Air-Conditioning
and Refrigeration
Technology Institute, Inc.

A not-for-profit
organization for
scientific research
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The Air Conditioning and Refrigeration Technology Institute (ARTI) invites all prospective bidders to submit proposals for the following research project:

ARTI Project No. 09003
Life Cycle Climate Performance Model for HVAC&R Systems

Proposal Submissions

Proposals are due by Monday, 26 April 2010.

Ten (10) copies of the technical proposal and five (5) copies of the cost proposal should be mailed to:

Mr. Steven R. Szymurski
Air Conditioning and Refrigeration Technology Institute
2110 Wilson Blvd., Suite 500
Arlington, VA 22201-3001

Electronic copies of proposals may also be emailed to: sszymurski@ahrinet.org

Scope of Work

The proposed scope of work is outlined in the attached work statement. Contact for technical questions concerning the scope of work:

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Proposal Evaluation Criteria

Proposals will be evaluation against the below criteria and weighting:

Understanding the problem 25%
Approach to solving the problem 25%
Probability of (timely) success 15%
Qualifications and experience of key personnel 25%
Quality of facilities to perform the work 10%

LIFE CYCLE CLIMATE PERFORMANCE MODEL FOR HVAC&R SYSTEMS

BACKGROUND

Over the lifetime of a refrigeration or air conditioning system, refrigerant may be emitted during manufacturing, installation, servicing, and disposal at the end of equipment useful life; over the same period, energy is consumed, possibly resulting in CO_2 emissions, to manufacture the product, to ship it, to provide the input power for it to operate, and to dispose of the product. At the end of life, if the refrigerant charge is reclaimed and the materials are recycled, embodied energy savings can be credited to the unit [Goetzler et al., 2001]. Hence, to fully understand the total global warming impact, both direct and indirect effects have to be considered. Life Cycle Climate Performance (LCCP) is a concept that identifies all the warming impacts due to the use of a certain product through its lifetime, including both the direct effect of refrigerants and possible blowing agent emissions from the product and the indirect effect of carbon dioxide emissions related to the energy consumption of the product. A concept comparable to LCCP is Total Equivalent Warming Impact (TEWI). Studies of the comparative total warming impacts of a variety of refrigeration and air conditioning equipment types were undertaken during the 1990s[Fisher et al., 1991 and 1994, Sand et al., 1997, Dieckmann et al. 1999].

Recently, a group of researchers developed “The (GREEN-MAC-LCCP)© Global Refrigerants Energy & Environmental-Mobile Air Condition-Life Cycle Climate Performance model” [Papasavva et al., 2008]. The model assesses the lifecycle energy and greenhouse gas (GHG) emissions associated with the production, use and disposal of alternative refrigerants and mobile air conditioning (MAC) components. The GREEN-MAC-LCCP© is a comprehensive analytical tool that takes into consideration key MAC system characteristics such as Coefficient of Performance (COP), evaporator cooling capacity data (Qe) obtained from bench tests and integrates them with other vehicle and alternative refrigerant inputs such as: annual driving time, A/C on time, weather data, vehicle lifetime, refrigerant leakage rates, MAC system mass requirements, energy requirements due to manufacturing, and end-of-life impacts of alternative refrigerants and MAC components. The model provides CO_2-equivalent emissions due to A/C installation, operation, and disposal on a vehicle. The output can provide results for i) Three vehicle classes ii) Fifteen cities, iii) Four alternative vehicle fuels, and iv) Several alternative refrigerants such as: HFC-152a, R-744, refrigerant 'H', DP-1, AC-1. This tool was developed based on input data harmonized by the industry and it is intended to become the global standard for assessing the life cycle greenhouse emissions associated with the use of alternative refrigerants.

Currently, there is no standardized methodology and simulation tool for evaluating the LCCP of stationary HVAC&R equipment. A tool similar to the GREEN-MAC-LCCP© should be developed for the product classes or applications of interest to the industry.

JUSTIFICATION OF NEED

This project will advance the state-of-the-art by developing a standardized methodology using the LCCP concept, and a user-friendly simulation tool using the methodology to evaluate the total environmental impact of stationary HVAC&R equipment. For a particular application such as residential air conditioning, a standard model will be developed to calculate the lifecycle energy consumption and related CO_2-equivalent emissions associated with different system layouts and types (i.e., split and package), cooling capacities, energy efficiency levels, regional conditions, and commonly used refrigerants.

The developed standardized methodology and simulation tool will not only consider direct climate impact of refrigerant emissions, but also take the indirect climate impact into account for stationary HVAC&R products. The results will provide a basis for engineers and policy makers to make decisions on alternative competing technologies.

The simulation tool will enable the comparison of LCCP values in different regions for systems having the minimum SEER of 13 but of different types; fixed-capacity compressors, variable capacity compressors, and other variations. Evaluations of the LCCP values of systems with SEER values above 13 in regions with differing climates will reveal whether there are regions where higher SEER systems provide only marginal LCCP benefits. The effect on LCCP of a refrigerant's GWP and emissions during a system's operating life can be calculated for several refrigerants and assumed emission histories in different regions/climates to show the relative significance of refrigerant choice on direct global warming vs. indirect global warming.

OBJECTIVES

The project has two main objectives: 1) Establish a standardized methodology to calculate HVAC&R products LCCP and 2) Advance the aforementioned methodology to a user-friendly simulation tool which can perform HVAC&R products LCCP calculation and comparison within a class of equipment based on either user defined or default inputs.

SCOPE OF WORK

The research is a multi-phase project. Only one class of equipment will be addressed in each phase. The scope of the project in the first phase is limited to one class: residential heat pumps. The specific tasks are as follows.

Task 1: Literature Survey

- Summarize the GREEN-MAC-LCCP study and the methodology developed from it.
- Conduct a literature review of previous studies on LCCP and TEWI analysis. (A brief study just to get impressions of what has been done is sufficient for our purposes.)
- Compile currently available methodologies and simulation tools for LCCP calculation that are within or could be potentially implemented to HVAC&R applications.

- Determine the strength and weaknesses of each approach, and identify the uncertainties and areas that need to be improved.

Task 2: Classification of HVAC&R equipment

Categorize HVAC&R products class by class, such as residential air conditioning, commercial air conditioning, residential heating, and so on.

Task 3: Development of Standardized Calculation Methodology

Though the current scope is limited to residential heat pump systems, the standardized methodology shall be generic, so that other classes of equipment using different refrigerants under various climate regions can be modeled by following the same procedure although their inputs and weather data may vary depending upon the classes and locations.

- Identify any technical content or methodology from the GREEN-MAC-LCCP model which could be applied to this study.
- Identify and categorize CO_2-equivalent emission sources (direct and indirect) throughout a product's life time (from raw materials to end-of-life recycled and disposed materials).
- Collect and compile essential information on the energy consumptions and emissions in terms of equivalent CO_2 amount for all related processes, and recommend reasonable assumptions on critical parameters based on surveyed literature if data are not available directly.
- Formulate and perform indirect emission calculations by including all sources throughout a products lifetime. The CO_2-equivalent emissions per kWh from the mix of power generation facilities that provide the electricity for residential systems in the selected regions shall be used together with the systems' operating energy consumption to calculate equivalent CO_2 emissions from operation. Considering the CO_2-equivalent emissions of power generation varies at different temperature bin conditions, the contractor shall find out the availability of sources of information on temporal (by season and time of day) variations of the CO_2 emission for power generation.
- Collect COP, capacity and seasonal performance information from the AHRI directory of certified products and all other parameters related to indirect emission calculation from manufacturers
- Formulate and perform indirect emission calculations. In the process, the hours of full load operation and hours of part load operation of products have to be taken into account. A model of the performance of heat pump systems in cooling and heating modes in different temperature bins shall be used in the calculations.
- Document the developed methodology in a well structured (step-by step or flowchart) manner.

Task 4: Development of a User-friendly Simulation Tool

The final delivered simulation tool shall be able to calculate the annual CO_2-equivalent emissions of equipment with different refrigerants and efficiencies at various locations which are specified by PMS members. Specific requirements are as follows.

- The simulation tool shall be based on the methodology developed from Task 3, and developed to be a Microsoft Excel©-based model with well-organized multilayered spreadsheets.

- The tool shall be structured in such a way that different classes of products and different climate zones can be further implemented into its calculation routine for the future phases of the study. Consequently, the classes of equipment and climate regions shall be modeled in a modular fashion.

- It is required that critical parameters, such as leakage rates for the same class of equipment, be identified and set as user-defined inputs with recommended default values. The tool should perform parametric studies based on user-defined inputs, including user practices in terms of energy procurement (e.g., if a user participates in a program to buy "green" power).

- The tool shall be capable of calculating the annual CO_2-equivalent emissions for selected cities based on the performance of the system in different temperature bins and the number of hours of operation per season in each bin, adding up to total system energy consumption. For selected locations the total calculated LCCP CO_2-equivalent emissions is categorized in terms of the indirect and direct emissions. The calculated total LCCP CO_2-equivalent emissions shall be further broken down by the emissions due to atmospheric degradation products, the manufacturing of the A/C components and refrigerants, end of life processes, recovery/recycle/disposal of refrigerant, the transportation of the A/C equipment, refrigerant leakages, and the operation of the A/C system.

- A "simple" LCCP calculation option that employs SEER and HSPF with annual hours of operation also shall be provided

Task 5. Recommendations for Ways to Use the Tool to Compare Systems with Different Features and Refrigerants

Heat pumps are applied in different locations and climates. Heat pumps may have one or more indoor units per outdoor unit. The compressor may employ a fixed displacement and single-speed motor, or may have variable capacity achieved through inverter drives, two speed motors, or other capacity-varying features. Heat pumps are available at several levels of efficiency ranging from a minimum SEER of 13 to levels above 18. Power plant CO_2-equivalent emissions per kWh vary among regions. Several refrigerants are used in heat pumps today or are proposed for heat pumps in the future: R-410A, CO_2, hydrocarbons, and new, very-low GWP refrigerants such as HFO-1234yf.

- The contractor shall propose specific applications of the tool to compare the LCCPs of different types of systems and different refrigerants, taking account of the variations cited above and others that may be recognized as the project is carried out.

- The types of the systems to be evaluated are as follows,
  - i.) Baseline: 13 SEER R-410A heat pump system,
  - ii.) Intermediate level: 14.5 SEER Energy Star Single-stage heat pump system,
  - iii.) 14.5 SEER Two-stage heat pump system.

  The actual system will be selected by the project monitoring subcommittee (PMS). The actual performance and bin data will be provided by manufacturers.

Task 6. Demonstration of the Tool

- The tool shall be demonstrated by performing an LCCP study for one of the proposed applications to be chosen by the PMS.

REPORTING & DELIVERABLES SCHEDULE

The output from this project shall be a technical report that compiles the information generated throughout the project and a Microsoft Excel Workbook electronic file of the LCCP model. The contractor shall provide the following:

- Monthly invoices and letter reports on progress and task results,
- Quarterly progress reviews in the contractor's facilities and/or by teleconference, with the PMS to assess the work-in-progress,
- Draft technical report, executive summary, and tabulated data documenting the procedures, conditions, and findings, for review by and a presentation to an ARTI project monitoring subcommittee
- Final technical report, executive summary and tabulated data resolving review comments provided by ARTI,
- Technical journal article or technical presentation/paper of progress or final results to be presented at a conference in the continental United States of ARTI's selection.

Unless otherwise specified by ARTI, printed material will be delivered on standard 8-1/2 by 11 inch paper. Electronic documents shall be delivered as a consolidated document file that integrates all text, figures, tables, and photographs into a single file on CDs in both Microsoft Word and PDF file format; the LCCP model shall be in Mircosoft Excel workbook file format..

Unless otherwise specified by ARTI, the contractor shall deliver the following as scheduled:

Invoices & Letter Reports on Progress (Printed or emailed electronic document)	Monthly, within 30 days of reported period
Quarterly Review Presentation Materials (Printed or emailed electronic document)	Within 1 week after review
Technical Papers/Presentations (1 printed copy; 3 CDs)	30-days prior to submission due date

Draft Final Technical Report; Executive Summary and Tabulated Data (1 printed copy; 3 CDs)	60 days prior to contract completion date
Final Technical Report; Executive Summary; and Tabulated Data (1 printed copy; 3 CDs)	30 days after receipt of ARTI comments

LEVEL OF EFFORT

Completion of the first phase of this project is expected within 6 months of elapsed time at a cost not to exceed $75,000. It is anticipated that the contract for this work will be awarded at a lower price than budgeted based on selection from competitive proposals. However, price will not be the only factor weighed in the selection process. Prior experience and expertise in the field of study, access to information sources required for the completion of this project, and competitive prices will all be considered in selecting a contractor for this project.

<u>Limitation</u>
Solicitation of this project does not commit ARTI to award a contract, pay any cost incurred in preparing a proposal, or to procure or contract for services or supplies. ARTI reserves the right to accept any or all proposals received, or to cancel in part or its entirety a solicitation for this work prior to the signing of a contract agreement, when it is in ARTI's best interest. ARTI reserves the right to negotiate with all qualified sources.

PROPOSAL EVALUATION CRITERIA & WEIGHTING FACTORS

Understanding the problem (25%)
Approach to solving the problem (25%)
Probability of (timely) success (15%)
Qualifications and experience of key personnel (25%)
Quality of facilities to perform the follow-on laboratory/field measurement work (10%)

REFERENCES

Dieckmann, J.T. and Magid, H., "Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications", Arthur D. Little, Inc., final report to the Alliance for Responsible Atmospheric Policy, 1999.

Fischer, S.K., Hughes, P.J., Fairchild, P.D., Kusik, C. L., Dieckmann, J.T., McMahon, E.M., and Hobday, N., "Energy and Global Warming Impact of CFC Alternative Technologies", U.S. Dept. of

Energy and AFEAS (Alternative Fluorocarbons Environmental Acceptability Study), 1991.

Fischer, S.K., Tomlinson, J.J. and Hughes, P.J., "Energy and Global Warming Impacts of Not-in-kind and Next Generation CFC and HCFC Alternatives" U.S. Dept. of Energy and AFEAS (Alternative Fluorocarbons Environmental Acceptability Study), 1994.

Goetzler, W., Dieckmann, J., "Assessment of the Commercial Implications of ASHRAE A3 Flammable Refrigerants in Air-conditioning and Refrigeration Systems", Arthur D. Little, Inc., ARTI Report: ARTI-21CR-610-50025-01, 2001.

Papasavva, S., Hill, W.R., Brown, R.O., "GREEN-MAC-LCCP: A Tool for Assessing Life Cycle Greenhouse Emissions of Alternative Refrigerants", SAE Technical Paper 2008-01-0828, 2008.

Sand, J.R., Fisher, S.K. and Baxter, V., "Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies", Oak Ridge National Laboratory Report (sponsored by the U.S. Department of energy and the Alternative Fluorocarbon Environmental Acceptability Study), 1997.