INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1964-TRP, Optimizing Heating System Performance in Warmup and Setback Modes

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: TC 1.4 Control Theory and Application
Co-sponsored by: TC 7.5 Smart Building Systems

Budget Range: $280,000 may be more or less as determined by value of proposal and competing proposals.

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

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EST, December 16th, 2024. 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: 1964-TRP, Optimizing Heating System Performance in Warmup and Setback Modes, 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
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For Administrative or Procedural Matters:
Manager of Research & Technical Services (MORTS)
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Contractors intending to submit a proposal should notify, by mail or e-mail, the Manager of Research by December 1st, 2024 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. Hardcopy submissions are not permitted. **In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EST, Monday, December 16th, 2024.**
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)

Night setback and optimum start are control strategies that are currently required in building energy standards (ASHRAE 2022 and California Title 24). Guideline 36 provides control sequences for night setback and references the use of optimum start but does not provide a specific sequence or algorithm, instead deferring the specifics to each BAS manufacturer as there are varying existing strategies for implementing optimum start. Guideline 36 also specifically defines a distinct system warmup operating mode. The start of the warmup mode is to be determined by optimum start and the end is determined by the scheduled start of occupied mode. During warmup mode, ventilation is disabled (as the building is unoccupied), normal supply air temperature setpoints are overridden to provide warm air (up to 90F if a heating coil is available), and normal zone airflow limits are overridden to maximize terminal heating capacity. With these measures and the prescribed step change rise in zone heating setpoints at the start of warmup mode, best practice today maximizes zone heating demand, creating artificially high heating system peak loads.

Existing logic, often proprietary, employed by BAS manufacturers is typically used for optimum start. Unfortunately, a common perception is that optimum start does not work in real buildings, whether due to logic issues, lack of tuning, radiant impact of cold building surfaces, or other. Anecdotal data suggest that optimal start is rarely used in practice and often disabled by building operators. Possible risks are that the logic is not tuned or is tuned in the wrong season, causing the logic to not recover in time on cold mornings. Disabling optimum start and warmup mode due to real or perceived performance issues may be significantly detrimental to building energy consumption by unnecessarily extending system run hours and by unnecessarily ventilating buildings prior to the expected start of occupancy.

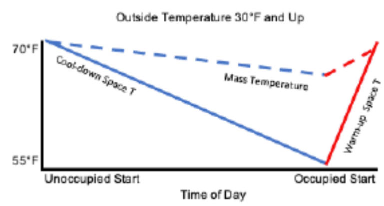
The optimal start control algorithms commonly used in standard practice are generally based on research that is several decades old. The algorithms aimed to ensure occupant comfort while minimizing energy consumption based on common HVAC equipment at that time, e.g., Seem et al (1989) and Armstrong, Hancock, and Seem (1992). Chapter 43 of the ASHRAE Handbook of Applications (ASHRAE 2023) outlines a successful algorithm for determining a heating recovery time based on zone and ambient temperature, occupied and setback zone heating temperature setpoints, and learned coefficients based on past recovery performance. These strategies all aim to minimize recovery time, without consideration of the resulting peak heating load. With changes in HVAC equipment, different variables need to be optimized.

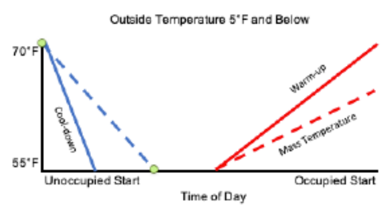
Buildings and HVAC systems have changed in the decades since much of the original research on night setback and optimum start was conducted. Building envelopes in new construction have improved with increased insulation levels, high performance glazing, and reduced infiltration. These changes in construction practices may have reduced the magnitude of envelope energy losses that were to be avoided with night setback. The need to minimize HVAC system operating time is also partially diminished by changes in HVAC equipment operation. Where fans were typically previously constant flow or modulated with inlet guide vanes, the widespread use of variable speed drives in fan systems today allows fan energy to be reduced significantly during part load conditions. The availability of modern boilers and heat pumps with modulating capacities also improves efficiency at part loads.

Limitations of past modeling studies include overly simplified zoning, unrealistically high and non-stochastic internal gains, and long simulation time steps that don't effectively capture system dynamics. Previous simulations employed simplified boiler and hot water distribution models that did not account for boiler cycling losses and pipe distribution losses, or for the capabilities of new HVAC equipment in practice today, such as variable speed drives, condensing boilers, and air-to-water heat pumps. More recent studies have continued to evaluate the same approach to optimal start but with a focus on the algorithm to determine recovery time, leveraging optimization and model predictive control (MPC), e.g., Yang et al (2003) and Seem et al (2016).
At least one BAS manufacturer provides default morning warmup logic that employs an exponential rise in heating setpoint from the unoccupied to the occupied levels. In contrast to the typical step change rise, the exponential approach provides a mechanism to gradually recover allowing for a longer duration and reduced peak load. A small field study explored the use of this exponential rise and found that longer warmup periods led to significantly lower morning warmup heating peak loads with no discernable negative impact on energy use. This same study also evaluated the edge case of eliminating night setback altogether which eliminated the recovery

load altogether, but at the expense of significantly increased heating energy (unpublished but submitted for publication by Cheng et al).

Previous studies also evaluated air temperature alone for optimum start recovery, but few have evaluated the impact of thermal comfort considering operative and mean radiant temperatures. Putta et al (2013) evaluated MPC approaches that evaluated predicted mean vote based on operative temperatures and noted discomfort at the beginning of occupancy periods but did not offer a solution. In cold climates, optimal start strategies may lead to thermal discomfort during morning hours even if air temperatures are recovered to occupied heating setpoints because of radiant heat transfer from cold building mass that may not have recovered from deeper setback temperature. The simplified figures below illustrate air vs mass temperature during unoccupied night-time periods. Though mass temperature may not be a significant factor during mild weather, mass temperatures take much longer to recover in cold weather leading to a risk of unacceptably cold operative temperatures due to cold interior building surfaces.





Justification and Value to ASHRAE

The project is expected to develop simple control strategies that will improve heating system efficiency and performance, and facilitate the industry shift to all-electric heating. The resulting strategies will be simple modifications from current practice with negligible cost for new construction, and potentially minimal cost for retrofits. Where the new strategies allow for smaller equipment sizing and avoid the need for replacing existing infrastructure in retrofits, the new warmup strategies may reduce both first costs and operating costs. These novel warmup strategies are expected to align with ASHRAE's of reducing carbon emissions from the commercial building sector.

Objectives

This project will provide ASHRAE members with guidance on improving HVAC system performance during morning warmup leading to improved thermal comfort and reduce costs and greenhouse gas emissions.
This research project will:

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1. Confirm whether a slow morning warmup mode provides superior energy and operating cost performance compared to relying on optimum start and warming up as fast as possible (per Guideline 36).
2. Confirm that slow morning warmup modes reduce peak heating loads and allow for smaller heating equipment sizing.
3. Develop a practical control approach that reduces heating energy consumption and peak morning heating load, compared to existing strategy in Guideline 36

Scope
Research will include building energy simulations to evaluate HVAC control strategies. The parametric analysis shall include the following:

- Climate. Four climates at a minimum: Oakland (3C), Chicago (5A), Atlanta (3A), Phoenix (2B)
- Building type.
  - Modified prototypical medium office building with detailed zoning and stochastic internal gains schedules. Model definition exists in EnergyPlus using the Energy Management System (Pang et al 2020) and Spawn of EnergyPlus (Zhang et al 2022)
  - An alternative building type to be recommended by research team with PMS approval, such as academic/school or an office building with an appreciably different form factor than above. Second building model shall also employ detailed zoning and stochastic internal gains schedules.
- Building vintage: Modern (meet Standard 90.1 requirements by climate) vs older vintage. Assume HVAC equipment meets minimum Standard 90.1 requirements in both cases.
- HVAC System: VAV reheat (plus supplemental perimeter heating in cold climates) meeting recent Standard 90.1 requirements and relevant Guideline 36 control sequences.
- Heating system type. Four types (with PMS approval, parametric may be streamlined to exclude heating systems that are not common in different geographic regions, e.g., do not simulate electric resistance heat in Oakland where it is generally not allowed by California Title 24):
  - Condensing boilers. Two boilers each sized for 50% of design peak load per conventional practice.
  - Air-to-water heat pumps
  - Gas furnace at VAV system and electric resistance at reheat terminals
  - Electric boilers (performance of electric boilers may be evaluated based on loads from other runs, with simple post-processing to minimize the number of unique simulations required)
- Utility rate structure
  - Establish 3 utility rate structures for modeling that represent a range of incentivization for electrification based conceptually on actual utility rates observed.
    - Flat gas and electric rates
    - Time-of-use electric rates
    - Time-of-use electric rates with high winter morning rates representing electrical grids with heating dominated peaks
  - Select rate typical for each building size/geography?

Building energy simulation tool used shall be capable of modeling 5-minute or shorter timesteps and accurately model detailed control sequences consistent with ASHRAE Guideline 36 (e.g., EnergyPlus with EMS or Spawn of EnergyPlus).

The goal of this study is not to improve on optimum start logic in the traditional sense of determining the right start time to minimize the duration of warmup mode, but rather to evaluate how longer warmup periods and alternative warmup approaches can provide improved energy performance and first cost benefits. For example, alternative approaches may employ a ramped zone heating temperature setpoint rise, limit the maximum zoneairflows and/or the maximum hot water supply temperature setpoint during morning warmup.
Evaluate thermal comfort impact of building thermal mass during morning recovery for each condition based on operative temperature.

This study may consider analogous concerns around cooldown and setup modes but it is not required. Though these control strategies are complementary to warmup and setback, the primary factors of concern for this study relate to the heating condition.

Report simulation results as site energy, energy cost, and greenhouse gas emissions (assume time-of-year grid factors typical for each climate).

Task 1. Background Literature Review
Review existing literature and current best practices, including but not limited to peer-reviewed publications, guidance from building automation system manufacturers, current best practices by practicing designers, and as-

installed control strategies. In particular, consider regionally-varying practices for night setback and morning warmup in different U.S climates and what attention is given to thermal comfort. Include interviews with at least 4 building operators in at least two different climate zones about current practices around optimum start and morning warmup to provide an understanding of current perceptions and issues that may inform the development of alternative strategies.

Deliverables:
Summary report of existing literature, best practices, and current practices.

Task 2. Model Development and Pilot Modeling
Gather or develop base building models with particular attention to operating and control issues often overlooked in modeling studies:

- Realistic zoning and modeling of building construction/mass.
- Detailed and realistic heating and airside equipment sizing (assuming common industry practice).
- Internal gains schedules that reflect realistic diversity and stochasticity, lighting loads that track occupants.
- Custom equipment performance curves based on recent boiler testing data (PG&E, 2012; Wang et al, 2022) and best available AWHP data.
- ASHRAE Guideline 36 control sequences as baseline, including 2018 addendum y, particularly dual max VAV logic, varying airflow limits in different modes, hot water supply temperature reset via trim and respond, and boiler staging. Incorporate optimum start in all runs, except where otherwise noted.
- Attention to building mass, operative temperature, and occupant thermal comfort.
- Piping distribution losses (Raftery et al, 2023)

Pilot Modeling: The goal of this step is to conduct limited modeling to evaluate various alternative strategies and sensitivities under a limited set of conditions. Results of this phase of modeling will be used to develop and identify recommended warmup control strategies for expanded testing in the next task.

- Test of impact of depth of night setback on energy performance and thermal comfort, assuming optimum start
- Test energy and thermal comfort performance of warmup mode via conventional optimum start from night setback
- Test approaches to reducing warmup peak, including but not limited to:
    - Gradual ramp in zone heating setpoint from unoccupied to occupied levels (intentionally slower than optimum start). Evaluate impact of varying durations on energy performance and thermal comfort.
    - Limit maximum hot water supply temperature during warmup mode.
    - Limit zone airflow to design heating maximum during warmup mode (instead of design cooling max during warmup mode per Guideline 36)
- Evaluate influence of modeled building mass and vary this to evaluate sensitivity (though not required as an variable for Task 3 parametric analysis)
- Identify best practice night setback and morning warmup strategies for each HVAC system type. New strategies need not employ mathematical optimization but should focus rather on providing consistent and robust improvement over existing practice, and being readily implementable in real building automation systems. Report on occupant thermal comfort, energy, operating cost, and greenhouse gas emissions results.

Deliverables:
- Pilot modeling plan [PMS review before proceeding]
- Preliminary modeling report

Task 3. Parametric Modeling & Analysis
- Develop comprehensive parametric modeling plan based on best strategies identified in Task 2 and considering PMS feedback.

- Full parametric analysis for attributes described above, plus setback/warmup strategies identified in previous task
    - Conventional practice: start normal system operation at a fixed number of hours prior to occupancy (ventilation throughout)
    - Current best practice per Guideline 36: optimum start, warmup mode (no ventilation, high zone airflows)
    - Improved practice: one or more strategies identified in previous task
- Evaluate differences between conventional heating equipment sizing practice and the resulting peak heating loads for each case, identifying the potential opportunity for reducing equipment sizing, space needs and first costs.

Deliverables:
- Modeling plan for comprehensive parametric analysis [PMS review before proceeding]
- Modeling report

Task 4. Field Demonstration
A limited field demonstration shall provide independent validation of the potential benefits of improved warmup strategies in a real building, as energy models may not be accurate with respect to modeling the temperature recovery of thermal mass, and the impact on peak loads at the zones and plant. The field demonstration is intended to complement and support the simulation results, but is not expected to be the basis for model calibration. Contractor shall evaluate the performance of the newly developed control strategy relative to typical current practice in an occupied nonresidential building during the heating season.

Demonstration building must have the following attributes at a minimum:
- Occupied, nonresidential building with largely office or classroom type occupancies, scheduled HVAC operation (not 24/7), and capable of using night setback control
- Served by a VAV reheat system with DDC and fully programmable zone controllers (Guideline 36 control sequences or similar preferred but not required)
- Minimum of 10 zones
- Heating system includes a hot water plant (condensing boiler and demand-based hot water supply temperature reset controls preferred but not required)
- HVAC energy monitoring capable of providing interval energy monitoring data.

Demonstration shall focus on the impact of varying zone warmup strategies on heating hot water loads and overall building HVAC energy consumption. At least three control strategies shall be evaluated, including typical step-change approach and one recommended strategy from previous tasks. Revisions to hot water plant control to demonstrate performance impact from warmup strategies may be considered (e.g., improved equipment staging or supply temperature reset) but are not required. Demonstration study shall be evaluated with rapid measurement & verification (M&V) techniques (e.g., alternate control strategies on a weekly or similar basis) to minimize seasonal differences between each strategy or with a traditional baseline then post-retrofit period over a long enough duration to provide statistically significant results and consideration of weather normalization techniques.

Report on impact to peak loads, site and HVAC end-use energy, energy cost, and greenhouse gas emissions.

Deliverables:
- Field demonstration plan describing proposed study site and implementation approach and timeline, including plans and drawings for building, controls drawings and points lists, and detailed description of existing and proposed HVAC control strategies [PMS review before proceeding]
- Field demonstration report

Task 5. Technology Transfer
The contractor shall develop a Continuous Maintenance Proposal (CMP) for ASHRAE Guideline 36 to incorporate the new control sequences, using ASHRAE CMP forms. This shall include:

- The final PMS approved sequences of operation in Guideline 36 format

- Control points list of required and optional control points in Guideline 36 format
- Control schematics showing minimum control points required to implement the sequences

The contractor shall also provide written summaries of the findings and recommendations as appropriate for at least 3 other ASHRAE standards, guidelines, design guides, or handbooks (such as ASHRAE Standard 90.1 and Building Decarbonization Retrofit Guide).

Deliverables:

- Continuous Maintenance Proposal for Guideline 36
- Written summaries appropriate for 3 or more ASHRAE standards, guidelines, design guides, or handbooks

Task 6. Reporting
The contractor shall produce a comprehensive Final Report detailing all the work undertaken in the project.

Deliverables:
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 (1964-RP) at the end of the title in parentheses, e.g., (1964-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
It is expected that this project will require a duration of twenty-four (24) months to be completed at a total cost of $280,000.
Estimated effort breakdown by task:
Other Information to Bidders (Optional):

1. Background Literature Review: 2%
2. Model Development and Pilot Modeling: 20%
3. Parametric Modeling & Analysis: 35%
4. Field Demonstration: 35%
5. Technology Transfer: 3%
6. Reporting: 5%

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	Background Literature Review	Y1 Q1
2	Model Development and Pilot Modeling	Y1 Q2
3	Parametric Modeling & Analysis	Y1 Q4
4	Field Demonstration (coordinate with PMS to test during winter conditions)	Y2 Q3
5	Technology Transfer	Y2 Q4

Proposal Evaluation Criteria
Proposals submitted to ASHRAE for this project should include the following minimum information:

No.	Proposal Review Criterion	Weighting Factor
1	Contractor's understanding of Work Statement as revealed in the proposal.	15%
2	Qualification of personnel for this project • Experience of Principal Investigator with fundamental HVAC controls and simulation analysis. • Breadth and quality of contractor team experience with control system design and ASHRAE Guideline 36 (especially writing control sequences) Breadth and quality of contractor team experience with field testing, commissioning, and data analysis	35%
3	Quality of methodology proposed for conducting research. • Modeling software and procedures • Methods for identifying field study building and plan for carrying out control intervention and gathering monitoring data • Organization and management plan	20%
4	Probability of contractor's proposal meeting objectives • Detailed work plan with major tasks and key milestones • Suitability of proposed field site to meet demonstration objectives, if included in proposal • All technical and logistic factors considered • Reasonableness of project schedule	25%
5	Performance of contractor on prior ASHRAE projects (no penalty for new contractors).	5%

Proposal Evaluation Criteria

Proposals submitted to ASHRAE for this project should include the following minimum information:

References

1. Armstrong, P. R., Hancock, C. E., & Seem, J. E. 1992. Commercial building temperature recovery- part I: Design procedure based on a step response model. ASHRAE Transactions, 98(1).
2. Armstrong, P. R., Hancock, C. E., & Seem, J. E. 1992. Commercial building temperature recovery-part II: experiments to verify the step response model. ASHRAE Transactions, 98(1).
3. ASHRAE. 2018. ASHRAE Guideline 36: High Performance Sequences Of Operation for HVAC Systems.
4. ASHRAE. 2022. ANSI/ASHRAE/IES Standard 90.1-2022. Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings.
5. ASHRAE. 2023. 2023 ASHRAE Handbook, HVAC Applications.
6. Putta, V., Zhu, G., Kim, D., Hu, J., & Braun, J. 2013. Comparative evaluation of model predictive control strategies for a building HVAC system. In 2013 American Control Conference (pp. 3455-3460). IEEE.
7. PG&E Emerging Technologies Program Boiler Research Report. 2012 https://www.etcc-
8. ca.com/sites/default/files/OLD/images/boiler_research_project_-_ats-te_final_report_pcb_05092012.pdf
9. Wang, J., Stein, J., Choi, K. Mustacich, P., Waltner, M., Achong, G. 2022. Boiler Research Project Final Report In Support of ASHRAE Standard 155P. PG&E.
10. Raftery, P., Geronazzo, A., Cheng, H., and Paliaga, G. 2018. Quantifying energy losses in hot water reheat systems. Energy and Buildings, 179: 183-199. https://escholarship.org/uc/item/3qs8f8qx
11. Raftery, P., Vernon, D., Singla, R., & Nakajima, M. 2023. Measured Space Heating Hot Water Distribution Losses in Large Commercial Buildings. https://escholarship.org/uc/item/46h4h28q
12. Seem, J.E., Armstrong, P.R., & Hancock, C.E. 1989. Algorithms for predicting recovery time from night setback. ASHRAE Transactions, 95(1).
13. Seem, J. E., House, J. M., & Alcala, C. F. 2016. Model Selection for Predicting the Return Time from Night Setback. International High Performance Buildings Conference. Purdue University.
14. Yang, In-Ho, Yeo, M, and Kim, K. 2003. Application of artificial neural network to predict the optimal start time for heating system in building. Energy Conversion and Management, 44: 2791-2809. https://www.sciencedirect.com/science/article/abs/pii/S019689040300044X