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Perspective

Challenges and Opportunities in Engineered Retrofits of Buildings for Improved Energy Efficiency and Habitability

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Introduction

In contrast to almost every other artifact produced by modern industrial society, (automobiles, jet aircraft, locomotives, ocean going vessels, etc.) the design, construction and operation of buildings is still highly fragmented and comparatively unsophisticated. This is the case even though the construction industry amounts to over one trillion dollars of the US economy. Materials of construction, coatings, cladding, as well as electrical, mechanical and other components (windows, roofing, heating, ventilation, air conditioning etc.) may be selected independently with little, or no, thought given to their interactions and the effects of their coupling on the building's performance. For some architects and building owners, especially of high-end structures for urban office space, the principal goal of design has often been visual impact, which is to say that form dominates function. This kind of architectural statement is accomplished only with enormous up-front capital investments and with huge penalties in downstream operating costs due to low efficiencies inherent to the design. To say that energy efficiency suffers most in such buildings is an understatement. The financial model in such cases is that the architectural statement will be afforded with collection of very high rents. In some cases, little or no consideration is or was paid to the habitability of the space in other words the building's indoor ecology was at best of secondary importance.

There are notable examples of such extravagant buildings in almost every large American city, as well as around the world; they are not hard to find, but they are emblematic of a by-gone era. These buildings, constructed in the 20th century, symbolize much of what must be changed in the 21st century building industry; functionality and performance must trump excesses of form. As evidence that the society's view of these buildings and buildings in general is changing rapidly, the premier icon of the "sky-scraper era", the Empire State Building, has undergone a deep retrofit to bring its efficiency to the level of LEED Gold and this symbolizes the new standards that can be achieved for older commercial buildings as we move further into the 21st century[1,2] (Figure 1).

Even as new buildings are being designed and constructed to more exacting functional standards, such as LEED, however, in many cases even these buildings under perform. Given that the components are at the state of the art, it becomes apparent that even more care must be given to the processes of design, construction and operation of buildings. For existing buildings, the optimal retrofit is even more technically challenging to accomplish than are green field design and construction of a new building. Existing buildings have such long useful lifetimes that the stock of such structures is large. Since they are highly inefficient at these rates of replacement (1–2%), existing buildings will dominate the energy demands of this sector for most of this century. Hence, there is a global call for change and so an economic opportunity presents itself to devise and to develop new and highly integrated approaches to the engineered retrofitting of existing buildings.[3,4]

One primary goal of engineered retrofitting is to raise the energy efficiency of the commercial building sector by as much as 50% in 10 to 15 years. Another goal is at the same time to improve their indoor ecology for enhanced habitability.[5,6,7] However, both of these must also be accomplished with better economics than are represented by doing nothing. This is a problem of significant challenge and new solutions will not come forth if we approach the problem incrementally with small improvements to the current methods used

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Figure 1. Empire State Building.

The Empire State Building design is a registered trademark and is used with permission by ESBC.

by the industry. Wholly new and much deeper thinking about the problem of an engineered retrofit is needed to achieve economically the twin goals of energy efficiency and improved indoor ecology. The design, construction and operation of commercial buildings must be taken on by professionals who are used to complexity, to using model-based design principles, to controlling systems of systems and to operating within tight economic constraints.[8,9,10] The objectives of this article are to review the problems and issues that need to be overcome to achieve these goals and to point out that chemical engineers have the training, insight and disciplinary culture to contribute significantly to this enormous national and international challenge and that they can play a leading innovation for this sector. In fact, as we shall see, some chemical engineers have already begun to actively participate in this endeavor.

Motivations for Retrofitting

Today, the U.S. expends nearly 100 quads (quadrillion BtUs) of energy per year to drive the economy.[11] This represents all the various uses of energy that we deploy on a daily basis for the generation of electric power, for transportation, and for all other forms of industrial activity. Overall, this nation accounts for about half of the global use of energy, and of the 100 quads expended each year in the US, over 50% of the energy we produced is lost and does no useful work (Figure 2).

Drilling deeper, approximately 40 quads of energy are used every day in buildings and these buildings use about 75% of the electricity produced each year in the U.S. The energy is used to heat, ventilate, and condition the air in our offices and workspaces and a significant fraction of it is wasted. Much of this usage arises from the need to make work and living places comfortable no matter what the external conditions. Because energy was relatively cheap in the past one hundred years, and since there were no other extenuating factors, such as a concern for global climate change, buildings were constructed with low-energy efficiency. Simply put energy was so inexpensive that until the latter decades of the century these costs were not a major factor in the building's design considerations.

Presently, in the U.S. and elsewhere, when new buildings are constructed, there is considerable emphasis placed on energy usage and habitability. The leadership in energy and environmental design (LEED) standard exemplifies this new trend.[12] Created in 2000 by the U.S. Green Building Council, LEED is a certification process that is meant to provide an international framework for the construction, operation and maintenance of efficient, low-environmental impact buildings with healthy internal spaces for their occupants. This is a clean break with past practice. For example, we know that in the midst of the first "energy crisis" in the 1970s, and for about a decade thereafter, there was an emphasis placed on insulating and sealing buildings to prevent interdiction and to raise energy efficiency. While the motivation was sensible, the outcome was undesirable as it was soon realized that in such tightly sealed buildings indoor air quality became a serious issue. The decrease in indoor air quality brought on by the pursuit of decreased energy use was an important factor in the rapid rise in asthma over the last three decades (Figure 3).[13,14] Thus, LEED is very much focused on the threefold problem of reducing energy usage, decreasing the environmental impact of construction and operation of the building, and maintaining a healthy indoor environment for occupants.

However, LEED is only a starting point and much more needs to be done. For example, although LEED can be applied to the retrofitting of existing buildings as well as to new construction, engineered retrofitting is a much harder problem. Also, while the design of a building, or its retrofit may be done in a manner that is consistent with standards that should provide the benefits promised by the certification, in practice, the actual performance of a certified building may fall below technical and occupant expectations.[15–17] In other words, in addition to design and construction meeting these standards, the building also must be operated and maintained in a way consistent with the standards in order to perform up to those standards. Hence, control of the building as a system of systems becomes a significant problem. For LEED to be more than merely fashionable, it must be proven that for the majority of buildings to which it is applied the investment made for certification will prove economical with simple payback in a relatively short time frame (3–5 years).

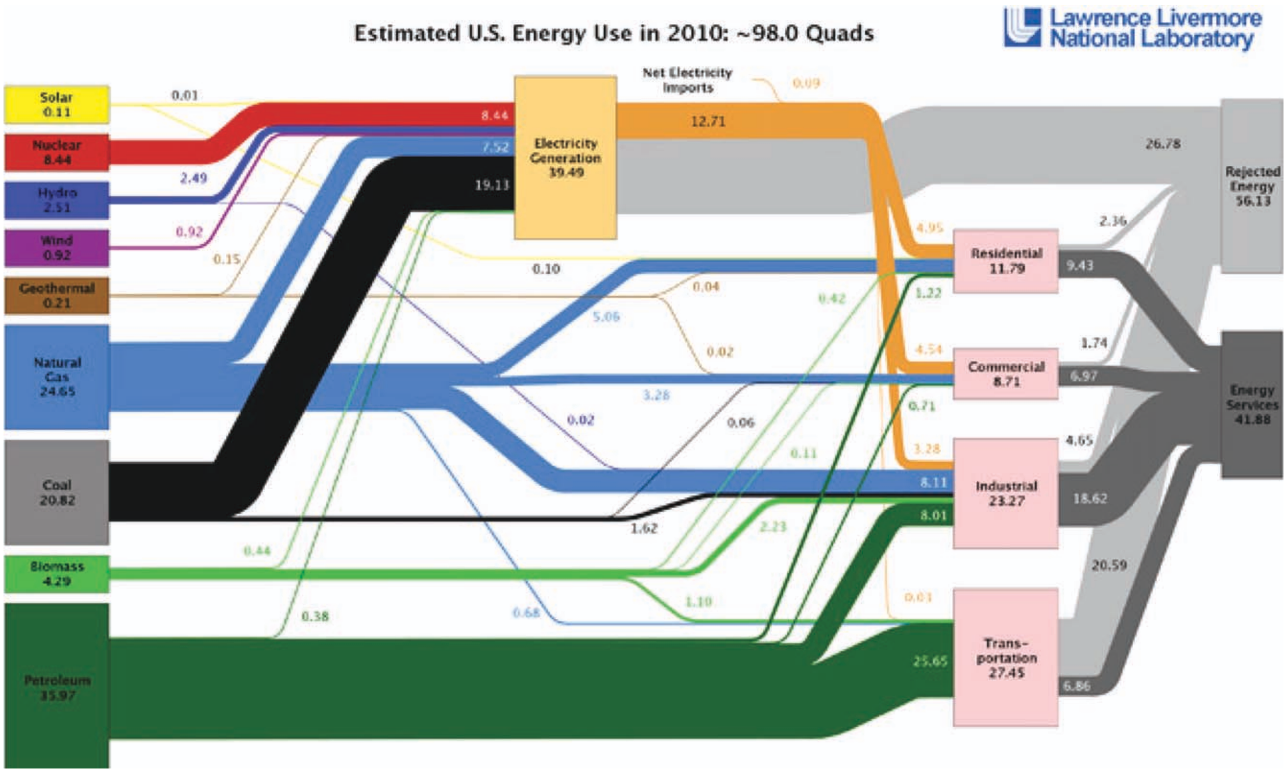

Figure 2. Estimated energy use in the U.S. in 2010.

See https://www.llnl.gov/news/newsreleases/2011/Nov/NR-11-11-02.html.

Without this evidence most building owners will not make the extra investments in an engineered retrofit that are necessary to meet certification.

While the technology of designing and constructing buildings has improved, retrofitting of existing buildings has not yet come to the level of sophistication necessary to meet the real needs and expectations of the market, or to reach the goal of cutting the use of energy in this sector from 40 quads to 20 quads per year or less. Retrofitting of existing buildings is necessarily more complex than the design of new buildings. However, like new buildings, retrofitted ones must be considered as integrated systems of systems, consisting of smart new materials for envelopes and coatings, better sensors for control, and cleaner, more efficient HVAC systems. All these systems are coupled and must be operated dynamically around a global optimum that responds to external conditions and to occupant needs and their behaviors.[8,18] To accomplish effective engineered retrofitting of buildings, new thinking must significantly reorient the current industry with much better approaches to old problems, with new materials and control systems, more powerful tools for design and economic analysis and with wholly new business models.[19,20]

Issues and Opportunities

Aside from the iconic buildings of the 20th century, there are still approximately five million commercial buildings in the U.S. that have a total of 71,658 million square feet of space and that are highly deficient in terms of their energy efficiency and indoor ecology (Table 1).[21]

Most of these commercial buildings are far from iconic, and their design had little or nothing to do with architectural achievement. Rather, their design and construction were motivated by the objective of managing capital investment to achieve simple pay back in as short a time as possible with a window of three to 5 years being typical. In almost all these cases, decisions and tradeoffs were often made ‘‘on-the-fly’’ during construction and well after the design process was finished. Construction managers often seek to take advantage of any cost savings that can be had with changes made to the specified by the design. Critical components such as heating, ventilation and air conditioning, as

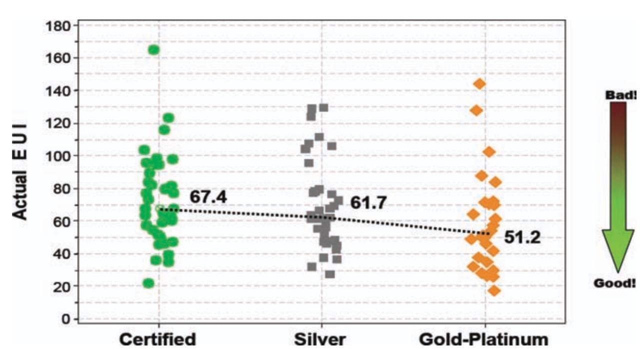

Figure 3. Actual energy use index (kBtU/ft^2/yr) for LEED certified buildings.

well as the materials of construction, coatings and carpeting, become fungible during construction due to the absence of rigorous oversight and business models employed by the industry. Besides swapping of components, short cuts often are taken in construction methodology in order to drive down labor costs and to shorten construction time. In some cases, changes that are made under these circumstances are far from innocuous and show a reckless disregard for the design. Using the wrong methodology for installation may obviate any benefit that that a certain set of components or materials were intended to have had on the building's performance. In short the building as constructed was and often is quite different than the building that was originally conceived and designed by the architect. LePatner provides an insightful critical review of the current construction and the issues faced in seeking to modernize the industry.[22]

We can see the cumulative effects of this level of process *disintegration*, in operating data of buildings. Even now, for recently constructed buildings, buildings that are built to the apparently exacting standards of LEED certification, we see wide variations in their actual vs. theoretical operating performance (Figure 4). New buildings that are LEED certified show this kind of variation in performance, presumably because they were not constructed and operated according to design. If new LEED certified buildings are constructed in such a way that even they do not perform to certification, then using the same methods during retrofitting can lead to no better results and will probably lead to worse results. Without tight, overarching management and control of all processes and procedures from design to construction on through to operation, the retrofit is most likely to fall short of expectations or to even fail. Therefore, engineered retrofits must be planned, carried out and operated with far more rigor and at a level more like that used to design, build and operate chemical plants and refineries. Kiernan and Timberlake articulate the case for this kind of new approach and call for transformation of the industry.[23] Hence a great deal of what has been learned in the chemical process industries (as well as in other manufacturing industries) can be brought over into this sector for real advantage.

Table 1. Numbers of Buildings by Ranges Based on Floor Space

	Number of Buildings (thousand)	Total Floorspace (million sq. ft.)	Mean Square Feet per Building (thousand)
All Buildings	4,859	71,658	14.7
Building Floorspace (square feet)			
1,001 to 5,000	2,586	5,922	2.7
5,001 to 10,000	948	7,033	7.4
10,001 to 25,000	810	12,559	15.5
25,001 to 50,000	261	9,382	36.0
50,001 to 100,000	147	10,291	70.2
100,001 to 200,000	74	10,217	138.6
200,001 to 500,000	26	7,494	287.6
Over 500,000	8	7,550	937.6

Source: Energy Information Administration. 2003 Commercial Buildings Energy Consumption Survey.

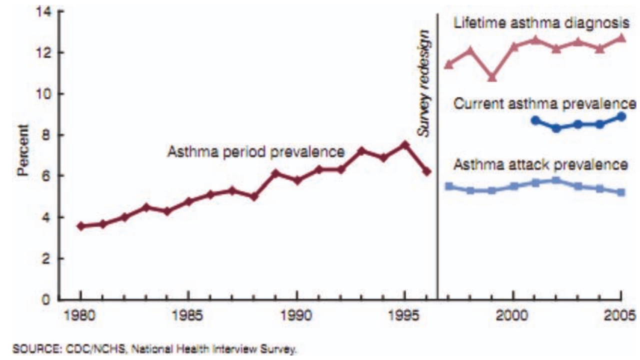

Figure 4. Estimated incidence of asthma for people who reported an asthma attack during the preceding 12 months, persons who reported having asthma during 12 months, and persons who reported current asthma in the U.S., 1980–2004.

Virtual Design and Validation

It is a credit to the profession that chemical engineers designed the many complex and highly integrated plants that they did for decades prior to the entry of the digital computer into the field. However, with the development of cheap, powerful and readily available computing on a small scale, process engineering and design was revolutionized. Process simulators of the kind that have been developed over the last 30 years have made design and, especially plant retrofitting, a much more streamlined and transparent process.[24] Tied together with tools for effective cost engineering and financial analysis, many, many different design options and their relative economics can be evaluated and assessed in ways that were barely imaginable in the three quarters of the twentieth century.*

Today with even better simulation tools and even better tools for computer supported cooperative work (CSCW), chemical engineers have unprecedented power to do even more creative design and modeling.

Imagine, then, how surprising it is to learn that design tools in the building industry are still quite comparatively rudimentary. This is not to say that effort has not been made to create useful simulation tools. Building information management (BIM) tools do exist for construction management and new tools will also be created to integrate into existing BIM methodologies,[25] especially tools for operation and control. However, BIM still leaves much to be desired compared to the model-based design tools used by chemical process engineers. Other tools sets are available to partially fill the gaps. A visit to the Dept. of Energy's Office of Energy Efficiency and Renewable Energy (EERE) buildings technologies program's website (http://www1.eere.energy.gov/

*In the early 1990s the author had the privilege of seeing concurrent research, development and design in action while regularly consulting for the DuPont Company on the problem of quickly replacing chloroflurocarbons (Freons) with hydrofluorocarbons. As research chemists working at the bench conducted experiments with new catalyst compositions, the quantitative performance of those new catalysts could be immediately analyzed economically by entering even simple conversion and selectivity data into the plant simulation and assessing their effects on size, operation and costs of the very expensive downstream separations stages. As a result, a new plant for HFC-134a was taken from design to operation in under four years. Even just a few years earlier this would have taken seven to ten years to accomplish by linear rather than concurrent engineering RD&D.

buildings/) will show the reader that there are scores of software packages that can be used for simulating different aspects of buildings.

Among these the DOE's building technologies program has produced its own computational package called EnergyPlus.[26] This package affords designers the tool needed to evaluate a building's heating and cooling loads in terms of its overall mass, and heat balances and building parameters. However, the package stops at this point and it is not as user friendly as are more highly developed simulation software tools. Another useful software tool is Modelica, an open-source, object oriented modeling language that can be used to simulate a building's electrical, mechanical, thermal and control subsystems.[27] In the hands of a skilled professional, this is an elegant and powerful tool, but it too, only goes so far. At another level CATIA is a CAD/CAM/CAE modeling suite from Dassault Systemes that was developed for 3-D modeling in the aerospace industry, and it has been also used successfully in the automobile and ship building industries.[28] CATIA has seen some limited use by some architectural engineering firms for building design, but there is no industry standard.[29,30] Furthermore, it is interesting to note that physical scale models of buildings are created first and then these are scanned to digitize them for virtual rendering within CATIA.[31] Other familiar tools sucha s COMSOL®, MatLab® and Mathematica® may also be used for different aspects of the design and control problem.

While each of these tools are promising and useful in their own right, they all require too much effort from a designer, or team of designers to be efficient. Each is a language unto itself, they are not interoperable and so results cannot be readily transferred between packages. Furthermore, it is unclear how one intelligently selects a package to use from among the plethora of packages that are available. There simply seems to be no equivalent in the building industry to HYSYS®, ASPEN® or CHEMCAD®.

With this in mind, now consider the problem faced in doing individual building retrofits. Each building is different; they were built in different eras and they exist in different climate zones.[10] They have different skeletal structures, envelopes, fenestrations, materials of construction, heating, lighting and air conditioning systems.[32] Some have distributed controllers and others have centralized controllers. Often even the most rudimentary levels of building baseline performance are lacking. It is not unusual to be forced to use energy bills as a proxy for performance data and only if they are available. Other buildings and natural features in their surroundings affect any given building's performance as well. All of these considerations must be integrated into the engineered retrofit design process.[33] Imagine then the kind of analysis that must be done to determine the optimal extent of a retrofit for any given building; simply put, this is a hard problem. At one extreme the building may be stripped back to its superstructure with removal of everything including the envelope, all mechanical and electrical systems and other components. It is then ready for a deep retrofit or an "extreme makeover". At the other end of the spectrum, the building may simply be made slightly more energy efficient with some added insulation and other rather rudimentary improvements of a temporary or permanent type and whose effects may be more apparent than real. Between these two where does the optimum engineered retrofit lie? This is the critical question to be answered and it should be answered with reasonable certainty before capital is invested in the project. At present this is not possible to do well, thus the risk to capital is high, and the rate of investment in such retrofits remains low.

Since, the retrofitted building should not only be energy efficient, but also healthy, improvements to indoor environmental quality (IEQ) are by definition costly, so they too must be deemed worth the investment that has to be made in them.[34] If the building is to be occupied by tenants who are attune to such matters and are willing to afford them, then the enhanced indoor ecology and energy efficiency provided by the retrofit may induce them to pay higher rents. This can provide the owner with the higher revenues necessary to lead to acceptable simple payback times. Based on what we know of the sector, a building's retrofit must pay back to the owner in a range of three to five years even to be considered as a viable investment in the first place.[20,35] Thus, the objective function to be optimized is, as always, strictly economic for most building owners. Net present value of the retrofit is made up of capital investments and costs for the purchase and installation of new higher technology for HVAC, coatings, windows, roofing, control systems and other components. The cost of these investments must be offset by the sum of the discounted cash flows in year over year savings in energy costs and enhanced revenues from higher rents.[14,20,35] For now the latter depends on having informed tenants who appreciate the improvements to efficiency, indoor air quality and overall habitability and who are willing to pay for them.[19,36,37] Through better methods of analysis, simulation, and modeling, we must be able to provide tighter designs, better construction management and operational efficiency to reduce cost and the risk to capital so that great adoption of engineered retrofits will occur.[38†]

There is then a vast "trade space" for the design options that can be undertaken, and this is what makes finding an optimum for the engineered retrofit of any given existing building a truly hard problem. Even with good simulation tools this would be a challenge, but with the paucity of integrated tools for simulation it becomes almost an impossible problem to solve with sufficient certainty. An immediate need is for highly integrated building simulation tools that approach the levels of sophistication that chemical engineers have come to expect with process simulators. At the same time without such modeling tools, it becomes very difficult to do rigorous control of the building once it is constructed.

Control and Interoperability

After a building has been retrofit, and even if the best of technologies have been incorporated following the design specifications and their installation modalities, as we have seen, it is still quite possible and even likely, that the performance of the building will lag expectations. Why this is the case must be must asked because the building owner

[†]Exogenous market forces, i.e., government policies and regulations, such as carbon taxes or new technology subsidies, driven by societal concern for continued emissions of greenhouse gases, may arise in the EU, and elsewhere, and these can swing the economics of the engineered retrofit from a marginal investment to favorable or even highly favorable.

who has made the investment to do the retrofit certainly will. One reason is often simple—inadequate building operation.[39] This can stem from the lack of an integrated model to be used as the basis for control, because without this mathematical description of the building, its sensor network, and externalities, it becomes difficult to manage building behavior under any and all conditions. Not surprisingly methods and approaches such as distributed model predictive control that have been developed for problems in chemical engineering may be nicely as a means to more sophisticated control of buildings.[40–42] In fact, with such methods, we can even begin to anticipate changes short time changes (hours to minutes) to the external building's conditions. For instance, truly advanced methods of control for large buildings with multiple zones eventually will integrate into the predictive control model localized weather forecasts that are provided in real time.[43,44] In this way building conditions can be adjusted such that the anticipated the change in conditions leads to more gradual changes in set points and in a way that accounts for those processes with long-time constants within the structure that lag those that have short-time constants. Put another way, by anticipating a change in weather and by predicting its effect on the different parts of the building and its multiple zones, time variation in buildings control set points can be made smoothly and continuously. Doing this allows the controls to operate the building with higher overall energy efficiency than can be had by making abrupt changes in response to an external change of conditions. This kind of proactive control of a building, as opposed to reactive control, must be distributed and model based, and, hence, more sophisticated than what is done in buildings today.

While having overall heat and mass balances for the building is basic and necessary, in most cases it is not sufficient. Buildings exist in an ever-changing outdoor environment. Ambient temperature fluctuations, precipitation, wind patterns and air circulation around the building, human ingress and egress all combine to give a great deal of variation in conditions that need to be accounted for and responded to in real time if performance is to be optimized. Variations in external conditions affect the building's pseudo-steady-state. Radiation for example affects different parts of a building at different times of the day and with strong seasonal variation in many climate zones. Envelopes and fenestrations have an effect on energy and mass transport into and out of the building, as does foot-traffic through revolving and hinged doors. Inside the building, the fluid dynamics of air flows within corridors will affect mass and heat flows from room to room and between floors. These factors affect occupant comfort and their behavior. Having effective transient responses to these kinds of perturbations in order to provide optimal control requires models that go well beyond basic heat and mass balances. Such high-level control paradigms also require highly distributed sensing. Yet, models and sensor networks of this kind are rarely available in buildings; thus, most buildings are not adequately instrumented to do dynamic control of a kind that will provide optimal energy usage and habitability.

Rigorous CFD models that are highly accurate are typically complex and costly. Although very detailed models can be developed for any given building, it seems unlikely that such complex models can be constructed for each and every building to be retrofitted since the cost to do so at present is still prohibitive. Therefore, we need models that are "good enough", meaning much better than we have now and, yet, not so detailed as to be infeasible for broad application and use.[47] Some elements of the building, such as windows or doors, will require more fine-grained modeling for accuracy. However, other flows of air and transport of energy may be modeled at a coarser level while still maintaining requisite accuracy. It is the case, then, that reduced models based on detailed simulations that span multiple lengths and time scales need to be developed to provide results that are accurate enough to represent the stiffness of buildings dynamics without being computationally too burdensome.

Indoor Ecology and Sustainability

The use of synthetic materials within buildings is ubiquitous. New polymers have led to better coatings, flooring materials and fabrics.[46,47] It is also the case that these materials have components that outgas for significant periods of time, typically following an exponential decay. Volatile organic compounds (VOCs) combined with natural entities degrade indoor air quality. Much has been done in HVAC systems to alleviate the VOCs load in building air, but new materials that outgas less, or that outgas more innocuous volatiles are of increasing interest. Having polymers that are sourced from naturally occurring monomers is of considerable interest. In contrast to those that are derived from synthetics, they are sustainable because the carbon within such polymers can be recycled indefinitely. However, the economics of using such materials must be competitive, or at least comparable to those derived from petrochemicals. Still, cost remains a significant hurdle to be overcome before much market penetration by renewable materials can take place. Nonetheless, it is a worthy area of research for now and the future.

New less costly materials also are needed for windows that can vary in tinting dynamically with conditions. There are windows that respond to increased light flux or a variation in voltage in this way by using photochromic, or electrochromic layers applied to glass to do this, but they are very costly. Finding ways to reduce the costs of these components will bring them into much wider use. Similarly, layers applied to glass that are photocatalytic can make for self-cleaning windows. In climates where the persistence of sunlight during the day, day in and day out, is high, roofing and cladding should become an active component for energy production. Clearly, some smart materials of this kind are being introduced to the market, but much more research and development is needed to design even better materials and, just as importantly, to find new processes for mass production that can drive down their costs.

For dynamic, distributed control new kinds of sensors are also needed that are cheap, effective, reasonably long lasting and that can be deployed in a massively redundant fashion. The national initiatives in nanotechnology over the last decade should provide new approaches to designing and fabricating sensors needed for new smart buildings. Being able to incorporate nanosensors for temperature, oxygen, carbon

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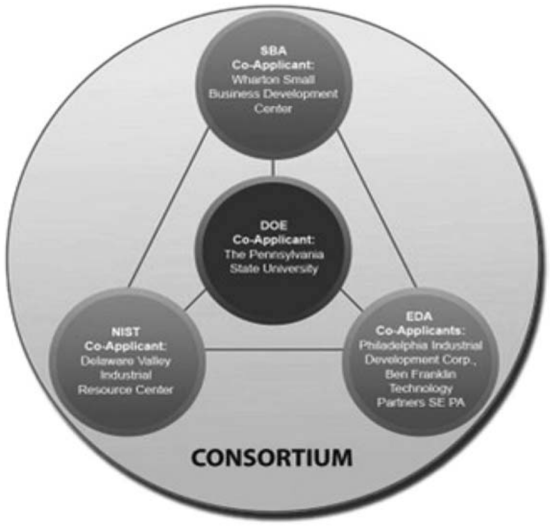

Figure 5. The member organizations of GPIC the DOE hub for energy efficient buildings.

dioxide, carbon monoxide, ozone, volatile organics, particles, etc., into coatings as they are applied to surfaces would be a huge advance. Short of that and in the nearer term just having lower cost sensors that can be distributed massively throughout inside spaces, and on the outside surfaces of buildings will begin to provide the level of data needed for distributed control that will ensure health and provide energy efficiency.

Innovation and Entrepreneurship

Looking deeper at the retrofitting problem, one recognizes that in addition to much better tools for design, economic analyses, better control systems and operation, we need a wholly new and integrated approach to the business model for building retrofits. Today, retrofits are done in a piecemeal fashion by many different subcontractors. Even though an architect carries out the initial design and even though there is a construction manager, the subcontractors subsequently do their work rather independently—from installing new HVAC systems to plumbing, insulation, walls, fenestration, roofing, etc. It is doubtful that anything as sophisticated as we anticipate a retrofitted building will have to be to achieve high performance can be designed and constructed in this *disintegrated* way. There will have to be new ways of integrating all the work that is done during a retrofit and of managing the outcomes at each stage to much more exacting standards. This is why is likely to be necessary to create wholly new business models.

For example, is it possible that the ultimate approach to deep retrofitting will involve the manufacturing of modular inserts that could be designed and produced off site for any given building and then installed in block and build methodology? If so, could the same materials, methods and manufacturing tools then be used over and over again to create unique solutions for each different kind of building to be retrofitted, that is can "mass customization" be done here? To move in this direction would require having not just new materials, and high-level modeling tools for design and control, but a new hierarchical approach to the engineered retrofit problem. Innovation as we know can create a new industry where this nothing like it today; entrepreneurs who take on this challenge will lead us to the best approach.

Similarly, for a retrofitted building to achieve its performance goals, it is necessary to have more centralized control and operations. If so, it may become possible to create a new business model for operations and building management that operates remotely via the web from an operations center that will cover multiple buildings via in-cloud services. Furthermore, such a cloud-based service could be economically viable, because it could handle many geographically distributed buildings at once.

Energy Efficient Buildings Hub

This past year in August, 2010 the Dept. of Energy awarded the national Hub for Energy Efficient Buildings to Penn State and its team of academic, corporate and nongovernmental organizations[48] (Figure 5). The Hub is located at what was the Philadelphia Naval Shipyard, or the Navy Yard as it is called. The Hub in Philadelphia as funded by DOE ($122 million over 5 years) is focused on the science and engineering of retrofitting existing buildings. Different than the first two Hubs,[‡] the one in Philadelphia is the first *Energy Research Innovation Center* (ERIC). As a result this Hub is tasked to do more than science and engineering research in building retrofits; it is expected to produce economic lift for the Greater Philadelphia region by spurring new business development in this industry. Hence, it is engaged in education at all levels, informal as well as formal, and in catalyzing the growth of an entrepreneurial, creative class who will take new science and technology to market.

For this reason, the Energy Efficient Buildings Hub is called the Greater Philadelphia Innovation Cluster to reflect that it is an ERIC, and because we also received funding ($3 million) from NIST, the EDA and SBA in addition to DOE. Reflective our mission we have divided our work for the next 5 years into five main tasks that run in parallel. As articulated in the Statement of Program Objectives (SOPO),[48] and elsewhere,[49] these are:

1. Integrated Modeling and Design: The goal of this task is to deliver accessible, usable, affordable, calibrated and validated computer based tools built on open architecture to support integrated design of energy efficient retrofit projects by architects and engineers focused on average size commercial, multiunit residential, and mixed-use buildings. The tools must be adoptable at reasonable time and cost and available to small and midsize A&E design firms and suppliers in a cloud application environment.

2. Integrated Technologies and Systems: The goal of this task is to identify and develop optimal configurations of integrated component and subsystem technologies as building system solutions for various classes of building retrofits. The system solutions are to be scalable, reliable and cost-effective for energy efficient retrofit of buildings and are expected to vary in content with commercial building functionality, size, and aspect ratio, as well as with multiunit residential and mixed-use buildings.

3. Policy, Markets, and Behavior: The goal of this task group is to create policy and market environments that support full-spectrum energy efficient retrofit of average size commercial, multiunit residential, and mixed use buildings in Greater Philadelphia. Included in this effort is establishment of a regional database of the commercial building stock to provide underlying rationale in the formulation of innovative policy incentives, customer value propositions, and business models for industry suppliers involved in the energy efficient retrofit market.

4. Education and Workforce Development: The goal of this task is to ensure a skilled workforce at all levels of the retrofit life-cycle process, including building energy auditors, designers, equipment and material suppliers, contractors, commissioning agents, operating engineers, and others. Particular emphasis in Budget Period Two will be placed on establishing training and educational materials and career path opportunities for building operation engineers, commercial building energy efficiency and performance auditors, and building controls experts.

5. Demonstration and Deployment: The goals of this task are to create jobs in Greater Philadelphia, to help transform the energy efficient building retrofit industry from serial fragmentation to an integrated systems approach, and to improve GPIC design and delivery methods, system design tools, integrated component and subsystem technologies, public policy approaches, customer value propositions, and business models. This will be achieved through ongoing transfer of Hub outputs to the building industry with continuous feedback to the Hub from the industry.

In order to demonstrate and to teach at the Navy Yard, we will be using Commonwealth of Pennsylvania funding ($30 million) awarded to Penn State to conduct a deep, engineered retrofit of building 661 in order to create from it a living laboratory in which the Hub will be housed. In addition, we are working with corporate entities that are our partners and that are already in the Navy Yard, such as Urban Outfitters, to demonstrate new technologies in retrofitted buildings that they will occupy in the near future. We are doing this as well as with new companies that are locating at the Navy Yard.

Conclusions

The technologies and problems in the engineered retrofitting of buildings are quite familiar to chemical engineers—heating, ventilating, air conditioning are unit operations after all. Building simulations, modeling and control, all depend on techniques that have been used in the development of solutions for a multitude of problems faced by the chemical process and petroleum industries over the last four or more decades. Control and operations of buildings must become model-based and distributed. For chemical engineers who are also entrepreneurs, there is an opportunity to be truly innovative and to create a whole new industry or industries on a base of information and process engineering technology. This sector needs innovation of a kind that it has never experienced before, and it will not likely experience the necessary wave of innovation unless new professionals become involved and break with the paradigms of the past.

Chemical engineering over the last one hundred or so years has proven to be one of the more flexible and innovative disciplines of all the engineering disciplines. Its practitioners are able to tackle problems that span a spectrum of length and time scales unlike any other. Equally adept at theory and practice, chemical engineers are consummate problem solvers, systems thinkers and they can also be entrepreneurs. Is this the right time to venture into a new area like the engineered retrofit of buildings? Is this too far afield for chemical engineers to travel? Is it even appropriate for chemical engineers? I think the answer is an unqualified ‘‘yes!’’ After all when, as an assistant professor, I once asked Bob Pigford ‘‘what is chemical engineering, really?’’ He smiled at me wryly and said ‘‘Hank, it is whatever chemical engineers do’’. There is a whole new industry waiting for chemical engineers to do something innovative.

[‡]The DOE also created two other Hubs; one is the Energy Innovation Hub-Fuels from Sunlight, devoted to research on the topic of using sunlight directly to synthesize fuels; it is led by CalTech and Lawrence Berkeley Laboratories. The Nuclear Energy Modeling and Simulation Innovation Hub is focused upon on the scientific design of a new generation of nuclear reactors and it is led by Oak Ridge National Lab.

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