Evaluation of Energy Code Trade-Offs

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ABSTRACT

In late 1999 the Commonwealth of Pennsylvania passed legislation to adopt one or more statewide building codes. In November 1999, Pennsylvania adopted the Uniform Construction Code (UCC) legislation into law, creating a statewide building code across Pennsylvania. Part of this act requires the state to develop regulations for prescriptive methods to implement residential building energy requirements. The Pennsylvania Housing Research Center (PHRC) at Penn State University developed a simpler and more flexible alternative chapter to replace the International Residential Code (IRC), Chapter 11, Energy Efficiency. This alternative includes trade-off tables that allow builders to use certain less energy-efficient components if their impact is balanced by more efficient practices elsewhere in the building. These alternative prescriptive paths and trade-offs were analyzed for energy use using PowerDOE, a powerful, visual-based version of DOE 2.1E. In all cases, the proposed alternative code results in a net reduction in energy use relative to the IRC. This paper describes the process and presents the results of the energy modeling.

INTRODUCTION

In November 1999, Pennsylvania's governor signed the Uniform Construction Code (UCC) legislation into law, creating a statewide building code across Pennsylvania. The Act requires the Pennsylvania Department of Labor and Industry (DLI) to promulgate regulations to implement the requirement of the legislation. Chapter 3, Section 301 (c), Prescriptive Methods for Energy Conservation, requires the DLI to promulgate regulations for prescriptive methods to implement the energy requirements that take into account the various climatic regions in the Commonwealth. In deriving these standards, the law mandates that "the DLI shall seek to balance energy savings with initial construction costs."

It appears that the DLI will adopt the International Residential Code 2000 (IRC) (ICC 2000b) for use in residential structures in Pennsylvania. Chapter 11, Energy Efficiency, of the IRC 2000 contains national prescriptive standards. The Pennsylvania Housing Research Center's Industry Advisory Council charged the PHRC with developing an alternative code that was simpler, more flexible, and focused on Pennsylvania. This code was to be equivalent to the IRC 2000 Chapter 11.

In response, the PHRC has developed the PA-Alternative Chapter 11 for use with residential structures in Pennsylvania. This report is related to a companion paper in these proceedings, "The Development of an Alternative to Chapter 11 in the IRC 2000 for Use in Pennsylvania," which contains a general overview of the process that led to the alternative chapter.

This paper documents a study to compare the energy consumed for space conditioning by representative houses designed to meet the provisions of three different energy codes:

1. IRC 2000, Chapter 11: The first code is Chapter 11, Energy Efficiency, of the IRC 2000. This code is based on 15% window-to-wall area and is essentially the same as Chapter 6, Simplified Prescriptive Requirements for Residential Buildings, Type A-1 and A-2, of the 2000 International Energy Conservation Code (IECC) (ICC 2000a). This code will serve as the base case to determine equivalency of energy performance.

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TABLE 1
Table PA1103.4,
Above-Grade Thermal Envelope Trade-Off

Zone	Option[1]	Maximum U-Factor [Btu/(h·ft^2·°F)]		Minimum Thermal Insulation R-Value [(h·ft^2·°F) / Btu]	
				Wall	
		Fenestration[2]		Type A-1	Type A-2
		Type A-1	Type A-2		
S	a	0.50*	0.55	R-15	R-13
	b	0.55*	—	—	—
C	a	0.45*	0.53	R-16	R-13
	b	0.50*	—	—	—
N	a	0.40*	0.51	R-19	R-15
	b	0.45*	—	—	—

For S1: 1 Btu/(h·ft^2·°F)=5.68W/m^2·K, 1 (h·ft^2·°F)/Btu = 0.176m^2·K/W.
1. Option a allows a combination of higher fenestration U-factor and lower wall R-value. Option b allows only a higher fenestration U-factor.
2. Excluding skylights and opaque doors.

TABLE 2
Table PA1103.5,
Foundation Thermal Envelope Trade-Off

Zone	Minimum Thermal Insulation R-Value [(h·ft^2·°F) / Btu]			
	Floor over nonconditioned space	Slab perimeter R-value and length	Basement Walls	Crawl-space walls
S	R-19	R-4, 2 ft.	R-7	R-11
C	R-19	R-6, 4 ft.	R-8	R-13
N	R-21	R-9, 4 ft.	R-9	R-19

For S1: 1 Btu/(h·ft^2·°F)=5.68W/m^2·K, 1 (h·ft^2·°F)/Btu = 0.176m^2·K/W.

2. PHRC PA-Alternative, Chapter 11: The second code is the general thermal envelope requirements in the PA-Alternative Chapter 11 proposed by the PHRC. This code reduces the number of climatic zones across the Commonwealth from six (as found in the IRC 2000 [ICC 2000b]) to three. This approach results in a simpler code and provides more uniformity across the state.

3. PHRC PA-Alternative, Chapter 11, Trade-offs: The final code is the PA-Alternative Chapter 11, Section PA1103.8, Trade-offs, proposed by the PHRC (PHRC 2000a). These trade-offs will allow home designers and builders to make limited energy-neutral changes to the thermal envelope if especially airtight construction is used or if high-efficiency heating and cooling equipment is used. This approach results in more design flexibility without requiring the designer to go to the more complicated 2000 IECC (ICC 2000a). An abridged copy of Section PA1103.8, Trade-offs is contained in the Appendix. The trade-offs are specified in Tables 1 through 3.

OBJECTIVE AND SCOPE

The primary objective of this study was to determine whether the trade-offs being proposed in the PA-Alternative Chapter 11, Section PA1103.8, provide energy performance equivalent to that provided by the IRC for the Commonwealth of Pennsylvania. The secondary objective was to affirm the findings of another PHRC study (PHRC 2000b). This report found that general thermal envelope requirements of the PHRC PA-Alternative Chapter 11 are equivalent to the 2000 *International Energy Conservation Code* (IECC), as well as to the IRC 2000 Chapter 11.

In order to establish the energy effectiveness of these alternatives, the energy use of two model houses constructed in accordance with the PA-Alternative Chapter 11 was compared with a house constructed to the prescriptive standard in IRC 2000 Chapter 11. The proposed alternative prescriptive path was deemed acceptable if the space conditioning energy use of the house using the PA-Alternative was less than or equal to the house built to the IRC 2000.

This evaluation was limited to determining equivalence of the space conditioning energy for the various codes discussed above. It was also limited to looking only at the effect of the codes on single-family (Type A-1) houses in Pennsylvania's climate.

METHODOLOGY

Software

To evaluate the energy use implications of the trade-offs proposed in the PA-Alternative Chapter 11, two software packages were used. The primary software is PowerDOE (EPRI 1999). It performs an hour-by-hour simulation of the building over an entire heating and cooling season. The

TABLE 3
Table PA1103.6,
Equipment Requirements for High Efficiency Equipment Trade-Off

Climatic Zone	TYPE OF HEATING AND COOLING EQUIPMENT			
	Gas & Oil (Furnace or Boiler) with Central Air Conditioning		Air-Source Heat Pump	
PA Zone	Minimum AFUE	Minimum SEER	Minimum HSPF	Minimum SEER
S	90	any or none	7.8	12
C	92	any or none	8.0	any
N	92	any or none	8.2	any

Note: A building with multiple gas furnaces or heat pumps having different AFUE or HSPF/SEER values shall use an arithmetic average of the efficiency ratings of the installed equipment to determine whether the building complies with the minimum equipment performance requirement.

TABLE 4
Case Labels for Thermal Envelope Trade-Offs Modeled and Corresponding Sections in PA-Alternative

CASE			TRADE-OFF		SECTION IN PA-ALTERNATIVE	Software	
						PowerDOE	MEC*check*
1U-IRC 2000	1 Story	Unconditioned Basement	IRC 2000	Base Case		X	
1U-PA-Alternative			PA-Alternative			X	X
IU-PA1103.8.1.2			Reduced Inf	Lwr foundation	PA1103.8.1.2	X	
1U-PA1103.8.2.2			Hi-eff HVAC	Lwr foundation	PA1103.8.2.2	X	X
1U-PA1103.8.2.3				No Basement Ins	PA1103.8.2.3	X	
1C-IRC 2000	1 Story	Conditioned Basement	IRC 2000	Base Case		X	
1C-PA-Alternative			PA-Alternative			X	X
1C-PA1103.8.1.2			Reduced Inf	Lwr foundation	PA1103.8.1.2	X	
1C-PA1103.8.2.2			Hi-eff HVAC	Lwr foundation	PA1103.8.2.2	X	X
2U-IRC 2000	2 Story	Unconditioned Basement	IRC 2000	Base Case		X	
2U-PA-Alternative			PA-Alternative			X	X
2U-PA1103.8.1.1.a			Reduced Inf	Lwr window & wall	PA1103.8.1.1, Option a	X	
2U-PA1103.8.1.1.b				Lwr window	PA1103.8.1.1, Option b	X	
2U-PA1103.8.2.1.a			Hi-eff HVAC	Lwr window & wall	PA1103.8.2.1, Option a	X	X
2U-PA1103.8.2.1.b				Lwr window	PA1103.8.2.1, Option b	X	X

1U: One story, unconditioned basement; 1C: One story, conditioned basement;
2U: Two stories, unconditioned basement

secondary software was MEC*check* (PNNL 1998), which looks at the thermal envelope for compliance with the CABO *Model Energy Code* (MEC) (CABO 1992). MEC*check* was the initial tool used because it is specifically designed for builders and code officials to check whether alternative designs comply with the MEC. Although the MEC has been replaced by the 2000 IECC, the procedures are the same for Pennsylvania's climatic zones. MEC*check* cannot, however, handle the infiltration trade-off proposed in the PA-Alternative. Therefore, PowerDOE was used to examine the infiltration trade-off and as a second check of the other options.

PowerDOE is a state-of-the-art, building energy use, simulation program that combines DOE 2.2 with a graphical interface (EPRI 1999). PowerDOE is an hourly, whole-building energy analysis, computer program that calculates energy performance and operating cost. The DOE 2.2 software was developed with Lawrence Berkeley National Laboratories and is widely used by researchers and architectural and engineering firms to evaluate and optimize building performance. The software has also been used by the U.S. Department of Energy and others to develop various energy codes and to verify the accuracy of other simplified software packages.

The software performs detailed calculations based on the following:

- Hourly weather files for each location that are based on long-term weather data that include temperature, relative humidity, wind, and solar radiation data.
- Building description language that allows geometric description of the building and its various components. This includes the building's location and orientation, building materials and envelope components (walls, windows, shading surfaces, etc.).
- Thermal mass of the building and its effect on the energy usage of the building.
- HVAC equipment descriptions and controls, which are tied into occupancy schedules and account for variable equipment efficiency under partial loads and variations in outdoor temperature.

Because of the accuracy and the breadth of the variables that PowerDOE incorporates, this software was chosen as the primary evaluation tool. The software adequately addresses the energy effect of infiltration, solar gain, and thermal mass within the building's thermal envelope.

The other software, MEC*check* (Version 2.07), was developed by Pacific Northwest National Labs (PNNL) for the U.S. Department of Energy. This compliance tool is intended to make it fast and easy for designers and builders to determine whether new homes and additions meet the requirements of the CABO *Model Energy Code* (MEC).

MEC*check* allows builders or designers to vary insulation levels in the ceiling, wall, floor, basement wall, slab-edge, and crawl spaces; glazing and door areas; and glazing and door U-factors. MEC*check* calculates the total UA-value for a building. The U-factor is the heat loss coefficient for a particular material. The UA-value is simply the sum of the values of the product of U-factor and surface area for each of the individual components. By comparing the project's UA-value to the value required for the climatic zone, the software determines whether the project meets the MEC (2000 IECC) requirements. The software also allows the trade-off of heating and air-conditioning equipment efficiency.

This software was selected because it is a DOE-recognized tool for determining compliance with the MEC (2000 IECC). However, it does have some limitations. It evaluates the thermal shell of the building and not the annual energy use of a building, as PowerDOE does. It does not include any provision for infiltration, which typically accounts for 30% to 50% of the heat loss occurring in a single-family house. Therefore, its use was not appropriate for evaluating all of the various trade-offs. Table 4 shows the PA-Alternative trade-offs that were checked using the MEC*check* software.

Model Houses

The houses considered in this evaluation were based on the model houses developed for the U.S. Department of Energy by PNNL (PNL 1995; see also discussion in PHRC 2000b). To adequately represent Pennsylvania's housing, two house types were considered: single story and two story, each with a floor area corresponding to the national average size (1890 ft^2) (PNNL 1995). Both houses are single-family buildings (Type A-1) and both have full basements and an attached

TABLE 5
Characteristics of the Modeled Houses

Feature	One Story	Two Stories
Floor Area (ft^2)	1890	1890
Floor Dimensions (ft)	30×63	27×35
Basement Floor Area (ft^2)	1890	945
Wall Area – Gross (ft^2)	1488	1984
Window Area (15% Wall Area) (ft^2)	225	300
Doors	2	2
Ceiling Area (ft^2)	1890	945
Foundation Perimeter (ft)	186	124
Lighting (Wp)	756 (0.4 W/ft^2)	756 (0.4 W/ft^2)
Equipment (Wp)	360 (0.19 W/ft^2)	360 (0.19 W/ft^2)
Infiltration (Air changes/hour)	0.57	0.57
Occupants	5	5

TABLE 6
Wall Insulation Detail

Target R-Value	Batt Insulation	Insulated Sheathing[1]
R-15	15	--
R-16	13	3.1
R-18	13	5.2
R-19	13	6.3
R-21	13	8.3

[1]Insulation R-values reflect available product performance.

garage. Basements were modeled as unconditioned and conditioned spaces to identify whether that affected the alternative's acceptance. The base case building was assumed to have insulation on the basement walls. Table 5 describes the basic building characteristics used in the modeling. Both house types were oriented with the long walls facing north and south.

Several wall details were used to model the various wall R-values required in the different climatic zones and codes. The walls were modeled with the same construction (drywall, batt insulation, oriented-strand board or insulated sheathing, and vinyl siding) except that insulation levels were varied in the stud cavity and in the insulated sheathing. Table 6 shows the various insulation combinations used to achieve the required R-value. The walls were modeled with wood framing 16 inches on center, which correlates to 25% framing according to ASHRAE (1997).

The windows were selected on the basis of the U-factor requirements of the various codes. The window sizes reflect a 15% window-to-wall-area ratio. The windows were distributed in a uniform proportion between the north, east, south, and west orientations of the model houses. The shading coefficients and the visible transmittance values were representative of available windows of similar U-factors.

Infiltration

The PA-Alternative has a trade-off table for buildings with a "*maximum effective air change rate due to infiltration of 0.35 air changes per hour, as documented following a post-construction blower door test in accordance with ASTME779*" (ASTM 1987). In comparison, the 2000 IECC, section 401.1.3.10 Air Infiltration, specifies that the standard design should have an **annual average** air changes per hour (ACH) of 0.57 × W where W is a weather factor from ASHRAE Standard 136 (ASHRAE 1993). For cities in Pennsylvania, W ranges from a low of 0.76 in Harrisburg to 1.00 in Erie. This requirement of 0.57 × W appears to derive from Standard 136 wherein the "effective air change rate due to infiltration" is defined as:

$$A_I = L_n \times W \tag{1}$$

where

L_n = normalized leakage area, according to ASHRAE Standard 119 (ASHRAE 1988).

The Standard 136 does state that A_I, the effective air change rate due to infiltration, is an annual average value, making it consistent with the intent of the 2000 IECC.

The infiltration model used in PowerDOE is the Sherman-Grimsrud model developed at Lawrence Berkeley Laboratory. This model was chosen because it is the most accurate of the PowerDOE options and it is consistent with the ASHRAE standards mentioned previously. It also makes use of leakage area derived from blower door tests in accordance with ASTM Standard E779. Thus, there is a connection, albeit difficult to follow from one standard to another, between the test method used to measure air leakage and the code-specified annual average infiltration rate.

ASTM Standard E779 explains how to use measured fan pressurization data to determine the effective leakage area, L. ASHRAE Standard 119 explains how to convert L into L_n, normalized leakage, a dimensionless value defined by

$$L_n = 1000L/A(H/H_0)^{0.3} \tag{2}$$

where

L = leakage area of the space (ft^2 or m^2), as determined by a blower door test and ASTM E779,

A = floor area of the space (ft^2 or m^2),

H = height of the building, measured from "the lowest grade level to the highest ceiling of building space" (ft or m),

H_0 = height of a single story (8 ft or 2.43 m).

Normalized leakage L_n was intended to be used as a standard for airtightness of buildings. The standard defined acceptable limits of L_n using a map, a location table, or a calculation of infiltration degree-days. As a point of reference, an L_n limit of 0.57 (as used in the IECC standard design) applies to climates with infiltration degree-days of 9000°F-days (5000°C-days), which includes all of Pennsylvania.

To relate L_n to annual average air change rate due to infiltration, A_I, ASHRAE Standard 136-1993 makes use of W, the weather factor, as explained earlier. Thus, we now have a path that connects the effective leakage area from fan pressurization tests to annual average leakage rates:

$$A_I = 1000L/A(H/H_0)^{0.3}W \qquad (\text{ACH}) \tag{3}$$

To determine the L to be used in the Sherman-Grimsrud model in PowerDOE, this equation is solved for L:

$$L = A_I A(H/H_0)^{-0.3}/(1000\ W) \qquad (\text{ft}^2 \text{ or m}^2) \tag{4}$$

Interestingly, this equation clearly shows that if a code specifies A_I, then the leakage area that is allowed depends on several factors including (1) the building height, (2) the floor area, and (3) the location as defined by W. Perhaps the most significant consideration relates to building height. A two-story house would need to have a smaller leakage area than a one-story house with the same floor area in order to comply with the code, i.e., have the same annual average air infiltra-

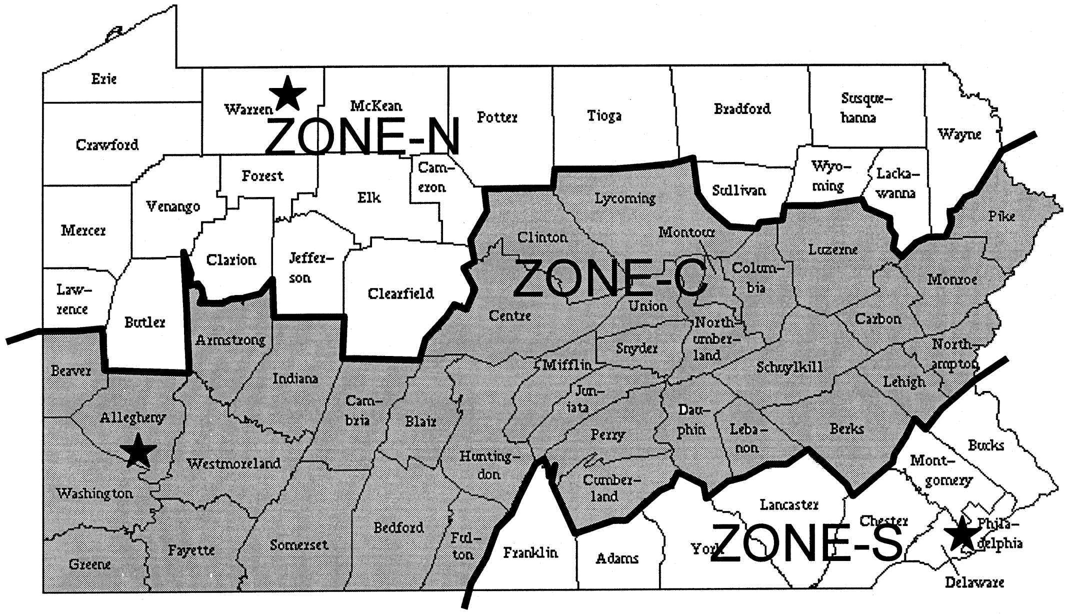

Figure 1 *City locations and PA-Alternative Climatic Zones.*

TABLE 7 Summary of Trade-Offs in PA-Alternative

Section of PA-Alternative		Trade-Offs	
		Improved	**Reduced**
PA1103.8.1	1, Option a	Low Air Infiltration	Lower window and wall performance
	1, Option b		Lower window performance
	2		Lower foundation performance
PA1103.8.2	1, Option a	High Equipment Efficiency	Lower window and wall performance
	1, Option b		Lower window performance
	2		Lower foundation performance
	3		Elimination of basement insulation if space is not conditioned and less than 12 inches of basement wall is exposed.

tion rate. This recognizes that a two-story house tends to leak more both because it is exposed to higher wind pressures and because the stack effect will be greater. In practical terms, it means that a builder will have to build two-story houses even tighter than one-story houses in order to achieve the infiltration level of 0.35 for the trade-off.

Other Modeling Features

Internal heat gains due to occupants, lights, and equipment usage were modeled as shown in Table 5, along with hourly schedules such that the average internal sensible heat gain was equivalent to 3000 Btu/h (879 W) as specified in section 402.1.3.6 (ICC 2000a).

Two HVAC (heating, ventilating, and air-conditioning) systems were considered for each house: a gas-fired furnace with electric split system air-conditioning (whole-house AC), and an electric heat pump. Equipment efficiencies were set to the minimums as defined in the IRC 2000 (0.78 AFUE for a gas furnace, cooling SEER of 10.0, and HSPF of 6.8 for heat pump). Where a trade-off involving high-efficiency equipment was considered, HVAC efficiencies in Table PA1103.6 were used. In the case of a conditioned basement, no duct losses were assumed since the ducts were assumed to be located inside the conditioned space. For an unconditioned basement, a duct loss factor of 0.80 was used according to section 402.1.3.9 (ICC 2000a).

To adequately represent the state of Pennsylvania, three towns were used in the analysis: Philadelphia, Pittsburgh, and Bradford (See Figure 1). These three cities correspond to the south (S), central (C), and north (N) climatic zones defined in Figure 1. Incidentally, the prescriptive requirements proposed in the PA-Alternative correspond directly to those in IRC 2000

TABLE 8
Energy Effectiveness of Proposed Trade-Offs for Philadelphia, Climatic Zone S (PowerDOE)

CASE	TRADE-OFF		GAS (MBtu)	CHANGE (%)	HEAT PUMP (MBtu)	CHANGE (%)	AVERAGE CHANGE (%)
1U - IRC 2000	Base Case		83.0	BASE	52.6	BASE	BASE
1U - PA-Alternative	PA Alt		83.3	0.4	52.8	0.4	0.4
1U - PA1103.8.1.2	Red Inf	Lwr foundation	71.0	–14.4	44.1	–16.3	–15.3
1U - PA1103.8.2.2	Hi-eff HVAC	Lwr foundation	73.6	–11.3	46.8	–11.1	–11.2
1U - PA1103.8.2.3		No Basement Ins	78.8	–5.1	48.9	–7.1	–6.1
1C - IRC 2000	Base Case		80.6	BASE	54.1	BASE	BASE
1C - PA-Alternative	PA Alt		80.9	0.4	54.3	0.4	0.4
1C - PA1103.8.1.2	Red Inf	Lwr foundation	68.2	–15.4	45.8	–15.2	–15.3
1C - PA1103.8.2.2	Hi-eff HVAC	Lwr foundation	72.1	–10.6	47.9	–11.4	–11.0
2U - IRC 2000	Base Case		74.6	BASE	49.6	BASE	BASE
2U - PA-Alternative	PA Alt		74.9	0.4	49.8	0.4	0.4
2U - PA1103.8.1.1a	Red Inf	Lwr window & wall	69.8	–6.4	47.1	–5.1	–5.8
2U - PA1103.8.1.1b		Lwr window	70.5	–5.5	47.3	–4.8	–5.1
2U - PA1103.8.2.1a	Hi-eff HVAC	Lwr window & wall	69.9	–6.3	45.7	–8.0	–7.2
2U - PA1103.8.2.1b		Lwr window	70.4	–5.6	45.8	–7.8	–6.7

1U: One story, unconditioned basement; 1C: One story, conditioned basement;
2U: Two stories, unconditioned basement

TABLE 9
Energy Effectiveness of Proposed Trade-Offs for Pittsburgh, Climatic Zone C (PowerDOE)

CASE	TRADE-OFF		GAS (MBtu)	CHANGE (%)	HEAT PUMP (MBtu)	CHANGE (%)	AVERAGE CHANGE (%)
1U - IRC 2000	Base Case		89.6	BASE	52.8	BASE	BASE
1U - PA-Alternative	PA Alt		89.9	0.3	53.0	0.4	0.4
1U - PA1103.8.1.2	Red Inf	Lwr foundation	78.0	–13.0	47.5	–9.9	–11.4
1U - PA1103.8.2.2	Hi-eff HVAC	Lwr foundation	79.7	–11.1	48.3	–8.4	–9.8
1U - PA1103.8.2.3		No Basement Ins	86.0	–4.0	51.1	–3.1	–3.6
1C - IRC 2000	Base Case		86.5	BASE	52.8	BASE	BASE
1C - PA-Alternative	PA Alt		86.8	0.3	53.0	0.4	0.4
1C - PA1103.8.1.2	Red Inf	Lwr foundation	74.1	–14.3	47.1	–10.9	–12.6
1C - PA1103.8.2.2	Hi-eff HVAC	Lwr foundation	77.3	–10.6	48.8	–7.6	–9.1
2U - IRC 2000	Base Case		79.1	BASE	52.3	BASE	BASE
2U - PA-Alternative	PA Alt		79.4	0.4	52.5	0.4	0.4
2U - PA1103.8.1.1a	Red Inf	Lwr window & wall	72.8	–7.9	48.9	–6.5	–7.2
2U - PA1103.8.1.1b		Lwr window	74.6	–5.7	50.2	–4.0	–4.8
2U - PA1103.8.2.1a	Hi-eff HVAC	Lwr window & wall	72.8	–7.9	49.6	–5.2	–6.5
2U - PA1103.8.2.1b		Lwr window	74.4	–5.9	50.6	–3.3	–4.6

1U: One story, unconditioned basement; 1C: One story, conditioned basement;
2U: Two stories, unconditioned basement

TABLE 10
Energy Effectiveness of Proposed Trade-Offs for Bradford, Climatic Zone N (PowerDOE)

CASE	TRADE-OFF		GAS (MBtu)	CHANGE (%)	HEAT PUMP (MBtu)	CHANGE (%)	AVERAGE CHANGE (%)
1U - IRC 2000	Base Case		109.9	BASE	67.1	BASE	BASE
1U - PA-Alternative	PA Alt		110.4	0.5	67.4	0.4	0.5
1U - PA1103.8.1.2	Red Inf	Lwr foundation	88.1	–19.8	55.1	–17.9	–18.9
1U - PA1103.8.2.2	Hi-eff HVAC	Lwr foundation	96.3	–12.3	61.4	–8.6	–10.4
1U - PA1103.8.2.3		No Basement Ins	107.0	–2.6	66.8	–0.5	–1.5
1C - IRC 2000	Base Case		109.2	BASE	68.5	BASE	BASE
1C - PA-Alternative	PA Alt		109.7	0.5	68.8	0.4	0.5
1C - PA1103.8.1.2	Red Inf	Lwr foundation	84.0	–23.1	53.6	–21.7	–22.4
1C - PA1103.8.2.2	Hi-eff HVAC	Lwr foundation	96.2	–11.9	63.0	-8.1	–10.0
2U - IRC 2000	Base Case		91.6	BASE	60.1	BASE	BASE
2U - PA-Alternative	PA Alt		92.1	0.5	60.4	0.5	0.5
2U - PA1103.8.1.1a	Red Inf	Lwr window & wall	81.4	–11.1	54.3	–9.6	–10.4
2U - PA1103.8.1.1b		Lwr window	81.7	–10.8	54.7	–9.0	–9.9
2U - PA1103.8.2.1a	Hi-eff HVAC	Lwr window & wall	85.7	–6.5	57.9	–3.6	–5.0
2U - PA1103.8.2.1b		Lwr window	85.8	–6.3	58.2	–3.1	–4.7

1U: One story, unconditioned basement; 1C: One story, conditioned basement;
2U: Two story, unconditioned basement

Chapter 11 for these cities (except for the opaque doors, as discussed later).

In the interest of limiting the number of modeling cases studied, cases were selected for the housing type (one-story or two-story) that would be most critical. The two houses, while having identical floor areas, have dramatically different sizes of various components of the thermal envelope, as can be seen in Table 4. Because the one-story house has a larger basement (twice the floor area of the two-story house) it is the most critical case for determining the equivalence of trade-offs related to basement insulation. The logic underlying this is that if the trade-offs make sense for the larger basement, then they should also make sense for the smaller basement in the two-story house since the energy impact of basement changes is less. Similarly, only the unconditioned basement was considered for the two-story case, again because of the smaller basement and the fact that the single-story house cases were justified.

Because the surface area of the walls and windows is considerably larger for the two-story house, a two-story house was selected to evaluate the above-grade portions of the trade-offs. Table 7 shows the relation between the proposed trade-offs and the cases considered here. Even though only the critical cases were looked at in order to reduce the number of runs, this analysis required a large number of computer runs. Consider the following:

PowerDOE:
15 Cases × 2 HVAC Systems × 3 Locations

+ MEC*check*:
7 Cases × 2 HVAC Systems × 3 Locations

= 132 Computer runs

RESULTS

PowerDOE

The results for the PowerDOE analysis for each city are shown in Tables 8, 9, and 10. These tables show the annual energy use for each case, in million Btu of purchased energy. They include the HVAC efficiencies and, therefore, are the appropriate values for comparing energy effectiveness. However, because they do not include energy costs, the numbers do not necessarily correspond to cost or cost-effectiveness. The percent change column is the most relevant information for determining how the trade-off compares with the base case house built to the IRC 2000. If an alternative is acceptable, it will have a negative (or zero) percent change, meaning that the alternative uses less (or the same amount of) energy than the base case.

TABLE 11
MEC*check* Results

Case	Philadelphia, Climatic Zone S		Pittsburgh, Climatic Zone C		Bradford, Climatic Zone N		Average
	Gas	Heat Pump	Gas	Heat Pump	Gas	Heat Pump	
1U-PA-Alternative	–2.5%	–2.5%	–0.8%	–0.8%	–1.8%	–1.8%	–1.7%
1U- PA1103.8.2.2	–13.1%	–14.0%	–10.9%	–10.3%	–12.9%	–14.8%	–12.7%
1C-PA-Alternative	–1.9%	–1.9%	–2.0%	–2.0%	–1.1%	–1.1%	–1.7%
1C- PA1103.8.2.2	–13.8%	–12.5%	–8.1%	–7.5%	–12.9%	–12.3%	–11.2%
2U- PA-Alternative	–4.9%	–4.9%	–5.3%	–5.3%	–3.3%	–3.3%	–4.5%
2U- PA1103.8.2.1.a	–10.8%	–10.2%	–9.8%	–9.3%	–9.2%	–11.2%	–10.1%
2U- PA1103.8.2.1.b	–9.6%	–9.1%	–7.8%	–7.2%	–6.1%	–8.2%	–8.0%

1U: One story, unconditioned basement; 1C: One story, conditioned basement;
2U: Two stories, unconditioned basement

TABLE 12
Summary of Energy Effectiveness

PA-Alternative			Case	Average% Difference[1]	
				PowerDOE[2]	MEC*check*[3]
General Thermal Envelope Requirements			1U-PA-Alternative, 1C-PA-Alternative, 2U-PA-Alternative	0.4%	-2.6%
PA1103.8 Trade-offs	PA1103.8.1	1. Option a	2U-PA1103.8.1.1.a	–7.8%	--
		1. Option b	2U-PA1103.8.1.1.b	–6.6%	--
		2	1U-PA1103.8.1.2 1C-PA1103.8.1.2	–16.0%	--
	PA1103.8.2	1. Option a	2U-PA1103.8.2.1.a	–6.2%	-10.1%
		1. Option b	2U-PA1103.8.2.1.b	–5.3%	-8.0%
		2	1U-PA1103.8.2.2 1C-PA1103.8.2.2	–10.3%	-11.9%
		3	1U-PA1103.8.2.3	–3.7%	--

Notes:
1. A negative number indicates energy savings or lower energy usage.
2. Average % difference between the proposed code requirements compared to the IRC 2000, Chapter 11.
3. Average % difference between the proposed code requirements compared to the 2000 IECC (MEC).

The first comparison to observe is between a house built to the PA-Alternative with one built to the IRC 2000. The only difference for the cities chosen for analysis is in the required U-factor for the opaque doors. The IRC 2000 maximum U-factor is 0.35 and the PA-Alternative is 0.39. This very slight increase in the PA-Alternative results in a slight increase in the annual energy use, ranging from 0.3% to 0.5%. This very small change is considered acceptable and demonstrates that the PA-Alternative, for these cities, is essentially equivalent to the IRC 2000.

In the case of the trade-offs considered as proposed in the PA-Alternative, in all of the 54 trade-off cases modeled (shown in Tables 8 to 10), the alternatives are acceptable. In fact, in many cases the alternatives use significantly less energy (up to 23% less) than the base case, indicating that further trade-offs may be appropriate, particularly for the reduction of infiltration.

MEC*check*

The MEC*check* analysis was performed on cases that the software could adequately address. This included high-efficiency equipment trade-offs (PA1103.8.2) and also the general thermal envelope requirements for the PA-Alternative, but not the below-grade trade-offs. Each case was run for the three Pennsylvania cities and with the two HVAC systems as previously discussed.

The results from the MEC*check* computer runs are presented in Table 11. These results are the percent change in the overall UA-value of the model house. Again, a negative value indicates less energy use and increased efficiency. Each of the seven cases not only passed the MEC*check* for compliance with the MEC (2000 IECC) but would also provide improved energy performance over that required by the MEC (2000 IECC).

The computer runs for the cases evaluating the PA-Alternative indicated a savings of 2.3% more energy than the 2000 IEC, a result that confirms the findings in the PHRC Report No. 70, *Thermal Envelope Assessment of Energy Code Provisions for Pennsylvania*. This report states that the PA-Alternative's improvement over the 2000 IECC would be around 1.8% for a 15% window-to-wall area ratio.

CONCLUSIONS

This study demonstrates that it is feasible to define trade-offs in the prescriptive requirements of building energy codes that result in equivalent (or better) energy performance. These trade-offs provide a degree of flexibility for builders that is not available without using the more complicated and costly performance-based compliance path.

The proposed trade-offs in Section PA1103.8 were modeled to determine annual energy use. Two computer programs were used to evaluate the energy effectiveness of both the trade-offs and the general thermal envelope requirements of the PA-Alternative Chapter 11. PowerDOE was the primary modeling software that modeled overall energy use of the model houses, and MEC*check* was used to determine compliance with the MEC.

Table 12 provides a summary of the 132 computer runs required to model the various codes and trade-off options. This table averages the energy impact of the PA-Alternative and the various trade-off sections. For each case the average includes the two HVAC systems, three locations, and in some cases unconditioned and conditioned basements.

It should be noted that the numbers in the percent difference columns in Table 12 have different baselines, i.e., for the PowerDOE and the MEC*check* runs. This is because the PowerDOE software compares the various cases to the IRC 2000 Chapter 11 prescriptive requirements, while the MEC*check* compares the thermal envelope requirements against the MEC (2000 IECC) performance requirements. In addition, PowerDOE models the building hour by hour over a complete heating and cooling season, while MEC*check* simply compares the thermal envelope requirements. Therefore, while both columns indicate energy savings, they are not exactly equivalent.

In all cases the trade-offs proposed in Section PA1103.8 of the PA-Alternative result in a reduction in annual energy use relative to the base case constructed to meet IRC 2000 prescriptive standards. These savings range between 0.5% and 23.1%. On this basis, therefore, the trade-offs investigated are justified and acceptable.

The results of the comparison of the general thermal envelope requirements for the PA-Alternative were consistent with the findings of PHRC Report No. 70, which indicated a 1.1% decrease in thermal envelope performance between the PA-Alternative and the IRC 2000 for 14.2% window-to-wall area ratio while the PowerDOE model anticipated a 0.4% increase. Additionally, Report No. 70 indicated that the PA-Alternative would provide an overall improvement in the thermal envelope over the 2000 IECC of 3.2%; the MEC*check* software indicated a 2.6% improvement. This report further supports the findings of Report No. 70 that the PA-Alternative is equivalent to the 2000 IECC.

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APPENDIX

Proposed Trade-offs in the PA-Alternative to Chapter 11 –Energy Efficiency, International Residential Code 2000:

PA1103.7 Trade-offs. Qualifying buildings shall be permitted to apply either the low air infiltration trade-off

(PA1103.7.1) or the high-efficiency HVAC equipment trade-off (PA1103.7.2) or both.

PA1103.7.1 Low air infiltration trade-off. Buildings with a maximum effective air change rate due to infiltration of 0.35 air changes per hour, as determined (in accordance with ASHRAE Standards 119-1988 and 136-1993) by a post-construction blower door test done in accordance with *ASTM E779-87, Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*, shall be permitted to adopt one of the following revised compliance criteria for building thermal envelope components:

The above-grade portions of the building's thermal envelope shall comply with Table PA1103.4 for the building type and climatic zone where the building is located, **or**

The foundation of the building shall comply with Table PA1103.5 for the building type and climatic zone where the building is located.

PA1103.7.2 High-efficiency equipment trade-off. Type A-1 buildings with high-efficiency equipment meeting the requirements specified in Table PA1103.6 shall be permitted to adopt one of the following compliance criteria:

The above-grade portions of the building's thermal envelope shall comply with Table PA1103.4 for the climatic zone where the building is located, **or**

The foundation of the building shall comply with Table PA1103.5 for the climatic zone where the building is located, **or**

Type A-1 buildings having basements that are unconditioned areas and basement walls with an average exposure not greater than 12 inches (305 mm) above adjacent grade are not required to meet the minimum R-value for Basement Walls in Table PA1103.5. This means that neither the basement walls nor the floor above needs to be insulated.