Computational Modeling of an Energy Audit

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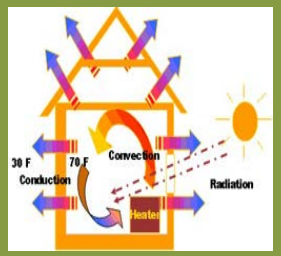
Introduction

An energy audit is the analysis of a home's energy consumption. It helps determine the areas of the home that are not energy efficient. The audit consists of inspecting the home's walls, ceiling, foundation, appliances, insulation, and thermography. Additionally, a blower door test is conducted to understand the air flow from inside the home to the outside and vice versa. Improvements and updates (Retrofits) are then made to reduce energy consumption which then lowers energy bills and environmental impact.

Heat is a form of energy that can be transferred through:

- Conduction
- Convection
- Radiation

This research involves the use of Fortran to create a software that calculates heat loss through walls, ceiling, air leakages, and foundation necessary for an energy audit.



Fortran Program

Fortran (FORmula TRANslation) is a computer programming language designed for scientists and engineers that is suitable for numerical calculations and used in many large computational packages.

- Our main program contains most variable declarations and asks users to input parameters such as dimensions of the house, R-values, insulation configurations, temperatures, and more
- The main program saves all these inputs into a file and then calls the recursive subroutine.
- The recursive subroutine contains all equations and calculates heat loss using the file created in the main program
- The recursive subroutine can call itself within the program, and this path is followed when calculating heat loss if adding a retrofit to the home

Figure 1: Sections of code in our program depicting execution statements and calculations

Calculations

Heat transfer occurs spontaneously from higher to lower temperature gradients. Calculations coded in the program use:

- **Heating degree days (HDD)**, a measurement of the average number of days the temperature falls below 65°F
- **R-values** refer to the thermal resistance value of a material, that is, how well that material resists heat flow. Walls, ceilings, and basements are all composed of various materials and insulation types each with a specific R-value

Walls and Ceiling:

$$Heat\ Loss\ \left(\frac{BTUs}{h}\right) = \frac{Area(ft^2) \times Temp.Difference\ (°F)}{R-Value\ \frac{ft^2°Fh}{BTU}}$$

$$Seasonal\ Heat\ Loss = \frac{Area}{R-Value} \times 24 \times HDD$$

Air Leakages:

$$ACH50 = \frac{CFM50\left(\frac{ft^3}{min}\right) \times 60\ (min)}{Building\ Volume\ (ft^3)}$$

$$Heat\ Loss = \frac{1.08 \times ACH \times Volume \times Temp.Diff\ (or\ HDD)}{60}$$

Basement Heat Loss

Heat is transferred from the basement to the soil surrounding the house. Unlike the air above ground, he soil surrounding the house is not uniform and thus has properties that are modelled via the unique basement heat loss calculations. Two calculation methods were analyzed.

In soil, heat transfers by:

- Conduction through soil/water in soil
- Advection by ground water
- Convection of water vapor through pores between soil particles (voids)
- Radiation in the soil voids
- Phase changes of water

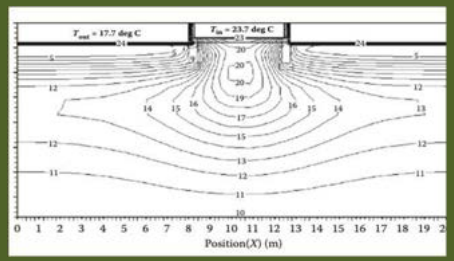


Figure 2: Soil temperature isotherms for a basement slab during winter[1]

Krarti Basement Calculations

This method uses a set of equations dependent on parameters such as soil properties and basement dimensions. The equations also contain coefficients that are dependent on insulation placement (uniform, partial, horizontal, vertical).

$$Q_m = U_{eff,m} \times A \times (T_m - T_r)$$

$$U_{eff,m} = m \times U_o \times D \qquad U_o = \frac{k_s}{(A/P)_{eff,b}}$$

$$D = \ln(1+H)\,1 + \frac{1}{H} \qquad H = \frac{(A/P)_{eff,b}}{k_s \times R_{eq}}$$

Q_m = mean heat loss, A = basement area, T_m= soil temperature, T_r=basement temperature, P = perimeter, k_s=soil thermal conductivity, R_{eq}= R-value

Mitalas Basement Calculations

Mitalas splits the basement into 5 segments (above grade, below grade, center) because thermal conduction of these different regions differ significantly. He develops S_n and V_n steady state and periodic shape factors dependent on basement, insulation type, and soil properties.

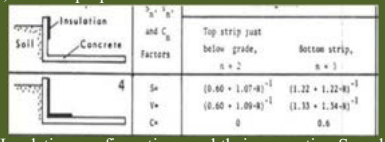


Figure 3: Insulation configurations and their respective S_n and V_n values[2]

$$q_{1,m} = A_1 \times U\,X\,(\theta_B - \theta_{o,m})$$
$$q_{2,m} = A_2 \times [S_2 \times (\theta_B - \theta_G) - V_2 \times \sigma_2 \times \theta_v \times \sin(30(m+\Delta t_2))]$$
$$q_{3,m} = A_3 \times [S_3 \times (\theta_B - \theta_G) - V_3 \times \sigma_3 \times \theta_v \times \sin(30(m+\Delta t_3))]$$
$$q_{4,m} = A_{4,s} \times S_4 \times (\theta_B - \theta_G) - A_{4,v} \times V_4 \times \sigma_4 \times \theta_v \times \sin(30(m+\Delta t_4))$$
$$q_{5,m} = A_{5,s} \times S_5 \times (\theta_B - \theta_G) - A_{5,v} \times V_5 \times \sigma_5 \times \theta_v \times \sin(30(m+\Delta t_5))$$

A_n = basement segment, $q_{n,m}$ = average heat loss from segment A_n, σ_n = amplitude attenuation factor, θ_B = basement air temp , θ_G = mean ground temp, θ_v = amplitude of first harmonic of the ground surface temp, Δt_n = time lag

The Cutler House Results

A prior energy analysis was done on the Cutler house using the Energy-10 software package. The program successfully calculated the heat loss through walls, ceiling, air leakages, and basement using both the Krarti and Mitalas method to determine basement heat loss. Compared to Energy-10's results, both methods of calculation estimated a lower total house heat loss.

Figure 4 : Our code executed and printed to the screen

Heat loss (Btu)	Krarti	Mitalas	Energy-10
Total Wall	5.297 x 10^7	5.297 x 10^7	
ACH	6.7 x 10^4	6.7 x 10^4	
Ceiling	1.42 x 10^7	1.42 x 10^7	
Foundation	3.06 x 10^7	3.5 x 10^7	
TOTAL /area	104 kBtu / ft^3	128kBtu ft^3	153 kBtu / ft^3

Figure 5: Calculation results for the Cutler House from our program compared to Energy-10 software

Acknowledgments

- Professor Sally Meyer for providing support and guidance throughout this experience
- The Dean's office grant for Faculty-Student Collaborative Research

References

1. Krarti, M. (2012). *Weatherization and energy efficiency improvement for existing homes: An engineering approach*
2. Mitalas, G. 1987. Calculation of below grade heat loss—Low-rise residential building. *ASHRAE Transactions* 93(1):743–83.
3. Krigger, J. *Residential Energy Cost Saving and Comfort for Existing Buildings*