Analysis of Energy Consumption, Rating Score, and House Size

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1. INTRODUCTION

In two different community scale projects, IBACOS has been investigating the relationship between house size, relative energy savings and absolute energy savings. This is in response to setting performance standards for master planned communities where houses vary in size from small attached and detached units up to large single family homes. When extrapolated to a public benefit program like a regional or national green building program, it is important to understand what the impact of setting a single energy and building performance standard is, and how that standard could create a skew in types of homes that participate based on house size. IBACOS has researched this in a cold and hot humid climate zone (represented by Pittsburgh PA and Charleston SC) and has developed a methodology that can balance rating scores with the desire to save energy for a range of house sizes.

2. IS A SINGLE STANDARD PRACTICAL FOR A WIDE RANGE OF BUILDING SIZES?

Our experience in developing standards for Summerset at Frick Park in Pittsburgh PA lead us to investigate the impact of a single energy performance standard for a range of house sizes. In the current method (RESNET 2002) used to determine Home Energy Rating System (HERS) scores, the thermal shell component areas of the reference home (i.e. walls, windows, ceilings, etc,) from which the point score is derived are the same as to the rated home, except for windows. This factor gives an indication of the relative energy efficiency of the home compared to a 1993 Model Energy Code version of itself, and in theory allows for the comparison of homes across a range of sizes. The rating method uses the loads for space heating, space cooling and water heating to generate the score. The method is documented in the Mortgage Industry National Home Energy Rating Systems Accreditation Standard (RESNET, 2002).

One artifact of this method is that as houses of a given occupancy get smaller, the energy consumption for space heating and cooling is lowered, and domestic water heating becomes a larger relative component in the final rating score. This is due in part to the fact that as houses get smaller, the ratio of envelope area to floor area increases. This has the tendency to make it more difficult for smaller homes to achieve the same score as a larger home, provided both houses have the same number of bedrooms.

While setting a performance standard based on a rating score does allow a significant amount of flexibility to the designer and builder, the variety of houses at Summerset has shown that two different size houses with the same number of bedrooms will likely have to incorporate different energy features to reach the same score. Generally as house size decreases for a given number of bedrooms, larger relative investments in energy improvements need to be made to achieve a given score. This potentially has serious impacts in a number of areas. First, smaller homes are typically targeted to the more affordable sectors of the housing market. If smaller houses need more costly energy efficiency features to achieve a given score, that can prevent the adoption of energy efficient construction practices in smaller homes where long-term energy affordability is perhaps most critical. In addition, while scores demonstrate the relative levels of energy efficiency across house sizes, the reality is that given the same envelope and mechanical system characteristics smaller houses inherently use less energy than larger houses for a given occupancy. As such, smaller more efficient house designs for a certain occupancy or number of bedrooms can be a method of encouraging energy efficiency. Between 1987 and 2001 the average size of a new house in the United States increased from 1,905 square feet to 2,324 square feet (2003). While energy codes have improved over that period of time, the growth in the size of the home seems to be a fairly well established trend. The overall percentage of new homes 1,200 square feet or less has also been decreasing over that time period, and the percentage of new homes 2,400 square feet or greater has increased from 21% to 38% (2003). At the same time, household size in the Unites States has decreased from 2.66 to 2.62 (2002b). Smaller homes will also generally use less material, so there should be less volume of waste generated and a lower overall embodied energy content for the project.

2.1 Existing Green Building Programs and House Size

Several emerging Green Building Programs have been exploring the concept of house size in their systems. The Vermont Built Green Program has developed a matrix that in essence allows smaller houses with a certain number of bedrooms to be certified by meeting the minimum program requirements, whereas larger houses with the same number of bedrooms will have to meet the program minimums and get a certain number of points from the checklist to be certified. As the house size increases for a given number of bedrooms, the number of points needed for certification also increases. The Florida Green Home Standard awards points based on smaller house sizes; however, it is not keyed to number of bedrooms, which is a factor that should probably be included to consider all houses equitably. The City of Austin's Green Builder Program gives a fixed number of points for houses that meet a certain threshold of size for a given number of bedrooms.

All of these programs are beginning to grapple with the difficult issue relating to house size in the context of environmentally responsible construction. One part this issue is a technical one, in that some basis needs to be made for how to allocate points for various sizes of houses. This is also a social policy and regional economics issue, in that there is currently no universally accepted definition of how big a house should be. In some parts of the country, a small home may have five or more occupants. In another part of the country (or another part of the county), smaller houses are being torn down in order to build much larger houses that will be lived in by two people. Much of this is driven by the economics of the region, however the success of Sarah Susankas' book The Not So Big House (1998) indicates that a growing number of consumers are looking for smaller, higher quality alternatives to what many builders and designers are providing in the marketplace.

3. ANAYLSIS OF ENERGY CONSUMPTION RATING SCORE AND HOUSE SIZE

3.1 Shell Area and Occupancy Factors

To begin the process of understanding the technical energy issues surrounding house size and occupancy, IBACOS has performed a limited analysis on several home sizes built to meet the EPA Energy Star Home® level of energy efficiency. The home energy rating score is driven by space heating, space cooling and domestic hot water energy consumption and loads, and as such, there are two primary factors to look at when trying to understand the relationship between energy and house size: surface area of the shell of the building and number of bedrooms (as a surrogate for occupancy). The surface area of the building is a driving force in the space heating and cooling loads, and while the various characteristics of the thermal shell (such as window to wall area ratio or overall U-value of the envelope) will impact how energy efficient a house is, these do not necessarily reflect changes in the overall size of the house. The number of bedrooms in a house is what home energy rating tools use to estimate the domestic hot water consumption and associated energy use in the rated and reference home. In order to develop a methodology for community scale design standards or for use with Green Building Programs that allocates energy use according to house size and occupancy, IBACOS has studied the effects of normalizing energy consumption based on shell area and occupancy. IBACOS has performed energy modeling on a number of homes built to meet the EPA Energy Star Home® level of energy efficiency using IBACOS' in-house energy simulation and rating tool (QuEST). Pittsburgh, PA and Charleston, SC were used as the climate zones for the modeling. For this analysis, the domestic water heating efficiency was kept constant at an EF of 0.56, and the above grade envelope insulation characteristics were modified to achieve as close to a HERS score of

Table 1 House characteristics to achieve a HERS 86 score in Pittsburgh, PA (R-Value in ft2●h●°F / Btu).

	Pittsburgh PA					Charleston SC				
	House Size					House Size				
Component	**912 sf**	**1537 sf**	**1922 sf**	**4060 sf**	**5564 sf**	**912 sf**	**1537 sf**	**1922 sf**	**4060 sf**	**5564 sf**
Walls	R-19 +R-5	R-19 +R-5	R-19+R-5	R-13+R-4	R-13	R-19 +R-0	R-19 +R-0	R-19 +R-0	R-19 +R-0	R-19 +R-0
Ceilings	R-38	R-38	R-38	R-38	R-30	R-38	R-38	R-38	R-38	R-38
Windows & Glass Doors	U – 0.32 SHGC 0.34	U – 0.32 SHGC 0.34	U – 0.32 SHGC 0.34	U – 0.38 SHGC 0.34	U – 0.41 SHGC 0.55	U – 0.38 SHGC 0.39	U – 0.38 SHGC 0.39	U – 0.38 SHGC 0.39	U – 0.55 SHGC 0.61	U – 0.71 SHGC 0.88
Doors	R- 2.2	R- 2.2	R- 2.2	R- 2.2	R- 2.2	2.2	2.2	2.2	2.2	2.2
Basement walls above grade	R- 11	R- 11	R- 11	R- 11	R- 11	R-11	R-11	R-11	R-11	R-11
Basement walls below grade	R- 11	R- 11	R-14	R- 11	R- 11	R-11	R-11	R-11	R-11	R-11
Duct location	Inside envelope	Inside envelope	Inside envelope	Inside envelope	Inside envelope	Inside envelope	Inside envelope	Inside envelope	Inside envelope	Inside envelope
Heating efficiency (AFUE)	93%	96%	93%	80%	80%	80%	80%	80%	80%	80%
Domestic water heating efficiency	40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.56 EF
Air tightness	.2 ACH Nat	.2 ACH Nat	.2 ACH Nat	.2 ACH Nat	.2 ACH Nat	0.28	0.28	0.28	0.28	0.43
Air conditioning SEER	10	12	10	10	10	10	10	10	10	10
Floors over unconditiond space	N/A	N/A	N/A	19	N/A	N/A	N/A	N/A	19	N/A
HERS Score	85.7	85.7	85.9	85.9	86.0	85.8	85.5	86.0	86.1	86.0

86 as possible. All homes were modeled with conditioned basements or crawlspaces, all ducts were modeled inside the conditioned envelope, and all homes were modeled with an estimated

air change rate of approximately 0.2 ACH under natural conditions, which was varied somewhat to achieve the desired 86 rating score in some cases. The primary characteristics of each home and its associated rating scores for the two climate zones are shown in Table **1**.

In order for all houses to achieve similar scores, improvements need to be made to the thermal envelope (and to the mechanical equipment in the cold climate) of the houses that are less than 2000 square feet compared to the houses that are larger than 2000 square feet. To some extent this is driven by the decision to keep domestic water heater efficiency held constant. While smaller houses could trade off water heater energy savings with other components if a more efficient domestic water heater was installed, the higher efficiency water heating would still represent additional costs. As can be seen in Table 2, as house size decreases the difference between water heating loads and total loads (heating, cooling and hot water) used to calculate the rating score increases.

Table 2 Comparison of water heating load to total (heating, cooling and hot water) load.

Pittsburgh PA				**Charleston SC**			
House Size (sf)	**Water Heating Load(MMBtu)**	**Total Load (MMBtu)**	**Water Heating as % of Total Load**	**House Size (sf)**	**Water Heating Load (MMBtu)**	**Total Load (MMBtu)**	**Water Heating as % of Total Load**
912	16.32	38.64	42%	912	12.96	30.12	43%
1537	19.68	46.08	43%	1537	15.60	40.80	38%
1922	20.40	61.32	33%	1922	16.20	50.28	32%
4060	20.40	85.92	24%	4060	16.20	69.00	23%
5564	24.48	130.68	19%	5564	19.44	113.64	17%

3.2 Methodology for Calibrating Rating Score to House Size and Occupancy

A number of different normalization procedures were explored in this analysis to develop a methodology for adjusting rating score based on house size and occupancy. Normalization factors studied were 1000 square feet total shell area per occupant, 1000 square feet above grade shell area per occupant, and just occupancy. The two combinations of loads that were studied were the sum of the normalized modified end use loads (as defined by the RESNET Rating Method, RESNET 2002) for heating and cooling for the rated house from the rating tool ($nMEUL_{HEAT} + nMEUL_{COOL}$), and the total normalized end use load (space heating and cooling and domestic hot water - $TnML = nMEUL_{HEAT} + nMEUL_{COOL} + nMEUL_{HW}$) from the rating tool. After analyzing all of these options, IBACOS came to the conclusion that normalizing by above grade shell area and occupancy gave a reasonable upper limit, as these are the two factors that most significantly drive energy consumption in residential buildings. Because shell area and occupancy were considered, we used the total modified load, which included energy used for water heating, which is driven by occupancy. A Shell Occupancy Factor (SOF) was generated for each house by dividing the above grade thermal envelope shell area (in thousands of square feet) by the projected occupancy. This in effect gives an occupancy-based measure of the shell area of the various sized houses. The occupancy was assumed as two for the first bedroom and one for each additional bedroom. Equation 1 was used to normalize total loads.

$$TML_N = TnML / SOF \qquad \textbf{(1)}$$

where

TML_N = total modified load normalized for shell area and occupancy units
$TnML$ = total normalized modified load from rating tool units

$$SOF = \frac{\text{Above grade thermal envelope shell area(in thousands of square feet)}}{\text{Occupancy (\# bedrooms +1)}}$$

The next step was to create projected total loads (PTL) for each house using the normalized load of the 1922 SF house as the base. The 1922 SF house was chosen as it represents the somewhat "average" house size. The PTL was computed using Equation 2.

$$PTL_{house} = TML_{1922} * SOF \tag{2}$$

where
PTL_{house} = projected total load of the rated house based on the TML_n of the base house(MMBtu)
TML_{1922} = total normalized modified load normalized for shell area and occupancy of the base house (MMBtu)
SOF = shell occupancy factor of the rated house

From these projected total loads, rating scores were developed using the formula from the Mortgage Industry National Home Energy Rating Systems Accreditation Standard (RESNET 2002) shown in Equation 3.

$$Target\ Score = 100-((PTL/TRL) *20) \tag{3}$$

where
PTL = projected total load of the rated home from Equation 2
TRL = total normalized modified load of the reference home from rating tool

The PTL and rating scores are shown in Table 3.

Table 3 Projected Total Load and Target Score Normalized Using Above Grade Shell Area (1922 square foot house base).

	Pittsburgh PA		***Charleston SC***	
House Size (sf)	PTL_{house}	***Target*** Score	PTL_{house}	***Target*** Score
912	42.17	84.4	34.58	83.7
1537	46.77	85.5	38.35	86.4
1922	61.32	86.2	50.28	86
4060	58.63	90.3	48.07	90.3
5564	74.68	92	61.23	92.4

The next step was to evaluate the rating score and loads of these houses if they all were built with the same energy features. We took the 1922 square foot house and developed an energy efficiency package that brought the house to a nominal score of 86. The energy features of this house are shown in the “1922 sf” column of

Table 1. This package was then applied to each of the other house sizes. Figure 1 shows the associated scores for each house and a Same Characteristics Curve (SCC) that represents the trend in score for that package.

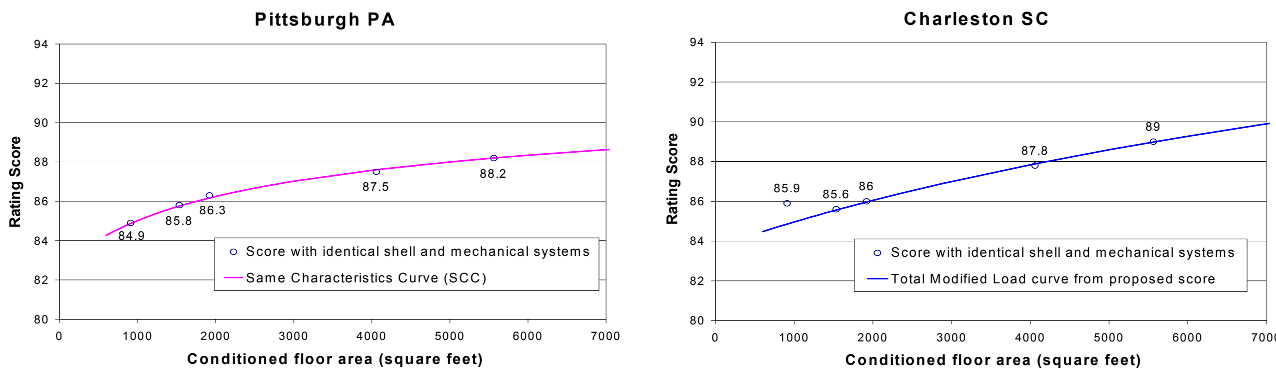


Figure 1 Same Characteristics Curve that represents the trend in score for houses with the 1922 square foot house HERS 86.3 energy features.

Figure 2 shows the associated scores for the normalized loads in Table 3. From this data, a curve was generated (Proposed Rating Score Curve, or PRSC) that minimizes the lowering of the rating score for small houses below that of the 1922 square foot house with HERS 86 energy characteristics, and generally fits to the ratings of the larger houses with the normalized loads.

Figure 2 Rating Scores for Houses with normalized loads vs. SCC and Projected Rating Score Curve.

A target score was then calculated for each house size from the PRSC, and from that rating, a target total modified load (TML) necessary to achieve that target score was calculated. The original TML and the PRSC (target) TML are compared in Figure 3, Table 4 and Table 5 to evaluate the absolute energy impact of the PRSC method.

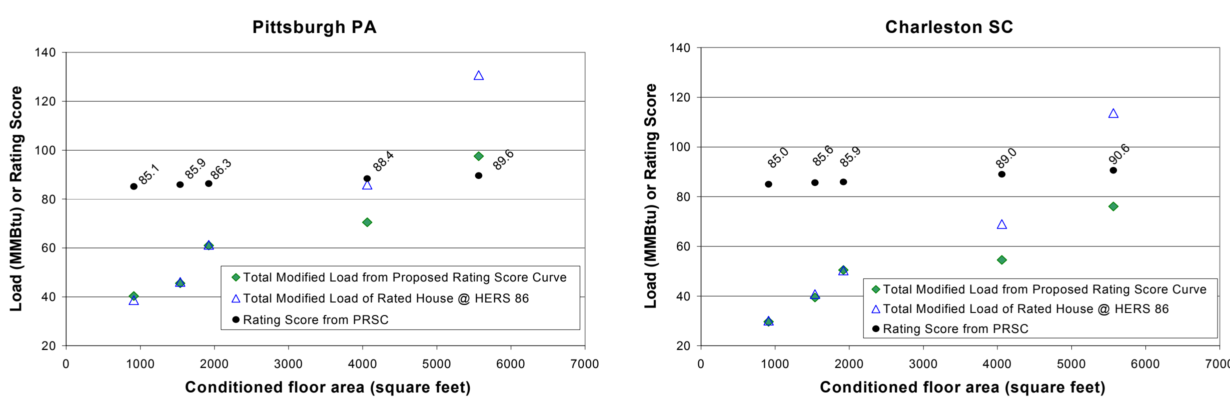


Figure 3 Comparison of total modified target loads using PRSC methodology and total modified loads from all homes at HERS 86 rating.

Table 4 Loads and scores associated with the PRSC Pittsburgh PA.

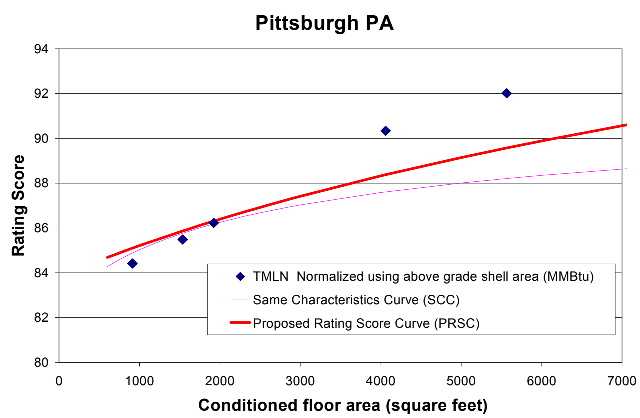
House Size (sf)	TML of HERS 86* House (MMBtu)	TML from PRSC (MMBtu)	Relative Difference (%)	Absolute Difference (MMBtu)	Original Rating Score*	Target Score from PRSC
912	38.64	40.33	-4%	-1.69	85.7	85.1
1537	46.08	45.55	1%	0.53	85.7	85.9
1922	61.32	60.98	1%	0.34	86.2	86.3
4060	85.92	70.49	22%	15.43	85.8	88.4
5564	130.68	97.54	34%	33.14	86	89.6

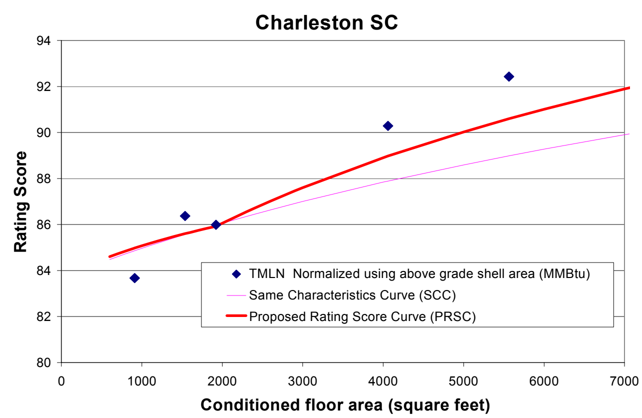
Table 5 Loads and scores associated with the PRSC Charleston SC.

House Size (sf)	TML of HERS 86* House (MMBtu)	Target TML from PRSC (MMBtu)	Relative Difference (%)	Absolute Difference (MMBtu)	Original Rating Score*	Target Score from PRSC
912	30.12	29.65	2%	0.47	85.8	86
1537	40.8	39.40	4%	1.40	85.5	86
1922	50.28	50.52	0%	-0.24	86	85.9
4060	69	54.57	26%	14.43	86.1	89
5564	113.64	76.07	49%	37.57	86	90.6

While there is a very small deviation from the calculated energy consumption in the smaller houses the target values for the largest houses are significantly lower, both in percentages and in absolute values.

The final analysis was to understand what the energy characteristics would be for these houses to





meet these target values. The characteristics for each house are shown in Table 6.

Table 6 Comparison of energy features for homes meeting the PRSC (R-Value in ft2●h●°F / Btu).

	Pittsburgh PA						**Charleston SC**				
	House Size						**House Size**				
Component	**912 sf**	**1537 sf**	**1922 sf**	**4060 sf**	**5564 sf**		**912 sf**	**1537 sf**	**1922 sf**	**4060 sf**	**5564 sf**
Walls	R-13 + R-5	R-13 + R-3	R-13 + R-4	R-19 + R-5	R-20 + R-5		R-13 + R-5	R-13 + R-5	R-13 + R-5	R-13 + R-5	R-13 + R-5
Ceilings	R-38	R-38	R-38	R-38	R-38		R-38	R-38	R-38	R-30	R-30
Windows & Glass Doors	U- 0.32 SHGC 0.34	U- 0.32 SHGC 0.34	U- 0.32SHGC 0.34	U- 0.32SHGC 0.34	U- 0.32SHGC 0.34		U-0.38 SHGC 0.39	U-0.38 SHGC 0.39	U-0.38 SHGC 0.39	U-0.35 SHGC 0.35	U-0.35 SHGC 0.35
Doors	R- 2.2	R- 2.2	R- 2.2	R- 2.2	R- 2.2		R- 2.2	R- 2.2	R- 2.2	R- 2.2	R- 2.2
Basement walls above grade	R-11	R-11	R-11	R-11	R-11		R-11	R-11	R-11	R-11	R-11
Basement walls below grade	R-11	R-11	R-14	R-11	R-11		R-11	R-11	R-11	R-11	R-11
Duct location	Inside envelope	Inside envelope	Inside envelope	Inside envelope	Inside envelope		Inside envelope	Inside envelope	Inside envelope	Inside envelope	Inside envelope
Heating efficiency (AFUE)	80%	96%	93%	96%	96%		80%	80%	80%	93%	93%
Domestic water heating efficiency	30 gal, 0.58 EF	40 gal, 0.56 EF	30 gal, 0.58 EF	40 gal, 0.58 EF	40 gal, 0.84 EF		40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.56 EF	40 gal, 0.61 EF	40 gal, 0.61 EF
Air tightness	0.2 ACH Nat	0.2 ACH Nat	0.2 ACH Nat	0.2 ACH Nat	0.2 ACH Nat		0.28 ACH Nat	0.28 ACH Nat	0.28 ACH Nat	0.28 ACH Nat	0.28 ACH Nat
Air conditioning SEER	10	12	12	12	12		10	10	10	12	12
Floors over unconditioned space	N/A	N/A	N/A	19	N/A		N/A	N/A	N/A	19	N/A
HERS Score	85.4	85.9	86.3	88.4	89.6		85.8	85.5	86.0	89.9	90.7

3.2.1 Factors Impacting the Method. One issue with this method that needs to be considered is climate zone and the attributes of the thermal envelope that drive energy consumption. In cooling dominated climates, the same building shell yielded virtually the same rating score for the 912, 1522 and 1922 SF houses. In the heating climate, significant improvements needed to be made in the thermal envelope and mechanical systems to achieve the same score. The decision to set water heater efficiency as the one variable that would be kept at a fixed efficiency was also somewhat arbitrary, however it is critical that the components chosen for the base house must be achievable by all house sizes. For example, if the base house is a one-story home and 2x4 framing at 24 in. o.c. is the framing characteristic, this cannot be achieved in a two-story home due to the requirements in Table 2308.9.1 in the International Building Code (2000) and other model codes that are still being used across the country.

In addition, the package used to establish the SCC is critical. This in effect becomes the prescriptive package for many homes in the size range smaller than the base house. As such, it is important to make sure that not only the energy efficiency but also the health and safety of the occupants and the durability of the shell are ensured. In this example, minimum efficiency water heating equipment was specified; however, the standards should be written to eliminate the possibility that the by-products of combustion can be introduced into the home. This can be achieved by requiring either direct vent, power vent, or sealed combustion equipment, or by locating the equipment in conditioned space that is airsealed from the remainder of the house. In some climate zones, it may be possible to locate the water heater in unconditioned spaces; however, this is not feasible in cold climates.

One other factor that needs to be evaluated is the level of building envelope moisture tolerance that can be achieved cost effectively, and what impact that has on building durability. In smaller houses with higher occupant densities, the envelope will likely be subjected to higher internal moisture loading than the same occupancy in a larger home. Standards for air tightness and vapor permeability of the envelope need to be evaluated and decided upon to minimize the possibility of building envelope damage due to moisture movement through air leakage and vapor diffusion. Reductions in energy scores for smaller houses should not necessarily be interpreted as allowing for houses that are not well airsealed and do not have controlled mechanical ventilation.

Finally, it is necessary to have a rating tool that generates individual end use loads for the reference house. IBACOS used it's own internal tool to perform this analysis, primarily because no other commercially available rating tool will provide these values explicitly. In order for this type of analysis to be performed more readily across the country, IBACOS recommends that rating tool developers consider making the energy consumption values for the reference home available, perhaps under a researcher or analysis licensing agreement.

3.2.2 Policy vs. Technical Decisions. It should be noted that there is no technical basis for the selection of the 1922 square foot house as the base for the development of the PRSC. The 912 square foot or 1537 square foot house could have been used as the home that scores 86 to generate the PRSC. Alternately, once the curve was generated, the scale could be shifted to make the 86 score land at virtually any house size. This is where a community developer or Green Building Program must look at their goals and determine which house size should represent the appropriate size for a given occupancy, and use that as the base for this methodology. The smaller the base house, the higher the target scores will be for larger houses. IBACOS studied this using smaller houses as the base for the PRSC, however it had the tendency to push large home scores up above a 93, and IBACOS' research indicates that it is not likely that scores above 90 - 91 would be acceptable to most of the industry at this point in time. It appears that using a house size in the range of 1900 to 2300 square feet as the base house yields a reasonable balance.

Using the smaller houses as the base that scores 86 will also likely have the impact of increasing the slope of the SCC, as achieving a score of 86 in a small house will require improvements in the thermal envelope, advanced airsealing, and heating, cooling and domestic hot water equipment improvements. This package of "across the board" improvements will likely mean even greater improvements as the house size increases, which may not be cost effective.

3.2.3 Impact of the Method on a Larger Number of Homes. Another issue that must be looked at in the use of this method is the variability in rating scores for the same house based on orientation, and for a product offering being built by a single builder. Typically builders IBACOS has worked with have asked for a worst-case package of building components in an integrated design that will get them to a given energy performance standard. This single package allows them to simplify their purchasing and construction process. By using this worst case package, the "fleet average" across a given house size or group of house sizes within the builders offering will be higher than the standard. While the worst-case package for smaller homes using the PRSC method may represent a slight decrease in energy efficiency, it is likely that the fleet average will be higher, and may actually meet the 86 level.

4. CONCLUSION

The use of a single home energy rating point score as a threshold of performance is a simple and equitable method to analyze energy savings in new and existing houses. As the housing industry is maturing to attempt to evaluate the relative energy efficiency of housing and the associated total environmental impact, new methods for defining performance and encouraging lower energy and resource use are necessary.

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