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RESEARCH REQUIREMENTS IN THE EVAPORATIVE COOLING FIELD

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ABSTRACT

This paper focuses on potential applications of evaporative cooling (EC) and an associated survey of research requirements of EC as supplied in residential and small commercial buildings. To prepare this work, the literature in the field was reviewed and people active in the field were contacted. Sixteen recommendations are presented and described in the paper including institutional issues, appropriate roles for EC systems, necessary analysis and testing, proper applications, and hardware development needs. These recommendations represent composite opinions from the literature review and phone conversations as analyzed by the authors.

INTRODUCTION

There are potential applications for EC systems and related research issues that are not fully understood by most government agencies, utility companies, engineers, industries, decision makers, and the consuming public. However, as energy costs rise there will be increasing demand for operationally inexpensive cooling systems. Thus, information on the potential of EC systems could benefit these parties.

This paper focuses on residential and small commercial building applications of EC. Most of the published technical work in the EC field has been done for large industrial and commercial building applications, but in no way do these analyses, systems, and approaches generally pertain to residential buildings. However, these papers and reports have been collected and reviewed to assess available techniques and conditions under which they might have residential applications. Due to economy of scale, the large systems are often able to employ expensive peripheral equipment and ductwork, which is not cost-effective in smaller buildings. Also, commercial systems generally receive scheduled maintenance, in excess of the norm for residential units.

Thus the problems and solutions of residential EC systems separate from large commercial systems are worthy of study. The intent of this paper is to recommend what research is required to

- identify appropriate roles for residential EC systems,
- describe necessary analysis and testing,
- place applications into proper technical and economic perspective, and
- improve components, systems, hybrids, and applications.

To prepare this report, the literature in the EC field published by researchers, manufacturers, and vendors was collected and reviewed. People active in the EC field were contacted by telephone and asked, "What is the state of residential EC technology, and what research needs to be done?" The recommendations in this report represent composite opinions of this literature review and phone conversations as analyzed by the authors.

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In this study, "effective" or "practical" means a technical and economic (T&E) perspective. Technical performance refers to the quantity of energy required to operate the cooling system over a year and also the maintenance required. Economic performance is often dependent upon one's perspective. Many homeowners consider only first cost and occasionally annual energy costs. However, a more comprehensive economic assessment involves a life-cycle-cost (LCC) analysis, an approach not often understood by homeowners. Thus, part of a program designed to assess residential and small commercial EC systems will have to reduce economic analysis to a form understandable by the consuming public.

LCC refers to economic analysis that accounts for all lifetime costs of ownership, where all costs are normalized to a specific time. Various items must be considered including first cost, recurring costs (including fuel expenditures and maintenance), energy cost escalation factor, interest rate, and possibly salvage value or dismantling cost. All of these items are subject to the time value of money and contribute to the real cost of ownership over the system life. Thus an "economic analysis" can be quite simple or complex, depending upon the needs and sophistication of the user.

One form of system technical performance analysis is to estimate the hours of operation per year over which the cooling system must operate. For a given building, this gives a coarse estimate of the building annual energy consumption, which is a major input to the LCC analysis.

RECOMMENDED FUTURE R&D AREAS AND ITEMS

The recommendations prescribed below were obtained from a number of sources: manufacturers and their representatives; researchers; and the review of technical papers, reports, and the available commercial literature. The authors edited the disparate inputs from the various sources, so that the recommendations represent the composite contributions of each source. In cases where sources disagreed, the controversies are noted.

The format of each recommendation is a short statement, followed by a discussion to describe the project of research need. The research recommendations of this study are discussed below.

Low-Cost and Effective Heat Exchangers (HXs) for Indirect (ID) Systems Need to be Developed

Several manufacturers of ID EC systems indicated that the biggest problem is the lack of a good but inexpensive HX design. Because each system and manufacturer have a somewhat different approach, there is no single design that could be integrated into every system. Plastic plate units may offer a good possibility for an inexpensive unit.

One source suggested the possibility of a replaceable, modular, plastic plate HX, sufficiently inexpensive so that it could be discarded after a few years when scaling and fouling would reduce performance. The T&E performance of replaceable HX modules, likely made from plastic, should be examined. Mass production of HX modules would bring the price down.

Kettleborough (1983) conducted an analytic study on plastic plate HXs in counterflow. More work, including experimental verification, needs to be done in this area.

Criteria for general HX design and fabrication techniques would benefit the entire industry. Tradeoffs of thermal resistance between the two fluid streams and increased pressure drop, which gives rise to increased fan power requirements (lowering efficiency), need to be promulgated for different designs in a systematic manner.

Coatings of HX tubes, which increase wetability between spray and drip streams and tubes and thus increase performance, need to be developed. Nobody presently knows how long existing water-adhering coatings will last.

Several manufacturers did not think that government research should be directed toward specific HXs but to parameters that would enable ID EC acceptance by the public. Thus such parameters as necessary efficiency, pressure, and size need to be considered. Goals for HX design would be useful to the industry. However, each company should be

responsible for developing its own HX. The Government should treat the HX as a black box and indicate what its properties should be. Many companies have spent appreciable time and money developing ideas and patents. There have been squabbles and lawsuits to establish ownerships and rights. Some people opined that specific government research into HX development would exacerbate that problem.

However, as a perspective, one source indicated that the EC industry does not have the money or resources to conduct innovative research and testing. Then, in contrast, that source indicated that the government should keep out of HX research because market positions might be upset.

Because the HX cost dominates the capital cost of an ID system, development of an effective low-cost HX unit would be a tremendous boon to widespread adoption of indirect/direct (ID/D) EC systems. A general matrix of HX approaches needs to be analyzed and tested without violating existing scaling and performance degradation issues.

HXs Should be Optimally Sized in an ID System

Several papers indicated that no one knows how to correctly size the HXs. No one indicated that any precise criteria are available for determining exactly how large the HX should be relative to other components to optimize LCC. All agreed that such criteria would be welcome. The HX size is presently determined by experimental adaptation.

There are many levels of "optimization." One researcher at an ID/D EC company indicated that he had done HX optimization for 5 years. By "optimization," he meant that he had looked at different stock HXs in different stock systems and conducted computer studies to determine which permutation gave best performance. He had not done a mathematical optimization and does not think one exists. Also, the literature search did not reveal such a study. He thinks that a general indepth HX mathematical model optimization study, revealing general design criteria, would be useful.

The kind of optimization contemplated involves mathematically modeling the technical performance of each component in a system as part of a system analysis. The cost of each component is related to performance characteristics, and the sum of the component costs comprises the system cost. The system cost can also be expressed in the form of a LCC, where annual energy consumption must be estimated. Whatever the form of the cost, it is subject to minimization, and the cost appears as an objective function that is to be optimized. There are several constraints relating to system performance and component interaction that must be satisfied simultaneously. This is a classic mathematical optimization analysis, similar to studies that have been done in other fields, which will provide design criteria on optimal sizing of all components relative to other system components.

It is cautioned that such system optimization is difficult because there are so many variables resulting in many tradeoffs. Turner (1986) did a first-cut analysis to illustrate the analytical technique and produce preliminary design parameters.

The Use of Heat Pipes in ID HXs Should be Examined

Heat pipes are being used for large industrial ID/D EC units. It maybe worth a feasibility study to determine if heat pipes could be practical and cost-effective in smaller residential ID systems. Scofield (1986) gives a fine analysis for a large (120-t) commercial system.

HXs Can Serve a Useful Winter Function

In air-conditioning (AC) units featuring an air-to-air HX, the HX can be used for winter ventilation heat recovery. In situations where ambient winter air is drawn into a heating, ventilation, and air-conditioning (HVAC) system, the value of recovered heat impacts on the LCC analysis. Also, where a hydronic heating system is used, a water-to-air HX can be used both winter and summer, providing double usage and improving amortization. This system worked in a school in Texas but might be difficult in a residential system. If the HX were employed in winter, it would impact the optimal size (making it larger).

Because exhaust air from the house contains moisture, frost formation inside the HX on the exhaust side is possible. This ice can block the system. The processes and conditions for frost formation and the possibilities for ice removal need to be studied.

Research is needed to determine the practicality, limitations, and requirements for winter use of the HX. When the HX is used in winter systems, the annualized T&E impact needs to be included in the LCC study.

Low-Cost Effective Wetting Pads Need Development

According to Dr. J. Watt (1985) "...the only R&D area requiring attention for direct EC is to improve aspen pad wetting fillers, which have been used for 50 years." Aspen pads are only good for a year, and the performance tapers off. High efficiency volumetric fill (HVF) is presently best; it is good for several years and causes little trouble. However, HVF forces a redesign of existing coolers and that is probably why it is not used extensively for residential applications.

The packing of most residential EC systems produces a wetting (saturation) efficiency of 70-80%; if the unit is incorrectly installed, it may be 50% or lower. Aspen wetting pad performance also degrades with time. HVF comes in modules up to 1 ft (30 cm) thick and can produce a saturation efficiency between 80 and 95%, depending upon design. Performance does not degrade as rapidly with time. If an improved fill could be developed for direct EC residential systems, system performance would be increased. It is necessary to keep pressure drops low to maintain low brake horsepower. Many manufacturers of ID/D systems use HVF or other cellulose packing in the direct wetting stage because the expense of the system required high performance and reliability in the direct component.

LCC comparisons for direct EC comparing aspen pads versus HVF would be useful. One company uses a single HVF instead of three or four aspen pads. The HVF does better with a lower pressure drop and has better life.

LCC Studies for ID/D EC Systems are Needed

Virtually everyone contacted agreed that technical performance and economic analysis for residential ID/D EC units are needed in all parts of the United States. Dr. J. Watt (1985) said, "...ID EC can reach out into every part of the continent!" ID EC system applications are not restricted to the arid southwestern United States. In most places an ID unit alone cannot provide the same performance as an AC unit, but EC units may become competitive against AC in some U.S. locations with direct boost. Such general studies are lacking, especially for residential applications. This is the single most important area of a general program in EC research.

The base case for systematic comparison would be a stand-alone, conventional compressor AC system that maintains the considered house in the thermal comfort zone throughout the cooling season. The economic comparisons should be based on different possible increases in electricity rates, as well as different costs of money (interest rates). For example, the higher the power rate, the more places EC is competitive. This is somewhat shown in papers by Supple (1982) and Eskra (1980). In some humid areas, where an ID/D EC system alone might not provide satisfactory performance, the LCC for a hybrid system consisting of an ID/D EC precooler in series with a conventional compressor AC as a final stage needs to be evaluated.

To reduce the amount of computation and data handling, technical performance in different locations should be evaluated, using both ASHRAE 2-1/2% summer data and also the TRY bin summer data to determine what correlation factors are needed so all analyses can be made from just a few inputs. This would facilitate analyses if a useful correlation can be found. The ASHRAE Handbook - 1984 Systems outlines a technique for this in Chap. 36.

Supple (1982) concludes "...the ID/D EC approach can significantly reduce total cooling power requirements in a large area of the U.S. (Such) schemes are presently cost-effective where the WBT coincident with the design DBT is below 64 F (18°C)." However, Supple was looking at commercial systems, not residential. Supple also states, "As the cost of electricity continues to rise, while at the same time the cost packaged ID/D EC components drop as the demand increases, the payback will improve for a given

wet-bulb design. ...higher design WBTs will become practical, and additional areas of the country will become candidates for ID/D cooling systems." In his comparison between ID/D EC and conventional AC, Supple suggests a 1/18 power ratio between ID/D EC system and refrigeration AC. Most studies (like Supple's) appear to be for commercial and institutional systems. Studies for residential applications are nearly nonexistent. The recommended series of studies would also consider the type of building, because a heavily insulated tight building has a lower load than a glass-predominated building. Thus, an ID/D EC might work in a low-load house but not in the high-load house next door. Note that the poorer the insulation in a building, the more advantageous EC becomes compared to AC because of the constant air changes versus the closed-circuit heat removal by AC. This result is likely true in all parts of the country.

An industry source pointed out that customers do not want to be guinea pigs, and industry itself does not have funds to develop innovations for residential applications. Thus, government demonstrations are needed.

After computer simulations indicate that a considered system can be technically and economically effective in a given U.S. location, demonstration projects are needed to verify computer technical performance studies. Both computer and demonstration studies need to consider representative off-the-shelf equipment, not research modules, with normal maintenance. Perhaps a side-by-side study with negligent maintenance would be worthwhile to quantify the need for maintenance.

The recommended LCC economic comparison would allow engineers, architects, and residential consumers, as well as government agencies and utility companies, to make intelligent and informed decisions among alternatives based on performance, money, and energy. Such studies should also serve to educate the public about the options for summer space cooling. For example, one source felt that there is no residential or commercial role for compressor ACs in Utah, Colorado, Idaho, and other intermountain states and that staged EC units can do the cooling job at savings to the consumer. But engineers, architects, and consumers in general do not accept this.

LCC Studies are Needed from the Viewpoint of Government Agencies and the Electric Utility Industry

Because reduction of energy consumption is in the national interest, the impact of widespread adoption of EC equipment either replacing or augmenting AC units should be quantified in different regions. Federal or state tax credits in certain areas could be for the public good, just as solar tax credits have stimulated the adoption of solar energy equipment by homeowners. Most of the EC hardware deployed in the United States. is American-made, but a strong new industry could develop an export status. The study should evaluate criteria of tax credits for conversion from AC to EC and supplementing AC with EC.

In some states energy codes should be updated to include points or credits for EC versus AC. For example, the California Title-24 calculation does not give sufficient weight to this tradeoff. The suggested study could provide useful guidance in such cases.

Electric companies like consumers to install EC systems instead of conventional AC because EC systems reduce the peak summer demand load. To discourage summer peak electric consumption, some electric companies have introduced a commercial billing schedule that includes a "ratchet clause." This clause states that "... the billing demand for the current month will be not less than 85% of the highest fifteen-minute measured demand occurring during the preceding 11 months." This rachet penalty means that in January, when refrigeration equipment is shut down, the owner must pay for 75% of the peak kilowatt input to the building realized during the hottest day of the preceding summer. This type of demand billing is one of the only viable ways that a public utility company can hope to recover the soaring costs of construction for new generating facilities to meet increasing demand. Although ratcheting has been applied to commercial - and not to residential - customers, it does reflect the utility's concern about peak power demand.

Another disincentive to peak consumption by ACs has been installed in New Mexico. Commercial building owners there pay a "demand charge" like $10/kW(e) if the company uses refrigeration AC but no demand charge if EC is used. This applies to summer months. Both ratcheting and demand charges need to be taken into account in all LCC studies when they apply.

A Southern California utility's peak summer load is 13,000 MW, and 25% is for AC. The company suggests that if 25% of AC systems used EC preconditioned air, then at least one major power plant could be eliminated.

Because widespread deployment of EC units replacing AC units reduce peak consumption, technical and economic studies need to be conducted from a utility perspective to determine what a systemwide impact could be. These studies could indicate how much support an electric company could provide to promote conversions from AC to EC and would identify the kinds of customers that would make the biggest impact. This support is similar to insulation programs in which some utility companies provide financial assistance to homeowners to install or upgrade insulation against winter peak heating consumption.

The Public Should be Surveyed to Determine What it Will Accept

A public poll in different parts of the United States to determine what technical and economic parameters are acceptable in ID/D EC systems relative to AC systems. What should design goals be? What are public perceptions and reactions to EC? What government or utility incentives (if any) are needed to stimulate EC adoption? What is the acceptable cost for an ID/D EC system? How can installation costs be brought down? The EC industry needs to have cost goals for equipment in different parts of the country, and generally small companies cannot conduct such market penetration studies.

There are at least four problems with ID/D EC units for residential uses:

- high initial cost,
- uncertain reliability relative to compression units,
- large floor area and weight, and
- possibly larger ducts needed than for conventional AC.

These issues need to be resolved and understood, specific concerns include:

Many contacts felt that homeowners would not buy EC systems without some kind of subsidy (government or utility). Just as there are solar tax credits for energy-saving systems, perhaps there is a need for EC tax credits. An electric utility company can perhaps have rate credits to cover the capital cost of avoided new capacity. This ties in with Recommendation 7 above.

Suppose there were a few days when conditions could not be maintained in the ASHRAE comfort zone? Normally an ID/D unit can get a 5-6 F below ambient wet bult temperature (WBT). Also, since EC supply air temperatures are often higher than for AC, larger duct sizes (costing more money) are needed unless the EC systems are window units. (Note: window units can produce unacceptable noise.)

Most companies contacted do not think that there is a substantial ID/D EC residential market, and they cater to industrial, institutional, and commercial customers. The problem is the high cost of the HX.

Cooling Towers (CTs) May Have a Role in Residential Cooling Systems

Many houses and businesses in Southern California used to have CTs. They worked well, but became obsolete in the 1940s with the advent of the drip cooler. Scale was (and is) a problem with CTs. They used to have copper coils cleaned with acid, but this treatment was expensive, and leaks could develop after several years.

CTs are being revived for space cooling. Some companies make large industrial cooling coils. They have great performance when new, but research is needed to determine performance dropoff with time as scale accumulates. Also, research is needed to determine maintenance procedures, especially for the residential market. We need to know how to reduce scale buildup and maintenance.

CT cooling systems will generally have HX cooling coils inside the conditioned space, with a fan to help transfer the heat from the chilled coils to air. HXs inside a building can also tie in with any hydronic system, including hydronic solar. Thus the equipment in some cases can be amortized winter and summer.

Studies and demonstrations are needed to determine if CTs can be incorporated into residential AC and EC cooling units and, if so, where. Because CTs are widely used in industry, there is a base of mature technology. Technical and economic studies are needed in different parts of the country.

Analysis should also consider the possibility of a large water tank to store night-cooled water for daytime usage. This could result in a smaller CT and could be effective in terms of both cost and technology. Computer modeling and field demonstrations are needed.

For residential usage, it is necessary to look at maintenance issues, because homeowners often avoid preventative maintenance and wait for a breakdown before maintaining a system. Replacement may then be expensive. Water is generally pumped through HX coils (condensers), and condensers are generally cleanable in commercial systems. In large systems, one can install computer monitoring on a minute-by-minute basis and have a separate HX clean water loop transporting coolness from the CT water. Perhaps there is some way this can be done in a residential system. Research for self-cleaning systems (high bleed rates, chemical packages, nighttime batch water dump, coatings, etc.) to minimize fouling of HXs and other surfaces will be required for the home unit market.

Hybrid Systems Need Research

It may also be effective to stage EC systems to supplement the performance of other cooling systems. In this study "effective" generally means from both technical and economic bases, as measured via LCC studies and field demonstration programs.

ID precooling coils with a second-stage refrigeration AC are already used in some large cooling systems, where two-stage (ID/D) EC alone cannot provide complete satisfaction. In such situations there are periods when the EC alone can supply the needed coolness, but peak cooling demands require the AC boost. Such arrangements are not common in residential systems, but are worthy of study in areas where two-stage EC may provide marginal performance.

Another way to use a D and/or ID EC with a conventional AC cooling system is to use the output from the EC unit to cool the AC condenser coil. In many vapor compression AC systems, a fan blows ambient air over the condenser coil for heat rejection. If, instead, the moistened air output of an ID/D EC were blown over the coil, the heat rejection would take place in a cooler environment, increasing AC coefficient of performance (COP). Because a heat rejection air blower is used anyway, the EC would not represent a significant increase in power expenditure. Another possibility is to drip the EC-cooled sump water over the AC condenser coils. A caveat in this approach could be scale deposition on and corrosion of the AC condenser coils.

Peng and Howell (1981) have considered a hybrid absorption evaporation system, which they claim is versatile and has advantages over absorption-only systems. Low-grade thermal energy between 55-80°C (131-176 F) is required to power the system with good claimed performance. Note that this is within the capability of a good flat-plate solar collector. Generally higher temperatures are required in absorption units. Peng and Howell conclude that more research is needed on this approach.

Hybrid systems composed of various components are subject to optimization. Components that are optimized when working alone may be suboptimal in a multicomponent hybrid, or in different climates, or different applications. Optimization studies based on LCC analyses are needed for different locations and conditions, specifically for three-stage (ID/D/AC) systems, with demonstration projects as followup when warranted.

Controls for hybrid units could be complicated, especially for residential applications. Also the cost of a multicomponent system may have prohibitive high costs or bulk for home units. However, there may be some niche application where such hybrids could outperform competitors, and such specialty applications should be identified.

Gas Research Institute and others are actively researching component design for desiccant systems. Much research is needed before desiccant cooling systems can provide a widespread contribution. Heat is needed to regenerate the desiccant, but relatively small quantities of electricity are required relative to AC systems. Desiccant units are also very costly. However, research may identify suitable niche applications if

large quantities of waste or solar heat are available at sufficiently high temperature. Many desiccant cooling system designs employ ID/D EC in a final stage, and very few people in the EC industry are looking at this. Thus, it could be important to determine what are the ideal characteristics of an EC unit incorporated in a desiccant cooling system.

Clark et al. (1981) looked at EC enhanced desiccant systems and concluded that improved computer codes are needed to model system performance. They state that the task is not straightforward.

Health Issues Need to be Studied

Health issues pertaining to EC systems fall into two broad areas: (1) a negative issue associated with the equipment itself, and (2) a positive factor, alleviation of indoor pollution in tight houses.

Research should identify issues (and nonissues) of disease, odor, algae growth, bacteria growth, and perhaps mosquito breeding in EC systems. One manufacturer researcher said, "The threat of Legionnaires Disease (LD) is a black cloud which hangs over the EC industry!" He and others feel that someone needs to put the LD problem to rest. A government study directed toward EC consumers would be more convincing than an industry study. It is suggested that a university biology or medical department review existing research in the field. If further study is warranted, the study team should run units in different parts of the country, take cultures, or even deliberately impregnate test EC units with disease organisms to see if they can even be maintained.

The Center for Disease Control in Atlanta showed that only where water temperatures above 49°C (120 F) are sustained can LD develop. The famous LD outbreak came from CTs handling industrial waste heat, which was normally maintained at 43-49°C (110-120 F). Many labs have researched LD. It has been found in hot tubs but never in tap water. ASHRAE has several position papers published over the last 2-3 years on LD. LD has not been related to ECs.

No one interviewed had even heard of LD in any EC unit. One dissenting opinion strongly urges that there be NO study on diseases associated with EC, because there is no problem and a study will confuse most people. He states that the consuming homeowner does not associate LD with ECs.

In some residential and commercial systems, a roof-mounted EC unit can sit idly in the sun for several days. The water and filter heat up and could harbor bacteria. This situation might be explored. More needs to be known about algae growth in EC units and CTs, especially in stagnant untended units as in home applications. What kinds of treatments, if any, are needed? Chlorine can attack metal surfaces and has an unpleasant odor.

In some applications odors are a problem with direct EC systems. Under what conditions do odors arise, and how can they be suppressed?

Indoor pollution (IP) should be examined with regard to radon, formaldehyde, smoke, and grease in tight houses. Much of the IP research is being done by state agencies. New houses often have an initial emission of formaldehyde. Because EC units introduce and exhaust large quantities of outside air, EC units may reduce or eliminate IP problems. Where ID systems are used, the HX may be used in winter to preheat incoming ventilation air. Another area that should be examined is the effect of relative humidity introduced by EC versus AC systems.

Standards are Needed in the EC Industry

The EC industry has not established standards for performance because there are too few people in the field, and ID systems are too new (7-8 years old).

A standard test procedure is needed to evaluate D and ID coolers. But the standard needs to be accepted and enforced, whereby an independent testing agency could evaluate various claims in a disinterested manner. Just as the American Refrigeration Institute (ARI) tests and approves compressor AC units, there needs to be an independent test

agency for the EC industry. Promulgation of standards without enforcement or testing authority would be bad because some people would still make fallacious claims. Standards need to be established, and an independent agency should make tests against these standards.

Many industrial contacts brought up the standards issues, but nobody knows just what the standard(s) should be. One individual felt there should be two or three given dry-bulb temperatures (DBTs) with coincident WBT conditions for which system output would be measured. Standards similar to those of ARI were suggested as an approach. Other suggestions included seasonal, weighted EERs for different locations (note the EER would be variable and dependent on each location).

As of June 1986, the ASHRAE Technical Committee 5.7 has submitted a work statement to the Research and Technical Committee for solicitation of a proposal to develop a standard for direct EC.

Storage of Coolness Generated at Night by ECs Needs Study

It is possible to chill a rock mass at night with air chilled by an EC unit passing through the rocks. As the cool air passes over the warmer rocks, the rocks are cooled and the air is warmed. Because the moist air is being heated, moisture does not condense, so mildew of fungus does not form. The warmed moist air is vented out, leaving chilled rocks. The following day when AC is needed, air from the house passes through the rock bin, is cooled, and returns to the house through the duct distribution system. Such a system works best in a semi-arid location where nocturnal WBTs are low in summer.

Karaki and Armstrong (1978) studied such a system, but the results were inconclusive. Other people have also looked at rock bin storage, both in the United States and Australia. However, such a system has not yet been conclusively demonstrated as practical. This is the subject for further research, both as a stand-alone system in a residence and in tandem with a conventional backup AC.

Many solar air-heating systems incorporate rock bins, which tend to be expensive. In some climates (i.e., very hot) a winter solar system may not be cost-effective, because the major space conditioning problem is summer cooling. A rock bin system designed for summer cooling only, and not part of a solar system, should be examined for LCC performance in different climates and verification demonstrations conducted where appropriate.

In a variation, a small rock bin can be night cooled via an EC, and it used 24 h/d to cool a refrigerator condenser. Having cooler air available to the condenser should increase the refrigerator COP. Furthermore, because the refrigerator heat rejection system would be in contact with the outside ambient, rather than air in the kitchen, the reject heat would not enter the kitchen, decreasing the building summer cooling load. This method should work in the right residential situation and should also work well in the winter anywhere without an EC.

Because rock bins are expensive and bulky, the feasibility of an insulated water tank holding water cooled at night via an EC unit or a CT should be researched. This could require a hydronic system in the house, with a fan coil in each room. But such a system could be effective only if scale and other maintenance problems can be resolved. The system should have low operating cost, although it could have a high capital cost. How large should the water tank and the cooling tower be? What bleed rates are necessary? What should the flow rates be? Where would the approach work? An LCC analysis and eventual demonstration are needed.

Peck et al. (1979), Crowther (1979), and others have suggested storing night coolness in the massive walls of masonry houses, as well as in air floors. If a masonry wall has embedded pipes, then EC-produced cool night water can be pumped through the walls, cooling them for the next day. In the case of a mass wall with external glazing (Trombe wall), chilled night air can be passed through the plenum between the mass wall and the glazing. The glazed wall should be shaded during the day.

Generally, a systematic assessment of night storage of coolness in massive buildings should be compiled in different climates under varying operating and occupancy conditions. Guidelines and aids for the design of passive and EC hybrid buildings need to be developed and published. This must include full-scale experimental testing of real houses.

Night scavenging of ordinary wood-frame houses with an EC system can cool the interior and reduce the cooling load the following day. This result is worth quantifying.

Systems Controls Research and Development is Needed

An area of concern is the control system, especially for complex three-stage systems (ID/D/AC). It is necessary to have each system working, when optimal, to obtain the best performance from the system. Most individual control components are simple in operation, but integrated logic networks require these components to be accurately calibrated. Ideally, controls should accommodate changing performance, because EC pads alter due to wear and scaling. In any case, proper controls are necessary for the optimal performance of any system.

A nonindustrial researcher suggests that an appropriate control system can improve life of pads for direct EC. The frequent industry solution of bleed-off can be bad, because at night water and minerals are left on the pads. The water evaporates and leaves scale, reducing pad life and degrading performance. A solution would be a control system, which at shutoff causes the entire sump water to dump. Freshwater flushes the pad, and new water washes concentrations off the pad and out of the system. This procedure might last for perhaps 5 min, and it reduces accreted minerals on pads and scale-producing water. Such a "draw and fill" control is currently available in commercial/industrial EC systems and might be investigated for residential units.

Maintenance Issues Need Research

Maintenance procedures are important, and not much is understood on maintenance and lifetime of equipment, especially ID units, which have been commercially available for only 7-8 years. However, a 20-year lifetime is needed, and direct experience is not available. Accelerated testing is needed. Calcium and scale deposits on HX plates degrade performance and eventually can mandate HX replacement. Although spraying the exhaust side can help the HX surfaces approach the WBT, spray coils units are at risk because of water hardness, which can result in deposits, corrosion, erosion, and scale.

A tube coating is needed that can protect tubes but allow chemical removal of scale, with minimal impact on thermal performance. An epoxy coating over HX elements can reduce corrosion on the wet side and reduce buildup of deposits, but it may be possible to develop better coatings.

The cost of maintenance on ID EC systems should be quantified and procedures specified. This is especially true for residential applications, because homeowners tend not to maintain equipment on schedule like companies. Should there be particular water treatments or periodic batch flushing? It is generally thought that satisfactory control of scaling can be obtained by bleeding off at a rate equivalent to one-half the amount of water evaporated. However, many homeowners do not appreciate the necessity for bleeds or water renewal, so built-in self-cleaning could be necessary for satisfactory system life.

No one knows about long-term heat transfer rates in ID systems. If tubes are coated, no one knows how long the coatings will last.

EC Systems Can Complement Solar Systems

A Russian paper, Kakabaev et al. (1982) analyzes the effects of EC and solar cooling devices both separately and in combination. During the day, when the sun can operate the solar refrigerator to produce substantial cooling, the EC would be relatively ineffective. But at night, when the WBT and DBT are both lower, the EC can provide supplemental cooling. The daily behavior of the two units, working separately, is mutually complementary. This could be an interesting combination in some parts of the United States, and a study should be conducted to assess economics of such a system. Where in the United States would such a system be practical? The solar unit also contributes to the winter heating load and probably the year-round domestic hot water load. The system might be integrated with a thermal storage unit. The Russian paper indicated that the daily cooling capability of the hybrid system is somewhat uniform over a 24-hour period and that an ID/D EC is effective in this hybrid.

Generally, literature in the solar cooling area should be reviewed to determine how and where EC could contribute.

When an ID EC unit is used in summer in a hydronic solar heating system, the same HX can be used for the winter solar heating. The fan, coils, pumps, and controls have already been incorporated. A technical and economic feasibility analysis should be conducted.

CONCLUSION

Single-stage EC units are employed in some areas of the United States to provide summer space cooling for homes. With increasing electricity rates, there is motivation to assess whether improved EC technology can reduce energy consumption relative to vapor compression AC units. It is necessary to determine what locations could benefit from EC usage and what technical advances are needed. Therefore, a research program has been outlined in the form of 16 recommendations, which are stated and described.

Economics is a critical factor, and thus several of the recommendations suggest LCC analyses from several vantage points. Recommendation 6, LCC comparing EC versus AC for residential systems in various U.S. locations, is the most important single study. The results will place in proper perspective the locations where different approaches can be applied and describe what prevailing energy costs, first-cost goals, and performance parameters are necessary for one approach to be preferred over another.

Several recommendations (e.g., 1 - 5 and 14) call for development or analysis of various components. Number 2 features size optimization of all components in a considered system, consistent with the minimum cost system that will produce a given effect. Several recommendations seek analysis of hybrid systems that incorporate EC units.

Any program designed to advance a technology will have peripheral areas of interest. Thus, study areas are recommended that include maintenance issues, health effects, standards, controls, integration, and consumer acceptance surveys.

If a program of development and technological assessment similar to that described in this paper were instituted, it could provide the consuming public in some parts of the U.S. with an option that could save money and energy for summer space cooling.

REFERENCES

ASHRAE. 1984. ASHRAE Systems Handbook, Chap. 36.

Clark, J.E.; Mills, A.F.; and Buchberg, H. 1981. "Design and testing of thin adiabatic desiccant beds for solar air conditioning applications." Transactions of the ASME Journal of Solar Energy Engineering, Vol. 103 (May), pp. 89-91.

Crowther, K. 1979. "Cooling from an evaporating, thermosiphoning roof pond." Proceedings of the International Solar Energy Society, Vol. 1 (May), pp. 696.

Eskra, N. 1980. "Indirect/direct evaporative cooling systems." ASHRAE Journal, Vol. 22, (May).

Kakabaev, A. et al. 1982. "On the combination of the effects of evaporative and solar cooling devices." Applied Solar Energy, Vol. 18, No. 2, pp. 51-54.

Karaki, S., and Armstrong, P.R. 1978. "Air conditioning by nocturnal evaporative cooling of a pebble-bed." Proceedings of the Third Workshop on Solar Cooling.

Kettleborough, C.F. 1983. "The thermal performance of the wet surface plastic plate heat exchanger used as an indirect evaporative cooler." Transactions of the ASME Journal of Heat Transfer, Vol. 105 (May), pp. 366-373.

Peck, J.F., et al. 1979. "Two stage evaporative cooling using a rockbed associated with the active clearview solar collector." Proceedings of the International Solar Energy Society, Vol. 1 (May), pp. 697-701.

Peng, C.S.P., and Howell, J.R. 1981. "Analysis and design of hybrid double-absorption cooling systems for low grade thermal energy applications." Transactions of the ASME Journal of Solar Energy Engineering, Vol. 103 (November), pp. 331-338.

Scofield, M. 1986. "The heat pipe used for dry evaporative cooling." Proceedings of the IECEC Conference, Anaheim, CA (August).

Supple, R.G. 1982. "Evaporative cooling for comfort." ASHRAE Journal, Vol. 24 (August).

Turner, R.H. 1986. "Indirect evaporative cooler system optimization." Proceedings of the IECEC Conference, Anaheim, CA, August.

TVA. 1986. "Desiccant cooling workshop." Chattanooga, TN, June 11-12.

Watt, J. 1985. Personal communication to R. H. Turner, on evaporative cooling, July.

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