INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1865-TRP, “Optimizing Supply Air Temperature Control for Dedicated Outdoor Air Systems”

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 8.10, Mechanical Dehumidification Equipment and Heat Pipes

Budget Range: $180,000 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: April 1, 2020 or later.

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EST, Monday, December 16, 2019. 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 should read: 1865-TRP, “Optimizing Supply Air Temperature Control for Dedicated Outdoor Air Systems”, 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
Jingjuan Feng
TRC Advanced Energy Services
436 14th Street
Oakland, CA 94612-2703
Phone: 510-366-3139
E-Mail: dovefeng@gmail.com

**For Administrative or Procedural Matters:**
Manager of Research & Technical Services (MORTS)
Michael R. Vaughn
ASHRAE, Inc.
1791 Tullie Circle, NE
Atlanta, GA 30329
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 2, 2019 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, EST, December 16, 2019. 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)

Dedicated outdoor air systems (DOASs) usually have heating, cooling, and dehumidification capability, and often have outdoor air energy recovery and possibly run-around heat recovery systems. They typically serve local (zonal) space temperature control systems such as variable refrigerant flow (VRF) fan-coils, 4-pipe fan-coils, water-source heat pumps, chilled beams, and radiant systems. The amount of ventilation air delivered by a DOAS also varies if there are high-occupancy areas in the building and demand-controlled ventilation (DCV) is required by Standard 90.1 or building codes. Advocates of DOASs argue that the systems can save energy by eliminating (or nearly eliminating) simultaneous cooling and reheat that would otherwise be needed to provide adequate dehumidification in humid climates (ASHRAE, 2017). However, the overall energy performance of a DOAS depends highly on the actual control sequences implemented (Feng and Cheng, 2018).

The primary functions of DOASs are to deliver ventilation air and to remove latent load in the ventilation air and the space, and at the same time it provides sensible cooling as air is cooled due to dehumidification. Depending on the terminal system type that is coupled with the DOAS, the basic psychometric purposes of the DOAS, and consequently the control strategies, could be quite different, especially when they operate at part load conditions.

- Four pipe fan-coils, zonal heat pumps or Variable Refrigerant Flow (VRF) units usually have some capability to dehumidify supply air. In particular, under part load conditions when the zonal units’ design capacity is larger than space sensible load, they can remove space latent load or even ventilation air latent load. The DOAS supply air could be dehumidified just enough for ventilation air latent load removal, overcooled to provide supplemental cooling (Shank and Mumma 2001), or cooled and heated back to a neutral air temperature (e.g. using heating coils or energy recovery) as some practitioners do for simplicity.

- For four-pipe chilled beams or radiant panel systems that cannot handle any latent load, the DOAS must be adequately dehumidified to avoid condensation. A common conservative strategy is to cool air down to the chilled water supply temperature feeding the chilled beams, but this can cause excessive energy use at the DOAS to sub-cool the air and then reheat it back up either at the DOAS or at the local systems (Taylor 2018). More efficient strategies include using outdoor and space relative humidity sensors or condensate sensors mounted to piping such that the air temperature leaving the DOAS cooling coil can reset based on zone and ventilation latent load.

DOAS’s supply air dew-point and dry-bulb temperature control could also vary depending on climate and zone loads. Since a DOAS is a 100% outdoor air unit typically sized for design ventilation air flow rate, it cannot economize by increasing outdoor air flow rate. This is more significant in drier climates where, for much of the year, 100% outdoor air can be used for economizing without the concern of raising indoor humidity levels. But the DOAS can still provide some level of economizer by not operating cooling or heating components when free-cooling is available. Supplying neutral air during those economizer hours could result in significant heating and cooling energy waste, both at the DOAS and at local units, if local systems are predominantly in cooling mode. Accordingly, Standard 90.1 includes this prescriptive requirement:

6.5.2.6 Ventilation Air Heating Control

Units that provide ventilation air to multiple zones and operate in conjunction with zone heating and cooling systems shall not use heating or heat recovery to warm supply air above 60°F when representative building loads or outdoor air temperature indicate that the majority of zones require cooling.

However, this requirement lacks enough detail to readily implement in real control systems. DOAS control approach could also vary depending on the amount of ventilation air required for different building types. In buildings with high-occupancy areas such as schools, the DOAS is usually sized for the peak ventilation flow rate which can be much higher than the minimum ventilation rate as DCV requires reduction of outdoor air intake below design rates when the actual occupancy of spaces is less than design occupancy. In these buildings, it is possible to increase the DOAS air flow rates to be above the minimum requirement to provide free-cooling if the outdoor air condition is favorable. With LED lighting and effective plug load management, actual internal heating gains in modern buildings now are usually dramatically lower such that supplying sub-cooled ventilation air, as suggested by the ASHRAE DOAS Design Guide (ASHRAE, 2017), may be adequate for meeting the cooling load. On the other hand, with low building loads, supplying minimum ventilation air at low temperature may also cause significant reheat energy waste.
While DOASs need to achieve their primary functions of cooling, heating, and dehumidification, conservatively conditioning the outdoor air to achieve those functions may result in significant energy waste. In the design industry, one simple and common approach is to supply neutral air temperature from the DOAS, which involves dehumidifying the air through sub-cooling, and then heating it back to neutral temperature (Paliaga, Farahmand, Raftury, & Woolley, 2017). The literature that has studied DOAS supply air temperature control is very limited. The ASHRAE DOAS Design Guide provides some general control considerations focusing on achieving the basic psychrometric functions (ASHRAE, 2017). It presents two example control sequences - both use a constant low temperature setpoint for air leaving the cooling coil when outside air temperature is higher than 55°F and then reheat the cold air to avoid overcooling the spaces. There is no evaluation of the energy impacts or suggestion on setpoint ranges for different climates. Another study (Shank & Mumma, 2001) suggests the supply air temperature leaving the DOAS should be no higher than 55°F, and the supply air dew-point temperature should be kept at 44°F. However, this conclusion was based on simulations using Atlanta weather data, which is relatively humid and hot. In addition, it assumes the internal loads are at 3-5 W/ft², which are much higher than typical given current lighting code minimum requirements. For buildings in drier or cooler climate zones with reasonable load management measures, these control approaches could potentially cause a significant amount of cooling and heating energy waste.

**Justification and Value to ASHRAE**

The ASHRAE Advanced Energy Design Guides Series (ASHRAE) has recommended DOASs as part of the HVAC design strategy for most climate zones and building types evaluated, including K-12 schools, hospital and healthcare facilities, small to medium offices buildings, retail buildings, etc. This project will recommend new near-optimal control sequences for DOAS systems and improve ASHRAE’s Advanced Energy Design Guides Series. The control sequences generated from the research will be submitted to ASHRAE Guideline Project Committee 36 “High Performance Sequences of Operation for HVAC Systems”. The results of the project can also improve the recently published ASHRAE Design Guide for Dedicated Outdoor Air Systems (ASHRAE, 2017).

This research addresses the following goals listed in the ASHRAE Research Strategic Plan 2010-2018.

- **Goal 1:** Maximize the actual operational energy performance of buildings and facilities.
- **Goal 2:** Progress toward Advanced Energy Design Guides (AEDG) and cost-effective net-zero-energy (NZE) buildings.
- **Goal 7:** Support development of tools, procedures and methods suitable for designing low-energy buildings.

Goal 9: Support the development of improved HVAC&R components ranging from residential through commercial to provide improved system efficiency, affordability, reliability and safety.

**Objectives**

This research project will:

- Provide ASHRAE members guidance on determining the DOAS supply air temperature control sequences that can achieve both the basic psychrometric functions and energy efficiency for different system configurations and various climates.

Develop near optimal and practical supply air temperature control sequences for the dedicated outdoor air system applications evaluated in the study, articulated in English and ready to be adopted into ASHRAE Guideline 36 and programmed into a commercial Direct Digital Control (DDC) system.
Scope:
Research will include and be limited to the following three DOAS systems as defined in the ASHRAE Design Guide for Dedicated Outdoor Air Systems (ASHRAE, 2017):

1. Heating Coil Cooling Coil

2. Heating Coil Cooling Coil Total-energy Wheel

3. Series Desiccant Wheel Preheat Coil Total-energy Wheel

Feedback from industry groups indicated these were the most common designs. Option 2 may have sensible-only or total energy recovery.

The DOAS shall be modeled with separate supply diffusers from the zonal systems (described below). There are many other common configurations, as described in the Design Guide for Dedicated Outdoor Air Systems, but they need not be modeled for simplicity and because optimized control logic is not expected to vary from one configuration to the others.

The DOAS shall be sized in two ways:
1. Standard 62.1-minimum
2. 30% higher than Standard 62.1, reflecting the LEED V4 Enhanced Indoor Air Quality Increased Ventilation credit. This rate is also close to California Title 24 ventilation rates and is compliant with Standard 90.1 Section 6.5.3.7.
The DOAS will each be applied to three zonal systems:

1. Variable speed 4-pipe fan-coils, which represents those systems that have dehumidification capability at the zone level. The system shall be modeled with the same cooling and heating source (plant) as the DOAS so tradeoffs in where heating and cooling are used (zone vs. DOAS) are not complicated by having different cooling/heating plant efficiencies.
2. Active chilled beams (ACBs), which represent systems that do not have zonal dehumidification capability and must have humidity limited to avoid condensation at the zone levels. For simplicity, heating and cooling for both the ACBs and DOAS will be the same plant (not dual temperature plants). Sequences from this
3. Water-source heat pumps, which represent systems that transfer energy between zones that are in different heat/cool modes. Sequences from this analysis are also applicable to heat recovery type variable refrigerant system. The DOAS heating and cooling shall also be from water-source heat pumps, again for simplicity.

The systems shall be applied to these two applications:
1. Offices including a mixture of offices and conference rooms
2. Schools including mostly classrooms

In both cases, the DOAS will have zone demand controlled ventilation (DCV) where Standard 90.1 requires it, and all zones must be pressure independent. Outdoor air supply fan speed must be controlled with static pressure setpoint reset off damper position per Standard 90.1. These two prototype buildings were used for RP-1547 (ASHRAE 2013) and RP-1747 (ASHRAE 2017a) using EnergyPlus as the modeling engine. The same basic architectural models should be used for consistency and to reduce development costs. The models have randomized internal load schedules to provide realistic load profiles. (If these prototypes are not used, bidders shall identify and describe in detail the buildings they plan to use.)

At a minimum, DOAS designs listed above shall be analyzed in these ASHRAE Climate Zones (ASHRAE 2013a).

<table>
<thead>
<tr>
<th>DOAS Design:</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather Zones:</td>
<td>2A, 3A, 3B, 3C, 4A, 4C, 5A, 5B, 6A, 6B</td>
<td>Total: 2A, 3A, 4A, 5A, 6A</td>
<td>2A, 3A, 4A, 5A, 6A</td>
</tr>
<tr>
<td>Sensible:</td>
<td>3B, 4C, 5B, 6B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If modeling and optimization can be automated, bidders are encouraged to do all permutations of DOAS designs and all 19 Climate Zones, except eliminating energy recovery where not required by Standard 90.1. For all cases, DOAS shall be modeled with all permutations of zonal types and building types.

**Task 1. Detailed Model Development**
The prescribed DOAS and zonal system types are generally described above but many details are lacking such as:
1. Cooling, heating, and fan equipment type and efficiency
2. Heat recovery system efficiency and pressure drop
3. Pump heads and fan pressures
4. Zonal control logic
5. Control points and sensors in DOAS and zonal systems
6. Energy cost rate schedules
7. And many other details

In all cases, the system designs and equipment efficiencies shall meet Standard 90.1.

Task 1 will be to fully identify all model inputs for PMS approval.

Deliverables will be in two steps: First, identify all modeling details that do not vary by climate zone. Once approved, the second deliverable will be model inputs that vary by climate zones such as cooling, heating, and fan capacity based on detailed load calculations. The energy modeling software can be used for system sizing if it provides results similar to those using the heat balance (HB) method per ASHRAE Handbook, Fundamentals, Chapter 18.
**Task 2. Optimization Technique Development**

To determine optimized sequences from so many model permutations will require an automated or semiautomated technique developed by the Contractor. A description of options for how this technique will be developed shall be included in Contractor proposals, but the details may be deferred to this Task. One possibility is the “brute force” optimization technique described in Hydeman 2007. It involves iterating on all valid variable setpoints (in discrete steps) and equipment staging options to generate a database of all possible operational options for each hourly timestep. The database is then queried to find the lowest energy cost for each timestep – this is the theoretical optimum performance. The various independent variables that compose this optimum are then evaluated to find trends and correlations that can be used to create sequences of operation (SOOs) that come as close as possible to the optimum. The resulting SOOs can then be tested using the database to see how close they achieve the optimum.

This is just one technique. The Contractor may propose to use any technique that can achieve the same result with similar assurances that true near-optimum SOOs can be identified.

**Deliverables:** Report identifying the optimization technique, including a simple example applying the technique, for PMS approval

**Task 3. Sequence of Operation Development & Testing**

The optimization technique shall be applied to one of the permutation options as a test. The SOOs developed must be simple enough that they can be programmed into typical direct digital control systems yet achieve near-optimal performance. Once developed, the SOOs shall be modeled to test how close to optimum performance is achieved. In addition, each run shall include a 70°F (neutral) supply air temperature run as a baseline for comparison only. (It is known that this is not an efficient strategy and disallowed by Standard 90.1 in cooling predominate applications, but it is a common practice and a reasonable baseline for comparison.)

An interim deliverable shall be a report showing how SOOs were developed for the test case and how well they perform relative to the optimum. The following shall be included:

- Overall annual energy usage
• Space dry bulb temperature and humidity in critical zones. Temperature and humidity in all zones shall meet ASHRAE Standard 55 and 62.1 requirements.
• Energy end uses by each DOAS component and the zonal units

Once the PMS has approved the interim report, the Contractor shall proceed to develop SOOs and reports for all permutations. The SOOs shall include English language sequences of operation, including critical setpoints, setpoint ranges for each application and graphs or tables that allow users to determine the setpoints.

**Task 4. Guideline 36 Continuous Maintenance Proposal**
The contractor shall develop a Continuous Maintenance Proposal (CMP) to 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

**Task 5. Reporting of Findings**
The contractor shall produce a comprehensive Final Report detailing all the work undertaken in the project.

**Deliverables:**
The project deliverable will be a set of near-optimal and practical supply air temperature control sequences for the dedicated outdoor air system applications, articulated in English and ready to be adopted into ASHRAE Guideline 36 and programmed into a commercial Direct Digital Control (DDC) system. A database of all models and simulation data will also be available. Upon completion of the project, a final project report and technical papers will be prepared to summarize the results of the research and present the validated model.

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. **Other reports required:** The project shall be reviewed by the PMS, and the Principal Investigator shall only proceed after receiving approval from the PMS after completion of the following stages:
1. Report of modeling details of the DOAS systems (Task 1)
2. Report identifying the optimization technique, including a simple example applying the technique (Task 2)
3. Report demonstrates the sequence of operation (SOO) development approach and how well it performs relative to the optimum for test cases as an interim deliverable for Task 3. Once it is approved, the deliverable from task 3 is the developed SOOs for all permutations. (Task 3)
1.4. Continuous Maintenance Proposal (CMP) to ASHRAE Guideline 36 for incorporation of the newly developed control sequences (Task 4)
c. 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.

d. 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 (1865-RP) at the end of the title in parentheses, e.g., (1865-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.

e. Data

Data is defined in General Condition VI, “DATA”

f. 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 project anticipates a minimum of 2 principal investigators (optimization/modeling expert and HVAC/controls expert) with about 3 months total effort, with the remainder of the effort by experienced energy modelers. It is expected that this project will require a duration of 24 months to complete at a total cost of about $180,000.
Other Information to Bidders (Optional):
The successful contractor should have a minimum of 2 principal investigators, one or more with expertise in optimization and energy modeling, and one or more with expertise in HVAC design (particularly DOAS applications) and HVAC controls.

Project Milestones:

<table>
<thead>
<tr>
<th>No.</th>
<th>Major Project Completion Milestone</th>
<th>Deadline Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Task 1: Detailed model development</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Task 2: Optimization technique development</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Task 3: Sequence of operation development and testing</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>Task 4: Guideline 36 continuous maintenance proposal</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Task 5: Report of findings</td>
<td>4</td>
</tr>
</tbody>
</table>

Proposal Evaluation Criteria

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

<table>
<thead>
<tr>
<th>No.</th>
<th>Proposal Review Criterion</th>
<th>Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Energy modeling experience of complicated HVAC systems</td>
<td>20%</td>
</tr>
<tr>
<td>2</td>
<td>Experience with optimization techniques and proposed optimization plan</td>
<td>25%</td>
</tr>
<tr>
<td>3</td>
<td>Applied experience in HVAC design (especially DOAS) and writing practical control sequences</td>
<td>30%</td>
</tr>
<tr>
<td>4</td>
<td>Understanding of the work statement</td>
<td>20%</td>
</tr>
<tr>
<td>5</td>
<td>Previous ASHRAE research project experience</td>
<td>5%</td>
</tr>
</tbody>
</table>

References

1. ASHRAE. (2013). ASHRAE 1547-RP CO2-Based Demand Controlled Ventilation For Multiple Zone HVAC Systems
15. Taylor S. (2018, December) 4-Pipe VAV vs. Active Chilled Beams for Labs, ASHRAE Journal