INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1947-TRP, Climate change driven extreme temperature effects for efficiency and resilience map of heat pump technology

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 2.05 Global Climate Change
Co-sponsored by: TC 4.2 Climatic Information, TC 2.8 Building Environmental Impacts and Sustainability

Budget Range: $265,000 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: **April 1, 2025** 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: 1947-TRP, Climate change driven extreme temperature effects for efficiency and resilience map of heat pump technology, 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
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Contractors intending to submit a proposal should so notify, by mail or e-mail, the Manager of Research by December 1, 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. In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EST, 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)

Institutions and the U.S. government are becoming increasingly concerned that infrastructure assets be analyzed for resilience to climate change.[13] Studies abound in modeling how energy increases due to climate change.[1,4,6,7] In addition to these, extreme weather event studies have also–addressed regional[8], urban[9,10], and individual building scales[11] for both energy changes and effects on resilience.[11] A recent study has also created global maps of how air-conditioning needs and desirability are shifting because of climate change.[20] Such global studies tend to neglect extreme events which are of increasing concern.

The U.S. DOE BTO is creating tools that are poised to explore how technology will affect decarbonization such as the SCOUT tool[26]. Also, building stock portfolios and load profiles for commercial and residential buildings have been generated with the COMSTOCK and RESTOCK tools.[28] These have not been applied to future weather cases though and are too extensive in nature to apply to stochastic future weather. Each of these tools accomplish important objectives to understanding decarbonization but do not provide information about stochastic effects of weather nor resilience. A critical gap relevant to ASHRAE therefore exists.

To better understand resilience issues associated with air-conditioning, extreme events for future projections are needed. Specifically, stochastic weather generators are a key part of quantifying uncertainty into the future.[2,3,5] Such generators require running large numbers of energy calculations in a Monte-Carlo type framework so that statistical distributions on energy use and other metrics can be quantified as probability distributions in the form of histograms.

Climate change projections, extreme temperature event downscaling, and energy analysis of heat pumps to cool buildings have not been analyzed systematically across the United States. These tools have not been synthesized in a way that makes understanding issues pertinent to the HVAC&R sector accessible.

A more thorough review of future weather's application to BEM is available in Villa et. al.[27].[24]

Justification and Value to ASHRAE

The emergence of anomalous, rapid climate change in the last couple of decades has made it necessary for energy calculations to estimate uncertainty in HVAC&R performance due to weather uncertainty. The warming trend observed along with rapid urbanization and population growth indicate that HVAC&R could become a significant positive feedback in the consequences of the emerging climate crisis. Positive feedbacks strengthen an affect. Several different issues contribute to this:

1. HVAC&R emit waste heat that often exacerbates urban heat island issues. This leaves populations with no access to HVAC&R increasingly vulnerable.
2. Carbon dependent HVAC&R burns fossil fuels leading to direct emissions that contribute to global warming.
3. HVAC&R uses electricity which will increase burdens on the grid and make it harder for the grid to reach 100% renewable energy status.
4. HVAC&R refrigerants can leak and have much higher global warming potential than CO_2.
5. When power outages occur, populations are increasingly dependent on HVAC&R for productivity and survival. This is likely to be an increasingly serious issue world-wide as global warming increases.

It is therefore extremely important that HVAC&R applications be decarbonized and hardened to future conditions.

ASHRAE is doing an excellent job of providing standards and input to technology specific issues concerning increasing energy efficiency, eliminating the need for fossil fuels, and quantifying standards for low global warming potential refrigerants. These are the first order measures that will make the most difference in the future. Further steps need to be taken. Second order measures that assess how, when, and what first order solutions to implement under constrained conditions could have equal importance. For example, delivery of heat pump technology that is 100% electric may have much less value in some areas where natural gas supplemental heating will become minimal as global warming increases. As a result, designers may be able to show that it would be better to invest elsewhere for a lower carbon future of their HVAC&R and buildings designs. There is therefore a gap in ASRHAE's contributions to decarbonization that start to be fulfilled by investment in this proposed study.

Energy modeling for future conditions is abundant in the literature, but is difficult to navigate due to the extremely large number of climate models, climate scenarios, technologies to evaluate, and extreme weather threat types. Specifically, reasonable methods for bounding uncertainty are needed that put confidence intervals on climate scenarios. ASHRAE can serve as an unbiased facilitator and provider of methods and tools to make needed information consistent and available.

The proposed analysis can be a fulfillment of ASHRAE's 2019-2024 Goal 1: "Position ASHRAE as an Essential Knowledge Resource for a Sustainable, High-Performance Built Environment." Standard 169 provides climate zones for building design. Taking this a step further to create a map of how climate change and resulting extreme heat pattern changes will affect heat pump technology, and many other metrics relevant to sustainability and resilience is of great value to ASHRAE members and the humanity in general.

The ASHRAE position document on climate change[19] states that "ASHRAE is committed to a leadership role in responding to and reducing building climate change footprints." This is true for efforts to produce low global warming potential refrigerants and to produce energy efficient HVAC standards but is lacking in ASHRAE's modeling research. ASHRAE contributes significantly to energy modeling and calculation standards through ASHRAE standard 205 and Guideline 14. This modeling needs to be extended to climate change issues. Though ASHRAE regularly funds building energy modeling and HVAC system modeling type research, most of it is focused on the rationale or accuracy correctness of models. Little or none is focused on climate change issues even though there is an extensive level of funding and published material on this subject external to ASHRAE.
Finally, this work is in harmony with the Future and Extreme Weather project already funded by DOE's BTO to Argonne, Oak Ridge, and Sandia National Laboratories.[29] The ASHRAE grant awardee will be able to work alongside these laboratories through cooperative research making acquisition of the needed weather files easier. This parallel funding will enable greater progress per dollar funded by ASHRAE.

Objectives

1. Inform ASHRAE Fundamentals Chapters 35 section 5 and Chapter 36 with quantitative discussion, graphs, and/or tables that show heat pump performance changes into the future by climate zone obtained from this study.

   Examples:
   • Fig 6 of Chapter 36 shows climate zones shifting. Another Figure is needed that shows how heat pump performance will shift. Showing how heat pump performance will change with changing ground and surface temperature and how that will relate to sustainability is one subject that ASHRAE can quantitatively address in its fundamentals text by funding this research.

   • Add extra text that complements statements like "Historical weather data and extremes many inadequately describe conditions faced by a project built today, even over a modest building lifespan" (Chapter 35 Section 5) to "heat pump performance will degrade ranging from X to Y in the south due to increasing temperature and continuous need for cooling" while performance will actually improve between X2 to Y2 in the North where warming conditions will make heat pump heating more efficient.

2. Systematize the process of running BEMs with a wide range of future weather files, including stochastic weather files. The heat pump application is one of the most definitive technologies that needs evaluation in the future and is therefore the subject of this first study. This systemization will become a resource by which future analyses can be conducted inside and outside of ASHRAE.

3. Make the types of results generated from BEM studies with future weather files easily understood. This requires the ability to rapidly present large amounts of information in statistical terms that are well known by technically minded decision makers.

Scope:

Team Requirements

The required work includes the need for a team that has strong skills in both building energy modeling and in software programming/computer science including web API development. Five or more years of practice in both fields is required. At least 1 multi-year project that uses both fields must have been completed. As a result, it may be desirable for a multi-member team to be formed that can cover both disciplines well. The team performing this work will have support from the expertise of TC 2.5, TC 2.8, and TC 4.2 to assure that existing energy models and resources are leveraged.

The team is not required to have expertise in creating future energy weather files.

DOE BTO Potential In-kind Support and Collaboration

Support for all future design days and hourly weather files is suggested to come from DOE BTO's Future and Extreme Weather (FEMY) project. In-kind support from DOE BTO is likely through the FEMY project but cannot be guaranteed. The future weather products that are available are:

1) The multi-scenario extreme weather simulator (MEWS) – www.github.com/sandialabs/MEWS -- contact Daniel Villa, dlvilla@sandia.gov
2) Future typical meteorological years (FTMY) – Oak Ridge National Laboratory (ORNL)
3) Dynamic downscaled actual future meteorological years – Argonne National Laboratory (ANL)

The winning bidder is not obligated to collaborate with these National Laboratories. All communication shall go through Mr. Villa who will serve as a liaison from all three labs if a collaborative relationship is formed.

General Requirements

1. All code shall be maintained in a suitable software repository (SVN, GIT, etc..) with revision control and backup versions created at least weekly.
2. Unit tests that run in less than an hour shall be included that are run on several platforms (at least Windows and Linux) as changes to the software are made. All code developed in this project shall be exercisable via one or more unit tests that exercise the basic use cases for inputs. Diligence to show 100% coverage of all active lines of codes shall be demonstrable.
3. All BEM models shall be maintained in a separate folder using the same software repository as for code.
4. All documentation shall be maintained in a separate folder using the same software repository as for code.
5. ASHRAE shall have continuous access to the software repository as code is developed.
6. The configuration of EnergyPlus models must be kept as simple as possible such that auto size is used for cases. Standard models already available in EnergyPlus shall be used.
7. Design days in the weather files should be adjusted to capture loads for future conditions.
8. The Multi-scenario extreme weather simulator (MEWS)[30] or another extreme stochastic weather generator shall be used.[30] Use of a different generator is permitted but will lessen or eliminate the amount that DOE BTO's Future and Extreme Weather project can collaborate to provide future weather products.

Heat pump/Future Weather BEM Study

An extensive parameter study of heat pump technology, future weather scenarios, and building energy models must be conducted. The results of this study will be used to create a dataset and geographic map web-application.

1. For stochastic weather files, the following future years shall be analyzed when available for weather files: 2020, 2040, 2060, and 2080. Additional years are permitted but not required.

2. The following Shared Socio-economic Pathways (SSP) shall be analyzed: 2-4.5, 3-7.0, 5-8.5.

3. For stochastic weather files, each SSP shall have runs for 5%, and 95% confidence interval (CI) for mean surface temperature with clear documentation of the ensemble of climate models used for each climate scenario (see example table below).

Model Information		**Scenarios Covered**					
Model #	Model Name	Historical	SSP119	SSP126	SSP245	SSP370	SSP585
1	AWI-CM-1-1-MR	X		X	X	X	X
2	BCC-CSM2-MR	X		X	X	X	X
3	CAS-ESM2-0	X		X	X	X	X
4	CAMS-CSM1-0	X	X	X	X	X	X
5	CanESM5	X	X	X	X	X	X
6	CESM2	X					
7	CESM2-WACCM	X		X	X	X	X
8	CESM2-WACCM-FV2	X					
9	CIESM	X		X	X		X
10	CMCC-CM2-HR4	X					
11	CMCC-CM2-SR5	X		X	X	X	X
12	CMCC-ESM2	X		X	X	X	X
13	E3SM-1-0	X					X
14	E3SM-1-1	X					X
15	E3SM-1-1-ECA	X					X
16	EC-Earth3	X		X	X	X	X
17	EC-Earth3-AerChem	X				X	
18	EC-Earth3-CC	X			X		X
19	EC-Earth3-Veg	X	X	X	X	X	X
20	EC-Earth3-Veg-LR	X	X	X	X	X	X
21	FGOALS-g3	X	X	X	X	X	X
22	FIO-ESM-2-0			X	X		X
23	GFDL-ESM4	X	X	X	X	X	X
24	INM-CM4-8	X		X	X	X	X
25	INM-CM5-0	X		X	X	X	X
26	IPSL-CM6A-LR	X	X	X	X	X	X
27	MIROC6	X	X	X	X	X	X
28	MPI-ESM1-2-HR	X		X	X	X	X
29	MPI-ESM1-2-LR	X	X	X	X	X	X
30	MRI-ESM2-0	X	X	X	X	X	X
31	NorESM2-MM	X		X	X	X	X
32	SAM0-UNICON	X					
33	TaiESM1	X		X	X	X	X

4. The latest version of two ASHRAE 90.1 DOE prototype models shall be analyzed: single residential dwelling, and commercial medium office.

   Each of the 16 ASHRAE climate zones must be covered for a single location.

Each of these buildings shall be altered to have the following configurations:

1. Baseline unaltered model with standard HVAC and electric element heating (for heating and hot water).
2. Baseline unaltered model with standard HVAC and natural gas heating (for heating and hot water).
3. Configuration (1) building schedules that periodically turn on and off HVAC by making equipment unavailable. This is intended to simulate power outages.

4. High efficiency unintegrated air-source heat pumps for HVAC and hot water

5. High efficiency ground source heat pump using a ground heat exchanger for HVAC and hot water
6. High efficiency integrated air-source heat pump (heat pump with waste heat exchange with hot water).

It is encouraged to use EnergyPlus or OpenStudio measures[31] or equivalent functionality that automatically reconfigures the models so that the changes to the models are easy to trace.
The following present and future weather conditions shall be analyzed. If specific future years are not available, then cases can be skipped for a specific year as long as at least one source of weather data includes every year.

1. All readily available Actual Meteorological Year (AMY) data for a specific site for the most recent 30 years. Use of the Do it yourself EPW tool is encouraged.[38]

2. TMY3
3. TMYx (2 variants)
4. If available: XMY (Crawley and Lawrie[23])
5. If available: FTMY from Oak Ridge National Laboratory[21]
6. If available: FAMY from Argonne National Laboratory (not yet released publicly)
7. 300 cases of extreme weather stochastic generated files with stochastic heat waves and cold snaps and TMYx baseline weather data.
8. At least 1 location for all 16 ASHRAE Standard 169 Climate zones shall be analyzed.

The above set of analyses requires a large amount of computation with the need for more than 8 million BEM simulations. As a result, the entire set of analyses shall be programmed such that additional buildings, years, and other inputs can be added to the analysis. The analysis shall be straightforward to rerun as needed. The team shall perform all calculations for a small subset of the features that only require less than 50,000 runs and evaluate the entire results including the formation of the map. The entire study required shall then be attempted one time. Any runs that fail in this first attempt shall be noted, but do not need to be fixed since the project scope is ambitious. If time permits the failed runs shall be attempted again but the team can move on to the map application as the priority.

The resulting scripts and data inputs shall all be compiled into a single repository that is delivered to ASHRAE along with clearly written instructions on how to re-run the analysis. The analysis should be configured such that it is able to run parallel on many processors and runs in several days if several thousand processors (e.g., AWS) are available. The programming shall enable the user to input specific cases to rerun rather than the whole set along with specific cases to retain all BEM model output. Otherwise, hourly BEM model output shall not be required to be retained to avoid massive long-term data storage requirements. No user interface is required, rather, a master program that has all major inputs clearly documented is required.

Metrics

The following annual metrics must be quantified for every run when applicable.

1. Cooling Degree Days (CDD)
2. Heating Degree Days (HDD)
3. External Difficult thermal conditions: °C-Hours above Wetbulb Globe Temperature 25°C in shade.
4. External Dangerous thermal conditions: °C-Hours above Wetbulb Globe Temperature 30°C in shade.
5. External Deadly thermal conditions: °C-Hours above WBGT 35°C in shade.
6. Number of extreme hot temperature days with temperature higher than the 90% CI 1991-2020 climate normal.
7. Number of heat waves
8. Average duration of heat waves
9. Number of cold snaps
10. Average duration of cold snaps
11. Energy Use Intensity (EUI)
12. Standard Thermal Comfort Metrics from ASHRAE Standard 55 calculated by EnergyPlus tabulated only during hours of normal occupancy (bedrooms 11pm – 7am, offices 9am – 5pm, dining/living other hours)
13. Internal Difficult thermal conditions: °C-Hours above Wetbulb Globe Temperature 25°C for worst zone tabulated only during hours of normal occupancy.
14. Internal Dangerous thermal conditions: °C-Hours above Wetbulb Globe Temperature 30°C for worst zone tabulated only during hours of normal occupancy.
15. Internal Deadly thermal conditions: °C-Hours above Wetbulb Globe 35°C for worst zone tabulated only during hours of normal occupancy.
16. Seasonal Energy Efficiency Ratio (SEER)
17. Heating Seasonal Performance Factor (HSPF)
18. Natural gas consumed per year per area
19. Mass CO_2 emitted for direct (e.g. natural gas consumption) and indirect emissions from electricity production.

20. Water use intensity (volume/building area/year)

22. Heat pump and other HVAC equipment sizing data
23. Internal cautionary thermal conditions: °C-Hours below Temperature 15°C and above 10°C for coldest thermal zone.
24. Internal difficult thermal conditions: °C-Hours below Temperature 10°C and above 5°C for coldest thermal zone.
25. Internal dangerous thermal conditions: °C-Hours below Temperature 5°C and above 0°C for coldest thermal zone.
26. Internal deadly thermal conditions: °C-Hours below 0°C for coldest thermal zone.
27. Peak load of entire building (kW)
28. Time of yearly peak load for entire building (hour, day of month, month, year)
29. Heating season peak load (kW)
30. Time of heating season peak load (hour, day of month, month, year)
31. Cooling season peak load (kW)
32. Time of cooling season peak load (hour, day of month, month, year)
33. HVAC EUI

Other metrics may be added by the team but further requests for metrics do not have to be supported unless the winning bidder agrees to add them.

For the ensemble of each set of stochastic weather, all the above metrics shall be compiled into histograms with 1/10th the number of bins as runs executed. The mean, standard deviation, and 95% confidence interval of all the above metrics shall also be calculated. Also, for the building configurations with HVAC turned off, the following distributions shall be calculated:

1. Mean rate of occurrence/yr of internal and external deadly heat (see definition above)
2. Mean rate of occurrence/yr of internal and external dangerous heat (see definition above)
3. Mean rate of occurrence/yr of internal and external difficult thermal heat (see definition above)
4. Mean length of duration for all the metrics for 3, 4, and 5.
5. Exponential distribution parameters of events for external and internal: 1) difficult, 2) dangerous, and 3) deadly conditions (see definitions above).
6. Histograms of the duration of external and internal: 1) difficult, 2) dangerous, and 3) deadly conditions.
7. Histograms of peak wetbulb temperature for external and internal: 1) difficult, 2) dangerous, and 3) deadly conditions.
8. Histograms of total ⁰C•hr above 1) difficult, 2) dangerous, and 3) deadly conditions for cold and hot extremes

Dataset Requirements

A post processing program on the raw results of the BEM/climate study is required to form a dataset of the above metrics. Each run shall be given a unique integer ID. Additional attribute shall be included with this ID to fully identify the run:

Dataset attributes

1. Study version number (to enable stacking of consecutive studies)
2. Latitude
3. Longitude
4. Location Name
5. Climate scenario (SSP)
6. Climate model confidence interval (5%, 50%, 95%)
7. Future year (or historic year)
8. Technology (i.e. heat pumps for this project)
9. Technology configuration (changes with technology)
10. Building type
11. Building configuration (i.e. specific changes to the building type made)

12. Weather file type (XMY, TMYx, stochastically generated, FAMY, FTMY)
13. Weather file name
14. Notes (for manual input as needed)

The entire dataset of metrics and attributes from the run shall be provided output as a netCDF formatted file or set of netCDF files that is automatically output from the post processing program. The netCDF output files from the BEM climate study shall be direct input to the map application described below with no manual steps in between the analysis run and postprocessing programs.

Map Application

A web-based application shall be created that enables geospatial selection and visualization of results from this study. This application shall be built on existing open-source resources to minimize the amount of new code development needed. If a pre-existing application can meet the requirements herein, then it should be used to minimize work in this area. Map applications such as the BTO projects map (https://www.energy.gov/eere/buildings/building-technologies-office-projects-map) embody much of the requirements. Results shall be explorable as seen in the BTO projects map below in Figure 1 where cases analyzed have a marker that can be selected so that another screen with data pops-up.

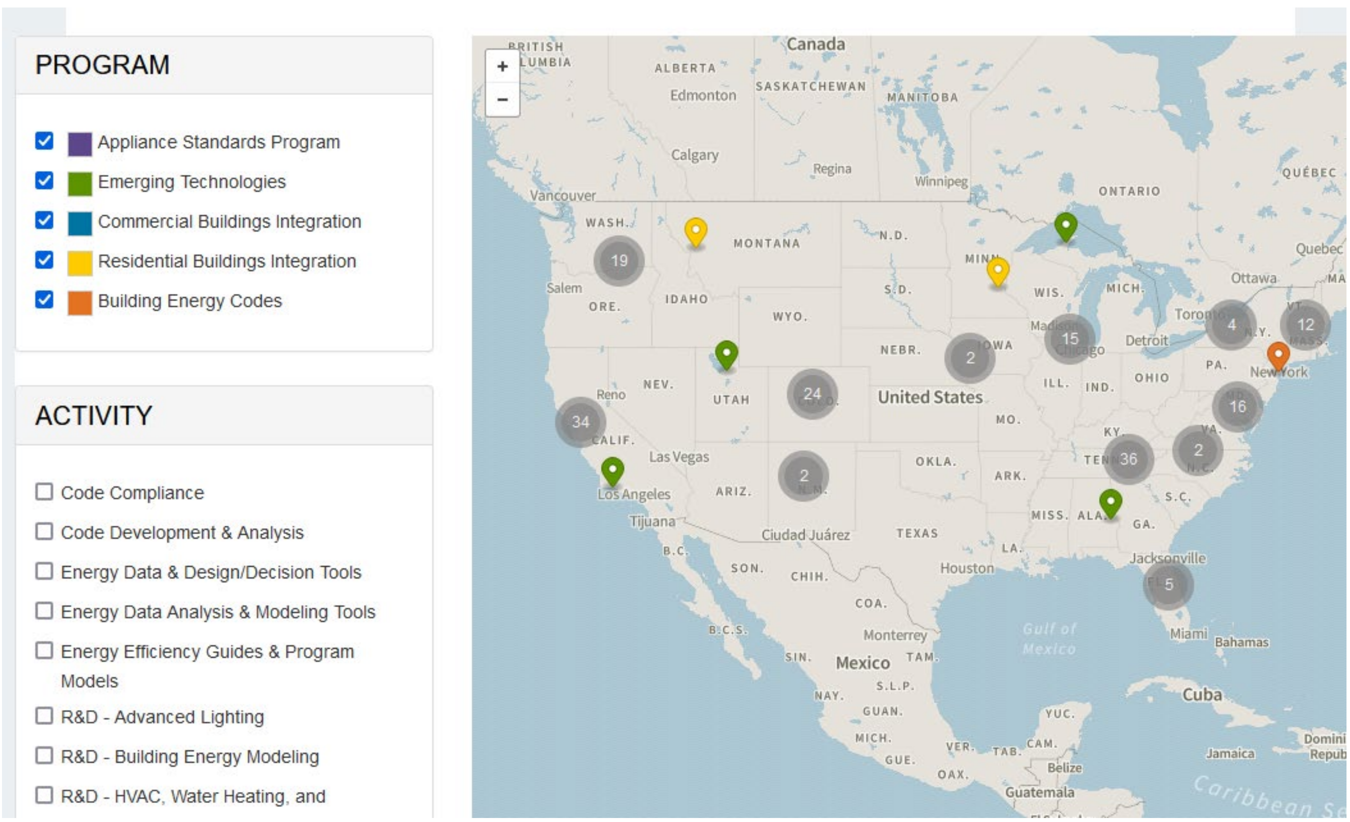

Figure 1 BTO project map example.

The application shall perform the following kinds of calculations on the dataset.

1. A user can select two cases and make a combination of their results. For example, the user can select a building type and assign a percentage of one technology, a second percentage of a second technology, etc. These percentages shall enable the capacity to evaluate how combinations of cases will perform for a

specific building type. The blend of results shall be a linear combination of the fraction of each case used.
2. A user can assign total floor areas for a combination of several building types and produce total metrics rather than area normalized metrics.

The application shall have the following capabilities:

1. A graphical map showing the ASHRAE climate zone boundaries and State boundaries on the United States. This map shall be an interactive tool that has a slider for future year, and technology type penetration level for combinations of technologies (as specified above). Each metric, and building type, SSP, technology type shall be selectable as single values that are presented in a legend. This map shall be able to show the difference in percentage and in values between any two arbitrary runs (different years, different technologies, different locations, etc..). This map shall enable interpolation of results between geographic locations such that color map plots of metrics can be used. The ASHRAE climate zones shall be boundaries for the interpolation scheme. (Note: this study will not create enough locations to create a meaningful colormap, but this capability will increase in value as more cases are added for finer resolution between geographic points) This map can be used to inform climate mitigation and adaptation strategies at local, state, and national levels. This will help policymakers locate and quantify the need for climate mitigation and adaptation.
2. Once two or more cases are selected, time series plots (by future year) with uncertainty bounds as box-plots for the stochastic weather results and single values timeseries plots for other weather products shall be accessible as a new pop-up window. Example plots of this type are shown below in Figure 2. All other attributes shall be selectable such that the differences between arbitrary configurations of attributes can be calculated. These time series plots shall update based on different selections of attributes.

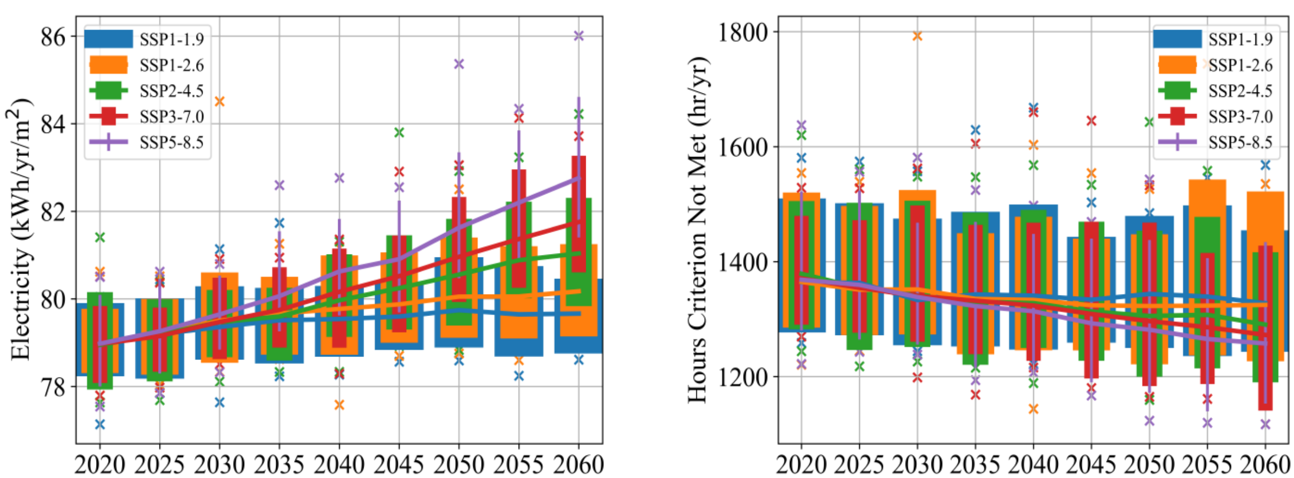

Figure 2 Example time series plots (taken from Villa et. al, 2022 [2]) – the 5 year increment is not required. Colors and style need not be the same either.

3. Capacity to download the data behind these two plots types (geographic and timeseries).
4. Capacity to download the entire dataset displayed as a flat CSV file or as the original netCDF format.

The application shall be extensible such that new studies for different technologies can be added later. It shall enable the user to visually select on a map or to query results on the dataset attributes.

SSP Baseline Offsite Electricity Emissions Scenarios

The locations analyzed shall use emissions factors for their respective U.S. states from the U.S. Environmental Protection Agency's Green House Gas (GHG) Emissions Factors Hub.[22] For each SSP, a scenario that alters these factors shall be constructed that shows how emissions free electricity generation grows into the future. Some inputs to define these scenarios may need to be defined. As a result, assumptions for the development of these scenarios shall be clearly documented but quick decisions can be made to keep effort in this area minimal.

Building Energy Model Reconfigurations
The Building Energy Models shall have equipment sized using FTMY weather for each year analyzed such that normal cases do not have undersized equipment for typical future conditions. The two BEM cases that lack heating and cooling are provided to explore how well climate zones that do not have heating or cooling will cope in the future, and to also investigate what the consequences of a long-term power outage or equipment failure might be. These cases can be controlled to turn off HVAC and all plug loads via equipment availability schedules and plug load schedules. The occupancy schedules shall remain the same though to enable investigating how human body heat may affect such a situation.

Power Outage Durations
The team shall choose power outage durations that occur periodically. A power outage duration shall be chosen that represents a worst-case extreme event for each climate zone based on estimation and literature review on power outages for each climate zone. This event shall be repeated as many times as possible in a full year. This only applies to configuration 3 of the model.

Extensibility
Though the deliverables for this research project are focused on a U.S. map, the team shall assure the tools can extend to a global map. This shall include the ability to run a unit test case where a single point at arbitrary latitude and longitude is added to the dataset successfully which demonstrates that the programming is not confined to the United States. In general, the 16 cases required in this project are intended to be replaced with a gridded approach for the BEM runs and weather files in some future project.

<u>Deliverables</u>:
1. Online map application with study results. An online private software repository with directories containing:
    1. Coding plan that lays out how the software will work.
    2. Code to run the BEM/heat pump/future weather parameter study where runs can be sent to parallel processors for each BEM run. This shall include inputs that can easily down-select to a much smaller subset of the runs. A unit-test of this down select capability shall also be created that exercises all the code and can be run in less than an hour.
    3. Code to post process the parameter study output to netCDF4 files.
    4. Code for web-based map application.
    5. Building energy models used including all configurations of each building type.
    6. All other input data besides weather files (due to storage constraints). This shall include light-weight versions of data designed for unit testing that exercises the code effectively without needing the entire input deck of weather files or the full netCDF4 output of an entire study.
    7. Unit tests exercising all code with test inputs.
    8. Documentation that specifies how to run the study.

This repository shall be accessible by ASHRAE for 10-years. A copy of the final version of this repository shall be stored in a data repository and a Data DOI link shall be created. All DOI links shall direct to a publicly accessible location that requires authentication to download data.

2. A zip file available in a long-term (10-year maintenance) online ftp site of all-weather files used in the main study. This file should be able to be dropped into the base path of an instance of the software repository so that the entire study can be rerun without extensive rearrangement and placement of files. A Data DOI link to this data shall be created.

3. A zip file containing netCDF4 output of the study in a long-term (10-year maintenance) online ftp site. A Data DOI link to this data shall be created.

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 final report on project closure that provides the PMS with the DOI link(s) specified above to the data above along with authentication method to access the actual data.

The results of this study will be applied in multiple chapters of ASHRAE's Fundamentals Handbook. For example, Chapters 35 part 5 on sustainability delineates that "Increased volatility in weather profoundly affects HVAC&R practice." It does not provide any quantitative information concerning this statement though. The results of this study and the map tool will give the responsible technical committees new information to add to their respective chapters with quantitative statements and references to this project.

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 (1847-RP) at the end of the title in parentheses, e.g., (1847-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

The analysis is a process of compiling existing resources and should not include development of new energy models from scratch (only reconfiguring) or creation of new future weather files. It mostly involves tying the various parts into a cohesive, code driven analysis that will allow ASHRAE to continue to replicate the results with new building energy models and new future weather files should it choose to do so in other future projects. If any one aspect of the study is holding up the process, then it is permissible with ASHRAE's consent to drop it so that the study can be finished.

For the first year it is estimated that the required work will involve full-time work for one individual for the duration of the project. This is likely to be a split between several persons part time. In addition to this, it is expected that there will be 15% support from a senior mentor overseeing the work. The second year will involve 50-75% coverage of one person's time with 10% coverage by a mentor. The third year is for wrap up and will consist of about 25% of one person's time. Consultations will also be available with the ASHRAE BEM and climatic information communities TC 4.2. These committees will serve peer review roles. The DOE future weather project may also provide support if MEWS, FTMY, and/or FAMY files are used in this study.

Year 1 (147 K)

Task 1.1 – Reconfigure building energy models (34K)
  Subtask 1 Baseline unaltered model with standard HVAC and electric element heating. (2K)
  Subtask 2 Baseline unaltered model with standard HVAC and natural gas heating (2K)
  Subtask 3 Baseline model with power outages (4K)
  Subtask 5 Baseline model with unintegrated air-source heat pumps (6K)
  Subtask 6 High efficiency ground source heat pump using a ground heat exchanger (6K)
  Subtask 7 High efficiency integrated heat pump configuration(6K)
  Subtask 8 Reconfigure output so that all hourly outputs are assured that are needed for metrics (8K)

Deliverable: Set of building energy models with all configurations

Task 1.2 – Create future weather database (39K)
  Subtask 1 Choose locations in climate zones to analyze based on availability of all weather products (2K)
  Subtask 2 Collect available present day weather resources for these location (TMYx, TMY3, …) (2K)
  Subtask 3 Create actual meteorological weather files for years with readily available data (4K)
  Subtask 4 Perform literature review and correspondence as needed to establish publicly available data (10K)
    Potential Sources: MEWS, FTMY from ORNL, FAMY from ANL, Gasperella et. al.[33], NASA POWER[32], Technical Comittee 4.2.
  Subtask 5 Create quality checking that establishes acceptance criteria for all future weather files to be accepted (10K)
  Subtask 6 Perform quality checks and compile all future weather data sources that pass (5K)

Subtask 7 Configure collections of files on web-query accessible site for download (4K)
Subtask 8 Document the future weather database (2K)

Deliverable: Set of all-weather files to be run on every building energy model

Task 1.3 – Compile and configure other inputs needed (20K)
Subtask 1 Create SSP emissions scenarios for future consumption of electricity for each location (10K)
Subtask 2 Create baseline CO_2 emissions levels for direct emissions for each location (10K)

Deliverable: Spreadsheet or code with all additional required input values

Task 1.4 – Plan code creation (20K)
Subtask 1 Either collaborate with SNL or other partners concerning implementation of the analysis code and web API or use other future weather products for conducting the study (10 K)
Subtask 2 Complete pseudo-code for how all coding will work together. (10K)

Deliverable – Written plan for code creation

Task 1.5 – Create code to run study (34K)
Subtask 1 Create run code including changes to EnergyPlus files that are needed based on other input data (10K)
Subtask 2 Create repository, unit testing, and code documentation (14K)
Subtask 2 Create post processing code to netCDF4 data format for metrics (10K)

Deliverable – Code repository that passes all unit testing.

Year 2 (80K)

Task 2.1 – Run the study (total funding 30K)
Subtask 1 – Test and configure platform to enable running the entire study (15K)
Subtask 2 – Run and post process study (15K)

Deliverable - netCDF database with study results

Task 2.2 – Create web-map application to analyze results (total funding 50K)

Subtask 1 – Design API conceptually and submit for review by ASHRAE/SNL (20K)
Subtask 2 – Code API and query unit test cases on test netCDF file from subtask 4.3 (20K)
Subtask 3 – Bring results from study into map application (10K)

Deliverable – Working map application with input from the netCDF database

Year 3 (35K)

Task 3.1 – Publication and coding using API to create output products (40K)

Subtask 1 Code to create interactive map, tables, and figures for ASHRAE standards (10K)
Subtask 2 Deliberation with TC 2.5 and TC 4.2 concerning
final products to be published in ASHRAE standards (5K)
Subtask 3 Writing and Presentation of ASRHAE Technical Paper (15K)
Subtask 4 Support transition of deliverables to ASHRAE (5K)

Deliverable – ASHRAE Technical paper presented at an ASHRAE summer or winter meeting

Travel required: Presentation of Technical paper for project end at ASHRAE summer or winter meeting, travel expenses granted: 3K

Total funding $265,000, Project duration: 3 years

Proposal Evaluation Criteria:

No.	Proposal Review Criterion	Weighting Factor
1	**Technical Merit -** The proposal shall reflect a clear plan for completing the work statement that shows that the tools and skills to finish this work are nearly already in place. The method to complete the large parameter studies shall be delineated with evidence that the study will be able to be repeated in a reasonable amount of time.	**35%**
2	**Team Qualifications** – The best teams will have significant experience in all software development, future weather issues applied to the built environment, and building energy models. A multi-partner collaboration may be necessary to get all these skills. Successful studies published using BEM and future weather are desirable.	**35%**
3	**Budget/Schedule –** The team shall demonstrate that they have thoroughly reviewed and revised the above schedule/budget to their own rates and estimates of how much the project will cost. The team shall give examples that show that they have been able to deliver on tasks in the past and shall demonstrate that they have the band-width to complete the work. If hiring will be needed to complete the work, the team shall give evidence that the skills needed can be learned and that sufficient time for mentorship will be given.	**30%**

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	Building energy model configurations complete (Task 1.1)	6
2	Future weather file database complete (Task 1.2, 1.3)	9
3	Code to run study complete (Task 1.5)	12
4	Study Run with Verification of accuracy of the results (Task 2.1)	15
5	Web-tool for exploring results complete (Task 2.2)	21
6	ASHRAE Technical Paper for tools and results created submitted for peer review	24
7	Delivery of code and data to ASHRAE	30
8	Presentation of Technical Paper at ASHRAE conference	36

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