INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1934-TRP, A Survey Study on the Development and Application of Data-Driven Model Predictive Control in Buildings

Attached is a Request-for-Proposal (RFP) for a project dealing with a subject in which you, or your institution have expressed interest. Should you decide not to submit a proposal, please circulate it to any colleague who might have interest in this subject.

Sponsoring Committee: TC7.5 Smart Building Systems

Budget Range: $100,000 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: **April 1, 2024** or later.

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EDT, December 15th, 2023. NO EXCEPTIONS, NO EXTENSIONS. Electronic copies must be sent to rpbids@ashrae.org. Electronic signatures must be scanned and added to the file before submitting. The submission title line should read: 1934-TRP, A Survey Study on the Development and Application of Data-Driven Model Predictive Control in Buildings, and *"Bidding Institutions Name"* (electronic pdf format, ASHRAE's server will accept up to 10MB)

If you have questions concerning the Project, we suggest you contact one of the individuals listed below:

For Technical Matters
Technical Contact
José A. Candanedo
CanmetENERGY-Varennes / Natural Resources Canada
1615 Boul Lionel-Boulet
Varennes QC J3X 1P7 Canada
Phone: 450-652-3126
E-Mail: Jose.Candanedo@USherbrooke.ca

For Administrative or Procedural Matters:
Manager of Research & Technical Services (MORTS)
Michael R. Vaughn
ASHRAE, Inc.
180 Technology Parkway, NW
Peachtree Corners, GA 30092
Phone: 404-636-8400
Fax: 678-539-2111
E-Mail: MORTS@ashrae.net

Contractors intending to submit a proposal should so notify, by mail or e-mail, the Manager of Research and Technical Services, (MORTS) by December 1st, 2023 in order that any late or additional information on the RFP may be furnished to them prior to the bid due date.

All proposals must be submitted electronically. Electronic submissions require a PDF file containing the complete proposal preceded by signed copies of the two forms listed below in the order listed below. **ALL electronic proposals are to be sent to rpbids@ashrae.org.**

All other correspondence must be sent to ddaniel@ashrae.org and mvaughn@ashrae.org. Hardcopy submissions are not permitted. **In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EDT, December 15th, 2023. NO EXCEPTIONS, NO EXTENSIONS.**

The following forms (Application for Grant of Funds and the Additional Information form have been combined) must accompany the proposal:

(1) ASHRAE Application for Grant of Funds (electronic signature required) and
(2) Additional Information for Contractors (electronic signature required) ASHRAE Application for Grant of Funds (signed) and

ASHRAE reserves the right to reject any or all bids.

State of the Art (Background)

Model-based predictive control and other advanced control approaches have been tested and deployed in field implementations in a large diversity of buildings, using diverse modelling approaches (full-fledged building simulation, reduced order models, machine learning models, etc.). Li et al. (2021) presented a thorough review of grey-box models for predictive control. Drgoňa et al. (2020) presented a thorough review of MPC in building operation.

Several experimental and field deployments of MPC over the last decade have been reported by Žáčeková et al. (2014), Sturzenegger et al. (2015), De Coninck and Helsen (De Coninck and Helsen 2016), Hilliard et al. (2017), Joe and Karava (2019), Wang et al. (2019), Cotrufo et al. (2020) and Kim et al. (2022). Kathirgamanathan et al. (2021) presented an overview with dozens of examples of data-driven implementations of MPC, reinforcement learning and other control strategies (e.g., fuzzy logic). Kim et al. (2022) also compiled a list of MPC implementations, mostly experimental studies.

Overall, the benefits of MPC as a useful control approach have been demonstrated, particularly when the mechanical plant is working appropriately (Granderson et al. 2018). However, a common trait of all these implementations is that they are based on models created in a "customized" manner, more or less *ad hoc*, for each test case, and there are virtually no examples of automatic, systematic implementations in a multitude of buildings.

Despite the abundant scientific publications on this topic, there is limited information about the perception of advanced controls from practitioners and the control industry. Potential hurdles include hardware and software limitations as well as the time and effort required to create custom models.

A preliminary informal survey was distributed in the context of Annex 81 highlighted some of the critical issues (data labelling, accessibility to sensors) and some of the most promising drivers (electrification/decarbonization of the grid, incorporation of renewables, machine learning) but these conclusions must be taken cautiously, given that all the respondents to that survey came from universities or research laboratories. The field of controls for HVAC systems urgently needs to incorporate the point of view of HVAC control companies, installers, building operators, utilities and policymakers.

Justification and Value to ASHRAE

From the perspective of ASHRAE, the proposed project will result in the following benefits:

- Bridging the gap between theory and practice in building operation. Recognizing the requirements and perspectives of the building industry will facilitate the dialogue between academic research and field deployment.

- Inform researchers about the industry needs. The collected information will provide insight to researchers about the most pressing practical problems so that research projects may be oriented accordingly.

Contribution to handbooks. In the long term, information from the survey could also be useful in the writing of ASHARE handbook and standards.

Objectives

1. To obtain information about the gaps between research and industry that impair the mainstream adoption of advanced control techniques.

2. To identify strategies to support the control industry and field practitioners in the implementation of these technologies.

3. To inform research initiatives so that they are more aligned with practical needs.

Scope:

Survey respondents and interviewees: control engineers, control companies, facilities management personnel, building operators, building engineers and other practitioners.

TASKS

1. Preparation of questions for the survey. The contractor will prepare a draft list with a minimum of 20 questions addressing topics such as:

a. Background of respondents
b. Perspectives about advanced control techniques, including model-based predictive control
c. Experience with data-driven tools (FDD)
d. Viewpoint about the main obstacles for the deployment of these technologies
e. Recommendations about technology drivers
f. Recommendations policy measures to promote the adoption of these technologies.

2. Sampling methodology and survey distribution. The contractor is expected to conduct the sampling exercise so that the participants provide a fair representation of the diverse components of the building industry, and common biases (e.g., self-selection bias of respondents, observer bias, etc.) are avoided as much as possible in the reported outcomes. The survey is expected to be distributed among at least 2000 professionals of the building industry.

3. Extended Interviews. At least 20 extended interviews will be conducted; the interviewees will be a subsample of the survey respondents.

- (a) estimate the distribution of surveys and expected number of participants that will result in statistically significant results
- (b) distribute the survey to obtain the expected number of statistically significant participation; (c) conduct extended interviews with volunteers to gain additional insights about details not necessarily included in the questionnaire.

4. Compilation and analysis of results. The contractor will collect data from the respondents, carry out quantitative analysis (tables, graphs) and identify patterns in the extended responses (e.g., word clouds, frequency distribution of the words).

5. Preparation and publication of results. The contractor will prepare an official extended report, as well as research papers summarizing the main results of the study. These papers will be submitted within ASHRAE's official channels (STBE, ASHRAE Transactions).

Estimated costs

Item	Person-hours	Cost ($US)
Development of sampling methodology	40	2000
Preparation of questionnaire for the survey	40	2000
Compilation of contact information of potential participants	40	2000
Survey distribution, collection and cleaning of results	40	2000
Preparation of questions for detailed interviews	20	1000
Conducting extended interviews (at least 20)	20	1000
Analysis of results (tables, graphs, statistical indices)	160	8000
Preparation of final report	40	2000
Other expenses	N/A	2000
TOTAL		$22,000

Deliverables:

- **D1.** Report on the sampling methodology, the survey questionnaire and the approach to the detailed interviews
- **D2.** Final report on the results of the survey and the interviews

Project timeline

- Month 1: Selection of bidder in accordance with ASHRAE regulations.

- Month 2: The contractor will meet the proposal evaluation committee to discuss the survey plan. The draft questionnaire and the results of the preceding study within IEA will be discussed.

- Month 3: This report will include details on how to obtain a representative sample of the different industry sectors (operators, control companies, consulting engineers, building owners) and a significant geographical distribution in North America. Final version of the following documents (D1): (a) Discussion on the sampling methodology; (b) Questionnaire for the survey; (c) detailed list of questions for extended interviews;

- Months 5-6: Distribution of survey to at least 2000 industry representatives. Moreover, at least 20 detailed interviews will be conducted.

- Months 7-10: Period of result collection and analysis of results.

Month 12: The contractor, in collaboration with the WS authors, will produce a (D2) final detailed version of the report for publication, including details of the methodology, the sampling approach, the number and distribution of respondents, general trends and observations, "word cloud" analysis and recommendations for the adoption of data-driven control strategies

Progress, Financial and Final Reports, Technical Paper(s), and Data shall constitute the deliverables (“Deliverables”) under this Agreement and shall be provided as follows:

a. Progress and Financial Reports

Progress and Financial Reports, in a form approved by the Society, shall be made to the Society through its Manager of Research and Technical Services at quarterly intervals; specifically on or before each January 1, April 1, June 10, and October 1 of the contract period.

The following deliverables shall be provided to the Project Monitoring Subcommittee (PMS) as described in the Scope/Technical Approach section above, as they are available:

Furthermore, the Institution’s Principal Investigator, subject to the Society’s approval, shall, during the period of performance and after the Final Report has been submitted, report in person to the sponsoring Technical Committee/Task Group (TC/TG) at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

b. Final Report

A written report, design guide, or manual, (collectively, “Final Report”), in a form approved by the Society, shall be prepared by the Institution and submitted to the Society’s Manager of Research and Technical Services by the end of the Agreement term, containing complete details of all research carried out under this Agreement, including a summary of the control strategy and savings guidelines. Unless otherwise specified, the final draft report shall be furnished, electronically for review by the Society’s Project Monitoring Subcommittee (PMS).

Tabulated values for all measurements shall be provided as an appendix to the final report (for measurements which are adjusted by correction factors, also tabulate the corrected results and clearly show the method used for correction).

Following approval by the PMS and the TC/TG, in their sole discretion, final copies of the Final Report will be furnished by the Institution as follows:

-An executive summary in a form suitable for wide distribution to the industry and to the public.
-Two copies; one in PDF format and one in Microsoft Word.

c. *Science & Technology for the Built Environment* or ASHRAE Transactions Technical Papers

One or more papers shall be submitted first to the ASHRAE Manager of Research and Technical Services (MORTS) and then to the "ASHRAE Manuscript Central" website-based manuscript review system in a form and containing such information as designated by the Society suitable for publication. Papers specified as deliverables should be submitted as either Research Papers for HVAC&R Research or Technical Paper(s) for ASHRAE Transactions. Research papers contain generalized results of long-term archival value, whereas technical papers are appropriate for applied research of shorter-term value, ASHRAE Conference papers are not acceptable as deliverables from ASHRAE research projects. The paper(s) shall conform to the instructions posted in "Manuscript Central" for an ASHRAE Transactions Technical or HVAC&R Research papers. The paper title shall contain the research project number (1934-RP) at the end of the title in parentheses, e.g., (1934-RP).

All papers or articles prepared in connection with an ASHRAE research project, which are being submitted for inclusion in any ASHRAE publication, shall be submitted through the Manager of Research and Technical Services first and not to the publication's editor or Program Committee.

d. Data

Data is defined in General Condition VI, "DATA"

e. Project Synopsis

A written synopsis totaling approximately 100 words in length and written for a broad technical audience, which documents 1. Main findings of research project, 2. Why findings are significant, and 3. How the findings benefit ASHRAE membership and/or society in general shall be submitted to the Manager of Research and Technical Services by the end of the Agreement term for publication in ASHRAE Insights

The Society may request the Institution submit a technical article suitable for publication in the Society's ASHRAE JOURNAL. This is considered a voluntary submission and not a Deliverable. Technical articles shall be prepared using dual units; e.g., rational inch-pound with equivalent SI units shown parenthetically. SI usage shall be in accordance with IEEE/ASTM Standard SI-10.

Level of Effort
$100,000, 18 Months

Other Information to Bidders (Optional):
Questions from IEA EBC Annex 81 Survey

1. Type of organization
2. Which method best describe your preferred modelling strategy to create a building model for control applications (white-box model, data-driven black box, data-driven grey-box, other)
3. Provide additional information on your preferred modelling strategy, software tool used or techniques
4. During the development of a model-based predictive control project, which percentage of the project's time is spent in the creation of the control-oriented model?
5. Elaborate on your previous answer about model creation.
6. Rank the following data-related obstacles to the deployment of data-driven controls (with #1 being the most challenging obstacle from your perspective):
    a. Data labelling and variable identification
    b. Data retrieval and sensor accuracy

c. Inadequate or inexistent BAS
d. Cost of additional meters
e. Non-calibrated or missing sensors.

7. Elaborate on your previous answer about data-related obstacles.
8. Rank which research trends or drivers seem the most promising (with #1 being the most promising) over the next five years:
   a. Machine learning/deep learning
   b. Reinforcement learning
   c. Urban scale models
   d. Leveraging IoT technologies
   e. Building-grid interaction
   f. Tools for building data analytics
   g. Electrification of buildings
   h. "Digital twins" tools.
9. Please elaborate on your previous answers on promising research trends
10. Rank which of the following practical problems (not related to data access) need to be most urgently addressed (#1 being the most urgent need from your perspective)
11. Please elaborate on your previous answer on practical issues
12. Rank the policy/regulatory measures listed below (with #1 being the measure with the highest potential impact) that may encourage data-driven smart buildings in your jurisdiction.
    a. Include operational requirements in energy codes
    b. Standards and guidelines
    c. Multidisciplinary training of engineers
    d. Economic or fiscal incentives
    e. Publicly available high-resolution datasets
13. Do you have additional comments on potentially helpful policy measures?
14. Please feel free to provide additional comments or suggestions to promote the adoption of data-driven advanced controls in buildings.

Evaluation Criteria:

No.	Proposal Review Criterion	Weighting Factor
1	Bidder's methodology	20%
2	Proposed strategy for a wide distribution of the survey among industrial participants and collection of data	30%
3	Credentials of personnel in charge of survey	15%
4	Proposed statistical analysis of data	30%
5	Previous ASHRAE research project experience	5%

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	Completion of methodology and design of the questionnaire (D1)	**3**
2	Completion of distribution of survey and interviews	**6**
3	Collection of results/survey responses	**9**
4	Final report (D2)	

References

1. Candanedo, José. 2021. "Preliminary Survey: Towards the Mainstream Adoption of Data-Driven Control - Results and Discussion." IEA EBC. https://annex81.iea-ebc.org/.
2. Cotrufo, N., E. Saloux, J.M. Hardy, J.A. Candanedo, and R. Platon. 2020. "A Practical Artificial Intelligence-Based Approach for Predictive Control in Commercial and Institutional Buildings." *Energy and Buildings* 206 (January): 109563. https://doi.org/10.1016/j.enbuild.2019.109563.
3. De Coninck, Roel, and Lieve Helsen. 2016. "Practical Implementation and Evaluation of Model Predictive Control for an Office Building in Brussels." *Energy and Buildings* 111: 290–98.
4. Drgoňa, Ján, Javier Arroyo, Iago Cupeiro Figueroa, David Blum, Krzysztof Arendt, Donghun Kim, Enric Perarnau Ollé, et al. 2020. "All You Need to Know about Model Predictive Control for Buildings." *Annual Reviews in Control* 50: 190–232. https://doi.org/10.1016/j.arcontrol.2020.09.001.
5. Granderson, Jessica, Guanjing Lin, Rupam Singla, Samuel Fernandes, and Samir Touzani. 2018. "Field Evaluation of Performance of HVAC Optimization System in Commercial Buildings." *Energy and Buildings* 173 (August): 577–86. https://doi.org/10.1016/j.enbuild.2018.05.048.
6. Hilliard, Trent, Lukas Swan, and Zheng Qin. 2017. "Experimental Implementation of Whole Building MPC with Zone Based Thermal Comfort Adjustments." *Building and Environment* 125: 326–38.
7. Joe, Jaewan, and Panagiota Karava. 2019. "A Model Predictive Control Strategy to Optimize the Performance of Radiant Floor Heating and Cooling Systems in Office Buildings." *Applied Energy* 245: 65–77.
8. Kathirgamanathan, Anjukan, Mattia De Rosa, Eleni Mangina, and Donal P. Finn. 2021. "Data-Driven Predictive Control for Unlocking Building Energy Flexibility: A Review." *Renewable and Sustainable Energy Reviews* 135 (January): 110120. https://doi.org/10.1016/j.rser.2020.110120.
9. Kim, Donghun, Zhe Wang, James Brugger, David Blum, Michael Wetter, Tianzhen Hong, and Mary Ann Piette. 2022. "Site Demonstration and Performance Evaluation of MPC for a Large Chiller Plant with TES for Renewable Energy Integration and Grid Decarbonization." *Applied Energy* 321: 119343.
10. Li, Yanfei, Zheng O'Neill, Liang Zhang, Jianli Chen, Piljae Im, and Jason DeGraw. 2021. "Grey-Box Modeling and Application for Building Energy Simulations - A Critical Review." *Renewable and Sustainable Energy Reviews* 146 (August): 111174. https://doi.org/10.1016/j.rser.2021.111174.
11. Sturzenegger, David, Dimitrios Gyalistras, Manfred Morari, and Roy S. Smith. 2015. "Model Predictive Climate Control of a Swiss Office Building: Implementation, Results, and Cost–Benefit Analysis." *IEEE Transactions on Control Systems Technology* 24 (1): 1–12.
12. Wang, Jiangyu, Shuai Li, Huanxin Chen, Yue Yuan, and Yao Huang. 2019. "Data-Driven Model Predictive Control for Building Climate Control: Three Case Studies on Different Buildings." *Building and Environment* 160 (August): 106204. https://doi.org/10.1016/j.buildenv.2019.106204.
13. Žáčeková, Eva, Zdeněk Váňa, and Jiří Cigler. 2014. "Towards the Real-Life Implementation of MPC for an Office Building: Identification Issues." *Applied Energy* 135 (December): 53–62. https://doi.org/10.1016/j.apenergy.2014.08.004.