Evaporative Cooling in California: Assessing the Market and Establishing Baselines for Evaporative Cooling Technologies in the Residential and Commercial/Industrial Sectors

Bruce Mast, Jennifer McCormick, and Patrice C. Ignelzi, Pacific Consulting Services, Albany, CA
Jane S. Peters, Research Into Action, Portland, OR
Lisa Skumatz, Skumatz Economic Research Associates, Seattle, WA
Shel Feldman, Shel Feldman Management Consultants, Middleton, WI
Cliff Gustafson, Taylor Systems Engineering, Fair Oaks, CA,
Mary O'Drain, Pacific Gas & Electric Company, San Francisco, CA

ABSTRACT

This describes the approach applied to developing a market baseline for indirect evaporative cooling technologies in support of Pacific Gas & Electric's (PG&E) Natural Cooling Programs. These programs are designed to assist evaporative cooling market leaders in their efforts to build sustainable businesses in the competitive marketplace. The market baseline approach incorporates the methodological framework outlined in *A Scoping Study on Energy-Efficiency Market Transformation by California Utility DSM Programs* (commissioned by the California DSM Measurement Advisory Committee) and the theoretical framework that has emerged from innovation diffusion research. The latter was used to develop a fuller understanding of the market and outline a theoretical framework for forecasting market effects and assessing sustainability.

Introduction

Background

Evaporative cooling is well suited to California's hot dry climate. PG&E is currently fielding two programs that are designed to affect the market for evaporative cooling technologies in both the residential and commercial/industrial sectors. These programs are designed to assist evaporative cooling market leaders in their efforts to build sustainable businesses in the competitive marketplace. The programs attempt to assess the market, promote demonstration projects, and provide strategic support to reduce the barriers that inhibit rapid and widespread adoption of evaporative cooling technologies in PG&E's service territory. Current program emphasis is on field testing and demonstration projects with limited manufacturer incentives for the more proven technologies.

The technologies of interest to these programs are, for the most part, in the early stages of commercialization. The technologies include indirect and indirect/direct evaporative cooling and evaporative condensing. Because these technologies currently have virtually no market presence and because PG&E anticipates intensified program efforts to commercialize them in future years, it commissioned a market baseline study to benchmark current market conditions and establish a basis for measuring future market effects. This paper describes the approach and methodology used to establish the baseline.

Baseline Study Scope

The market baseline study examined both the residential and nonresidential market sectors but limited itself to the various evaporative cooling technologies: indirect and indirect/direct evaporative cooling and evaporative condensing. Direct evaporative cooling was excluded because available evidence indicates the market for this technology is mature; that is, the technology does not present a notable market transformation opportunity.

Geographically, the study focused on the region within the PG&E service territory that offers the greatest promise of evaporative cooling applications; namely, California's Central Valley and surrounding foothills. However, initial engineering analysis and field testing indicate that the technologies under consideration are less sensitive to climate variations than the old direct evaporative cooling (or "swamp cooling").

The market baseline study was designed to accomplish the following three objectives:

- Characterize the market for evaporative cooling technologies
- Test for the existence and importance of expected market barriers
- Develop a theoretical framework explaining how programs might create sustainable supply-side and demand-side market effects

By satisfying these objectives, the study provided PG&E an overall view of the market dynamics associated with evaporative cooling technologies and an understanding of the market conditions contributing to the gap between actual and expected levels of investment in evaporative cooling. This information serves as a benchmark for measuring market effects of any future program interventions.

In developing the baseline study design, we drew heavily from research into diffusion of innovations as well as the the California Board for Energy Efficiency' (CBEE) evaluation guidelines (Eto, et al. 1998). Diffusion theory was incorporated into the study design to provide the following benefits:

- A thorough understanding of the process of transformation as well as the barriers to transformation
- More complete descriptions of the structure and functioning of information flows
- A better understanding of the role of the perceived characteristics of the cooling technologies in determining whether and how rapidly the technologies would be adopted and markets transformed
- A better understanding of how the market transformation process is influenced by the characteristics of those doing the adopting
- Insight into how the nature and importance of the market barriers change with each stage of the market transformation process

This study was conducted in three stages:

- Extensive review of published literature and secondary data sources
- Preliminary exploration of evaluation issues using qualitative data collection techniques
- Analysis based on systematic survey and interview efforts for key groups of market actors

Completion of each stage provided the basis for conducting the next stage. Each stage is discussed in more detail below.

Review of Published Literature and Secondary Data

As part of the research plan, we conducted an extensive review of published literature and secondary data. This review was essential because considerable market research has already been conducted concerning cooling technologies in California, particularly in the nonresidential sector. The literature review formed the basis for a preliminary market characterization that enabled the research team to pinpoint the gaps in our understanding of the market.

Qualitative Data Collection and Analysis

Qualitative data collection and analysis was included in the study design for two purposes. First, it provided additional narrative detail for completing the market characterization that emerged from the literature review. Second, it provided critical market intelligence for focusing the quantitative data collection on the key market participants and issues.

We used two types of qualitative data collection: Delphi interviews and focus groups. Delphi interviews were conducted with a panel of ten expert informants, drawn from manufacturers, ASHRAE members responsible for design standards, mechanical engineers with particular expertise in evaporative cooling technologies, and program staff at other utilities. Initial interviews were conducted to gain opinions/confirmations with respect to who the market actors are, as well as, more specifically, how many are active in the marketplace. Once initial interviews were conducted and the data synthesized, we then re-interviewed the group, informing them of what we had learned from their peers and inviting them to react to the information. The delphi interviews addressed issues such as

- Likely penetration rate of new evaporative cooling technologies in the region, in the absence of any market intervention by PG&E (base case)
- Likely penetration rates of those technologies given specific market interventions by PG&E (moderate and aggressive scenarios)
- Factors that might affect the penetration rate of these evaporative cooling technologies other than PG&E market interventions

The focus groups served as an inexpensive method to gain detailed insights into market dynamics, identify perceived and actual market barriers, and better understand customer valuation of cooling system attributes. We conducted four focus groups in all, one each with residential homeowners, nonresidential building owners and property managers, residential technicians, and nonresidential technicians. The two focus groups with nonresidential market participants were held in Sacramento, the two residential focus groups were held in Fresno.

Focus group discussions covered the following specific areas:

- **Decision-making process:** What are the roles of different market participants in the cooling equipment selection process? What are the key equipment characteristics and performance criteria that drive the selection process? Why would one choose an evaporative cooling system over a compressor system? Why would one choose to add an evaporative cooler to their compressor system, rather than purchase a new larger compressor system?
- **Communication channels and information sources:** Which broadcast and interpersonal channels of communication are most relied on for information about cooling technologies? How much credibility do those sources have? How much information does one need to make an equipment specification decision?
- **Market barriers:** What are the specific barriers to the adoption and acceptance of evaporative cooling technologies? Are they different for each of the market segments we are focusing on? What are their opinions regarding real barriers versus perceived barriers?

The focus group results lent themselves well to the next phase of data collection: survey design. We were able to identify specific areas where additional information was needed to characterize the market accurately. The most valuable part of the focus groups was the discussion of selection criteria. While the results were not all that surprising ("cost" is the most important factor), other factors considered “important” were tested to determine what, if anything, consumers are willing to “trade off” in selecting their equipment. In addition, many said that since the common term for evaporative coolers is still “swamp coolers" regardless of system type, we learned that perhaps a naming and branding campaign should be launched, rather than promoting new developments under an old name. We also discovered that technicians and building owners have completely different ideas about each others' roles and intentions. Contractors recommend specific brands because they are reliable, whereas building owners (particularly residential) think contractors recommend specific brands because they receive incentives for doing so. In addition, contractors think consumers “would never be happy with the performance of a swamp cooler,” whereas building owners generally can be convinced to try a specific technology as long as it proves to be successful.

Quantitative Data Collection and Analysis

Significant amounts of survey data were required to drive the analytical models. These data came from surveys of HVAC contractors. The decision to focus quantitative data collection on this group stemmed from focus group discussions with technicians (e.g., HVAC contractors, mechanical engineers, design/build contractors) and with building owners (both residential and commercial), which indicated that building owners relied heavily on their contractors for advice regarding specific technology choices. Building owners certainly set the general project parameters and control the purse strings, but we concluded that the technicians had the primary influence on the selection decision.

The quantitative analysis focused on developing a theoretical framework explaining how programs might create sustainable supply-side and demand-side market effects. This component of the baseline study involved

- specifying a set of forecasting models to describe the market penetration process for evaporative cooling
- identifying key inputs for those models
- measuring initial input values
- developing preliminary forecasts of market penetration based on expected changes to input values
- describing a process future evaluators can use to update the forecasts using true time-series data

We based the forecasting models on techniques described in the literature on diffusion of innovations. According to Mahajan, et al. (1990), "the purpose of the diffusion model is to depict the successive increases in the number of adopters and predict the continued development of a diffusion process already in progress." We thus used diffusion models to establish relationships between the wealth of measurable and observable baseline information gathered (e.g., market barriers, customer awareness, product availability, attitudes and perceptions of the technology, marketing activities, historical market penetration rates, etc.) and the two quantities of most interest to proponents of energy efficiency: adoption rates and time.

Our forecasting model was built on the basic Bass first-purchase diffusion model, which describes potential adopters of an innovation as falling into two groups: one that is influenced by mass media (including program promotional activities) and one that is influenced by word of mouth. The assumptions of the Bass model can be expressed mathematically as

$$n(t) = \frac{dN(t)}{dt} = p[m - N(t)] + \frac{q}{m} N(t)[m - N(t)] \tag{1}$$

In this equation, n(t) is the number of adopters at time t; N(t) is the cumulative number of adopters at time t; and m is the potential number of ultimate adopters; that is, the market potential. The first component of the equation, p[m-N(t)], represents adoptions due to buyers who are not influenced in the timing of their adoption by the number of people who already have bought the product. These people are likely to be motivated to adopt evaporative cooling by program messages or mass media. Thus Bass referred to p as the "coefficient of innovation." The second term, (q/m)N(t)[m-N(t)], represents adoptions due to buyers who are influenced by the number of previous buyers. These people will tend to adopt evaporative cooling technologies only after hearing positive endorsements from friends or colleagues. Thus Bass referred to q as the "coefficient of imitation."

Market Potential (m)

Historically, diffusion of innovation researchers have estimated the parameters q, p, and m econometrically from equation 1 (see, e.g., Bass 1969). More recent experience has shown that forecasting models in which market potential is estimated econometrically tend to be highly unstable when data are limited to early phases of adoption. Researchers have obtained more stable overall model results by estimating m independently and then constraining m to the estimated value in the econometric model (see, e.g., Heeler and Hustad 1980; Teotia and Raju 1986). Thus, for this project, we calculated market potential in three steps as the product of three quantities:

- Cumulative market population (P)
- Technical potential (T) (the fraction of the market population that is likely to adopt, based on technical considerations)
- Economic market share (M) (the fraction of the market population that is likely to adopt, based on economic considerations)

We defined the cumulative market population as being the number of residential and nonresidential customers in the target market area (i.e., northern California, excluding the coastal areas). Numeric estimates of the number of customers in each category came from PG&E's customer demographic data. PG&E's growth assumptions were adopted to project growth in the cumulative market population over time.

The primary potential for adopting evaporative cooling lies in situations in which purchase of a new cooling system is already under consideration. Such situations include existing buildings in hot or transitional climates that lack mechanical cooling, new construction, major renovation or "gut rehab" (to the extent that new HVAC is part of the renovation), and deferred maintenance or "replace-on-burnout," in which an existing nonfunctional cooling unit must be replaced. Thus, our estimate of technical potential was composed of three quantities; the fraction of existing buildings without cooling, the rate of new construction, and the rate of cooling equipment replacement (including replacement from renovations and deferred maintenance).

Our methodology for estimating economic market share is described below.

Economic Market Share (M)

Using a method called “ordered logit,” we developed quantitative models that predict market shares of alternative “standard” vs. “natural” cooling technologies. The models allowed us to estimate technology market shares under a variety of scenarios. This approach also enabled us to estimate the effects that potential policy interventions might have on technology adoption.

The ordered logit approach is a qualitative choice model that uses information derived from the rankings of a set of options by survey respondents. The individuals rank a set of technology alternatives that are described in terms of a set of attributes, which are varied for each alternative. The information from this ranking is then translated into a likelihood function, and then parameters are estimated that maximize the likelihood function. The parameters are used in estimating the value function, which can be directly translated into relative market shares. This approach is widely applied to problems in which researchers are trying to understand tradeoffs between alternatives that vary on a number of attributes. This method has several advantages: it does not require respondents to make a "purchase/don't purchase" decision, and, because it is able to use the information about the position of all rankings, it can generate results even in the case of relatively small sample sizes.

Setting up the survey and the modeling work required identifying a set of attributes to describe the systems, including important technical features, adoption barriers, and factors that might be able to be used as policy or market interventions to affect market share. The factors of primary concern in both the residential and commercial sector centered on several key issues:

- **Appropriateness**—size and appropriateness of technology to design and use of the building, location and installation concerns, performance/comfort, and weather considerations.
- **Financial**—first cost, rebates, operating cost, and payback issues.
- **Quality**—brand, warranty, reliability, performance/maintenance factors.

The number of separate factors modeled was limited by the maximum number of cards we were willing to have respondents rank. After comparing the limitations of several different research designs, we selected a design that would require customers to rank nine cards, each including a different set of attributes. The ranking of these nine cards allowed us to estimate the influence of a maximum of four separate factors, each taking on three values. The selected attributes were designed to represent, or serve as proxies for, the appropriateness, financial, and quality-type considerations that were identified as important decision criteria affecting the selection of systems. The factors included

- **System type:** We allowed three alternatives for system type, including one evaporative system
- **Demonstrated field experience:** As one measure of how "proven" a technology would be, we offered three options for the length of time a system technology had been in the field.
- **Warranty:** Warranties were used as another indicator of quality to the technicians, and we used it to represent a level of confidence that revisits could be minimized. We allowed three levels of warranties for parts and labor.
- **Rebates:** Three rebate levels were allowed, and the structure allowed the first cost for the natural cooling systems to be greater than and also less than the standard systems.

After being provided with a brief description of the type and location of the hypothetical building application, each HVAC contractor was provided with nine residential cards and nine commercial cards, and was asked to rank them from most to least preferred.

Finally, we were concerned that there might be factors beyond just actual physical attributes of the system that might affect system selections. Therefore, although we initially did not name the systems presented on the cards, we asked one more question of respondents after the rankings were complete. We asked whether their rankings would have changed if they were told that their high-ranking system was an evaporative or natural cooling technology. This question was incorporated to try to determine whether, regardless of actual characteristics, there is a bias against natural cooling technologies because of health fears, bad reputations, or other factors.

One very important caveat related to the estimated results is that choice modeling assumes that the systems are all known to the technicians, as are their characteristics or attributes. Therefore, the market shares are, in a sense, potential market shares after advertising; or, market shares assuming that decision-makers are educated about the existence and basic characteristics of the various system types.

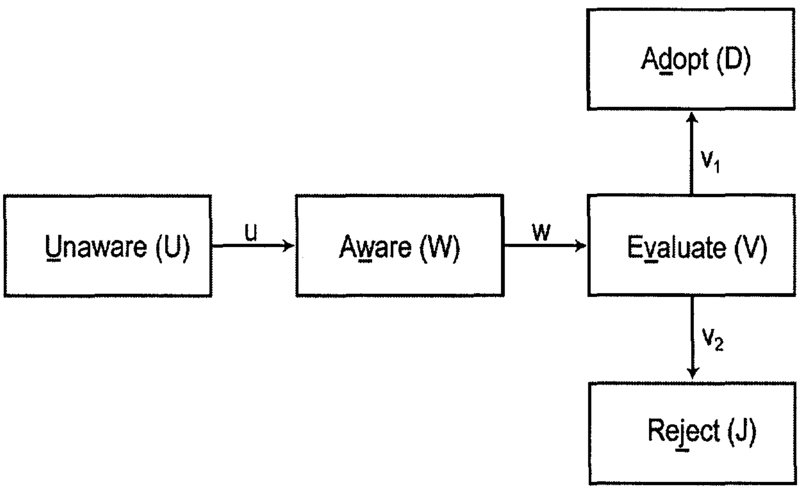
Cumulative Number of Adopters Over Time (N(t))

The usual application of a diffusion model is to estimate the model parameters p and q, given a historic time series of cumulative adopters over time, and then use the estimated parameters in the equation to forecast future adoption, ultimate adoption levels, and the timing of the adoption peak. However, the evaporative cooling technologies of interest have been introduced too recently to permit estimation of p and q based solely on historical data. To compensate for the lack of historical data, we developed short-term estimates of future adoption that we then used to estimate p and q and thus develop longer-term estimates of adoption. We developed estimates in two different ways, using delphi interviews and using an adoption process model.

Delphi survey estimate. We used the Delphi technique to develop consensus estimates from the panel of experts regarding the expected rate of adoption over the next seven years. They were also asked to specify a reasonable range around their estimate, and the factors that would cause their estimates to rise or fall.

Adoption process model estimate. Our second method for estimating the cumulative number of adopters over time used adoption process models. We used a five-state evaluate-adopt model, which is appropriate for one-time purchases of expensive technologies. This approach models potential adopters' progression from unaware to aware, to evaluate, and then to either adopt or reject, as illustrated in the following figure.

Figure 1. Five-State Evaluate-Adopt Model



In Figure 1, the quantities U, W, D, V, and J represent the number of potential adopters (or, alternatively, the fraction of the potential market) in each adoption state (unaware, aware, evaluate, adopt, and reject, respectively) at a given point in time. The quantities u, w, v1, and v2 represent the probability of making the transition (or, alternatively, the rate of change) from one state to another within a given timeframe.

Using survey data, we estimated the initial distribution of potential adopters among the five states.

Estimated values for the transition probabilities came from several sources. We tested several hypothetical values for u (the unaware-aware transition probability) given various advertising and promotion scenarios for future programs. We estimated w based on decision-maker surveys. Defining $v=v1+v2$ as the general probability of moving from the evaluate state to some action (either adoption or rejection), we estimated v based on decision-maker surveys as well. Given v, we used the ordered logit results described previously to determine the appropriate split between v1 and v2.

Coefficients of External and Internal Influence (p and q)

Given estimates of the overall market size and the cumulative number of adopters at various times as inputs, we generated a set of estimates for the coefficients p and q by statistically fitting a Bass diffusion curve to the input data. As a plausibility check, we compared them to estimates based on published results for similar technologies.

Conclusions

While quantitative results are not yet available at the time of this writing, a number of important conclusions have already emerged from the analysis. Our conclusions can be grouped into three categories, relating to

- General market-related findings
- Recommendations for future program design
- Recommendations for methodology modifications

Each category is discussed in more detail below.

General Market-Related Findings

Indirect evaporative cooling makes up such a small fraction of the overall market that quantification of its market share is problematic. Existing HVAC market share data sources do not provide data of sufficient detail to measure indirect evaporative cooling as a distinct category. Direct evaporative cooling comprises a measurable, though still small, fraction of the overall market.

Technicians play a key role in cooling specification. Their endorsement is critical (though not necessarily sufficient) for indirect evaporative cooling technologies to gain greater market success. Credible channels for communicating with technicians include manufacturers, equipment vendors, trade journals, and word of mouth from other technicians.

Building owners play a more passive role in cooling technology selection. They set general parameters and budgets and have final veto authority, but their selection decision is bounded by the recommendations they get from their contractors. Nevertheless, building owners need to be generally familiar with and positively inclined toward evaporative cooling for a contractor to make such a recommendation. Any building owner unwillingness to accept the technology, whether real or imagined, can act as a disincentive to the contractor to make the recommendation.

Market barriers relating to performance uncertainties appear to be the most important barriers to adoption. These barriers are partly attributable to negative associations with direct evaporative cooling and partly attributable to true shortcomings in equipment performance, at least in the past.

The term "evaporative cooling" clearly has negative connotations for a large segment of the market, judging from focus group discussions and choice model results. In response to choice model questions, approximately half the technicians reported their ranking of a particular cooling system would go down if it was an evaporative system. They cited a number of concerns with evaporative cooling relating to comfort and maintenance issues, among others. Clearly, the performance characteristics respondents associate with the term evaporative cooling are worse than those we attributed to evaporative cooling in our modeling. Our model attributes were developed to reflect actual equipment attributes, leading us to the conclusion that the perception of evaporative cooling is worse than the reality. Nevertheless, anecdotal evidence from delphi panelists and PG&E's previous case studies suggest the concerns are not entirely unfounded.

Delphi panelists generally agree some type of market intervention would be necessary to stimulate a noticeable increase in market penetration. Program interventions designed only to raise levels of general awareness are expected to have minimal effect. Interventions designed to reduce performance uncertainties are considered to have the best prospects of success. The median panelist sees the moderate intervention scenario as increasing penetration to no more than five percent (in the residential sector) or six percent (in the commercial sector). Under the aggressive scenario, the median participant anticipates greater gains, but still a limited market share—to eight percent in the residential sector and twelve percent in the commercial sector. One positive sign is the fact that only one panelist expects a drop in market share once the interventions are removed. In other words, the majority of those consulted believe that the penetration levels attained may persist after the program ends.

Methodological Recommendations

Markets for products such as evaporative cooling are inherently complex. Developing and implementing a well-crafted strategy for studying such markets—whether for documenting baseline conditions or measuring market effects—requires a careful, deliberative, process. In particular, it requires a detailed formulation of the research questions, ample time for methodology development, thorough pre-testing of data collection and analysis procedures, and flexibility to make inevitable adjustments.

The present study offers a methodologically sound approach for analyzing markets for both descriptive and prescriptive purposes. The combination of a thorough literature review with primary data collection from a variety of market actors provides a comprehensive picture of current and historical market conditions. The modeling techniques employed can provide a realistic assessment of likely future market conditions, and a means for testing hypothesized effects of various market intervention strategies.

Nevertheless, this study suffers from a number of limitations that stem both from its conception and its implementation. With these limitations in mind, it is our opinion that this study is capable of serving as a valid market characterization but requires additional data collection and analysis to serve as a valid quantitative baseline.

Most fundamentally, the study is limited by its design as a "snap-shot" at a single point in time. The modeling techniques, to produce robust results, require repeated data collection over several time intervals. Study results, based on inferred or extrapolated time-series data, should be considered illustrative of the methods rather than rigorous documentation of actual and future market conditions.

The study also encountered market conditions that were significantly different from the design assumptions used to formulate the adoption process and diffusion models. The adoption process models were developed as five-state models with an evaluation state, which is generally appropriate for one-time or infrequent purchases of "big ticket" items; that is, durable goods. Our selection of this model form was based on the assumption that building owners would be the primary decision makers. However, from the focus group discussions, we concluded we should treat the technicians (e.g., HVAC contractors, mechanical engineers, design/build contractors) as the primary decision-makers. This group makes equipment selection decisions on an on-going basis. Selection of evaporative cooling is not an either/or decision but a "how often?" and "under what circumstances?" decision. Thus, a durable goods adoption process model is not the best choice, even though the equipment in question qualifies as a durable good.

The diffusion modeling approach applied here appears overly simplistic in that it assumes awareness is the limiting factor in the adoption rate and that the word-of-mouth communication regarding the technology is uniformly positive. In practice, awareness of evaporative cooling technologies is relatively high but adoption is limited by performance uncertainties. One strategy for incorporating performance uncertainties into the model is to explicitly consider the effect of both positive and negative communication. The model should consider word-of-mouth communication that expresses doubts about the technology as well as conveys positive experiences. One source for guidance in this area is Mahajan, Muller, and Kerin (1984), which describes a version of the adoption process model that incorporates positive and negative word-of-mouth communication. A second source, Kalish and Lilien (1986), describes a method for incorporating positive and negative market feedback into the Bass diffusion curve.

Recommendations for Future Program Design

A number of recommendations for program design and implementation are implicit in the findings from the market characterization and adoption process modeling. In addition, we were able to explicitly test program design alternatives in the delphi interviews and choice models. Taken together, the findings can be summarized as follows.

Program interventions focusing only on increasing awareness appear to be of limited value. For existing technologies, at least, this is not the primary barrier. This conclusion is borne out by comments from delphi panelists, and from the adoption process models. The latter show high rates of self-reported awareness of existing indirect evaporative technologies among technicians, despite the fact that they specify or recommend these technologies only rarely.

First and foremost, program designers should focus on fully field testing any equipment the program endorses. Before promoting a technology market-wide, the program should be completely confident that advertised performance characteristics are consistent with the actual field performance characteristics; that instructions for installing, operating, and maintaining equipment are crystal clear; that the equipment will perform reliably once it is installed; and that high-quality, responsive support services are available in those (hopefully) rare instances when they are needed. In short, the program should be confident that the market's experiences with the equipment will be uniformly positive.

Once actual performance issues have been fully resolved, the program can productively address issues of perceived performance. Several strategies appear viable for addressing perception issues:

- Renaming new technologies to disassociate them from existing evaporative cooling (particularly direct evaporative cooling)
- Forming alliances with major manufacturers with long-standing name recognition and fully capitalized support infrastructure
- Offering extended warrantees

Beyond measures to address performance uncertainties, we also examined the potential role of financial incentives. On this issue, the results are more ambiguous. On the one hand, choice model results indicated that financial incentives could clearly be effective at increasing market penetration, at least for the price differentials we modeled for standard and efficient equipment. On the other hand, delphi panelists did not attribute large market effects to financial incentives. On this subject, they were quite clear in emphasizing that, if financial incentives are offered, they should go to the HVAC contractor rather than the manufacturer. These findings, along with previous market effects research, leads us to conclude that financial incentives may not be necessary to drive down purchase prices but may be useful in attracting attention and demonstrating the program's commitment to the technology.

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