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Energy In Buildings

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Overview of Building Energy Use and Economic importance

I will begin with a brief overview of the economic importance of energy use in buildings. This somewhat overlaps John Eberhard's presentation but has a different emphasis.

Consider the items that directly affect energy consumption in a typical commercial office building. These include the electrical and mechanical systems, lighting, elevators, insulation, upgraded windows, and measures to reduce air leakage. The cost of these items will vary from building to building, but will typically be one fourth to one third of the cost of the building. Thus, the construction cost of energy-related aspects of a building is a very significant fraction of the building cost.

The energy to operate a building typically costs fifty cents to two dollars per square foot per year — perhaps ten percent of the total rental cost. These two items will thus contribute 35 to 40 percent of the total cost of owning and operating a building.

The cost of energy used in U. S. buildings is approximately $150 billion per year or about four percent of GNP This is essentially equivalent to the gross farm income, so we spend as much for the energy used by buildings as the income generated by all farming activity in the United States. Everyone recognizes the importance of the agricultural industry to the country, but the magnitude of energy use in buildings is not so widely recognized.

I don't have hard numbers on the building construction employment due to the energy-related systems and components, but it must exceed one million jobs. I have examined engineering employment in the energy systems area, and it appears that about 100,000 engineers work in all facets of the HVAC (heating, ventilating and air conditioning) field including equipment design, equipment sales, building systems design and specification, etc. Energy-related employment in buildings is clearly a significant factor in the national economy.

The importance and overall economic impact of energy use in buildings depends on how it is measured, but it is obviously more than one percent and probably about five percent of GNP? This is a significant factor in the national economy.

Energy Retrofit: A Case Study

There are a numerous developments and topics regarding building energy systems that could be discussed. I will illustrate an important point with a short case history.

We recently studied energy use and potential measures to reduce use at the student recreation center at the University of Colorado. The University spends about $250,000 per year on all types of energy for this 150,000 square foot building. A number of steps had been taken to reduce energy use in this building subsequent to an earlier study of the building. One classic measure implemented was rescheduling the janitors to clean during operating hours instead of at night when the building was closed. This saved $25,000 per year in lighting cost. A related measure was delamping to further reduce lighting energy use. Insulation was added to make the locker rooms below the ice rink more comfortable, reduce their heating requirements and decrease the refrigeration requirements of the ice rink. A heat recovery system was added to the brine chillers to preheat hot water and improve the system efficiency.

These measures resulted in savings of about $50,000 per year, but this year's study found a large number of additional measures which can save an additional $70,000 per year for an investment of $70,000. Many of these measures were again very typical.

Outdoor air sensors are used to control baseboard radiation heating in the swimming pool area. These sensors were 11'F out of calibration. It is estimated that recalibration at a cost of $100 will save $5,000 per year in heating cost.

The usage recorded by a gas meter which meters clothes dryer consumption exceeded the rated consumption of the dryers operated 24 hours per day, and they are used less than 8 hours per day.

Interestingly enough, many of the fixtures that were delamped two or three years ago were fully lamped this year. The lamping crews had replaced all of the delamped tubes on their next pass through the building. The ballasts must be disabled to ensure that the building will stay delamped.

Reducing the exhaust air from a number of the building zones will show immediate benefit, Many fans continuously exhaust conditioned air. We also found that a pool cover would save several thousand dollars a year — and this isn't so typical, simply because few buildings have swimming pools. There were a number of other similar energy-saving measures identified which I don't have time to discuss now.

The major point illustrated is that (with the exception of the pool cover), every measure recommended by the current energy study was a change in building operation or an improvement in the energy-using systems within the building - not a change in the building envelope or configuration. This is typical of the majority of the opportunities for reducing energy use in the commercial building sector.

Recent Trends

Recent trends in new building construction show a major increase in the number of installations with variable air volume systems. Reheat systems are not nearly as common as they were in the past. Variable speed fans and motors are now being used in some buildings.

There have been numerous equipment improvements in the residential sector. The same is true in the commercial sector. Improved compressors and chillers are widely used; heat recovery from exhaust air is no longer a novelty. This morning we heard about new computer applications in buildings. The level of control which is possible today is much more sophisticated than was available only a few years ago. And this will continue to improve.

The use of unconditioned outside air for cooling when temperatures and humidity permit, so called 'economizer cooling,' is an extremely elementary concept; but it was very seldom used ten years ago. Today it is commonplace. The use of chilled water storage to permit use of off-peak power for cooling is not yet commonplace, but it is no longer a novelty.

Cogeneration of heat and electricity was widely studied and discussed in the late 1970s, but was seldom used. Recent improvement of the natural gas supply situation has sparked further interest. Cogeneration is now actively marketed by gas utilities and is increasingly used.

Typical building shell improvements like insulation and better glazing are almost universally used. Further improvements will come in these areas, especially as high performance glazing systems are perfected and marketed. Passive solar and daylighting are sometimes used in commercial buildings. I should also note the improvement in electric lighting systems. Third-party ownership has led to a significant number of active solar installations on commercial properties.

While these changes have generally resulted in substantial (and sometimes spectacular) energy savings, they have had a relatively minor impact on the overall construction process. They do require a better understanding of building energy flows and systems by the architects and engineers who effectively and efficiently design buildings with low energy use, so the major change has been the need for improved design skills.

Future Trends

The last decade's improvements in building energy systems, equipment and materials will continue. Beyond these changes, I believe we will see increased integration of components and systems in buildings. The design process will require practitioners with a deeper understanding of building energy systems and flows *and* who know how to integrate HVAC systems and components with the other systems in efficient and functional buildings.

An example is inclusion of thermal mass to reduce energy use. You can seldom afford to add mass to a building based on reduced energy cost. However, if mass is planned for structural, decorative or other purposes, it makes a lot of sense to design so the building obtains a maximum thermal benefit from the mass.

We had a talk this morning about 'smart' buildings or 'intelligent' buildings. Building control systems will be much more than just energy system controllers. They will often handle security, life safety systems, communications, etc. The energy related aspects of these systems will expand to include control of daylighting, thermal integration, building tightness, indoor air quality, etc.

I believe that acceptance tests based on the use of expert systems will eventually become commonplace. As we all know, after a building is built, the architect and engineer walk away and seldom look at it again. We need to go beyond just designing and constructing the building. The design data should be used in conjunction with an acceptance test to let an owner know that when a building is accepted, the energy systems perform as designed. If they don't, the building won't be accepted until the problems are corrected. We don't yet know enough yet about building and systems performance measurement to develop comprehensive diagnostics immediately, but it will be possible in a few years.

A related development will be diagnostic testing for existing buildings. Such tests will use a more limited data base but will still be very useful for maintenance and will provide valuable information for prospective purchasers.

Rehabilitation and retrofit will be continuous for functional purposes as well as for energy purposes. Perhaps one of the best illustrations of this need is the Enerplex South Building near Princeton University. The Center for Energy and Environmental Studies at Princeton assisted the design team and is now monitoring the building — designed as a state-of-the-art building. Several cost-effective retrofit measures have already been identified for this nearly new building. Variable inlet fans are used in this building. Today, variable speed fans are viable. Installing variable speed fans, reducing the night thermostat setting from 58°F to 55°F, and increasing the supply air temperature from 55°F to 60°F is projected to provide an additional 21 percent reduction in the already low heating requirements of this building. Note that none of these items will change the environmental conditions in the building during occupied hours.

This example illustrates that even state-of-the-art buildings can sometimes be improved by system changes. Consequently, I don't believe that the existing building stock will be retrofitted and improved to the point where further retrofits are no longer needed after five years or twenty-five years.

We can expect increased automation of the entire design and production process. Increasingly powerful CAD/CAM systems will be used as discussed this morning and more buildings, assemblies and components will be manufactured.

The changes discussed will lead to improved building environments and improved building quality. Both will be increasingly important in future buildings. Cost-competitive techniques have been discussed at length and are important. However, note that Japanese automobiles are not cheaper than American automobiles, but they offer higher quality; and the American consumer has learned to appreciate and purchase this quality. This will affect future building purchases as well.

I expect these trends to provide an impetus for industrialized construction. Energy considerations will not single-handedly bring about industrialized construction, but will encourage this transition. Tighter buildings with less air leakage will generally use less energy, and it is clearly easier to achieve reliably tight construction with industrialized construction techniques.

Finally, I will note an issue of particular interest from a university perspective. These changes will require a more integrated design team whose members have better skills and better education than is generally available today.

This will require changes in university curricula. As a specific example, we've had a lot of recent input from leading practicing engineers who say that the education received by HVAC engineers is deficient. The basic and applied thermal sciences education received by the typical engineer entering the field is less than one semester of his total education. It has been stated that HVAC engineers take much longer to become productive than structural engineers and others. This area must be addressed by universities.

Conclusions

Observation of the energy-related changes in buildings during the last decade and consideration of projected changes indicates that:

- Energy-related changes in buildings will not require major changes in the structure of the building industries;
- Technical developments will continue to improve energy efficiency for the foreseeable future. The degree of change will depend on energy prices;
- Energy retrofits will continue for decades;
- Consumers will demand improved environmental and construction quality in buildings;
- Energy-related factors will contribute to the trend toward industrialized construction; and
- Universities will need to provide better engineering education in the building sciences.

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I'm going to discuss two topics. First, I'm go ing to talk about the energy use in buildings, covering both residential and commercial, to establish sort of a data base for this subject. Then I'11 talk about residential energy use and what's occurring in that area. Dave will talk about commercial building energy use. We've made this split with the understanding that we occasionally waiver into each other's area because our interests are in both areas.

The office I head at DOE handles the regulatory and the research activities of the Department. Usually I find myself tormented by the regulatory parts of the job. So it's a great pleasure for me to be able to talk about some of the researching kinds of things, although we had gotten into some regulations.

The energy use in the building sector is about 26 quads, 16 of those in the residential area, 10 in the commercial area, and here you can see how the energy is used for different purposes in buildings: space heating, water heating, refrigeration dominates in the residential area; space heating, lighting and air conditioning in the commercial area. (See Figure 1).

In the residential building sector shown in Figure 2, here the six percent mobile home wedge refers to Don Carlson described as HUD-built, manufactured homes. When we talk about some of the modular and other manufactured portions of that market, that wedge would increase.

Figure 3 shows square footage of buildings rather than energy use in buildings. It indicates the diversity of different types of buildings, when we talk about the commercial building sector.

Now, what this means from a technical perspective is that there are a lot of different kinds of buildings that you are dealing with in terms of design materials or what have you when you talk about commercial buildings.

With that as the introduction, allow me to make a couple more points as far as energy use in buildings in the U.S. is concerned. The 26 quads represents about 36 percent of the nation's energy. The energy use in buildings in the U.S. has remained fairly stable during the past ten years in the 26 quad range. However, within that energy use, there have been some changes that are fairly interesting. Natural gas use has changed very little, gone down a small percent. Petroleum use has declined fairly rapidly, going from about 18 percent to about 10 percent. Making up that gap has been a fairly significant increase in electricity energy use in buildings, rising from about 50 percent to 60 percent.

The coupling that I think is starting between energy, the electricity use in buildings, and the electricity industry is becoming increasingly significant. As you know, a number of changes are taking place in the electric industry, and I think that interaction will be recognized as increasingly important.

As we look forward the gap between energy supplies and demand is expected to tighten during the last half of the 1980s and remain fairly tight during the 1990s, creating some upward pressures on prices. I hate to get into price forecasts, although we do some of that work, but I think that the pressure on prices will become more compelling during the latter portion of this period.

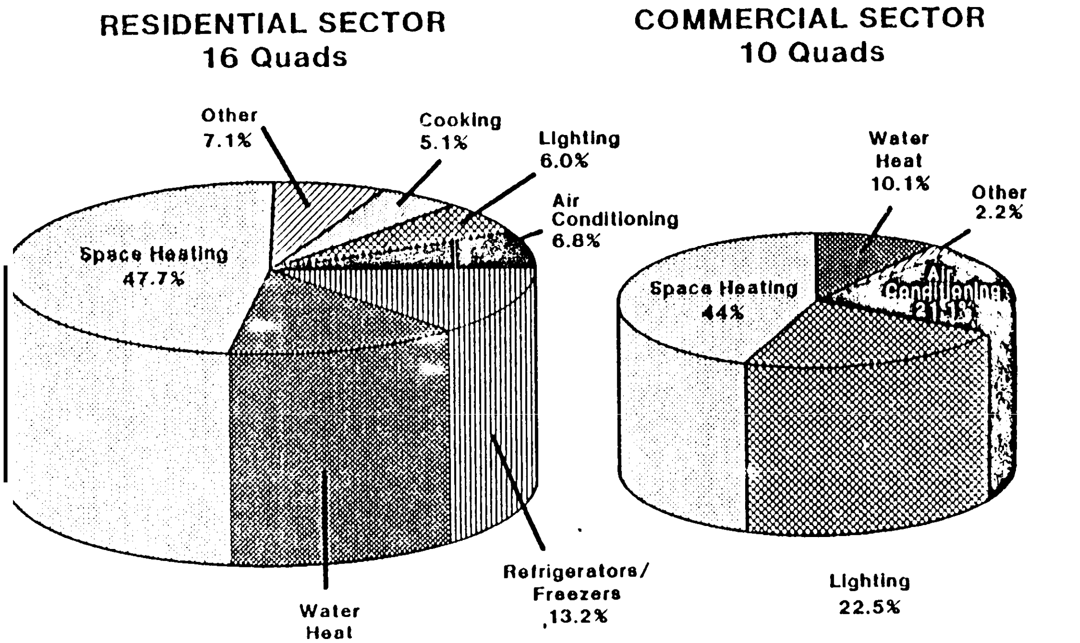
Some forecasts have been made about how energy will be used in buildings. Space heating will remain fairly high. Space cooling will become an increasing share, particularly in commercial buildings. Lighting will go down a bit as we get some more efficient lamps and fixtures and increase use of daylighting. Water heating will remain fairly stable.

The question that comes out of the energy use in the buildings portion is: to what extent will energy costs drive change? I believe that it will be a moderate-to-major driver during this period assuming the trends I've reveiwed are not interrupted. The possibility of interruption, however, means that there's an element of unpredictability about the extent to which energy costs will influence construction.

One of the things that should be mentioned although it's a fuzzy area, is the extent to which the embedded costs of existing buildings will be a significant factor during the next few decades. Many buildings erected when energy was not a significant cost factor will be in use for some

Figure 1

1980 ENERGY CONSUMPTION BY END-USE

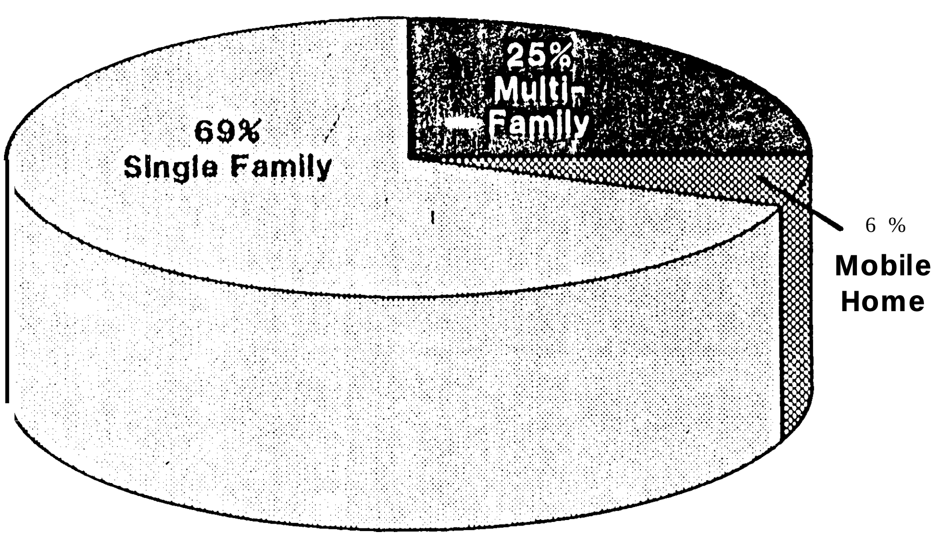


EIA 1981 Annual Report to Congress, Volume 3 Supplement 3

Figure 2

RESIDENTIAL BUILDINGS SECTOR

81 **Million** Occupied **Units in** 1980
- 69% **Owners**
- 31% Renters



EIA 1981 Annual Report to Congress, Volume 3, Supplement 3

time. The cost of building new structures will lend a certain economic and energy appeal to using existing buildings rather than replacing them with new ones.

I think that the relationship with electricity also will become increasingly important.

Now, I've completed my remarks about the energy use in buildings, and I'll look more specifically at how some of these affect what's taking place in the residential sector, and stray a few times into the other areas. I've followed the outline, looking at the new and emerging technologies, the way these technologies may be applied and impacts on the building construction industries. I will go through the first part of this fairly quickly and spend most of my time on the impacts.

If we look at residential or commercial buildings, we really look at three interacting systems: (1) the building envelope itself; (2) the HVAC equipment that meets the needs of the people using the building; (3) the community energy supply or utility system that supplies energy to the buildings. The efficiency that comes as the end result depends upon the relationship and the interaction among these three systems.

Now, when I talk about the technologies, I mean first, the building systems and HVAC equipment and then the community systems.

I think you might look at some of the kinds of technologies that are currently taking place as far as building systems are concerned. The kinds of things such as insulation material becoming significantly higher and possibly changing thermal resistivity. Coating that may be put on the outside of buildings may be either reflective of the energy coming in or absorbing, depending upon what is desired, and what serves the energy value of that building most effectively. Some 'smart' glazings make it possible to have two panes of glass with some material between, where electrical current may be passed through the material, causing it to be reflective or let light through, depending upon what is wanted,

I think these are areas in which work is being done on new technologies that should emerge in the near future.

We could spend a lot of time on indoor air quality. I think that area will be important, but not one I particularly want to discuss at length at this time.

I think another important area here is the retrofitting of buildings. It's harder to identify what research opportunities there are in the retrofit area. But because of what I think is the significance of retrofit of buildings, questions of engineering, optimization and selection will become increasingly important.

Also in the building equipment area, there are some very promising things going on. Thermally-activated heat pumps that have a COP of 1.7 to 2.0 should be coming into the marketplace in the 1990s. We already have heat-pump water heaters that are twice as efficient as electric-resistance water heaters. Combustion heating equipment with efficiencies over 90 percent, and advanced lighting concepts that have improvements from five percent to over 100 percent already exit. These high improvements normally involve some device for replacing an incandescent light with a flourescent light, but those technologies are available.

Integrated appliances are those which may be made into a single unit by moving thermal energy one way or another, rather than the separate major appliance units that we currently have.

Micro processors allow us to be much more sophisticated in our building control strategy. So there is a lot of technology there as well.

In the community systems area, I think the principal technologies of interest are district heating and cooling. Reducing the cost of district heating and cooling can be accomplished through lower piping costs, meters that are more accurate, heat meters, and automated combusters, five to 25 megawatts, self-contained coal-fired or petroleum-fired combusters.

This has been just a quick mention of some of the technologies, but it's representative of a sort of seething, exciting area of technological research that includes many, many more things of the kind we've discussed.

The next question is the way these technologies will be applied. One thing I think we already know, and have demonstrated fairly well, is that we now can build residential buildings that are extremely energy efficient in terms of reducing heating requirements in cold climates. That was one of the first targets at which we aimed. Single-family residences that have an energy requirement of something like one or two BTUs per square foot per degree day can be, and have been, built. These residences have a heating bill of a couple hundred dollars. We know how to do this. Less time has been spent attempting to make buildings energy efficient in hot climates where cooling is the principal concern, but we're talking about engineering applications not significantly different from those that we have used successfully in the cold- climate areas. Therefore, I think that with the application of research in this area we'll be able to solve that problem as well.

1 think the significant point in many of these areas is that it's not really the absence of technological capability that is going to slow progress. 1 believe it's going to be more a problem of 'know-how.' Getting information about how to use the available technologies throughout the infrastructure, and also some economic constraints, may be a hindrance, but not a lack of technology.

There will be an increase in attention given to how these technologies can be applied to existing residences. The quality of construction will also be given more attention. So far a large part of the research in the residential and commercial building areas has been spent looking at how component parts of buildings work. Increasingly important, now and in the future, will be to determine the interaction of these components and how to put all of the parts together so the entire building operates efficiently.

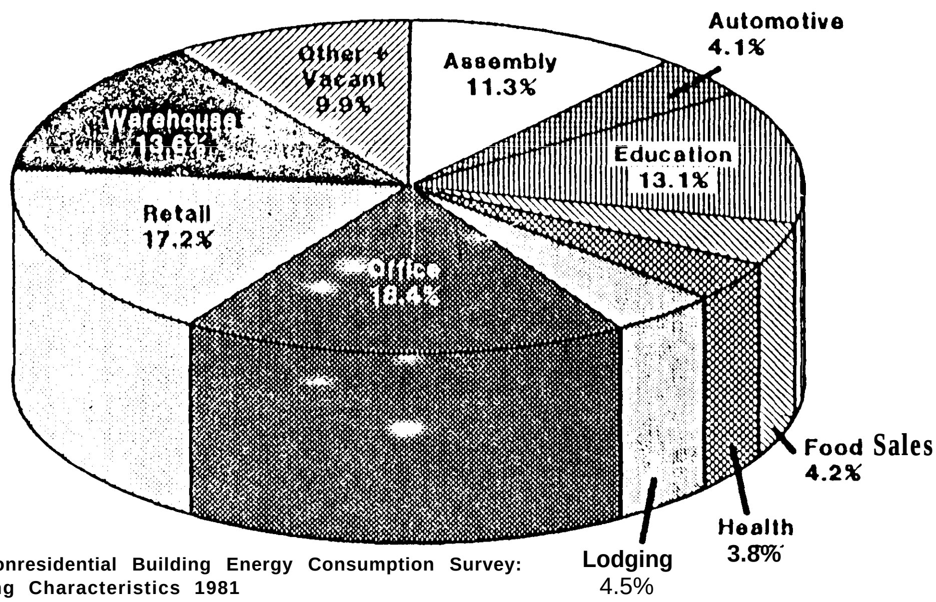
Similar kinds of changes can occur in the building equipment area. The increased 'envelope' performance of newly-built residences will call for smaller-sized HVAC equipment. The most cost-effective retrofits in existing residences will often be done in the equipment area rather than 'envelope' retrofits.

As a result of the coupling of utility policy with building policy, more attention will be given to utility load management. Micro-processors can be used to monitor how building equipment operates in terms of its demand for electricity. Such systems will enable utilities to better match load factors with demand rates.

Figure 3

COMMERCIAL BUILDINGS SECTOR

44.6 Billion **Square Feet in 1979**



EIA Nonresidential Building Energy Consumption Survey: Building Characteristics 1981

As a result of the technologies and other things that I've mentioned, there'll be more district heating and cooling systems initiated. Not the large central systems that we've seen, but more neighborhood-sized community systems.

With regard to the impacts of technology on the building construction industries, Don Carlson's paper contains some thought-provoking points. As a result of reading his paper, I'm not as confident about some of the things I said here as I was before. Nevertheless, I will goon in an attempt to continue to stimulate some more of the lively discussion that we have had.

Continued and increased attention to energy performance in new residences, along with many other factors, will contribute to pushing up the costs of conventional, single-family residences. Concern for affordability will continue and grow. The shift to multi-family dwellings compared to single-family dwellings will continue, and a shift to smaller residences will occur. Some residences we're seeing now are really very small in size. There are condominium units of as little as 240 square feet, which is about one-sixth of what is generally considered to be the usual size.

There will be great concern for the quality of construction because of the recognition of its significance to energy performance. Tighter houses will cause increased attention to indoor air quality and other safety issues, adding potential cost for improvements. The move to manufactured, modular and prebuilt housing will continue at a moderate rate.

I come from rural Iowa, and despite the predictions of his elimination that have gone on since the turn of the century, the family farmer still hangs on there pretty tightly. I think that the home builder is much the same breed, and there will be many home builders around long after the forecasts of their demise have run their course.

There will be some increased labor shifts. This is a controversial question, and maybe we can target it. At several points here, I have talked about the impact of technology on labor and tried to predict where the impact might least affect skilled or moderately skilled labor, It seems tome that it's at least arguable that manufactured housing will lead to some reduction in the skill level required for workers.

Home builders will continue to expand into the multi-family and small commercial area. The retrofit activity will increase and provide jobs to some of those unable to find employment in new construction. The retrofit field will become more sophisticated, however, involving computer simulation of various retrofit technologies.

The heating, cooling and appliance manufacturing industries will remain active, although their product lines will change. However, if these industries fail to make the product improvements that may be called for, they will leave the door open for increased foreign competition.

The interaction between building energy conservation activities and the utilities' planning policy will become more apparent. This will lead to increased planning and management activities in terms of that interaction.

Investment in district heating and cooling systems will create construction jobs in urban areas. This is another area where I think medium and mid-level skills could be employed. These systems could be included very effectively when considering investments for renovating the urban infrastructure.

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