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Technological forecasting: heat pumps and the synergy with renewable energy

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Abstract

The possession and use of air conditioning in the residential sector is increasing and shifting the electricity energy use peak from Winter to Summer in Europe. As the average income grows, electricity consumption is expected to be higher, especially in developing countries, as these appliances are linked to thermal comfort in dwellings. A great effort has been made, especially in Europe and China, to study and deploy technologies driven by renewable energy. Using the Delphi technique, specialists from all continents were questioned about the future technology of air conditioning for residential use in a 20-30 year future. About half of the specialists answered that vapor compression cycle will be the main technology with direct heat dissipation to outside air. The investment and operational costs were classified as the key evaluation factor together with the Seasonal Performance Factor to compare systems and technologies. Despite the low use perspective of solar thermal energy for air conditioning, it is expected to be almost a standard for DHW in a 20-30 year period.

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Keywords: Delphi methodology; Technological forecasting; Renewable Energy; Heat Pump

1. Introduction

The pursuit for sources to supply the increasing energy demand that reduces greenhouse gases emissions, are cleaner, renewable and, in addition, generates energy independence is a continuous task. The increase in the possession and use of air conditioning is a tendency worldwide; in Europe the electricity peak demand has shifted

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from Winter to Summer [1] and in Brazil the possession is expected to rise over 160% in the next 20 years [2]. The main technology used today is the vapor compression cycle, driven mainly by electrical energy [3].

The development of solar heating and cooling is the subject of groups and tasks of the International Energy Agency since 1977, as reported in the Agency's website. The large introduction of cooling appliances powered by renewable energy could reduce the pressure for more electricity generation and resources. The use of renewable heat in thermal driven air-conditioning systems may be one possible answer to this need. They are present in demonstration installations and becoming market available, even so most of them have high cooling output and are installed in commercial buildings. This survey was restricted to residential market, as it has some particulars features, such as millions of equipments with individual low output [3, 4].

Currently, there is more than one heat driven technology under development or attempting to initiate or increase its sales. The information available is still limited and even rarer for the residential sector. A critical analysis of future market developments may be too difficult to simulate with a good degree of certainty using statistical models. A survey with experts using Delphi technique was conducted to forecast the possible synergy of cooling cycles with renewable energy in the next 20-30 years for the residential market, inferring possible market adoption of new technologies.

Nomenclature

SPF	Seasonal Performance Factor
AHU	Air Handling Unit
COP	Coefficient of Performance
DHW	Domestic Hot Water
GSHP	Ground Source Heat Pump
PQI	Process Quality Index
SPF	Seasonal Performance Factor
UNEP	United Nation Environmental Programme

Subscripts

el	electrical
th	thermal
sys	system

2. Air-cooling systems

The vapor compression is the most used cooling cycle, which normally uses an electric compressor. After compressed, the hot refrigerant vapor rejects heat energy in the environment while condensing; the condensed and pressurized refrigerant passes through an expansion valve and evaporates. While evaporating it withdraws energy and cools the room. In the residential market, the withdrawn and rejection are normally made directly in the air. A second system is the open cycle, which produces conditioned air directly, creating a cooling effect by humidification, dehumidification or a combination of these processes [5, 6].

The sorption cycles are driven by thermal energy and can also produce cooling effect. The most known are the absorption and the adsorption cycles. The absorption cycle works with a pair of chemicals, one serving as a refrigerant and the other as an absorbent. The heat is used to generate a vapor of refrigerant and absorbent with low refrigerant concentration in the generator. The refrigerant vapor is condensed by cooling water and evaporated in the evaporator, generating a cooling effect. The refrigerant vapor is absorbed by the low refrigerant content solution that is pumped again to the generator [4, 6].

The adsorption cycle uses a solid sorption material. This sorption material adsorbs the refrigerant, usually water, which evaporates and generates a cooling effect. The system normally has two adsorption beds; while one bed is adsorbing, the second one is desorbing the water using the energy from a heat source. These systems and cycles are well described in many publications, such as Kim, 2008, and will not be fully described here [4, 6].

The cooling effect of sorption cycles usually exchange energy with a secondary chilled water circuit that is used to cool the room while the energy received from the heat source, and withdrawn from the cooled room, is rejected to the environment using a cooling water circuit.

The study looked for synergy potentials of locally produced renewable energy in equipments working in the cooling mode. The association of electrical heat pumps in heating mode with renewable energy extracted from the environment cannot be assumed in the cooling cycle; therefore, is not considered as a renewable synergy. These boundaries also excluded the renewable portion of the grid electricity; GSHP was considered here, as a consequence, a special design for the vapor compression cycle.

The natural synergy for the vapor compression cycle is the photovoltaic energy and solar thermal energy or heat from biomass for thermally driven cycles. The associations with waste heat and cogeneration processes were not considered, as the fuel may come from non-renewable sources, and may not be feasible for residential applications.

3. Technology forecast

The technological forecast study was conducted using the Delphi technique. An evaluation of the problem conditions indicated the suitability of this methodology: there is more than one technology in the beginning of market utilization; there is a shortage of data for the residential market, the forecasting is for a mid-long term, 20-30 years and the intention to get opinions from experts worldwide.

3.1. Delphi methodology

The Delphi Method is classified as an expert opinion methodology [7], and consists in a structured communication process of a group via iterative survey [8]. The key features of a Delphi study are: anonymity, iteration, controlled feedback, and the statistical aggregation of group response [9]. The group answers a questionnaire, then receives the results of the first round and is asked to revise their answers considering the group response, usually presented as statistical aggregation. The process is repeated until a stable result is reached [10].

In this survey, a questionnaire was developed and distributed using a web-based machine, www.questionpro.com. The questionnaire was improved using information collected in the first round and the statistical results of were added.

3.2. Expert search

Specialists from the research community and industry, as well as government agencies, were searched in recent publications related to the theme, using the search engine in the Elsevier Science Direct and Google.com webpage. Research publications are considered a good mechanism to find relevant experts in a field [11, 12]. The distribution of specialists retrieved is shown in Fig. 1 and may indicate government interest in a specific subject, as most research reported in publications are funded by governmental agencies [13]. Europe has more than half of the experts listed, followed by Asia and Oceania, mainly China, with another 21,9%. This concentration may suggest a relationship with energy demand and security. A relatively low number of experts in North America, less than 15%, may suggest that this technological path has lower interest, compared to other regions.

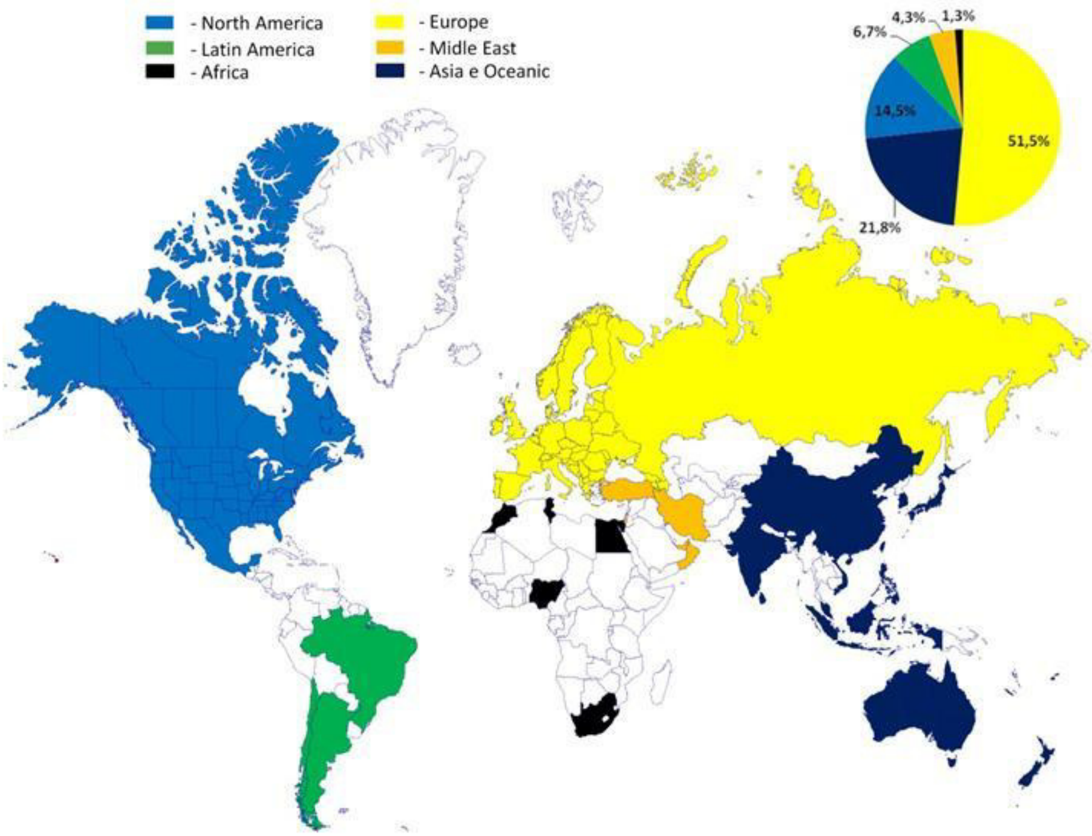

Fig. 1. Geographic distribution of experts grouped by regions.

4. Results

The survey was aimed to forecast the participation of thermally driven technologies in the residential market, considering no major political or regulatory change in a 20-30 year future. The synergy with locally produced renewable energy was also assessed. These boundaries were placed considering a specific market, to limit the answers to elements that would be under the control of the panelists. The questionnaire asked about parts of an air-conditioning system independently, e.g.: heat withdraw, heat rejection, thermodynamic cycle, renewable energy association, performance index etc. The answers of the second round were evaluated and the iteration process was ended in the second round, as stable results were achieved. References indicate that is common to have studies stopping in the second round [8, 9].

The results represent the opinion of the experts that answered the survey, considering the target application and the boundary conditions. They do not intend to produce statistically significant results [14]. Nevertheless, they express relevant opinions that ought to be considered while building or revising strategies.

4.1. Air-conditioning technology

The vapor compression cycle was pointed by about half of experts as the first market prevailing technology. Absorption cycle was indicated by about 30% as the first most used technology, and 26% pointed absorption as the second, Fig. 2. The answers indicating the absorption cycle as first or second technology suggests that this technology may be the most likely to compete with the vapor compression cycle in the future.

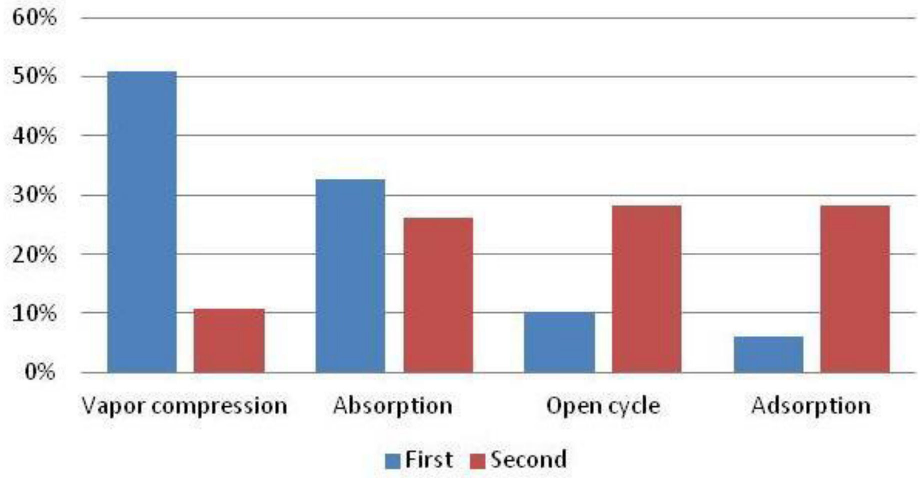

Fig. 2. First and second market prevailing technology according to survey

The result indicates, with a high probability, that the vapor compression cycle will continue to be the main technology used in dwellings and are in line with the answers for heat rejection and withdraw technologies. Although these answers had a more distributed response, the direct rejection to air and withdraw with ductless or AHU systems were the configurations with more “high” and “medium” answers.

4.2. Performance assessment

The coefficient of performance, COP, is a way to assess and compare different systems and technologies. It represents the desired effect, cooling, per energy spent. The specific energy spent may have different definitions, e.g. thermal, electrical or of the system as a whole. The loss of available work, exergy analysis, is another way to measure the system performance. As the COP depends heavily on the test temperatures, standard conditions are necessary to provide a meaningful comparison. The operating performance over a season is called Seasonal Performance Factor, and evaluates the system performance over a range of temperatures [5].

Technical coefficients were evaluated along with investment and operational costs, in order to rank their relevance. Over 80% of the participants answered that investment and operational costs have “high” importance and no one answered that it has “low” relevance. The technical coefficients that evaluate systems in a broader view received more frequent “high” and “medium” importance answers, as did the SPF and COPsys. Thermodynamics indexes, as exergy efficiency and PQI (COPsys/ COPideal), received the largest “low” answer frequency.

Although economics may play a secondary role in concept and technical feasibility phases, it plays a significant role in the adoption stage. The results presented in Fig. 3 show the importance to combine both aspects, technical and economic, evaluating the system in a broader spectrum.

4.3. Solar thermal energy

Despite the fact that thermal driven air-conditioning equipments seem not to become a marketing leader technology, the solar thermal energy is expected to have a different development. Fig. 4 shows that it may be associated to DHW in most dwellings in 20-30 year future. An additional use of solar thermal energy is space heating, which appears as second in “present” answers, followed by air conditioning. A “combined” use, which means the use for more than one option, e.g. DHW and space heating, received the second highest “present” answers.

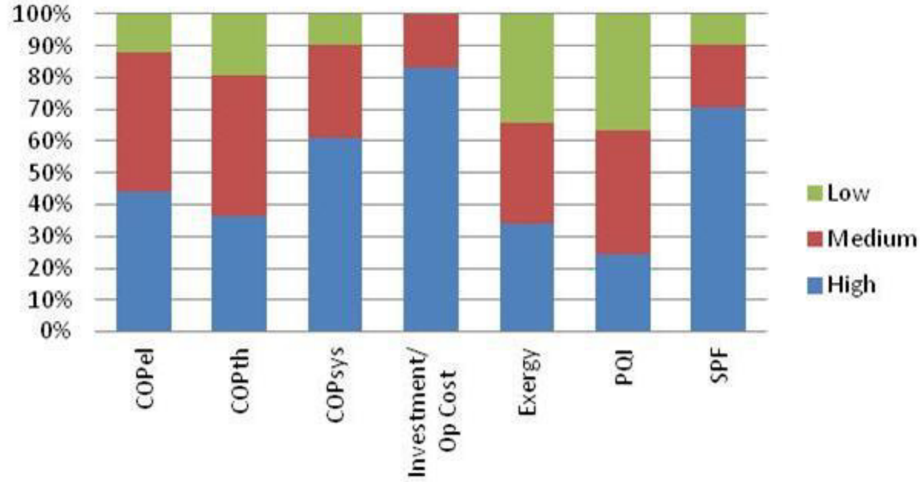

Fig.3. Importance of performance indexes and economic evaluation

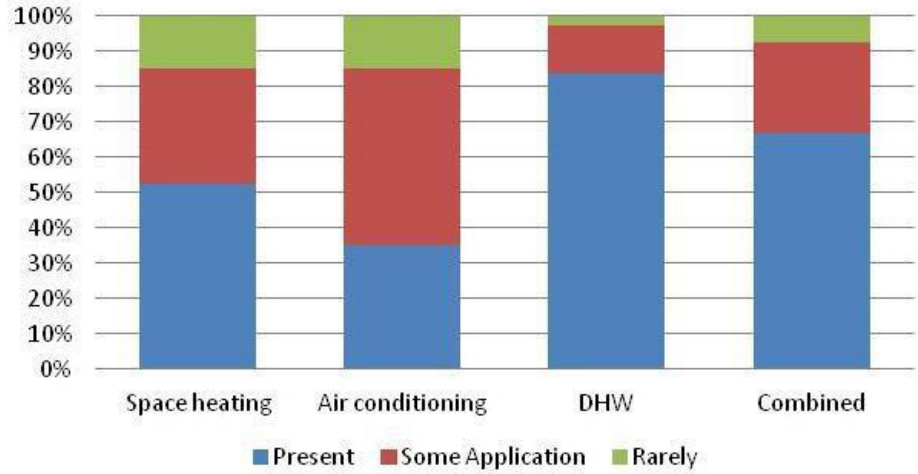

Fig. 4. Solar thermal energy uses in dwelling in a 20-30 year future

4.4. Barriers for renewable cooling

The first round pointed to a low participation probability of renewable cooling in the prospected period, when considering no major political or scenario change. The panelists were also asked, in the first round, for scenario changes that would modify their answers significantly. The free answer format returned about 90 contributions. A great number of comments addressed the cost issue by means of equipment cost, increase or decrease of fossil fuel prices, cost reduction of renewable energy and its equipments, carbon taxes, energy cost etc.

In the end of the first round, the ideas were organized and a short list was formulated based on the main topics for ranking. The experts were asked which one, among the four barriers would enable a wide use of renewable energy in small air-conditioning systems; multiple options were allowed. Almost 90% of the participants chose cost as the major barrier, Fig. 5. This result indicates that this obstacle, pointed by Balaras in 2007, is still primary [15].

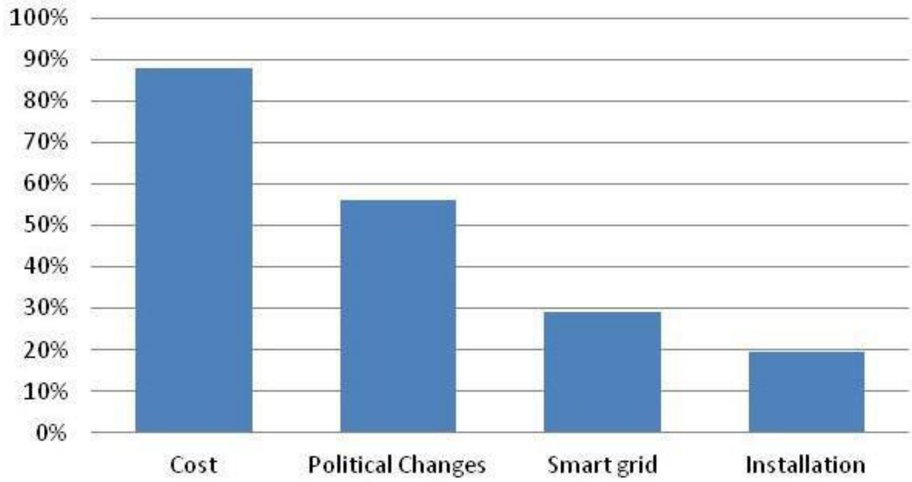

Fig. 5. Barriers to overcome a large-scale introduction of renewable cooling

Public policies may change the cost scheme, as a result of using different taxation or implementing special funding. These actions could also be seen as a way to interfere in the investment decision. Another change in policies may be related to technical and environmental requirements, e.g. restricting greenhouse gases emissions or refrigerant characteristics. This has happened in the past, with the phase out of Ozone depleting refrigerants. The established industry responded well and the implementation of this regulation is considered an example of success, as pointed in the Ozone secretariat of UNEP website. Smart grid may also change the energy cost pattern, thus altering the project economics and return of investment. Installation of demonstration equipments had the lower frequency.

4.5. Participants profile s

The participants working affiliation were: 71% from university or R&D institution, 24% from private companies and 5% from government or agencies. They evaluated themselves concerning their knowledge in the area; 71% of the participants considered themselves experts, with research in the area in the last three years.

5. Conclusions

The results indicate that vapor compression system will continue to be the main technology for air conditioning in the residential market in 20-30 years. The main initial challenge for an introduction of heat driven cycles is to cut down investment and operational costs. Political changes may have influence in the market, but its use may be actually effective only when the cost difference is much smaller than it is today.

The most known technologies were evaluated together, remembering that a new technology will have to compete with a well established one, and the technical performance rating indexes should be evaluated with economics. The importance of economical aspects over the technical ones reinforces that both aspects must be considered. When evaluating the adoption of a new technology, one may keep in mind that not always the best technical, or environmental, solution will prevail, and the current technology may also have its performance enhanced and surpass new barriers.

The survey findings presented here are not an absolute consensus and they reflect a possible future for the residential market; they represent the thoughts of a group of experts and may not be necessarily true for other segments. The use of solar thermal energy to produce DHW is likely to become a standard in the mid future. Perhaps the large application of solar thermal energy for DHW and space heating may create excess heat in the Summer and be a first step towards the use of solar thermal energy for renewable cooling.

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References

[1] European Commission. 2020 – 2030 – 2050 – Common Vision for the Renewable Heating & Cooling sector in Europe: European Technology Platform on Renewable Heating and Cooling. Luxembourg: Publications Office of the European Union, 2011.

[2] BRASIL, Ministério de Minas e Energia. Matriz Energética Nacional 2030, Ministério de Minas Energia: colaboração Empresa de Pesquisa Energética. Brasília: MME, EPE, 2007.

[3] Bertoldi P, Atanasiu C. Electricity Consumption and Efficiency Trends in the European Union - Status Report 2009. Luxembourg: Publications Office of the European Union; 2010.

[4] Solair Project. 2009. SOLAIR Guidelines: Requirements on the Design and configuration of small and medium sized solar air-conditioning applications. Accessed in 2012 Dec 20. http://www.solair-project.eu.

[5] Omer AM. Ground-source heat pumps systems and applications. Renew Sust Energ Rev 2008; 12:344-371.

[6] Kim DS; Infante Ferreira CA. Solar refrigeration options – a state-of-the-art review. Int J Refrig 2008; 31:3-15.

[7] Porter AL et al. Technology futures analysis: Toward integration of the field and new methods. Technol Forecast Soc 2004; 71:287-303.

[8] Linstone HA, Turoff M. The Delphi Method – Techniques and Applications. Online ed. Murray Turoff and Harold A. Linstone; 2002, available at: http://www.is.njit.edu/pubs/delphibook/index.html.

[9] Rowe G, Wright G. The Delphi technique as a forecasting tool: issues and analysis. Int J Forecasting 1999; 15:353-375.

[10] Linstone HA, Turoff M. Delphi: A brief look backward and forward. Technol Forecast Soc 2011; 78:1712-1719.

[11] Woon WL, Zeineldin H, Madnick S. Bibliometric analysis of distributed generation. Technol Forecast Soc 2011; 78:408-420.

[12] Losiewicz P, Oard DW, Kostoff RN. Textual Data Mining to Support Science and Technology Management. J Intell Inf Syst 2000; 15:99-119.

[13] Kleer R. Government R&D subsidies as a signal for private investors. Res Policy 2010; 39:1361-1374.

[14] Glenn JC, Gordon TJ. The Delphi Method. In: Glen JC, Gordon TJ, editors. Future Research Methodology, V-3.0. The Millennium Project, 2009, CD.

[15] Balaras CA, et al. Solar air conditioning in Europe—an overview. Renew Sust Energ Rev 2007; 11:299-314.