The Design and Implementation of Energy Efficiency Building Codes in Developing Countries: The Case of Jamaica

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Jamaica has developed an energy code for new commercial buildings and major retrofits. The Jamaica code draws heavily on ASHRAE's recent standard 90.1-1989, plus elements of several other energy codes. Many key requirements of the Jamaica code are more stringent than ASHRAE 90.1-1989 and the code is projected cost-effectively to reduce energy use by 30% or more compared with current practice. Yet the code's format stresses brevity and simplicity, resulting from experience in several countries in the Association of Southeast Asian Nations (ASEAN).

Jamaica's two years' experience in implementation has stressed in-country skill building and is producing changes in building design practice even before the code is mandated. Activities that Jamaican professionals have developed/presented include workshops, compliance guidelines, energy and economic analyses, and compliance checks on building designs.

The energy and economic analysis, via computer simulations of typical large and small office buildings, confirmed that the current code requirements are highly cost-effective. Also, the results indicate that if code requirements were to be set and implemented at economically optimal levels then the result would be energy reductions from pre-code practice of 50% or more.

The economic analyses were based on detailed actual costs in Jamaica, and have corroborated results from an earlier study of conservation potentials in Thailand using less detailed cost data. Furthermore, a variety of evidence indicates that such levels of conservation are likely to be cost-effective in other tropical countries.

Purpose

This paper describes the development and implementation efforts of an Energy Efficiency Building Code (EEBC) for Jamaica.[1] The code applies to all new buildings, major retrofits and renovations, except residential buildings of three stories or less. A major purpose of this paper is to describe the potential energy and economic impacts of the EEBC, and to discuss implications not only for Jamaica but for other developing countries in the tropics. This paper also explores potential uses of code requirements defined at economically optimal levels for use in tropical countries.

As in many developing countries, Jamaican commercial, hotel and institutional buildings use a substantial proportion of generated electricity, using over 1/3 of the electricity generated by the Jamaica Public Service Corp. (JPS). Imported oil is the primary fuel used to generate 90% of JPS electricity.

Since commercial, hotel and institutional floor space is expected to increase by more than 5% for each of the next five years or so, increases in efficiency of new building designs represent a substantial energy and cost savings to both building owners and to this island nation. Improved building energy efficiency will also assist Jamaica to avoid the need for additional electricity generating capacity. In consequence, the code that has been developed is viewed as a key element in a demand-side management (DSM) program under development in Jamaica. Another objective of the Jamaican effort has been to develop products and procedures that could be applied to other developing countries in the tropics.

Energy Code Context

Codes and standards have to date primarily specified *minimum* energy criteria to be met. These criteria typically apply in one of three ways: (1) to specific minimum prescriptive or performance criteria for energy-related building materials or components; (2) to specific minimum performance criteria for entire building subsystems; or, (3) to specify minimum performance criteria for whole buildings.

Industrialized countries have used energy efficiency codes for close to two decades, and are now using a second or third generation version. For example in the US, since 1975 three generations of ASHRAE voluntary energy standards for new commercial and high-rise residential buildings (ASHRAE Standard 90) have been widely used as major sources for energy codes. ASHRAE 90-based codes are also increasingly in use by electric utilities in new construction DSM programs as base lines for establishing program measures and for assessing program benefits. The 1975 version (ASHRAE 90-75) was estimated to reduce energy use by 25% to 40% from typical mid-1970's buildings (Willman et al. 1980). The second version in 1980 (ANSI/ASHRAE/IES 90A-1980) had only minor impact on energy savings (Reilly et al. 1983). Drafts of the third version in 1989 (ASHRAE/IES 90.1) were estimated to save an average of about 15% more than the 1980 version (Crawley and Briggs 1985).

In developing countries, the use of energy efficiency codes is a more recent phenomenon. A number of countries began developing energy codes in the late 1980s, including Indonesia, Jamaica, Malaysia, Pakistan, the Philippines, and Thailand.[2] In most of these countries, early drafts of the 1989 ASHRAE standard (then under development) were used as a primary source of code format and criteria, with modifications made to suit local climates and building industry conditions (SSPC 90.1 Committee 1989).

In most of the aforementioned countries, the levels of key requirements are substantially the same as those of the 1989 ASHRAE standard. For Jamaica the levels were set higher, with key energy requirements surpassing those required in the 1989 ASHRAE standard, based on experience gained in other countries and on the Jamaican energy code committee objectives. From analyses made of potential energy efficiency improvements, most countries could expect implementation of energy codes to potential reduce energy use in new buildings by about 18% to 24%. (Deringer and Levine 1990). Estimated efficiency improvements for the Jamaica code are higher at 30% to 36% (Cumper and Marston 1991).

To date the levels of requirements in ASHRAE standards for commercial buildings have been established primarily based on a consensus of professional judgment. In this process economic considerations typically have been employed only indirectly and implicitly, rather than as explicit economic criteria for determining appropriate levels of requirements. Recently, an effort has occurred within ASHRAE's residential standards development process to use economic criteria for determining energy requirements for selected products. For commercial buildings, two efforts are now underway to explore the use of explicit economic criteria as part of establishing the requirements of energy standards. One is a DOE-funded research project on whole-building energy targets (Jones et al. 1990), and the other is an effort underway to develop the next generation of the ASHRAE 90 standard.

Meanwhile, economic analyses *have* been widely used to assess the impacts of requirements that have been established by ASHRAE (e.g., Crawley and Briggs 1985; Reilly et al. 1983; A.D.Little 1976). Such studies have shown that the requirements were very cost effective. However, these studies have not addressed the question of how far the requirements might be increased on a cost-effective basis from a national or societal economic perspective. In other words, what levels of requirements would be economically optimal from a national perspective?

In contrast, the analysis of the Jamaican code energy requirements has addressed the question of potential economically optimal levels. For the analysis, "economically optimal" was defined for the national economic perspective as the point where the incremental life cycle cost of energy efficiency measures (construction and operations) equalled the incremental life cycle benefits via reductions in energy costs, where the incremental net present value (NPV) equals zero, using a 12% discount rate (real), a 20 year study period, and no duties or taxes.

The analyses conducted to date do not permit identification of the actual point of the economic optimum. However, the analyses do identify a boundary condition on the economic optimum for office buildings from a national perspective. Namely, economically optimal levels will produce energy reductions from current practice of more than 50%. Further economic analyses have been planned to refine these results, both to identify the location of the economic optimum and to extend the analysis to the hotel building type, but these analyses await additional funding. The analysis conducted to date is discussed in more detail below.

Energy Use of Jamaican Building Stock

Jamaica is an island country of about 2-1/2 million people. Alumina exports and tourism form the basis for its modern economy, replacing sugar and banana exports from prior eras. Almost 40 percent of the population resides in Kingston, its business center and principal city on the south coast. Most tourism is on the north coast, served by the airport at Montego Bay.

Jamaica is located in the Caribbean at 18° north latitude, about 500 miles due south of Miami, and has a typical hot, humid tropical climate. Jamaica's climate shares many features with tropical climates around the world, such as those in the tropical areas of Africa or in the ASEAN countries (Wilson 1989).

A recent survey of energy-related features of Jamaican buildings gathered general building data and consumption data for 99 office buildings (Ashby 1988). The average consumption was about 22 $kWh/ft^2/year$ (238 $kWh/m^2/year$) for the large office buildings and about 20 $kWh/ft^2/year$ (215 $kWh/m^2/year$) for the small office buildings. This is very similar to energy use levels and patterns from surveys in S.E. Asia and Africa.

In an ASEAN survey, actual office building consumption averaged 22.9 $kWh/ft^2/year$ (246 $kWh/m^2/year$) for a sample of over 70 office buildings in five ASEAN countries (Indonesia, Malaysia, the Philippines, Singapore, and Thailand) (Levine, Busch and Deringer 1989). Likewise, in the Côte d'Ivoire, West Africa, actual consumption for 14 office buildings, within a survey sample of 26 buildings, was 21.8 $kWh/ft^2/year$ (235 $kWh/m^2/year$) (BEE 1987). These samples were all derived during the mid to late 1980s in locations with similar climate regimes--hot and humid, with fairly uniform conditions year-round and high proportions of diffuse solar radiation. For hotels, a sample of 8 hotels in Côte d'Ivoire yielded an average of 265 $kWh/ft^2/year$ (286 $kWh/m^2/year$), while a sample of 34 ASEAN hotels produced an average of 285 $kWh/ft^2/year$ (307 $kWh/m^2/year$).

The similarity of energy use intensities does not mean that building features and operations are identical in all locations; however, some strong similarities do exist. The buildings in all regions have the following similarities: air-conditioning is the predominant energy use, at over 60%; there is widespread use of constant-volume systems; controls for energy-using systems are generally quite simple compared with those in industrial countries. There are some exceptions to these typical controls and ventilating and air-conditioning (VAC) systems. For example, Singapore and Malaysia, in comparison with the other countries cited, tend to use more efficient, but more complicated, variable air volume (VAV) systems and also to employ more sophisticated VAC control technologies. In a number of countries, illumination criteria are lower than those in recent use in the US. For the building envelope, insulation has been used only rarely in either walls or roof; amounts and types of glass used tend to be similar in different locations, and about 1/2 of office buildings use some combination of exterior overhangs and fins to shade windows from the sun. Also, in many countries building maintenance practices are erratic or almost non-existent, and building industry infrastructures are only partly formed.

The Jamaican Energy Code

Development

The origins of the Jamaican energy efficiency code for buildings began during the mid-1980s. A technical review committee was formed under auspices of the Jamaican Bureau of Standards, that contained diverse public and private sector representation.[3] Under direction of the review committee, three drafts of the code have been developed to date.

A first draft of the Jamaican code was completed in 1988, with main sources being the ASHRAE 1989 draft under development plus key energy code provisions from Florida, California, and Malaysia. A second draft, prepared in 1990 and designated as EEBC-90, did not change the requirements but rather was a substantial rewriting of the first draft, to shorten the text and to simplify compliance.[4] This draft was approved by the Jamaican Bureau of Standards in early 1991 for a public review process. As part of the implementation process, the code has been in voluntary use by the private sector. In mid 1991, it was made mandatory for government buildings at the direction of the Minister of Construction.

A public review of the EEBC-90 code occurred as part of the implementation program during 1990-1991. This public review identified a number of desirable refinements to the code, which were incorporated into a third draft of the code prepared in early 1992 and designated as EEBC-92. This third draft also incorporates joint metric/english units as part of a Jamaican metrication program. While this 1992 draft has refined a number of energy requirements from the 1990 draft, the overall energy impact remains essentially the same (Deringer and Dubin ed. 1990).

Similar energy code development and implementation programs are now underway in Columbia and in Côte d'Ivoire. For example, in Côte d'Ivoire the Jamaican code has been translated into a French metric version that will serve as a starting point for the development of an Ivorian energy code. A similar version in Spanish is planned for Colombia. In both Côte d'Ivoire and Colombia, energy and economic analyses are planned both to assess the impacts of the proposed energy code levels and also to develop the technical basis for the consideration of establishing further levels of code requirements based on economic criteria.

Implementation of the Jamaican Code

The work in Jamaica is unique among recent code efforts in developing countries in the extent of efforts to implement the code once developed. These implementation efforts have had widespread involvement of the Jamaican buildings industry, have produced several products, and are contributing to positive changes in building design and construction practices for energy conservation. The implementation activities have produced four key products:

- **Compliance Guidelines:** These focus on local examples of code compliance and include two aids to simplify compliance with the code: (1) code compliance forms, and (2) several computer spreadsheet programs. The compliance guidelines were written by a team of five Jamaican architects and engineers (Dundas et al. 1991). The team started from basic materials assembled from the US and elsewhere.

- **Energy and Economic Analyses:** An analysis of energy and economic impacts of the code was conducted by two Jamaican analysts. This work is discussed more fully below, and is also described in a draft report. (Cumper and Marston 1991).

- **Compliance Checking and Process:** As part of the implementation effort, the Jamaican EEBC Review Committee members conducted an exercise of checking the compliance of selected building designs with the EEBC-90 code provisions. These activities not only enabled the EEBC committee members to become thoroughly familiar both with the EEBC code and with compliance procedures, but also to identify a number of key refinements and improvements to the EEBC code and to the compliance process.

- **Workshops:** Three 2-day workshops were given to introduce the code and compliance procedures to architects, engineers and other members of the buildings community. Most workshop presentations were prepared and delivered by members of the Jamaican guidelines team, analysis team, or EEBC Review Committee.

These implementation efforts have led to a pragmatic approach to compliance and enforcement of the EEBC. The approach minimizes the need for additional infrastructure by building carefully on existing compliance capabilities and procedures. It is planned that the skills and experience resident in the EEBC Review Committee will continue to be used as part of this process.

Energy and Economic Analysis of Code Impacts

This effort sought answers to some key questions. How much energy could be saved by the EEBC criteria? How much reduction in peak electrical demand would occur? How much increase in construction cost would occur? What would be the financial impacts to building owners and the economic impacts to the nation? The Jamaica analyses were also structured to address another important question, namely what are economically optimal levels for establishing code provisions.

When the exercise was begun in 1990, it was anticipated from experience in other countries, that the code would reduce energy use at least 20% from current practice, and that the energy reductions would be very cost effective. Today, the results of the study, discussed at length below, indicate the energy reductions from application of the code are about 30% - 35% and that economically optimal levels of potential code requirements could produce energy savings of 50% or more.

Methodology

The methodology used is similar to other recent international energy and economic studies. Key steps include acquiring weather data, developing typical building descriptions, conducting parametric energy simulations from the base case buildings, plus simulations for energy code requirements and for more efficient building designs (e.g., Deringer et al. 1987; Ang Co et al. 1989; Chirarattananon et al. 1989; Noersaijidi et al. 1989; Busch 1990; Cumper and Marston 1991). However, in two key areas, the Jamaican analysis has gone further than previous efforts. Construction cost data is more detailed than that accumulated for other international studies. In turn, this has permitted detailed examination of cost impacts in the various parametric energy analyses. Thus, the analysis in Jamaica has a much better cost data analytical base than similar studies done elsewhere.

The ASEAM2D program (Fireovid et al. 1990) was used for the analyses.[5] While this program is simpler and more limited in capabilities than say DOE-2.1D (LBL 1989), it was selected because it was easier to learn and to use. The ASEAM2D program was considered sufficiently accurate for annual energy estimates. Selected checks against DOE-2.1D and against manual calculations were done for verification purposes. In a few cases, DOE-2 results are reported in place of ASEAM2D results. Existing hourly weather data for Jamaica's two largest cities - Kingston and Montego Bay - were prepared and formatted for

DOE-2.1D. Data for Kingston was also formatted for use with ASEAM2D.

Typical Buildings

Descriptions of typical buildings were developed to represent current Jamaican construction practice for 4 building types -- large offices, small offices, hotels, and stores -- and their energy-related features and construction costs were defined. Because of limited project resources, detailed analysis was done for two building types -- large and small offices. For these, energy and cost variations were identified for key building features, and parametric energy simulations and economic analyses were done.

While the building survey of 1987 provided valuable general data, the survey lacked sufficient detail about building energy features. Therefore, such details were developed by the analysis team through consultation with Jamaican building construction industry professionals. The resulting building descriptions were reviewed also by the EEBC Review Committee.

The large office is a square five story building, 140 ft (42.7m) per side, with 19,600 gross ft^2 per floor (1,821 m^2). Building gross floor area is 98,000 ft^2 (9,104m^2) and net conditioned area is 88,320 ft^2 (8,205m^2). The amount of glass used is estimated at 30% of total wall area. The large office's square configuration results in a reduced impact of solar loads compared with typical rectangular buildings used in similar energy studies in several ASEAN countries, because of the reduced wall surface to volume ratio of the square configuration, less than 75% of that for a rectangular configuration with 2:1 aspect ratio.

The small office is typical of buildings that are ubiquitous in many cities in developing countries. A three story structure with similar structures abutting on two sides, so that typically only the two smaller end walls and the roof are exposed to the outside air and to solar loads. Often, the ground floor functions as mercantile or service space, while the upper floors are office space. The front elevation can have considerable glass, while the back elevation typically has relatively little glass, especially on the ground floor. For the typical building configuration used, the glazing on the ground floor is extensively shaded because the second and third floors project over it by 10 ft. The three-thermal-zone configuration per floor is actually more efficient (and comfortable) than the single-thermal-zone configuration per floor that is often used for ventilating and air-conditioning (VAC) systems in such buildings. The building's footprint is 60 ft x 120 ft (18.3m x 36.6m), or 7,200 gross ft^2 per floor (669 m^2). Building gross floor area is 21,000 ft^2 (1,951m^2) and net conditioned area is 19,950 ft^2 (1,853m^2). Smaller versions of this same configuration are also prevalent.

Analyses Conducted

Three types of energy and cost analyses were conducted on both the large and small office buildings, using the base case descriptions that represent current practice in Jamaica. First, a set of energy and cost parametric analyses were conducted separately across multiple values of each of about 20 energy measures. Second, a set of changes was made to the energy features of each base case building so that it would comply with the EEBC-90 code requirements, and energy and economic analyses were conducted of this combined "EEBC-90" set. Third, another set of changes was made to each base case building so that the result incorporated the features selected for the "high efficiency" case, and energy and economic analyses were conducted of this combined set. Table 1 lists the key energy-related features of the large and small office base case buildings, and the values used for each of the of changes made for the three types of analyses.

Economic Analyses. An important feature of these analyses is that incremental construction costs have been identified for all changes from the base case values, whether for changes in individual parametric measures or for combined changes in multiple measures. This placed a few constraints on the values chosen for the parametric measures, for each value needed to represent a "real" combination of measures for which costs could be estimated. The cost data was acquired from in-country suppliers and building designers. A quantity surveyor (cost estimator) provided detailed input for envelope-related features, while glass, lighting, and VAC suppliers provided information on those respective systems. Building design professionals reviewed the data for reasonableness. In considering cost-effectiveness of measures that reduced loads, 60% of potential reductions in VAC sizing were used to calculate potential construction cost savings. For all construction costs, the amount of import duties and taxes were identified separately, to permit assessment of impacts of these policy elements on the cost-effectiveness of energy measures. For example, this approach permits an examination of the benefits of reduced import duties for building components.

In-country construction costs were identified whenever possible. When local costs were not available, as for energy products not yet used in Jamaica (such as daylighting controls), then US costs were used, with transportation costs, import duties and taxes applied. All costs were stated in US dollars, due to its more

Table 1. Base Case Building, Energy Code, High Efficiency Case, and Parametric Measures

	Measure Examined	Base Case	Code	High Effic	Parametric Values Examined
Envelope	WWR (Lg.Ofc.)	0.3			0.1, 0.3, 0.5, 0.7
	WWR (sml. Ofc.,front only)	0.35			0.1, 0.3, 0.5, 0.7, 0.9
	SCg (Lg. Ofc.)	0.61	0.45	0.15	0.61, 0.45, 0.27, 0.33, 0.15
	SCg (Sml. Ofc.)	0.72			0.72, 0.45, 0.27, 0.33, 0.15
	Overhangs (Lge Ofc only)	PF = 0.25	PF = 0.5	PF = 0.5	0.5, 1.0, 0.0, 1.0
	Vertical Fins	PF = 0.0			0.0, 0.0, 1.0, 1.0
	SCe (Blind/ Screen)(Lge)	SCe = 1.0			1.0, 0.7, 0.3
	SCe (Blind/ Screen)(Sml)	SCe = 1.0	SCe=0.25	SCe=0.25	1.0, 0.7, 0.3
	Wall Insulation	R = 0		R = 4	0, 4, 8, 12, 16
	Wall Colour (Lge Ofc)	CCF = 1.0	CCF=0.45	CCF=0.45	1.0, 0.83, 0.65, 0.30
	Wall Colour (Sml Ofc)	CCF = 1.0		CCF=0.45	1.0, 0.83, 0.65, 0.30
	Roof Insulation	R = 0	R = 4	R = 12	0, 4, 8, 12, 16
	Roof Colour	CCF = 1.0		CCF=0.45	1.0, 0.75, 0.52, 0.30
Lighting Systems	Total Installed Power Density	2.1 W/ft^2	1.6 W/ft^2	1.07 W/ft^2	
	Ballasts	Std. (11W)	Sup Mag (3W)	Electronic	Std (11W), Eff Mag (7 W), Sup Mag (3 W), Electronic
	Tubes	40WT12	36WT12	36WT12	40WT12, 36WT12, 32WT8
	Troffer/Lens	4 tube prismatic	3 tube prismatic	3 tube parabolic	4 tube prism, 3 tube prism, 3 tube parabolic
	Daylight Control Type	none	none	none	none, on/off, 2 step, cont.dim
	Visible Trans. (VLT)	0.35			0.35, 0.52, 0.72
Ventilating & Air-Conditioning	COPs (Lge Ofc)	2.5	3.1	5.5 (centr)	
	COPs (Sml Ofc)	2.5	3.1	4.5 (recip)	
	Fan Control	CV		ASD	CV, DD, IV, ASD
	Outside Air (CFM/pers)	15			10, 15, 20, 25, 30
	Temperature Setpoint	76			72, 74, 76, 78, 80

widespread use for energy-efficiency assessments internationally.

Both energy and economic impacts were assessed for each of the parametric measures. A financial analysis was done to assess impacts on a typical building owner. This analysis included the combined impacts of import duties and taxes. For the financial analysis, electricity costs used were current actual rates to the owner, including both kWh and kW components. Electricity rates increased twice during the course of the study, partly in response to fluctuations in the Jamaican dollar. A typical JPS "Rate 40" was used, with no time of day option, that applies to the small to medium sized commercial buildings being analyzed. In mid 1990, the rates increased. The "Rate 40" became US$0.072/kWh and US$4.41/kW/month (in US dollar equivalents). While the rates increased again in late 1991, all results of the financial analysis in this paper use the rates from the first rate increase in 1990. The results will soon be re-calculated using the newer 1991 rates. Since the 1991 rates are higher in US$ than 1990 rates, the cost-effectiveness to the building owner for all energy efficiency measures will increase compared with the results reported here.

An economic analysis was done to assess the national economic impacts of the measures to Jamaica as a whole. For this analysis, taxes and import duties were excluded. The following JPS electricity costs were used: capacity cost of US$157/kW/year, and avoided energy costs (excluding capacity) during the peak period of US$0.07/kWh (1991-97) and US$0.06/kWh (1998-2010). These costs data were derived from a separate study of utility generation costs (ESMAP 1991).

Parametric Analyses. About 20 energy efficiency measures were identified (which defined the energy parameters being examined), and several incremental values were selected for each measure. Then each value of each measure (each parameter) was tested one at a time, while holding all other measures and values constant. Table 1 lists summary information about key energy features of the base case, current practice large and small office buildings, the parametric measures examined and the values used, and the conservation measures and input values used for the energy code and the high efficiency cases. The values used in the various separate parametric analyses are listed in the right-most column of the table.

Energy Code Analysis. A set of changes was made to the energy features of each base case building so that it would comply with the EEBC-90 code requirements. The "Energy Code" column of Table 1 lists the measures that were changed from the base case "Current Practice" conditions. This analysis differs from the above parametric analyses in that the interactive effects of the entire set of measures were assessed.

In order to comply with the code requirements, only one set of changes was explored in the analysis, even though many combinations of changes might have been made, especially for the building envelope and lighting requirements, which both contain performance requirements for entire building sub-systems. For example, for the lighting system one could select a number of combinations of lamp, ballast and fixture improvements, etc, to reduce the lighting power from 2.1 W/ft^2 to 1.6 W/ft^2 (22.6 W/m^2 to 17.2 W/m^2). Likewise, for the wall thermal requirements one could select from many combinations of glass type and amount, shading devices, wall color and insulation, to achieve the required Overall Thermal Transfer Value ($OTTV_w$) requirement.

The specific sets of energy measures selected in the analysis to meet the EEBC-90 requirements were selected using the judgment of the analysis team. The team did try to choose a "reasonable" solution to meet the code requirements, but not explicitly attempt to choose either the most cost-effective or the most stringent combination for the analysis of code requirements. Also, the choice of measures to meet the code requirements were chosen prior to the completion of the energy and cost analyses for the parametric analyses, so that those results were not available to assist in the selection of measures. Thus, there may be more cost-effective and more energy-efficient combinations of measures for meeting the energy code requirements than the combination that was chosen for each typical building type.

High Efficiency Case. Energy and economic analyses also were conducted for a "high efficiency" case. These large and small office cases use combinations of energy features that far exceed the energy code requirements. The "High Effic" column of Table 1 lists the measures and values that were used to estimate the "high efficiency" impacts. Yet these high-efficiency designs use only "off-the-shelf" technologies; exotic, untested measures were not used. Also, not all readily-available technologies were used in these "high-efficiency" cases. For example, automatic daylighting controls were not incorporated into the high-efficiency designs.

Groups of measures for the high efficiency cases were selected by judgment of the analysts, from the sets of measures used in the parametric analyses. These measures and values were selected by the analysis team *before* the parametric analyses were conducted. As a result, the choice of measures did not benefit from the substantial information about the energy and cost-effectiveness of each measure that were derived from the parametric analyses. Consequently, the high-efficiency case results for the large and small offices do not necessarily represent either the highest levels of cost-effectiveness or the highest levels of energy efficiency feasible today with readily-available technologies. In fact, a "technical limit" (maximum technical potential) case was originally planned, but was not analyzed because of limited project resources.

Energy Results

Figure 1 summarizes the energy results from the parametric analyses of key measures examined one at a time without regard to their interactions. The energy results have been normalized as a percentage of change in total building annual energy use, relative to the base case. Thus, the figure indicates the relative proportional impacts among the measures shown.

The figure shows that for the office buildings examined there are measures within each major building sub-system that have significant impacts on energy use when varied over reasonable ranges. The results are generally consistent with other studies. Lighting measures are very effective, as are daylighting measures. For the building envelope control of solar load through combinations of glazing type and shading options are the first priority. For opaque surfaces, changing colors from dark to light have about the same magnitude of impact as adding the first increment of insulation (e.g., R-4). For ventilating and air-conditioning (VAC) systems, higher efficiencies and more efficient fan controls are both excellent strategies.

Figures 2 and 3 show the combined interactive effects of the two sets of measures examined for each office building. Jamaican large office buildings built to meet the EEBC-90 code requirements will use 30% less energy and have 30% less peak electrical demand than typical current

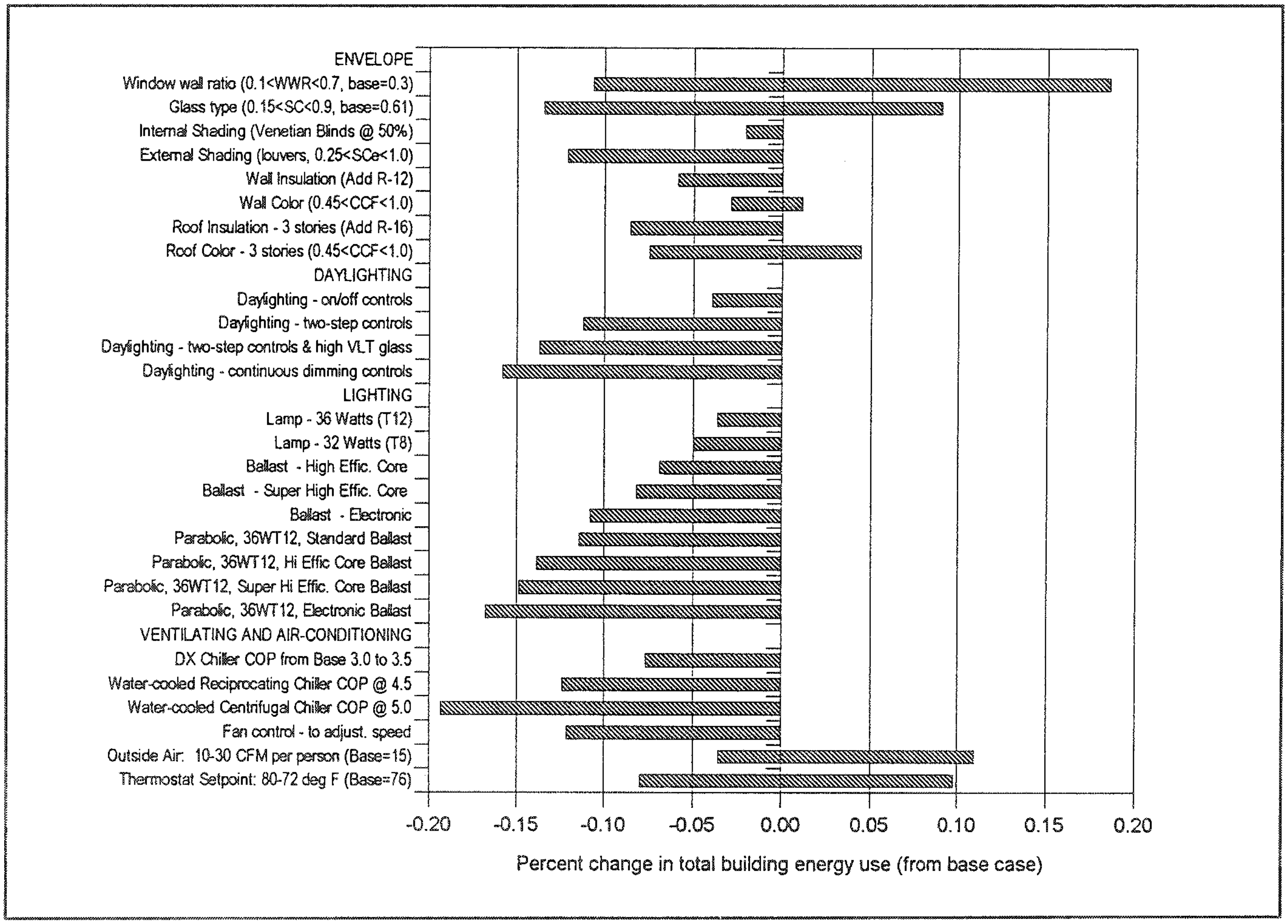

Figure 1. Energy Use Impacts of Selected Measures

practice. Small office buildings built to meet code requirements will use 36% less energy and have 35% less peak electrical demand than typical current practice.

"High efficiency" large office buildings will use 62% less energy and have 50% less peak electrical demand, while the "high efficiency" small office buildings will use 57% less energy and have 55% less peak electrical demand.

Economic Results

Parametric Results. Financial and economic analyses of all energy parametrics support the analyses of the energy code and high efficiency cases. Economic and financial parametric analyses were accomplished for all the separate measures and values listed in Table 1 above. Figure 4 shows an example of the economic output for the separate parametric simulations from the national economic perspective; in this case the results are for separate lighting and daylighting measures.

From both financial and economic perspectives, the lighting and daylighting measures examined are clear winners, with most strategies being highly cost-effective. For the building envelope, several glazing and shading combinations were clearly cost-effective, while others depend upon specific applications. Improved VAC equipment efficiencies are cost effective as well.

As the figure indicates, the all measures are easily ranked as to cost-effectiveness. Project resource limitations precluded conducting the next step of iteratively adding successive measures in descending order of cost-effectiveness until the combined incremental NPV hits zero. This procedure could precisely define the economically optimal point for the measures examined for each of the economic perspectives being considered. While such analyses are planned for the future, the results of analyses already conducted do establish a strong boundary condition on the economically optimal point

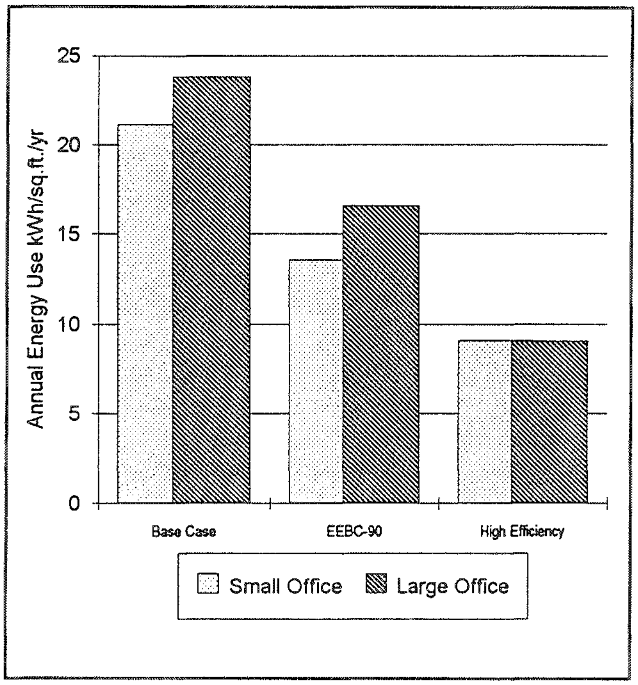

Figure 2. Energy Results for Energy Code and for High Efficiency Case

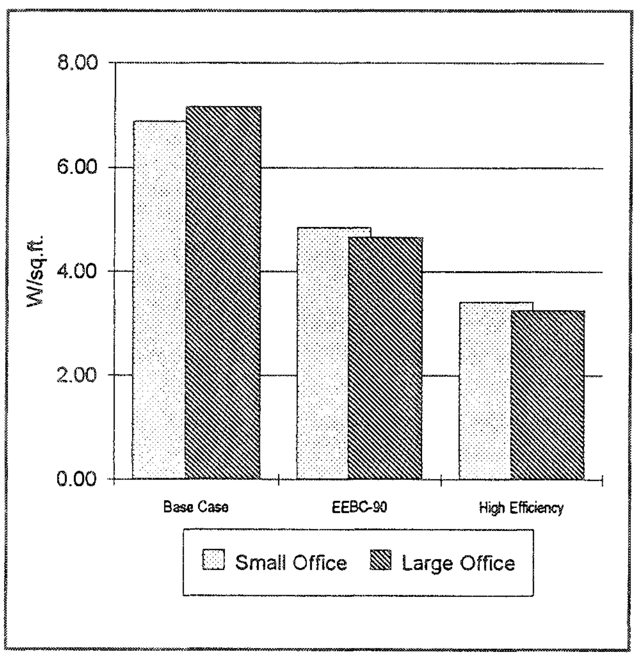

Figure 3. Peak Demand Results for Energy Code and for High Efficiency Case

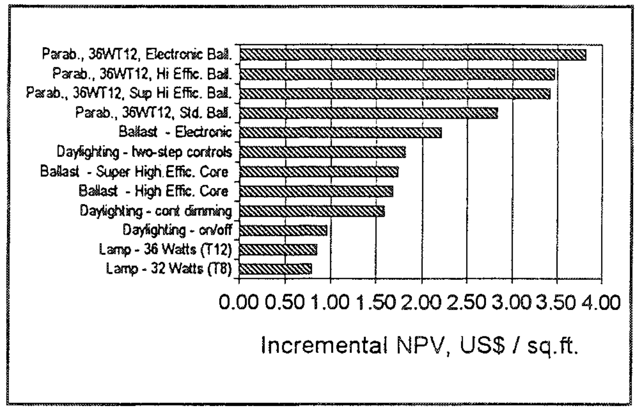

Figure 4. National Economic Perspective Results for Lighting Measures

from the Jamaican national economic perspective. This can be seen in the economic results for the "high efficiency" case discussed below and shown in Figure 6.

From Current Practice to The Energy Code. For the building owner in financial terms, the 30% energy code reduction in the large office produces a simple payback period of 1.3 years, and the 36% energy code reduction in the small office building produces a simple payback of 2.7 years. Net present values (NPVs) and benefit/cost ratios (BCRs) are high for all discount rates examined (10%, 15%, and 20%, real). See Figure 5.

From a national economic perspective, net present values and benefit/cost ratios are high. Figure 5 shows that the incremental net present values are almost US$6 per ft^2 of conditioned space. Also, the cost of conserved energy is only US $0.015/kWh for the large office and US $0.028/kWh for the small office. This is significantly less than the avoided cost to JPS.

High Efficiency Case. For the building owner in financial terms, the high efficiency case for the large office building produces a 62% energy reduction, with a simple payback period of 6.0 years, from current base case practice. The high efficiency case for the small office building produces a 57% energy reduction with a simple payback of 4.4 years, from current base case practice.

Figure 6 indicates that the high efficiency scenario results give mixed signals to building owners given current prices. For the "high efficiency" small office building,

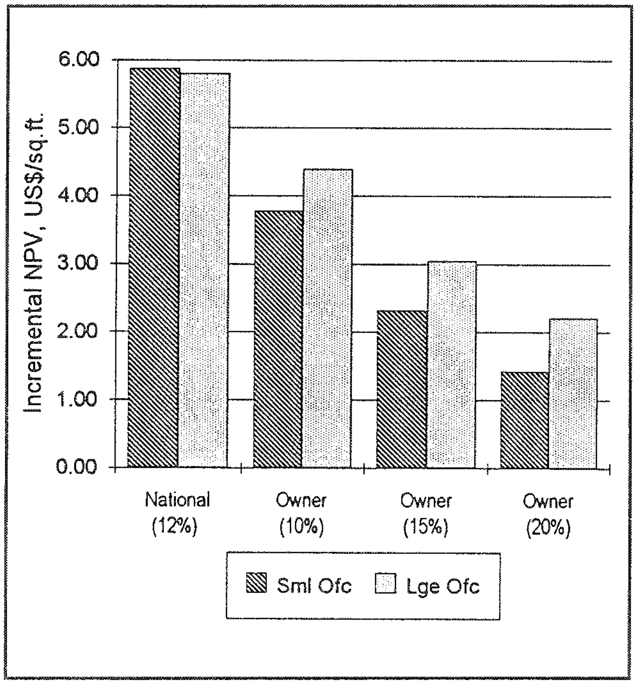

Figure 5. Economic Impacts of EEBC-90 Requirements

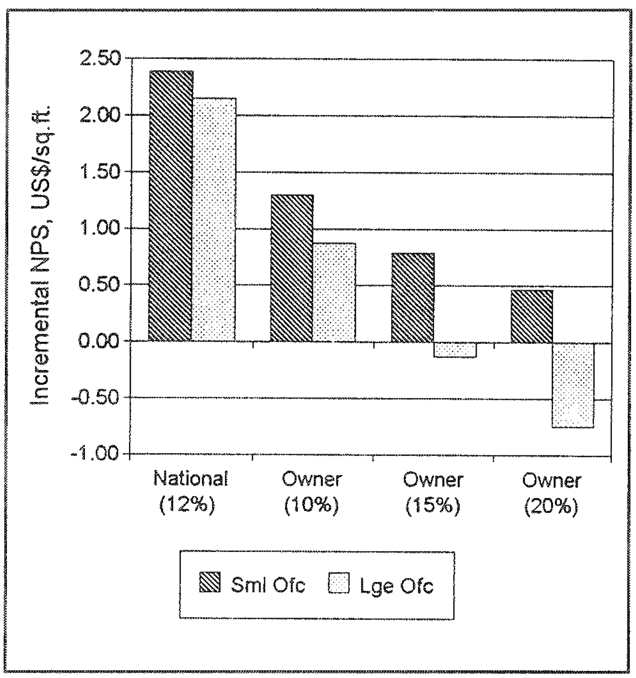

Figure 6. Economic Impacts of High Efficiency Case

net present values are positive and benefit/cost ratios are high for all discount rates. These values are computed relative to the energy code case. Thus, the high efficiency small office case is still cost-effective for the building owner, starting from the energy code case. However, for the large office building the net present values begin to go negative is the discount rate increases, and the B/C ratios begin to be less than one. These values also are computed relative to the energy code case. Thus, the high efficiency case for the large office represents at best only a marginal investment to building owners, given the current prices, and depending upon discount rates assumed.

From a national economic perspective, the high efficiency cases for *both* small and large offices are still very cost-effective for Jamaica, for both large and small offices. The cost of conserved energy for the large and small offices is still less than the cost to JPS to generate electricity. For the national economic perspective used, net present values and benefit/cost ratios are still quite high. The incremental net present values exceed US$2/ft^2. This result is important, for it indicates that the economically optimal point must be in excess of the results for this case. Thus, a lower boundary is established in excess of a 50% energy reduction from current practice. This result applies to both large and small offices.

Conclusions and Implications for Policy

Current Code Requirements Are Not Close to Economically Optimal Levels

The energy and economic results for Jamaica indicate that economically optimal levels for specifying energy code requirements would result in over 50% energy reductions from current practice. While a lower bound has been identified, the optimal level has not been identified, from the current analysis, for the optimal economic level from a national perspective is beyond the high efficiency case for both for the large and small offices.

Combination of Correct Prices and Information is Critical

Interest in conservation is currently high in Jamaica. One reason that interest is high is that with recent price increases, the cost of electricity to the consumer is approaching the cost of generation. The incentive caused by this change is being recognized by building owners and investors.

In conjunction, the recent code implementation and demand-side management (DSM) activities in Jamaica have been providing much needed energy-efficiency information and analysis tools. The information and tools are needed to properly and quickly respond to the increased interest.

Shift Focus of International Support

More international economic support and expertise can be invested to increase energy efficiency in buildings in countries like Jamaica. Such investment makes clear economic sense, from the national economic perspective of countries like Jamaica. Also, developing countries in the tropics are where the most rapid growth is occurring in commercial building stocks. This includes tropical locations in Asia, Central and South America, and Africa.

In Jamaica, there is a need for continued development of code implementation activities and a continued strengthening of code related institutions. For example, additional economic analysis is planned, including the important area of analysis of hotels, but awaits further funding. Another example is that discussions have recently begun on the potential of creating at the newly formed architecture department at the College of Art, Science and Technology (CAST) in Kingston a regional center for building energy design excellence for the tropics. Such a center might provide a vehicle for assisting the adaption of results to date to additional locations throughout the tropics.

Potential for Improved Energy Code

Energy codes are powerful information tools that embody cost-effective practice for use in conjunction with other policy measures and the implementation of demand-side management (DSM) programs. One can foresee the development of an energy code that provides better guidance toward the maximum levels of energy efficiency that are cost-effective for Jamaica from a national economic perspective. Such levels of efficiency might result in almost double the efficiency improvements as those required by present energy code requirements. If environmental externalities were included in Jamaican electricity prices, the cost-effectiveness of increased efficiency would be further enhanced.

Tropical countries may wish to use the analysis tools cited above to determine economically optimal levels or ranges for energy code provisions. The next step would be to determine the costs of moving from current levels of code requirements to the levels indicated as economically optimal. Given the number of barriers to attainment of economically optimal levels of conservation, one might have an interim code structure that would provide two levels of requirements:

(1) a set of minimum requirements, such as those requirements currently in the code; plus

(2) a set of optional requirements close to the identified economically optimal levels of efficiency from a national perspective.

Thus, energy codes can become even more powerful information tools for imbedding economically rational levels of investment in energy efficiency.

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Endnotes

1. The authors' roles in the EEBC project were: J. Gilling managed the EEBC implementation activities along with several other ESMAP program activities in Jamaica. J. Deringer provided technical coordination, input and review to the EEBC implementation activities as an international consultant. Two other international consultants assisted J. Deringer, J. Busch for the energy and economic analysis, and A. Sprunt for the compliance guidelines. The energy and economic analysis discussed in this paper was accomplished by two Jamaican engineers, S. Marston and J. Cumper.

2. Two known early adopters of energy codes were Singapore, which developed a code in 1979 based primarily on ASHRAE 90-75, and Kuwait, which developed a code in 1983 that included a significant in-country analysis effort using a modified version of the DOE simulation program.

3. The EEBC Review Committee is chaired by W. Wakefield, and its members include R. Ashby, G. Ashley, M. Baker, C. Broomfield, R. Chambers, D. Chung, R. DaCosta, M. Goodman, C. Rowe, and H. Sinclair.

4. The Jamaican EEBC also applied some formatting approaches adopted by Kuwait in 1983, in which only the requirements are listed within the code, while all reference materials are relegated to separate volumes containing compliance guidelines. This is quite different from the formatting approach used by ASHRAE and by organizations in the US and in many other countries.

5. The ASEAM2D program was made available for use in Jamaica on a beta-test basis courtesy of The Fleming Group, Albany, N.Y.

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