An Outlook on Residential HVAC&R Applications in 2020

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ABSTRACT

As a result of market trends and societal pressures being exerted on the appliance industry – government, environment, and consumer driven – homes of the future will be markedly different than those of today. This paper summarizes the market shift and changing business climate, speculates[1] how these may impact residential HVAC&R equipment and applications 20 years hence, and introduces a new research initiative (HVAC&R Research for the 21st Century, 21-CR) that is a first step in positioning HVAC&R stakeholders for this future.

INTRODUCTION

The U.S. heating, ventilation, air-conditioning, and refrigeration (HVAC&R) industry, which has been experiencing evolutionary growth for the past 50 years, is currently undergoing a period of unprecedented change. The pressures driving these changes – protection of the environment and conservation of our natural resources – will only become more pronounced in the future. These pressures are altering the U.S. HVAC&R market with resultant impacts on equipment and applications.

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1 As is normal in "crystal ball" forecasts, a caveat is needed to indicate that ideas expressed in this paper are only possibilities that could occur and not necessarily will occur. As such, the future portrayed here is not represented as being the view of my employer, equipment or service providers, nor other industry participants.

Industry Pressures

Refrigerant Phase-out: Industry stakeholders are all familiar with the refrigerant phase-out dates – CFCs are history and HCFCs have phase-out dates mandated for them. Viewing the world with a 1999 perspective, it is likely there will be continued pressures against the use of HCFCs in the future. Clearly, HCFC-22 (the dominant refrigerant used in residential comfort conditioning) will not be allowed in new equipment past the current phase-out date of 2010.

Energy Efficiency: Currently, the U.S. National Appliance Energy Conservation Act (NAECA; affects unitary residential equipment) is under review, and it is anticipated that new minimum efficiencies will become effective in 2007. Hence, at the point when the industry will begin a serious transition away from R-22, industry will also need to comply with new equipment efficiency requirements.

Market Consolidations: Much consolidation is occurring among HVAC&R contractors, where either they are being bought out or they are selling out. This is resulting in large blocks of well-established and well-capitalized firms that are spreading across the United States. These new firms have substantial clout and are developing a large market presence; making it harder for smaller, independent contractors to compete. It can also be expected that over the next 20 years the quantity of distributors and the number of independent equipment manufacturers will be reduced as well.

Technology Shifts: During the next two decades, there will be a continuation of technology spin-offs into the housing industry. New methods from other industries will be adopted in totally unexpected manners. Other technology transfers will be more predictable, and we should be positioning ourselves today to take advantage of the pending changes.

Societal Pressures

Indoor Environmental Quality: Indoor environment quality (IEQ) will become more important. IEQ is more than just temperature, particulate filtration, humidity and carbon dioxide control. It also includes sound, vibration, lighting, air velocity, and contaminant control. IEQ will become health- and productivity-based as opposed to comfort-based. It is unknown what these health-based or productivity-based IEQ metrics may be, but future HVAC&R applications will be expected to be responsive to them. It can be expected that 25 years from now, industry will be designing, selecting, operating, and maintaining equipment based on real health, real safety and real productivity feedback.

Environmental Impacts: The environment will continue to be an issue of intense focus. Essentially, the ozone depletion issue – with its related Montreal Protocol implementation issues -- is behind us. However, in front of us are all of the issues associated with global warming. Unfortunately, the global warming challenge – and what we have to do to rise to that challenge – will be considerably larger than what we had to face for ozone depletion. One can only hope that the industry subsequently proves to be up to this challenge. Obviously, there will be a continuing emphasis on refrigerant containment and recovery as well as on the efficient use of energy.

Sustainability: Sustainability will continue to grow support in the future. This means designing for easier recycling (everything will be recyclable) and end-life disposal. This implies that the materials in use today – and those which will be used in the future – will be selected more and more by their ability to be recycled. HVAC&R equipment – because of its high metallic content (aluminum, steel, copper, bronze) – is comprised of 95^{+}% recyclable components. [1] However, some products, such as the residential window-mounted air-conditioners, are using more composite materials for strength and durability, as well as to assure that the product is lightweight. This implies that after-market applications will need to be found for these engineered plastics in 10-15 years so that a disposal problem can be averted.

We will also look to use less natural resources, and to use those resources in a manner that has the least impact on the environment. There is a growing interest to assess the relative impact that the utilization of one component or material selection may have over others. We need to look at how much energy is involved in the extraction, fabrication, shipment, usage, and the disposal/recycling of components. It is possible that in 25 years there will be rankings for energy consuming equipment in terms of primary power. This could cause gas technologies to gain favor at the expense of electrically-driven equipment, especially if the ranking includes extraction and energy conversion losses.

Utility Deregulation Implications

Deregulation of the electric utility industry will induce significant changes on how energy is produced, distributed and marketed in the United States. Air-conditioning can become a service rather than a product. A utility or energy service provider may become a supplier of conditioned air. This means that homeowners may not necessarily own the equipment. Rather, the equipment is leased to the homeowner, or perhaps the homeowner will merely pay for BTUs of cooling or heating. If this occurs, it would transform the residential unitary market. The emphasis will go from a customer requesting the least "first-cost" equipment, to the utility or the energy service company demanding equipment that provides the least "life-cycle cost" over the term of a lease. The focus will no longer be on selling the least expensive unit (generally minimum

SEER), but perhaps selling a higher value unit that is more reliable, more robust and has better energy efficiency.

While this is going on, there will be great flux. Utilities will be partnering with manufacturers, utilities will be partnering with mechanical contractors, and there may be a certain amount of utility buyouts of manufacturers and contractors. [2]

As a result of deregulation, there will be real-time pricing introduced into many areas of the country. This will imply variable cost of electricity, even from hour to hour. It may very well be that when unconstrained demand exceeds available supply, consumers may have to pay in excess of a dollar per kWh. However, during off-peak hours – when there is very little utility load – the cost to consumers for electricity may be nearly zero. Obviously, on-peak operation will cost more. The implication is that future consumers may prefer HVAC&R equipment that is optimized for full-load performance and not for part-load performance, or they may prefer equipment that is powered during off-peak hours (e.g., ice storage applications).

On average, as a result of deregulation, generation cost and generation prices will be lower. However, as we face the uncertainty of global warming concerns and resultant energy policies, it is possible that retail energy will cost more in the future ... not by scarcity of overall supply, but by government regulation.

Taking Advantage of Real-Time Pricing Impacts

What will be the industry's response to real-time pricing? First, industry must do a better job educating homeowners on the value of energy efficient equipment so less energy is consumed during peak-load operation. Also needed are more efficient equipment coupled with smarter controls that can sense when the equipment is operating during peak-load, premium time. Perhaps these controls will allow the thermostat to have a higher set-point or prevent the unit from operating during that period of higher-priced electricity.

In the future, U.S. residential applications will be seeing an increased usage of thermal storage. As an example, in Japan, small tanks (similar to 40 gallon hot water tanks) are used for residential thermal storage to allow Japanese homeowners to shift part of their cooling load into the cheaper evening period.
It is also likely that we will see a rise of distributed on-site power generation as customers seek to further reduce their utility dependence. This is especially important in rural areas where there is not ready access to cheap and reliable power. Although not cost-effective today, micro-turbines and fuel cells may become suitable means to overcome electricity distribution shortcomings. It should be noted that these on-site

power capabilities are available today. Small natural gas turbines, integrated with a compact electrical generator, can produce ample power for residential applications. However, even in large multi-family buildings the load factors may not justify the purchasing and operating expenses for micro-turbine equipment. Utilities and automobile manufacturers are currently conducting field studies to ascertain the viability of fuel cells in their respective applications. Fuel cells utilize hydrogen and oxygen to produce electricity with water and heat as by-products. Fuel cells have an edge over micro-turbines in residential applications since fuel cells scale well for varying kW demands and the waste heat can be used for heating or hot water production.

As a result of these trends, especially with distributed on-site power, it can very well be possible that small distribution wires and small generation sets can replace large distribution wires and large generation equipment. What the industry needs to explore is how to best apply on-site power generation to HVAC&R equipment in the future.

This section was a quick overview on the industry drivers and changing business climate. Needless to say, what worked in the past is not likely to be fully satisfactory in the future. The old rules are rapidly disappearing, the new rules will vary and are subject to constant change. The following two sections will look at some possible consequences of this change.

EQUIPMENT TRENDS OUTLOOK

Regarding equipment, it can be said that currently the industry is providing products that are more energy efficient than user requirements. This is obvious when one looks at the unitary residential market. The best unitary residential system available today has an efficiency of 18 SEER. [3] However, the efficiency average for unitary systems shipped last year was around 11 SEER. [4] Obviously, the marketplace is not willing to pay the premiums needed to obtain higher efficiency equipment. Or stated differently, industry has not made a compelling case to consumers as to the value of higher equipment efficiencies. As a result, it is likely that in the near-term relatively minor changes will occur in the market. Near-term product offerings will continue to be smaller, lighter, more efficient, quieter, feature-laden, good looking, easier to maintain -- all elements of competition within the industry.

Further out, the trend towards increased use of multiple- and variable-speed controls and multiple- and variable-speed motors will continue. It is likely that belts and gear-driven equipment will disappear in the intermediate term. Additionally, there will be an expanded use of heat activated equipment. As evidenced today, there will be more and

more interest in desiccant equipment. We will also see more miniaturization of components and systems -- lesser material usage implies lesser cost.

Much longer term, it is likely that non-vapor compression technologies will find niche applications. These can include cycles like the transcritical carbon dioxide cycle, thermoacoustic cooling, advanced adsorption systems, and others. Of the 30-40 different technologies that can be looked at, probably only a half-dozen have any hope of future commercialization. Those cycles will need to be evaluated to ascertain what the limiting technologies are, and to explore ways to overcome these difficulties for the various niche uses.

At the same time, if regulations against HFCs were to be considered – for example, as a result of global warming concerns – it is possible that the U.S. might deploy equipment that use natural refrigerants. The type of equipment that would have to be developed to use these refrigerants would be very different from today's equipment, and may even entail a cessation of the air-to-air unitary equipment used today. What we may be looking at are mini-centrifugal systems – going to hydronic distribution – as replacements to unitary equipment.

Industry will need to develop more user-friendly proactive equipment. Perhaps cognizant learning controls can adapt to user habits and user idiosyncrasies. This would entail an increased dependence on electronics. If we apply these electronics with user friendly interfaces it may make it easier for consumers to use their equipment as well as for the installer and the contractors to work with the equipment. Additionally, in the future, service people may no longer use the standard manifold gauge and hose sets. Rather, servicepersons may utilize instruments that record measurements sent by factory-installed transponders located throughout the unit to obtain operating pressures, temperatures, contaminant levels, and refrigerant composition, all without physical connections to the equipment.

Continuing a current trend, there will be an increased usage of computer capabilities in industry endeavors. Electronic websites will at first augment, then replace, contractors' "plans" rooms and manufacturers' catalogs. Contractors and suppliers will do job take-offs from CAD drawings and specifications contained in engineering/architectural websites. Use of virtual reality in product design, production line changes, and cause-effect analysis will reduce iterations to bring out new products, as well as reduce the risks associated with introducing these new products to market.

RESIDENTIAL APPLICATION TRENDS

In looking at home construction trends in the next 25 years it is likely that heating and air-conditioning equipment will become integral to the form and function of the house, not just an adjunct to the building. Perhaps interior walls will be designed to act as heat exchangers. Perhaps, for ducted systems, a more energy-efficient air-moving method is utilized other than fans; maybe convection and conduction can eliminate these fans. Perhaps supply air is introduced under the floor to obtain a better distribution of air throughout the room. In this case, the carpet could serve as a filter where every five to seven years it is either replaced (perhaps in a redecorating effort) or sent out for cleaning. If a "form/function" approach were to materialize in home building, the architect's focus will shift from maximizing the efficiency of individual components to that of maximizing the efficiency of the overall structure. This will entail a more holistic method of home construction, wherein the designer considers such aspects as lighting (natural and electric), thermal envelope (e.g., insulation, window selection, sun exposure, etc.), plumbing requirements, and HVAC&R needs as one system.

New residences of the future will have a considerable higher percentage of off-site manufactured content – structural panels, prefabricated components and assemblies (such as complete bathroom modules) – resulting in improved quality and in better energy usage performance. Included in this is the introduction of HVAC&R equipment that will do a combination of indoor management functions. Perhaps there will be comfort conditioning units that will perform energy recovery, on-board monitoring of occupancy demand, contaminant control, and produce hot water in addition to heating and cooling (latent and sensible loads controlled separately). These can be add-on modules where the homeowner can mix and match desired features to achieve an optimized application. It is likely that an "indoor environmental appliance" will be developed that combines heat recovery and hot water production with comfort conditioning. This new appliance would pull the design away from the installing contractor and bring it back to the factory, where equipment manufacturers can exert better quality control while assuring a better performing unit.

The trend towards hydronic systems in residential applications may accelerate. Hydronic systems are easier to fit into manufactured modular houses, eliminate the need for ductwork, offer easier quality control of installation (leaks are obvious), and may permit the safe use of alternatives not considered viable today. Additionally, hydronic systems offer the opportunity to match refrigerant glide efficiencies and to perhaps permit recovery of waste energy (e.g., from clothes dryers, dish washers, gray water, etc.).

There will be an increased investment in smart products to meet energy, monitoring and control factors. It can be envisioned that future buildings will have wall sensors that ascertain and maintain optimum comfort levels for individuals as the occupants move throughout the home. Perhaps home health monitors are developed that will track individual physical activities while analyzing nutrition and exercise programs. For example, while a person is on a treadmill, the room senses that the exerciser is beginning to perspire and reduces supply air temperatures to maintain comfort levels. It is also likely that voice-activated products such as lights, air-conditioning, windows, computers, etc. will become commonplace.

To reduce energy costs, homes could be constructed with electrochromic or photochromic windows that turn opaque or transparent depending on thermal requirements. At the same time, future homes will use real-time controls that can respond to anticipated need. Perhaps the building can be informed that a new weather front is approaching and can start thermal compensation in advance. Maybe the house "learns" that occupants are in a car heading home and that it is time to come out of setback and turn-on the front-porch light.

HVAC&R RESEARCH FOR THE 21st CENTURY (21-CR)

As indicated earlier, there are a number of market and societal pressures that are necessitating radical new approaches (as opposed to evolutionary change) in comfort conditioning of buildings. Developing new technologies to address these pressures require a large concerted effort. The 21-CR initiative is a private-public sector research collaboration of the HVAC&R industry, with the mission to identify, prioritize, and undertake precompetitive research that focuses on decreasing energy consumption and increasing indoor environmental quality within buildings.

The program fosters an environment where technical barriers are identified, research priorities set, solutions investigated, and information shared. The effort will undertake precompetitive research that focuses on resolving technical hurdles and difficulties that prevent or impede manufacturers from introducing next generation HVAC&R systems and components. Once these technical challenges have been addressed, the various stakeholders are positioned with the tools, information, and data to produce products/services that satisfy market needs within the HVAC&R sector.

By establishing a solid basis for industry collaboration, the 21-CR program will catalyze progress in a number of strategic areas. When carried out as part of a coherent plan, the emphasis on precompetitive investigations advances the capabilities of the HVAC&R community to meet its broader energy and IEQ objectives.

21-CR Strategic Areas

In recognition of the needs for energy efficiency and minimal adverse environmental impact, projects will be undertaken in five areas of strategic focus:

- *alternative equipment* (investigations of HVAC&R cycles other than today's fluorocarbon vapor compression cycles);
- *high efficiency equipment* (improved heat exchangers, motor systems, compressors, controls and sensors, air handlers, testing, diagnostics, pumps and pump controls, etc.);
- *system integration* (improved distribution systems, zone control, waste heat recovery, integration of envelope and lighting with mechanical systems, advanced controllers, communications, etc.);
- *indoor environmental quality* (enhanced control of temperature, moisture, indoor contaminants, ventilation, etc.); and
- *environmentally-friendly working fluids* (refrigerants, lubricants, secondary heat transfer fluids, eutectics, etc.).

Implementation Structure

The 21-CR effort is guided by experts from industry, trade and professional organizations, national laboratories, governmental agencies, university research centers, utilities, and other interested stakeholders. The Air-Conditioning and Refrigeration Technology Institute (ARTI), a research entity associated with the Air-Conditioning and Refrigeration Institute (ARI), is the administrator for the effort. It is ARTI's role to provide guidance and cohesiveness to the overall investigation while providing an umbrella for related research by others which advances the goals of the 21-CR program.

Steering Committee: A Steering Committee assures that the work is of value to the industry and has a path to commercialization. The Steering Committee assigns priority levels and approves funding support of individual projects recommended by the five 21-CR Subcommittees (one for each strategic focus area).

21-CR Subcommittees: The five 21-CR Subcommittees, comprising senior industry engineers and technologists as well as capable, knowledgeable persons from various industry sectors, identify specific project needs, prepare work statements, prioritize the research, and identify contractors capable of performing the individual research. Once individual projects have been approved for funding by the Steering Committee, the pertinent Subcommittees provide technical review of contractor-submitted proposals,

recommend contractor selection, monitor and oversee the on-going research, perform site reviews, and review the submitted final reports.

Sharing of Research Results

Results from the 21-CR program will be disseminated at periodic seminars and symposia at suitable industry conferences. Final reports, for each individual research project, will be made available for a nominal reproduction/handling fee once the reports have been accepted for release. The intent is to maximize the information dissemination to benefit the construction and HVAC&R communities.

CONCLUSION

In the next quarter century, innovations such as not-in-kind equipment, zero-degree operation heat pumps, distributed on-site power generation equipment, and "indoor environmental appliances" are likely to be introduced into residential applications. These future technologies will require the development of evolutionary materials, controls, and operational strategies.

To achieve this future potential, as we carry on with today's business, industry needs to ensure adequate resources are applied for tomorrow's strategic growth. Continued innovation is the manner in which the U.S. housing market can do its part to conserve natural resources while providing enhanced occupant comfort.

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