Modeling Approaches to Building Energy Efficiency

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ABSTRACT

Buildings use a substantial portion of the world's energy. Advances in energy efficiency could therefore contribute to tackling climate change and energy security by reducing energy consumption. Many policy, technology and financial options are already available to achieve substantial energy efficiency improvements but progress has been slow and there is little consensus on the optimal combination of measures. Most attempts to address this problem have adopted a macro approach, considering likely adopted solutions in terms of efficiencies and their resulting impact at a global level.

This paper reports an alternative approach, using macro-level scenarios to feed detailed building sub-sector decision analysis. This combination of top-down scenarios and bottom-up decision modeling produces impact estimations of sector-specific policy and technology packages. For 25 selected sub-sectors, the model has produced results quantifying energy and carbon savings with financial impact, sufficient to permit aggregation to a global level.

The model is unique in combining energy impact with decision making models of stakeholders for sub-sectors, as modified by policy or industry actions. This must be considered in conjunction with the systemic effects of choosing one energy efficiency option over another. In one case studied, decision making models indicate low concern for first costs of CFL's with high concern for performance, and include trade-off these decisions make on heating and cooling system energy.

In addition to decision economics, solutions selected by stakeholders must be modeled in terms of their both financial and qualitative attributes. Further, overall efficiency ajd corresponding economics is a systems effect; it cannot simply reflect the efficiency increase of subsystems.

Introduction and Motivation

This paper presents an analysis of options for the building sector to achieve economically viable energy efficiency. It reports research by the Energy Efficiency in Buildings (EEB) project of the World Business Council for Sustainable Development (WBCSD)[1]. EEB identified barriers to greater energy efficiency (reported in a paper[2] presented under Panel 4) in the structure of the building sector, the knowledge, attitudes and working practices of building professionals. Developing from this analysis, the project has modeled the building sector qualitatively and quantitatively to assess the impact on energy efficiency of different combinations of policy and other influences.

[1] The EEB project is jointly chaired by Lafarge and Untied Technologies and involves these 12 companies: Actelios, Arcelor Mittal, Bosch, Cemex, Dupont, EDF, Gaz de France, Kansai, Philips, Skanska, Sonae Sierra and Tepco. See www.wbcsd.org

[2] Barriers to greater energy efficiency within the building industry

The approach taken differs from existing analyses because it combines macro-level scenario development with bottom-up analyses based on detailed adoption decision and building system energy impact data for a range of building sub-sectors. The modeling results in quantified outcomes to be presented for each sub-sector, based on specific energy, financial, policy and behavioral criteria relevant to that sub-sector.

After briefly summarizing the analysis of barriers, the first part of this paper reports a "top-down" qualitative approach to understanding how the sector can move towards the EEB vision of zero net energy. This is based on international scenario exercises carried out in China, Europe, India, Japan and the USA. Scenarios were developed to identify possible routes to energy efficiency, given the barriers identified in the project's early work. They include consideration of different policy, technology and financial measures in the light of differing assumptions about key issues such as energy and carbon costs.

Based on this top down scenario work, the project then carried out "bottom-up" analysis to quantify these scenarios and look for effective policy, behavior, and technological solutions to guide markets toward an energy efficient vision. The modeling work aimed to identify the impact of policy options on specific sub-sectors of the property market, and to roll up these submarket impacts in comparison to global energy consumption and carbon emissions.

The modeling work is based on an international building energy database constructed by the project, which provides the data and insights into energy characteristics by sector and sub-market across the eight geographic markets covered by EEB. This includes energy end use and energy sources, but also financial and non-financial purchasing and operational criteria. The analysis ranked building subsystem and operation alternatives against purchasing criteria defined for each geographic sub-market. It identified the mix of available solutions that best match the building purchasing expectations to provide the expected adopted solutions, given the decision maker's local decision criteria. The criteria depend on the assumed local policies, prices, behaviors, and geography. The result of this work is a comparison of available policy options for policymakers, as well as recommendations on technology combinations and standards needed for business and others involved in building energy efficiency. The second part of the paper reports the approach taken in this analysis.

Barriers

The knowledge, technology and skills are available to make dramatic improvements in building energy efficiency but they are not being widely used. EEB concluded that progress is hampered by barriers in the form of industry structure and practices, professionals' lack of know-how and support, and a lack of leadership.

The complex commercial relationships between the many specialists involved in the building sector, and their attitudes towards energy efficiency, are critical in determining the extent of energy efficiency action. The sector is characterized by fragmentation within sections of the value chain and non-integration among them. The complexity of interaction among these participants is one of the greatest barriers to energy efficient buildings. Overcoming this complexity to achieve progress on energy efficiency depends on people in the industry being aware of the importance of the issue, and being able and willing to act.

Research[3] commissioned by EEB in eight geographic markets investigated these two aspects of awareness and involvement. It found that awareness is high in most countries covered, but there are significant barriers preventing widespread involvement. There are serious gaps in knowledge about energy efficiency among building professionals, as well as a lack of leadership throughout the industry.

EEB concluded that three business levers can help to overcome these barriers:

- Use a holistic approach to building energy to encourage interdependence between different stakeholders
- Develop improved financial information and mechanisms to remove split incentives and other financial barriers
- Change user behavior to increase the focus on energy consumption.

The project also concluded that a supportive policy framework is also necessary for these levers to be effective. An appropriate framework would include factors ranging from urban planning to energy pricing.

Three Scenarios for Energy Efficiency

Scenarios were developed to create a systemic and shared view of the bigger and deeper picture around building energy efficiency. The scenarios are stories about the future that take us from known facts and trends into an unknown future. They give structure to the uncertainties and are designed to test the mental maps that decision-makers hold. Creating a common language and a shared context enables a strategic conversation about the energy efficiency challenge.

The scenario work used the analysis of barriers described above to explore the possible future of energy efficiency in buildings. The first step was to run pre-sessions with EEB member companies to set the agenda, identifying the topics to explore in a series of regional workshops. The following list of variables and uncertainties were identified as being key to understanding the future of energy efficiency in buildings and were addressed in the scenario workshops:

1. The speed of uptake of low-energy buildings: how fast will the demand for these kinds of buildings develop and how will that have an influence on the market?
2. Willingness to pay for “green”: is there already a latent demand for green buildings, how high will the premium on these buildings be?
3. User behavior: how will it change and on what scale?
4. Impacts of climate change on behavior: today most people do not notice change in our daily life as a result of climate change, but when will this change? And how will people react?
5. The price of energy: how will it develop in the future?
6. The price of carbon: will there be a price and how high will it be?
7. Energy and climate crises: what can we expect for the future and what influence will they have on the construction industry?
8. Policies and regulations concerning energy efficiency in buildings: what will be introduced and will they be enforced?

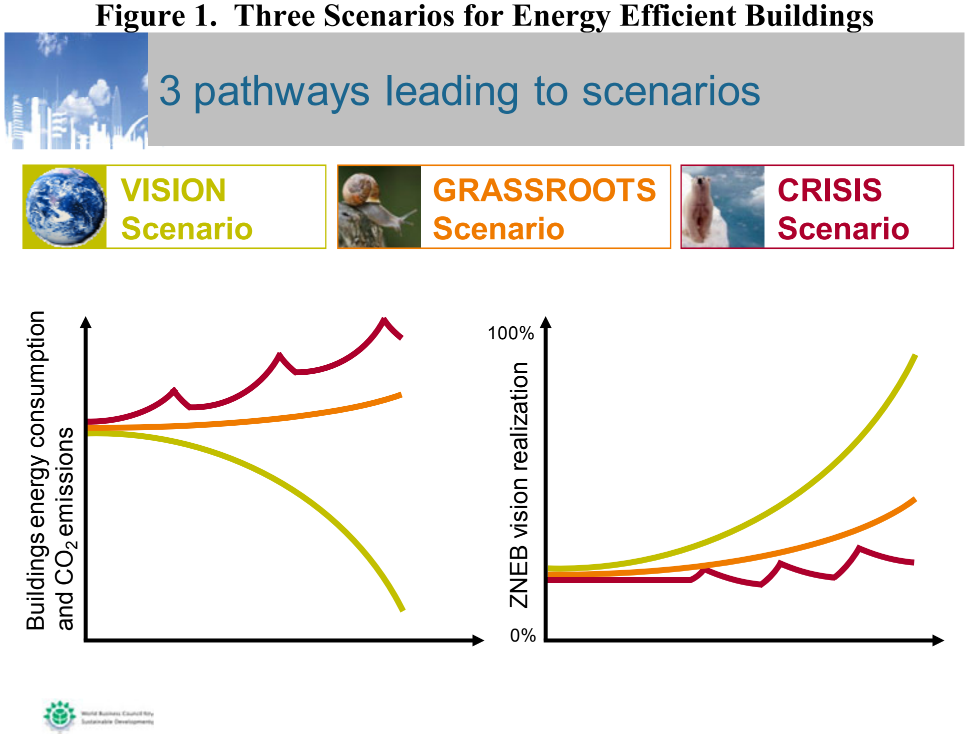
[3] Available at www.wbcsd.org

9. Economic growth: what level can we assume for the future and how fast will individual regions develop?.
10. Awareness and education among clients and experts in the building sector: how will skills and knowledge evolve?
11. The nature of the building sector: will stakeholders start joining forces?
12. Building materials: which will be used and at what cost? To what extent will alternative, more sustainable materials be used in the future?
13. Technologies for energy efficient buildings: how will they develop, which technologies will emerge and how fast and at which scale will they be implemented?

Regional Scenario Workshops

These variables were used to brainstorm ideas about energy efficiency in buildings in regional scenario workshops involving building experts and decision-makers from the public and private sector to. Workshops were held in China, India, Europe, Japan and the USA. Participants explored the barriers, the impact of a continuation of current trends and alternative scenarios. The regional workshops produced quite different outcomes that resulted in 11 scenarios, but a common thread ran through them which resulted in three archetypical stories, described as Crisis, Grassroots and Vision. These stories are summarized below and depicted in Figure 1.

Figure 1. Three Scenarios for Energy Efficient Buildings



Crisis. This scenario is based on a continuation of current trends, with a low price for carbon, continuing growth of population, urbanization, economic growth and energy use especially in Asia, Middle East, Russia and Brazil. The scenario pictures these trends resulting in a series of crises due to and creating a scarcity of fossil fuels. Oil prices will stay high in this scenario (>$100 per barrel) and could include price hikes to $250. The high price of oil will discourage the introduction of a global price for carbon dioxide. Extreme weather events as a result of climate change are also envisaged. The scenario sees a pattern of denial and overreaction, creating volatility and uncertainty which result in lower investment. Crises will push energy use in buildings higher up the corporate and political agenda, and solutions will follow. But the transition will be inefficient and painful, including panic measures which will prove to be counterproductive.

Grassroots. This scenario envisages an increasing awareness of the need to reduce energy use in buildings, resulting in political action to introduce a price for carbon emissions. Many people work on this transition towards a more sustainable future so change happens. But this is piecemeal rather than coordinated on a global scale. Some negative trends continue, such as continuing inefficient use of appliances and equipment. Most countries and regions evolve policies to promote energy efficiency in buildings, professionals working on it, suppliers working on more efficient materials and appliances and more and more property developers demand it. We see small signs of improvement and counter trends, but will they be quick enough and on a large enough scale? This question is especially relevant if the price of oil drops as alternatives come into play and once current investments in the search for new sources of oil, coal and gas bring more of these fuels into the market.

Vision. This scenario envisages energy based on fossil fuels remaining scarce, and therefore expensive (>$100) and a global price on the emission of greenhouse gases of more than $60 per ton of carbon. These two forces combine to create a coordinated response. The European Union achieves its 20/20/20 target (20% renewable energy and a 20% reduction in CO^2 by 2020), moves on successfully to 30/30/30 and the success encourages similar developments elsewhere in the world. R&D, tax credits and subsidies bringing improved technology to market. New building codes are written and enforced, new energy and climate change policies are implemented, new technologies are developed and applied, new skills are learned and new financing mechanisms emerge. All those involved change their behavior, including people living and working in buildings. Awareness, fashion and behavioral change drive the rapid adoption of increasingly energy-efficient technology.

Scenario Messages

There was a common message in all the workshops: individually widespread desire to build zero net energy buildings, but everyone blames everyone else for the inhibiting factors: tenants, those who commission buildings, policy makers, builders themselves, financiers. And the fragmented nature of the building sector makes it even more difficult to create co-ownership of the ambition. What is needed is coordinated action
and trust that change can be achieved collectively. The regional workshops came up with the following five steps as a path towards building energy-efficiency.

1. Measure buildings' energy consumption effectively. It is necessary to realize that we are on an undesirable path and need to understand better the current trends.
2. Adopt a common vision – a collective and shared vision towards a world in which buildings consume zero net energy.
3. Make best practices transparent around the world. New financing measures and mechanisms are being developed, new policies are being introduced, new technologies

are entering the markets, new behavior is being displayed and new solutions are being offered. These best practices need to be shared to motivate others and provide valuable learning into what works and what doesn't based on objective and transparent evaluation.

4. Act to implement technologies and policy measures. Good examples and proof of success will remove excuses for standing on the sidelines.
5. Create incentives that reward progress. High energy and carbon prices, combined with strict and enforced building codes will help to stimulate progress and correct the market failure which is impeding energy efficient buildings.

Sub-Sector Modeling

The scenario exercise produced useful top-down insights into what progress might be possible toward energy efficiency in buildings, at the policy, behavioral and macro-economic level for the eight markets. However, the relative effectiveness of alternative policies or technologies remained speculation. That is the nature of scenario work. On the other hand, government and businesses need more quantified information on which to act. What is more effective for residential houses versus commercial food service buildings – carbon taxes or stricter building codes? Which submarkets are more affected by mandatory maintenance programs? How does energy price affect compliance?

Scenario work cannot quantify answers to such questions. Rather, it defines the range of uncertainty on the top-down environment that building owners and stakeholders will find themselves into the future. The EEB project therefore carried out modeling to identify specific combinations of measures which would be most effective for specific sub-segments of the building sector in each regional market. Unlike other building energy modeling efforts elsewhere such as with the IEA, IPCC, the US DOE NEMS, or other organizations using the MARKAL family of models[4] this work was interested in more detailed within-building energy analysis and did not need primary source and distribution energy analysis. The other distinguishing feature of the modeling was the stakeholder decision-making component. Most other works ask what would be the case if various building stocks became a certain level of efficiency. This work asked under what conditions building stakeholders would make such selections.

In summary, the modeling effort aimed to identify priorities for building sector participants and quantify the likely result of these actions. The results were projected to estimate likely reductions in total energy demand for each submarket case, and the potential economic benefit.

Sub-Sectors Covered

The model has been applied to 25 sub-sectors across the eight geographic markets covered by the EEB, different climate types and a range of commercial, residential, new and existing buildings. The 25 sub-sectors include, for example:

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[4] Annual Energy Outlook Retrospective Review: Evaluation of Projections in Past Editions (1982-2006) DOE/EIA-0640 (2006), Paril 2007. REF O. Bahn, A. Haurie, S. Kypreos and J.-P. Vial, Advanced mathematical programming modeling to assess the benefits of international CO2 abatement cooperation, Environmental Modeling and Assessment, Vol. 3, Nos 1 and 2, pp. 107-116, June 1998.

- In Japan, single family residences in the Kensai prefecture, and commercial office buildings in the Kanto Prefecture
- In the US, food sales outlets in both cold and warm climates,
- In the European Union, residential apartment buildings in cold climates,
- Retail stores in several climate regions of the US, EU, India, and China.

Each sub-sector has been further subdivided as needed for differences in building stock (eg large supermarkets versus convenience stores) and for differences in stakeholders who make decisions on energy systems and operation (eg owner-occupiers-architect-contractors, owner-renters-contractors, speculator-contractors, etc). These 25 submarkets, while comprehensive as a sample, represent the first phase of work, to be augmented over time.

In each case the modelling work produces a series of results at five-year time periods, eg 2010, 2015, 2020 etc, out to the year 2050.

The model (depicted in Figure 2 below) is based on a comprehensive building database created by the EEB project in conjunction with four leading universities[5]. This work has identified the current state energy use characteristics of each sub-sector in all six regions studied across the globe.

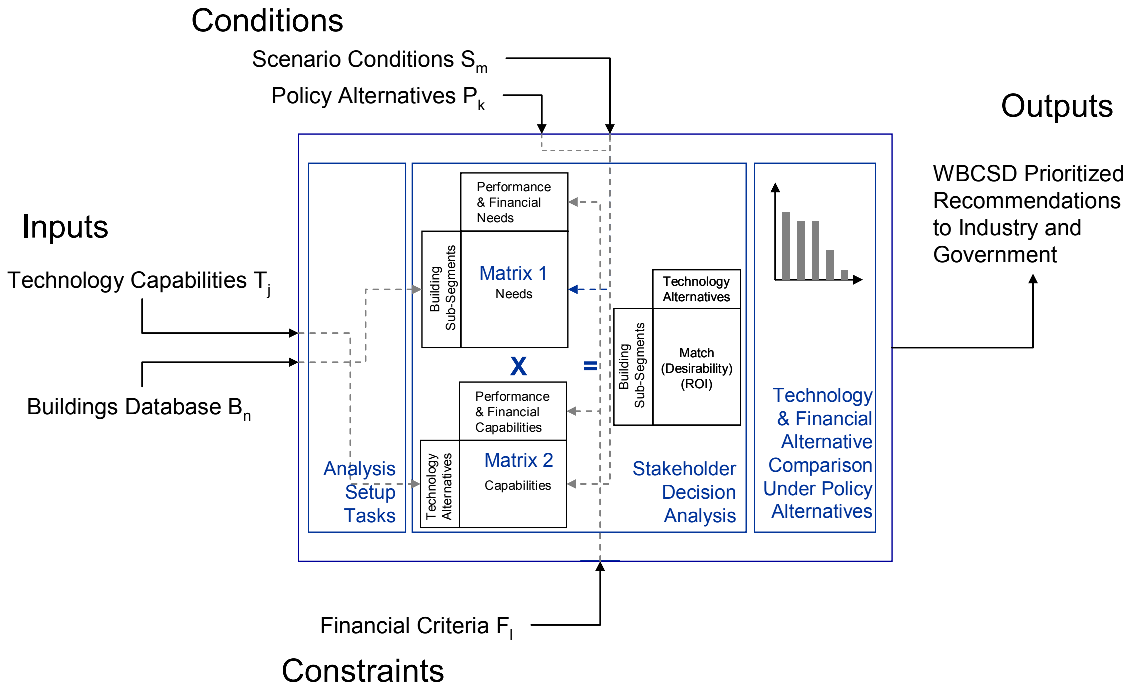
Separately, a different regional database was developed of technology and non-technical alternatives and their energy, costs, and technical capability projections. This provides understanding of the alternative solutions, whether new technology, behavioural (eg temperature setpoints, maintenance level, etc.), or synergies between systems (eg use of heat reclaim to provide hot water).

Lastly, the EEB project undertook a separate policy analysis to identify alternative policy initiatives that governments might undertake, such as tax, rebate, or code programs. These can have different timelines, compliance levels, cost and energy saving impacts. The model is used to quantify these, and to understand effectiveness of alternatives by submarket.

The model itself is a stakeholder decision model that, given the financial and non-financial criteria of stakeholders, compares alternative technologies for all subsystems, under assumptions about the scenario and policies under which the decisions are being made. Repeating this over alternative policies can provide insights into effectiveness of the policy alternatives. Repeating this over alternative scenarios can provide insights into the breadth of conditions that any policy remains effective.

[5] Birla Institute of Technology in India, Carnegie Mellon in the USA, Lund in Sweden, , and Tsinghua in China

Figure 2. The Conceptual Modeling Engine



We modeled nine aspects of building energy use, taking account of inter-relationships between them (lighting, space heating, space cooling, water heating, refrigeration, ventilation, plug loads, cooking, and other). We also model where energy comes from, whether grid electricity, grid fossil fuels (gas, oil, propane, etc), traditional fuels (coal, biomass, etc.), or solar (PV, thermal, daylighting, etc.). These energy uses and sources are related to 23 technologies ranging from air conditioning to window design. The energy impacts are calculated based on four kinds of assumptions, as follows.

1. **Design, technology & operational behavior assumptions**: The physical performance of each solution is analyzed, using building simulation methods, for potential of energy reductions and net energy demand (as grid demand relates to on-site power production). Solutions are assigned an estimated cost based on current price/cost models and/or trend models for increased efficiency.

2. **Financial and behavior preferences:**

   a. Decision maker classes are described based on owner/occupier/contractor percentages and the financial criteria of these stakeholders
   b. Each technology solution is evaluated against the financial criteria of the investor class within each market segment
   c. Technology solutions and choices about building types also affect building values – thereby changing the market value of buildings over time.

3. **Scenario conditions**: Solutions that meet investor thresholds, both in terms of investment horizons and market valuations, are selected as priorities. Scenario and policy factors to be considered in the financial analysis include:

a. Inflation rates (time value of money);
b. Effect on GDP growth (nationally, globally)
c. Investment time horizons: owner-occupier (+10); owner-leaser (+5yrs); owner-speculator (3-5yrs);
d. Ownership costs;
e. Code-mandated investments;
f. Risk ratings (energy volatility, low efficiency devaluation);
g. Return ratings (efficiency related appreciated value);
h. Productivity and health benefits resulting from energy efficiency choices
i. Cost of energy

4. **Policy decisions**: Policy factors were benchmarked and included in the base assumption matrix with various classes of policy actions, such as taxation, incentives, investment policy, regulations, codes, standards, and levels of prescribed conditions that must be met.

The analysis ranks the input assumptions against common purchasing criteria defined for each sub-market. A fit-matching exercise is then used to find assumptions that best match the building purchase expectations. These solutions are the ones that would be considered most advantageous under that set of scenario conditions (price of energy and any price addition of carbon).

Quantitative Outputs and Preliminary Results

For each case, the modelling answers the following questions:

- What solutions are stakeholders likely to adopt?
- What are the energy and emissions impacts of those decisions, scaled up globally in relation to existing projections eg by IPCC
- How will policy options affect stakeholder decisions?
- How will the different scenarios affect policy and stakeholder decisions?
- What are the combinations of technology, price and policies that achieve a given target?
- What are the economic cost and the associated impact on global GDP

As a simple example, consider the Food Service building within a cold climate zone of the US. For this segment, analysis of subsector data [6] indicates that currently 52% of energy use is for refrigeration systems, such as refrigerated freezers and display cases, and 16% of energy use is for lighting. 83% of energy used comes from electrical grid, and 16% from natural gas. Alternative sources are negligible.

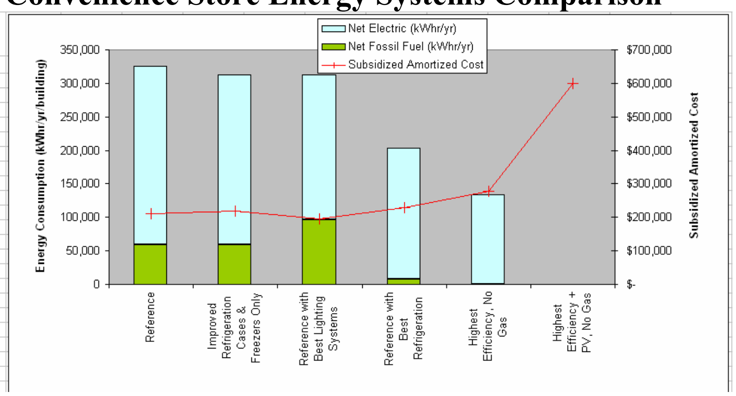
[6] http://www.eia.doe.gov/emeu/cbecs/

Against this background, there are a plethora of potential building systems that could be used with alternative overall efficiencies, first costs, operating costs, payback, and qualitative performance. With 24 energy related subsystems and for example 5 alternatives for each subsystem, there are 5^{24} alternative configurations. Against this variety, a path form current installed base to higher performing solutions in the eye of the stakeholder can be assessed. Alternative configurations of the subsystems are defined and evaluated on stakeholder performance. Figure 3 shows a typical result for six of the many alternative energy impacting subsystems. The graph depicts six alternative solutions for a new convenience store, where the leftmost is using baseline systems commonly purchased, showing the grid electrical energy used (blue) and grid natural gas (green). The next left depicts the same standard systems, but with high efficiency refrigeration display cases. There is not much impact. The 3rd from the left bar depicts the baseline systems but with high efficiency LED lighting, which reduced electrical demand but not overall demand, since space heating must be used to overcome the missing heat from lighting. Using heat reclaim for space heating and hot water off the refrigeration systems, the 4th from the left, has the most significant impact. Using high efficient equipment on all internal loads can reduce this slightly further, the 5th from the left. The last system is one using PV to provide the remaining electrical load to attain a net-zero energy.

The red line of Figure 3 refers to the amortized cost for these solutions, in US dollars. All are approximately equivalent in costs to the store owner, except for the PV solution, which is roughly triple in amortized cost.

Figure 3. Convenience Store Energy Systems Comparison

Scenario Conditions	
Food Sales	
Investment Parameters	
Investment Horizon (Years)	10
Interest Rate	10%
Costs Considered	
First Cost	TRUE
Maintenance Cost	TRUE
Energy Cost	TRUE
GHG Cost	TRUE
Type of Building	
New Building	0
System EOL	0
Policy Parameters	
Price of Fossil Fuels	0%
Price of Electricity	0%
Price of Carbon	0%
Energy Efficiency Equipment Rebate	0%

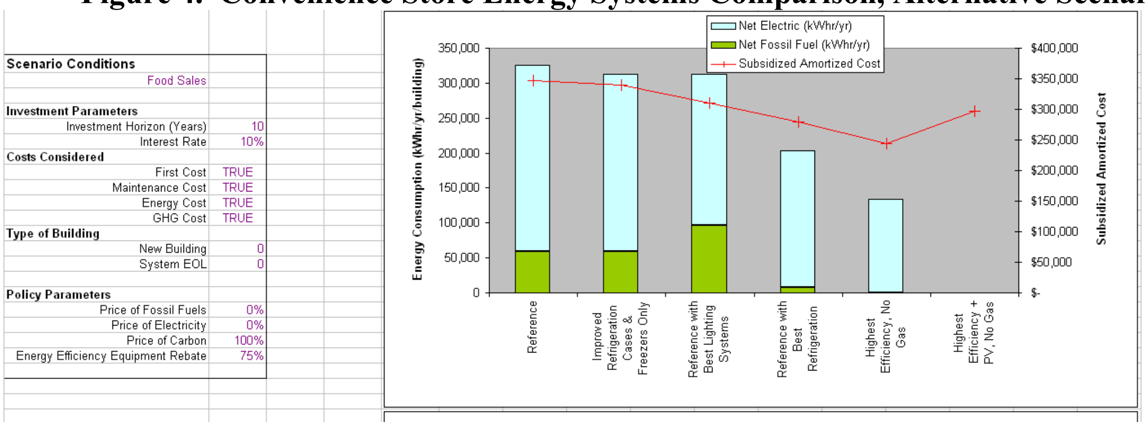


The above characterization is true for today's energy prices with no subsidies or energy taxes. One might wish to consider alternative scenarios and policies. For example, at what energy price does the net-zero solution become financially neutral? At what subsidy does the net-zero solution become financially neutral?

Figure 4 depicts the results for the same convenience store, but comparing solutions under a 300% energy tax and 75% price subsidy to energy saving systems. Under these rather extreme assumptions, a net-zero energy solution becomes financially neutral to a convenience store owner. The convenience store is admittedly one of the most energy intensive commercial buildings requiring large on-site generation to match the building demand, and so it is not surprising such large measures are needed to make on-site generation complete for that sub-segment. Others are less so.

The model is unique in combining carbon and energy impact with decision making models of stakeholders for sub-sector buildings, as modified by policy or industry actions. For example, consider recent activity of policy on lighting systems. Incandescent lighting systems are being phased out in preference for more electrical energy efficient fluorescent lighting. These policies are motivated in part due to the lack of natural inclination of submarket decision makers to adopt non-incandescent solutions of their own. Upon analysis, this result is very predictable. Incandescent lighting provides instant lighting with no delay and lighting performance exactly as desired. CFLs and others provide less ideal light at higher first cost. Decision making models indicate low concern for first costs of lighting and high concern for performance.

Figure 4. Convenience Store Energy Systems Comparison, Alternative Scenario



Non-incandescent lighting is also motivated for benefits to carbon production. This is true for many submarkets, primarily any in warm climates or markets where fossil fuels are used for electrical generation. Our analysis indicates CFL lighting over incandescent can reduce CO2 production in the southeastern United States by 21%, though only a small fraction would occur without total bans on incandescent lighting, which are forthcoming in stages under the new 2007 energy legislation. On the other hand, far different results can occur in other submarkets. In France, where electricity is primarily generated through carbon free nuclear means, use of CFL over incandescent in fact will *increase* carbon generation in the short term. This is due to the effect of the heat from incandescent bulbs no longer heating the space in winter, and thereby requiring increased space heating which is primarily natural gas which contributes to carbon. Energy consumption goes down, but carbon generation goes up. Use of higher efficiency space heating such as condensing boilers in the longer term would mitigate the increase in carbon generation.

The point is two fold. First, solutions selected by stakeholders must be modeled in terms of their decision criteria, including financial and qualitative criteria. Second, overall efficiency is a systems effect, it is not simply the efficiency increase of subsystems. Subsystem efficiency increases are misleading, such increases do not generally imply actual submarket efficiency increases. Building simulation models are required to understand system effects of subsystems changes.

Such quantified analyses completed over all sub-markets can indicate the effectiveness of alternative policies such as tax rates or rebates, as well as codes (changes to available technologies and their installed efficiency based on maintenance level).

Conclusion

This paper has described the scenario and modeling work carried out by the EEB project to assess the combinations of policy, technology and behaviors which will achieve progress towards zero net energy buildings. Our general conclusions are that industry and government policies must push for behavioral and purchasing decisions that encourage adoption of technologies that do not meet a typical 5 year payback period. More importantly, policies must encourage not adoption of simple single solutions such as lighting, heating or on-site solar generation individually, but rather must encourage only coupled integrated solutions of true near net zero buildings. Small solutions such as lighting efficiency increases only, or heating / envelope efficiency increases only; these impact energy consumption only moderately and will not provide necessary energy reductions. Incentives need be provided primarily to fully integrated solutions of combined lighting, envelope, heating and cooling and on-site generation integrated systems. Encouraging a smaller percentage adoption of such highly less consuming buildings has a much greater impact that encouraging larger adoption of small impact solutions.