Value of Energy Efficiency Improvements for Low-Income Housing in Developing Countries

Abstract This deeper look at the value of residential building energy efficiency in developing countries is based on the authors' research conducted through field studies, energy modeling, and material systems analyses; using actual modest residential structures in South Africa as subjects. Building on earlier findings that show the relationship between increased upfront capital costs for various energy efficiency measures and the reduction in life cycle costs due to decreased operating expenses, the authors now have data from improved modeling methods and field data collection that further support the value of including these basic energy efficiency measures in low-income housing units in developing countries, including those with moderate climates. This phase of the study has greatly improved the efficacy of the analyses utilized and will lead to better optimization of energy efficiency retrofits of the typical government built housing stock in South Africa and other developing countries. Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL. Keywords: building energy efficiency; affordable housing; energy modeling; energy monitoring; life cycle cost 1. Introduction Worldwide, buildings account for approximately 40-percent of all energy used by humans. Diminishing resources, national security, environmental concerns, climate change, social justice, and rising costs all point to theneed to make our buildings more efficient. Countries with developing regions such as South Africa, Brazil, and Mexico; have made progress advancing their building stock in recent years, but energy efficiency has fallen behind other measures taken. The primary reason for this lag is the concentration on initial capital costs and the lack of proper accounting for operating costs and benefits, maintenance, and other life cycle cost considerations. Here the authors provide a deeper look at the value of residential building energy efficiency in developing countries based on their research conducted through field studies, energy modeling, and material systems analysis; using actual modest residential structures in South Africa as subjects. The impact of this work is magnified by the great number of government built houses in South Africa – 1.6 million as of 2004 [1] and growing. 1.1. Background In this ongoing study, possible improvements in building energy efficiency are explored from the standpoint of current worldwide benchmarks, materials considerations, building energy modeling techniques, and life cycle cost analyses. This work utilizes modern building energy modeling techniques available in software packages such as Autodesk® Ecotect®, WUFI Plus®, and EnergyPlus® to investigate the long-term energy use of common South African residential structures before and after practical energy efficiency measures. Along with these energy models the authors give professional cost estimates for both typical and modified scenarios. Life cycle cost analyses that include both upfront capital costs as well as the predicted energy costs are completed for each scenario. The current phase of our study includes three years of monitoring of indoor and outdoor temperature and humidity of the subject houses as well as some targeted energy consumption monitoring to compare with the previous models. 1.2. Study structure This work is part of a long-term study that includes four primary phases. The first phase consists of using stateof-the-art energy modeling techniques to compare energy consumption of small to medium sized residential buildings as constructed versus the same buildings with various first-level energy efficiency measures. Life cycle cost analyses are then performed to determine the long-term financial benefits of the energy efficiency measures. A recent addition to this phase of the study is the use of WUFI Plus® in order to model moisture migration and phase change in the building envelope for the proposed measures. The second phase of the long-term study commenced in July 2011 with the installation of temperature and relative humidity monitors in the same homes modeled in first phase. Long-term monitoring is allowing for comparison of actual indoor environmental parameters with those predicted by the energy models. Outdoor conditions are also being monitored to verify the weather data used in the energy models. This monitoring is accomplished using Onset Computer Corporation's HOBO U23 Pro v2 temperature and relative humidity data loggers. The authors have also expanded this monitoring phase to include direct real-time monitoring of actual electrical energy consumption of some heating appliances for further verification and calibration of the models; however, most of the collected data has been incomplete due to a variety of heating systems used in the subject houses. The third phase of the study, which commenced in 2015, analyzes the resistance to heat flow of the building envelope materials systems proposed in the energy efficiency measures modeled in the first phase using ASTM C 1363 - Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus. This phase allows further validation of the modeling techniques through the verification of the thermal performance of the systems proposed, as well as giving the opportunity to measure the actual effects of individual modifications to the building envelope before embarking on the much more costly fourth phase of the study. The fourth phase of the study will involve the actual construction of pilot residential buildings similar to the buildings modeled, but with the energy efficiency improvements found to be most beneficial in the first phase of the study. In addition to the construction of new buildings, some energy efficiency retrofits will be completed on the buildings originally modeled in the first phase of the study. These buildings will then be added to those being monitored for indoor environmental conditions and energy use. This final phase of the study will allow for direct verification of the modeled energy efficiency improvements in both new and existing construction.

3. Results 3.1. Modeling results Using the life cycle cost analysis developed by the authors [2] and described in the Previous results section above, a thirty year cash flow model was developed for House 1, which is representative of typical government built housing in South Africa, and a comparison of results using the Ecotect model energy data versus that of the EnergyPlus model was made. The largest difference in the two energy models is that the Ecotect model uses a heating system with unlimited capacity allowing the interior temperature to be maintained at 18 degrees Celsius at all times. Given that the actual heating systems being used in the houses do not have the capacity to maintain this temperature, the model leads to unrealistically high predicted energy use. In the EnergyPlus model the heating system has a defined maximum capacity, enabling the realistic modeling of the actual heating devices being utilized. Predicted annual heating energy usage for House 1 in the Base Case condition using Ecotect was 3632 kWh, while the EnergyPlus simulation yielded a result of 1854 kWh per year. The lower energy usage predicted by the EnergyPlus model actually decreases the absolute energy savings when adding insulation materials because the energy usage for the Base Case condition is much lower already. The EnergyPlus simulation results and the results of the subsequent life cycle cost analyses are more representative of the savings that can be expected by implementing energy efficiency measures in government built housing in South Africa. The EnergyPlus simulation was run with both the Johannesburg (JNB) TMY2 data used in the initial analysis and Bloemfontein (BFN) TMY3 data. The results are shown in Figure 1 for selected energy efficiency measures and all four subject buildings. As expected, the area-normalized annual heating energy usage increases in every case when the BFN data is used due to the more severe heating season in Bloemfontein versus Johannesburg. Increases rangefrom 10-percent to 17-percent for the Base Case and 27-percent to 30-percent for Case D (insulated ceiling). The level of energy savings across the cases remains consistent and the ceiling improvement yields the greatest energy savings, regardless of house size or moderate changes in climate.   These changes to the modeling techniques utilized for this long-term study are shown to be significant improvements and will lead to simulated results much more representative of actual building conditions. This will allow for the models to be used to optimize the energy efficiency renovations of existing building stock and lead to improved design for low-income housing in developing countries.