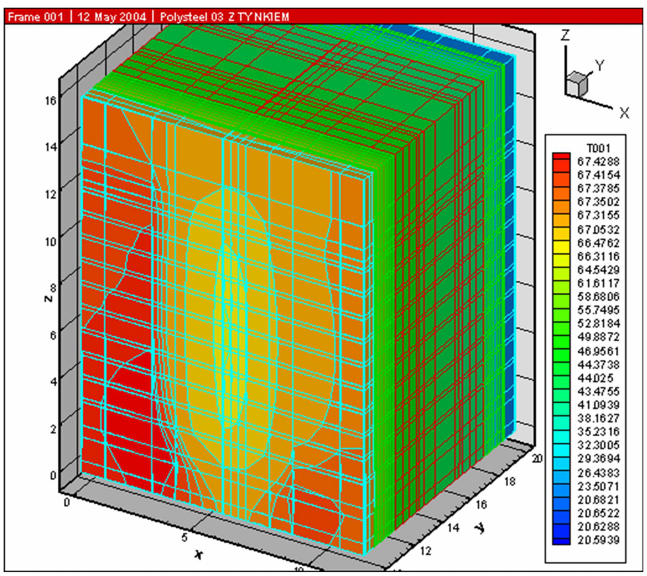



***Figure 7*** *Three-dimensional temperature field for fragment of the insulated concrete form (ICF) wall made of EPS foam.*

Later a simple one-dimensional model was developed for the ICF wall. Because computer programs such as DOE-2, BLAST, or Energy Plus can perform only one-dimensional thermal analysis, it is most likely that whole-building modelers would make a similar simplification.

The R-value calculated for the ICF wall using a simple one-dimensional model was 38% higher than the R-value calculated using detailed three-dimensional simulation.

Simple DOE-2.1E modeling was performed for Atlanta climatic conditions on a previously modeled ranch house to illustrate how inaccuracy in one-dimensional descriptions can affect simulation of cooling and heating energies. Equivalent wall generated for the EPS form was used as a base for this comparison.

It was found that DOE-2.1E runs utilizing one-dimensional approximations in input files generated 8% and 2% differences in predicted cooling and heating energies (respectively) when compared with DOE-2.1E simulations using equivalent wall. It was proved in earlier publications that the scale of similar discrepancies can exceed 10% and can be different for different climatic conditions (Kosny and Kossecka 2000). Similar miscalculations can be made for other building envelope components such as roofs, floors, or foundations.

## NEW ENERGY CALCULATION TOOLS REQUIRE APPLICATION OF MORE ACCURATE IMPUT DATA FOR BUILDING ENVELOPES

Due to rapid progress in development of building envelope technologies, it is expected that in the near future designers of energy-efficient buildings will have to treat a building as a collection of subsystems generating trivial energy effects if they are analyzed separately. However, if these small components are configured to optimized form and sequence, they may generate relatively significant energy savings. In that light, parametric analysis can be one of the key advantages of using future whole-building energy simulation tools.

A simple example of whole-house energy analysis is noted in Table 2 for two identical single-story (144 $m^2$ or 1540 $ft^2$)

**Table 2. Simple Example of Whole House Energy Analysis for a Single-Story Ranch**

| | Conventional 2×4 wood framing structure for walls, R-8.8 (R-50) attic insulation | SIPS structure 8.9 cm (3.5 in.) foam core for walls, 30.5 cm (12 in.) foam core for roof |
|---|---|---|
| Nominal clear wall R-value | **2.20 (12.5)** | **2.34 (13.3)** |
| Nominal attic R-value | **8.80 (50.0)** | **8.10 (46.0)** |
| **Difference in HVAC energy consumption for nominal R-values** | **about 1%** | |
| Effective whole wall R-value | **1.76 (10.0)** | **2.22 (12.6)** |
| Effective attic R-value | **6.11 (34.7)** | **7.57 (43.0)** |
| **Difference in HVAC energy consumption for effective R-values** | **about 6%** | |

ranches having different walls. To make energy performance comparisons simpler, the same infiltration rates were assumed for both houses. Energy simulations were performed again for the Atlanta climate.

In both houses, the roofs had triangular shapes. The traditionally framed building (8.5×16.8 m or 28×55 ft) had a pitched roof with rafters installed at 40.6 cm o.c. (16 in.) and a high point in the ridge of 1.6 m (64 in.). Nominal roof insulation was R-8.8 $m^2$AW/K or (R-50) (thermal conductivity, 0.0417 W/mAK (0.29); thickness, 36.8 cm or 14.5 in.). The ceiling was hung to the wood joists (25.4 × 3.8 cm [10 × 2]) installed at 40.6 cm o.c.(16 in.) and finished with a 1.2 cm (0.5 in.) layer of gypsum board with thermal conductivity of 0.16 W/mAK (1.1 Btu·in./h $ft^2$ °F). On 22% of the attic area, the declining roof surface reduced the thickness of the attic insulation. Consequently, the average insulation thickness was not 36.8 cm (14.5 in.) but 30 cm (11.8 in.). Moreover, wood joists penetrate the insulation at 40.6 cm o.c (16 in.). Based on all these facts, effective attic R-value was reduced by about 30%. In the case of the structural insulated panel (SIP) roof, similar R-value reduction was only about 7%.

In the simple computational exercise presented in Table 2, differences between two sets of energy calculations for nominal and effective R-values (for walls and roofs) were close to 5%. This 5% difference in energy consumption would probably not be accounted for if traditional energy simulation techniques were used. This exercise also shows how difficult it is for novel building envelope technologies to document (in an analytical way) their superior energy performance.

During the last two decades, energy simulation tools have been through a tremendous transformation. Most improvement projects were focused on refining energy calculation methods, improving computational engines, and developing user-friendly interfaces. At the same time, almost no attention was paid to the quality of material input data for building envelopes. Practically, the structure of the building envelope part of input files for Energy Plus is not any different from input files used by Tamami Kusuda in the 1960s for his underground shelter simulations (Kusuda 2001). It is very common for energy calculation tools supporting retrofit projects to use in-cavity R-values. In situations where houses have very "busy" elevations and it is difficult to identify clear wall area (see Figure 8), there is not a single energy simulation tool that would require use of whole-wall R-values incorporating all architectural details and intersections.

Therefore, a concept for "Interactive Envelope Materials Database for Whole-Building Energy Simulation Programs" was developed at ORNL to reinforce an accurate, fast, and simple parametric analysis of building energy consumption.

In 1994, ORNL introduced a whole-wall R-value procedure (Kosny and Desjarlais 1994) based on hot-box test results and three-dimensional heat conduction simulations. Whole-wall R-value combines thermal performance of the clear wall area with typical envelope interface details, including wall/wall (corners), wall/roof, wall/floor, wall/door, and wall/window connections. Results from these detailed simulations are combined into a single whole-wall R-value and compared with simplified "center-of-cavity" and "clear-wall" R-values. The Whole Wall Thermal Performance Calculator (Christian and Kosny 1996) is available on the Internet at http://www.ornl.gov/roofs+walls/calculators.


***Figure 8*** *Clear wall area in houses is difficult to find.*

In 1996, ORNL developed the equivalent wall concept (Kossecka and Kosny 1996), which transforms complex three-dimensional thermal characteristics of building envelope components into simple one-dimensional equivalents. A potential application of the equivalent wall theory in whole-building energy simulations was analyzed by ASHRAE project TRP-1145 (ASHRAE 2001b). Since 1996, ORNL has performed more than 20 dynamic hot-box tests. Based on results collected during these tests, dynamic thermal characteristics of over a dozen massive wall assemblies were derived (Kosny et al. 1998).

Three testing procedures were introduced by ORNL to collect experimental data on component air leakage (Kosny 2003). These procedures enable separate air leakage analysis for building envelope details, such as window and door perimeter, wall/ foundation intersection, wall/ceiling intersection, and wall/roof connection. At the beginning, a series of tests were performed on conventional wood-framed technology. Intersections incorporating a concrete basement wall, floor, above-grade wall, and wall/window interface were investigated. Several types of air-sealing methods were analyzed during these experiments.

The Interactive Envelope Materials Database for Whole-Building Energy Simulation Programs utilizes all the theoretical concepts and experimental procedures described above. It will consist of four computational modules:

1. Building geometry calculator
2. Whole-wall, roof, and ceiling thermal calculator
3. Air leakage calculator
4. Input file generator

The building geometry calculator remembers all geometry data for the building (e.g., building dimensions, number of corners, windows, and doors, shape of roof, size and distribution of structural members, etc.). It enables calculations of elevation area distribution for major building envelope components.

The whole-wall, roof, and ceiling thermal calculator consists of five independent sections:

1. Hot-box test results database
2. Clear-wall, roof, and floor R-value database and detail R-value database
3. Whole-wall, roof, and floor R-value calculator
4. Experimental dynamic thermal characteristics database
5. Dynamic characteristics calculator

All historic hot-box results for hundreds of wall, roof, and floor material configurations will be available in the ORNL hot box test result database. At present it is the world's largest material data base for wall technologies and the only material data base that contains wall transient characteristics. The R-value calculator will be based on the Whole Wall Thermal Performance Calculator (Christian and Kosny 1996). Its calculation capability will extend to roof and floor structures. Using thousands of already existing results of detailed three-dimensional heat transfer simulations for clear walls, wall details, and roof and floor details, it will process them into whole-wall, whole-roof, or whole-floor R-values.

Dynamic hot-box results and dynamic thermal characteristics for complex building envelope systems will be accessible as well. The dynamic thermal characteristic calculator will be based on the Equivalent Wall Program (Kossecka and Kosny 1997). It will generate a series of response factors, structure factors, and equivalent wall for a given materials configuration. It will also reconfigure dynamic thermal characteristics to incorporate the effects of building envelope details using computational procedures developed by the ASHRAE Research Project TRP 1145 (ASHRAE 2001b).

The air leakage calculator will utilize experimental results on component air leakage and will process detailed information linking available component air leakage experimental data with the type of building envelope, complexity of architectural components, type and number of windows and doors, etc. This calculator will simplify the process of whole-building air leakage analysis and minimize the possibility of errors and miscalculations.

At the end of the process, the input file generator will combine all data developed by all calculation modules and develop an envelope-related part of the input file for a specific whole-building energy simulation program.

## CONCLUSIONS

Parametric analysis will be a primary method of optimizing buildings' energy performance in the future. Eventual implementation of the full range of physical characteristics of building envelope components into whole-building energy simulation programs will require development of an advanced interactive materials database. Such a database would enable a modeler unfamiliar with advanced heat transfer analysis to develop simple and accurate descriptions of envelope systems in a form readable by most simulation programs. To reduce the cost of the designing process and minimize the potential for inaccuracies, developing architectural component descriptions in whole-building energy simulation programs has to be as simple as selecting the specific material configuration and setting dimensions and orientation.

Computational examples presented in this paper demonstrate that simply adding insulation to the building does not necessarily mean huge savings in energy consumption. Very often, proper analysis of the configuration of the building envelope can be more efficient and less expensive.

Analysis of building envelope assemblies containing thermal bridges often requires application of three-dimensional simulation tools. It is very common that application of a simplified (and inaccurate) one-dimensional description created for a single building envelope detail may generate relatively insignificant errors in whole-house energy consumption predictions. For a single building simulation, these kinds of "small errors" can be found in many points of the input file (thermal bridges in walls, attics, or floors, improper dynamic models of complex envelope assemblies, etc.). In some cases, when these errors are combined together, they can add up to over 5%. Complex massive structures and steel-framed assemblies are most sensitive to these inaccuracies, where errors in predicted energy consumption may reach 20%.

Several sophisticated whole-building energy simulation programs have been developed, but they cannot be fully utilized without the capability to develop and utilize accurate input files. The lack of an appropriate materials' database for building envelope technologies (especially for new non-wood technologies) is today one of major barriers in successful deployment of advanced whole-building energy simulation tools. That is why development of an interactive materials database is a critical step in introducing a new generation of whole-building energy simulation programs.

To serve this need, ORNL has introduced the Interactive Internet-Based Envelope Material Database for Whole-Building Energy Simulation Programs, which links experimental data on thermal and airtightness characteristics of building envelopes with advanced analytical methods available for thermal and energy analysis.

*Even the most advanced computer simulation tool will generate inaccurate results if innacurate imput data are used*.

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