2021

ASHRAE Research Strategic Plan

ASHRAE

ASHRAE Shaping Tomorrow's Built Environment Today

ASHRAE research is guided in part by the ASHRAE Research Strategic Plan. The purpose of the plan is to identify key HVAC&R research needs and provide that information to ASHRAE technical committees as guidance while they develop research projects and to the Research Administration Committee as it approves and funds research proposals. The Research Plan is not meant to take the initiative for research development from the technical committees within ASHRAE. Rather it is to use input from ASHRAE members to identify strategic research needs that are appropriate for many committees to collaborate on, that may require larger budgets and for which additional outside funding may be available to supplement ASHRAE's budget.

The most recent version of the plan started development in November 2019 and over a twenty-month period was completed with input provided by chapter members, technical committee members, research fund contributors and representatives from HVAC&R industry organizations.

The New Research Strategic plan provides the following 6 Research Initiatives:

1. Resilience
2. IEQ – Environmental Quality in Occupied Spaces and Impacts on Work and Learning Health and Well Being, and Transmission of Airborne Infectious Viruses
3. Sustainability, Decarbonization, Energy and Resources
4. HVAC&R Equipment, Components, and Materials
5. Tools and Applications
6. Education and Outreach

I would also like to take this opportunity to thank the members of the 2019-2021 Research Advisory Panel for all their efforts in helping to develop the 2019 – 2024 Research Strategic Plan

2019 -2021 Research Advisory Panel Members:

RAP Chair – Reinhard Radermacher
RAC Vice Chair – Mike Pouchak
Dr. Eckhard Groll
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Mr. Dawen Lu
Mr. Lawrence Markel
Dr. Chun-cheng Piao
Dr. Agami Reddy
Dr. Pawel Wargocki
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More information on the new Plan will be forthcoming in the coming months. And our hope is that it can be formally rolled-out to the TC Research Subcommittee Chair at their Sunday Morning Breakfast meeting in Las Vegas.

Complementing the Society's Research Strategic Plan is the Society's Research Implementation Plan, which documents all technical committee research topics that support the Research Strategic Plan or are tactical in nature (such as updates and new information for the *ASHRAE Handbook* and standards, etc.) and have been approved for further development into ASHRAE research projects. The implementation plan currently includes 65 projects in various stages of development. The estimated dollar value of these projects is $16.1 million. This, when coupled with the cost of projects already under contract, exceeds ASHRAE's current annual budget for research. ASHRAE hopes, however, to implement most of these projects in the near future.

Details about ASHRAE's research plans, active research projects, completed projects, currently available requests for proposals and guidelines for submission can be reviewed on the "Research" page of the ASHRAE website *ashrae.org/technical-resources/research.*

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Overall Goal of the ASHRAE Research Strategic Plan

Research plays a key part in ASHRAE's mission "to serve humanity by advancing the arts and sciences of heating, ventilation, air conditioning, refrigeration and their allied fields" in order to realize the vision of "a healthy and sustainable built environment for all." The scope of ASHRAE research includes specification, development and deployment of technology, equipment, and operating practices as well as education and training for the people who design, build, manage and inhabit the built environment. Such environments include but are not limited to:

- Residential, commercial, institutional, industrial and agricultural facilities,
- Semi-outdoor and outdoor environments occupied by people for extended periods,
- Land, sea, air and space transportation,
- Agricultural and industrial processes, and
- Conditioned/refrigerated cold-chain facilities and transportation for preserving goods.

ASHRAE's support for research goes well beyond funding; it includes enormous volunteer efforts to initiate, manage, review, and disseminate research projects and their results. The common objectives of ASHRAE's research initiatives are to improve the quality of the built environment and its structures, systems, and equipment with regard to:

- Efficiency of resource utilization,
- Occupant's comfort, productivity and well-being
- Occupant's health and safety, Reliability and resilience, and
- Environmental stewardship, including decarbonization.

The research initiatives of this Research Strategic Plan are deemed to be topics of essential relevance to ASHRAE's mission and for which ASHRAE has historically been and will continue to be a leader in advancing the state of the art. The ASHRAE Research Strategic Plan provides suggested directions and encouragement for cognizant technical committees to address overarching strategic research needs that could augment their traditional research activities by identifying:

1. Issues of increasing or newly recognized significance and current problems that need additional research support,
2. Topic areas that are appropriate for collaboration by multiple ASHRAE committees and broad membership, as well as collaboration with organizations outside ASHRAE; and/or
3. Topic areas for which meaningful research may require larger budgets, especially where additional outside funding may be available.

The ASHRAE Research Strategic Plan was developed with input from the Society's membership at large to refine and enhance past and current research areas while being consistent with the ASHRAE Strategic Plan for 2019–2024.

The broad topics described in this plan are frequently pertinent to the scopes of multiple TCs. It is an institutional challenge to develop more effective methods for multi-TC collaboration (e.g., faster work statement development and more inclusion of members from multiple TCs). Current multi-TC collaborative models usually involve only one member from each TC (co-sponsorship and formation of an MTG) and, in the case of the MTG, too long a time to develop a consensus work statement. In addition, ASHRAE has an untapped resource: Of the ~800 responses to RAP's survey of membership to identify and prioritize research needs, 65% were not members of an ASHRAE TC; this is a large pool of expertise that has expressed interest in ASHRAE research but is not contributing to TCs' development of research projects. Institutionally, TCs and TAC should both develop models for easier multi-TC collaboration and to attract more ASHRAE members to become active in TCs.

Research Initiatives

This section provides abstracts of six research initiatives. More detailed, two-page summaries of each initiative follow in the "Initiatives in Detail" section.

Resilience

Resilience of energy systems covers the response of different communities, buildings types, industrial facilities, and refrigerated transportation/storage applications to extreme weather events, climate change, and other extraordinary challenges. Occupants of buildings and communities face severe and increasing threats due to extreme weather, power loss, and other disruptive events. Current design practices and codes are inadequate since they are concerned more with normal operation than with building system response and occupant health impacts under such infrequent but disruptive events. Research priorities to enhance resilience of buildings and communities include: (i) improved design guidance that provides for extreme events, (ii) passive and active technological subsystems providing physical robustness, (iii) operational flexibility/robustness via automated control and management strategies/protocols, and (iv) rebound capability (the ability to recover quickly after partial or complete disruptions/failures).

IEQ: Indoor Environmental Quality in Occupied Environments and Impacts on Work and Learning, Health and Well-Being, and Transmission of Airborne Pathogens

Indoor environmental quality (IEQ) is characterized by thermal, acoustic, visual, and air quality conditions that comply with prescribed performance. Occupied spaces include buildings, transport, and outdoor areas where people spend a substantial amount of time. Low IEQ has consequences for health, well-being, work productivity, learning, and sleep. To ensure high IEQ in the future, a paradigm change is needed: the current approach of characterizing IEQ in terms of minimum requirements for a "typical" space and an "average" occupant should be replaced with an approach that emphasizes individually optimized conditions to account for differences between spaces as well as occupants' diverse needs and preferences. Research should support this change by developing solutions, best-practice guidelines, assessment, diagnostic and IEQ enhancement design tools, and economic models that can explicitly assign a monetary value to the benefits of enhanced IEQ. While the primary focus should be on spaces occupied by people, guidelines and standards should address spaces designed for different types of goods, animals, and plants.

Sustainability, Decarbonization, Energy, and Resources

The technical challenges and research need for sustainability, mitigating climate change, energy, and resource topics, are all longstanding thrusts of ASHRAE research and standards. As energy efficiency and sustainability regulations and guidance have become more stringent, the built environment has become more complex, and standards developed decades ago are either not representative of actual field performance or overly complicated and onerous. This section outlines several factors that contribute to the difference between predicted and actual energy/resource utilization and the research necessary to address them.

HVAC&R Equipment, Components, and Materials

The research initiative for HVAC&R equipment, components, and materials describes areas of research that expand the scope or application of past research projects in this area but could require collaboration across multiple Technical Committees and/or significant co-funding. Suggested topics are: Identify and evaluate low global warming potential (GWP) refrigerants; Improve refrigerant management and reclamation methods; Preventative maintenance triggered by monitoring equipment and system performance; Components to improve ventilation management and temperature control, both to mitigate aerosol-based pathogen transmission and to respond to individuals' comfort preferences; Increase use of recyclable materials in equipment; Update design guidance for potable water systems, including service water heating; and Improve control systems and sensors for grid-interactive buildings.

Tools and Applications

Design engineers use tools to analyze thermal comfort, airflow patterns, flow path of airborne contaminants, system and component performance, and the energy consumption of candidate designs. Codes, standards, and design guidelines often provide only high-level guidance focused on minimum requirements. Without simplifying tools, it is difficult to evaluate compliance and to evaluate design options beyond the minimum required. Customer-focused, user-friendly, high-fidelity predictive tools can make the design process more efficient and effective, yielding improved thermal comfort, indoor environmental quality, and resiliency. Research is justified to improve the usability, capability, and accuracy of existing tools and develop new tools where needed.

Education and Outreach

Education- and outreach-oriented needs include ensuring that ASHRAE's research is well-disseminated and that it enhances the education and career development of students and industry professionals. This can be accomplished by increasing engagement of the public, students, and the HVAC&R industry not only at the conclusion of the research but also during scoping and execution. The proposed education and outreach strategy is to ensure that research projects are designed and executed in ways that enhance engagement of diverse stakeholders from the HVAC&R industry, general public, and students and to increase collaboration with other organizations, including international organizations.

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Initiatives in Detail

Resilience

Objective:

Extreme events and conditions outside of normal design contingencies may result in partial or complete functional disruption or failure of the energy and space-conditioning systems of the built environment which covers buildings, communities, transport, and storage of goods, including refrigeration. Resilience of such systems consists of multifaceted abilities to anticipate, withstand, and maintain system functionality as much as possible, and to recover quickly when subjected to extreme events while minimizing the adverse impacts on occupants. The research objective is to develop and recommend design and operational improvements to enhance the resilience of the energy systems of the built environment while explicitly considering the environmental, social, and cost implications.

Technical Challenges:

Occupants of buildings and communities face severe and increasing threats due to extreme weather conditions (such as hurricanes, coastal surges, and heat waves), climate change, unintended or intentional physical, biological, or cyber threats on critical infrastructure. A primary factor contributing to this situation is that current design practices and codes are concerned more with normal operation than with building system response and occupant health during these infrequent but highly disruptive events. Designing for efficiency and cost gains during normal operation may compromise the resilience, robustness, and swift recoverability of engineered systems. This often is the result of design solutions that are solely focused on reducing initial and operating costs by avoiding redundancy and increasing connectivity and complexity; giving secondary importance to IEQ; ageing infrastructure; volatility of operating points due to increasing grid penetration of renewable systems; man-made threats, and other factors. Resilience of buildings and communities is a qualitative concept. Broadly, it refers to having certain capabilities, namely:

a. Threat categorization: Ability to identify location-specific threats and vulnerabilities related to short-term weather events (such as heat waves or poor outdoor air conditions); long-term weather events (such as more virulent and frequent storms); evolving design requirements due to climate change; pandemics that last several months; and physical, biological, or cyber threats that may lead to partial or complete disruption of building systems or power, gas, and water supplies.
b. Physical robustness (excludes structural aspects of buildings): Having certain passive and active technological capabilities, including passive thermal mass, active thermal energy storage , battery storage, stand-by generators, redundant systems, water cisterns, shelter-in-place rooms and bunkers operable windows, secure placement of outside air intakes, etc. along with some redundancy in system functionality.
c. Operational robustness: Having certain automated control features and flexibility in system operation and clear management strategies and protocols in place to minimize the effect of disruptions.
d. Rebound capability: Having systems and strategies that can recover quickly and thereby minimize the adverse consequences on human health and financial loss during and after the disruptions.

Needed Research:

1. Best practices guideline/standard documents
   a. Background of resilience concept, definitions and scope as applied to buildings and communities, what resilience specifically involves in terms of pragmatic capability.
   b. Define different types of challenges and extreme events and threats (e.g., climate change, natural disasters, accidents, disease, terrorism), both physical and cyber intrusions.
   c. Define standard scenarios of extreme events (which may be geographically specific) for which the resilience of buildings and communities needs to be evaluated and enhanced.
   d. Define ways to evaluate resilience status of existing buildings and communities (distinguished by different types) and propose the level of additional resilience capacity recommended while explicitly considering cost.
   e. Define capabilities for HVAC systems, networks, and devices to repel , detect, contain, and recover from cyber intrusions (e.g., ransomware).
   f. Identify current metrics to evaluate the above capabilities.
   g. New buildings: Best practice design and operation for enhanced resilience.
   h. Existing buildings: Methodology to assess current status of technological and policy measures in place; develop metrics and methods to quantify existing capabilities and identify standard options to enhance resilience.
   i. Develop /guides and codes to specify resilience and performance requirements for different building types and different threat scenarios.

2) Resilience programs and tools
    a. Software to enable professionals to evaluate resilience of buildings and communities.
    b. Educational programs and materials for adoption in classrooms and for professional training seminars
    c. Certification program for professionals in resilience assessment and consulting
    d. Document successful case studies.

3) Research projects to fill existing gaps
    a. Develop standard location-specific scenarios of different types of extreme events to which different building types and communities are exposed. Define different levels of resilience capability under such standard scenarios and associated building performance criteria.
    b. Develop benchmarking framework, including more realistic and representative metrics specific to type of building and community (size, population, demographics, services, etc.).
    c. Develop methodology and tools to ascertain/assess current state of resilience of buildings, campuses, and communities.
    d. Identify, evaluate, and model design and control solutions for buildings and systems that have large operational flexibility (e.g., load curtailment under short-term notification or variability of as-available renewable energy technologies, especially such as solar PV and wind power generation)
    e. Develop models of human health/wellness impacts (severity with respect to time period of exposure and demographic effects) when subjected to extreme temperatures and humidity.
    f. Develop testing and design methods to evaluate equipment life when exposed to harsher operating environment.
    g. Develop more robust equipment and systems designs that can withstand some amount of physical shocks and be able to recover, i.e., come back online after a catastrophic event (say, to be able to prevent refrigerant leaks due to an earthquake, and, if compromised, to be able to perform repairs quickly).
    h. Develop cyber-security, managerial, and administrative response plans to reduce physical damage and human suffering at individual building and community levels.

IEQ: Environmental Quality in Occupied Environments and Impacts on Work and Learning, Health and Well-Being, and Transmission of Airborne Pathogens

Objective:

The first goal is to advance the thermal, acoustic, visual, and air quality criteria in environments occupied by people that characterize their quality (IEQ); these environments include indoor and semi-outdoor spaces occupied by people but commonly used IEQ acronym is applied to describe their environmental quality. The aim is to enhance IEQ, ensuring that every occupant's basic and diverse requirements are guaranteed. This will foster a better quality of life: good health, comfort and well-being, optimal physical and mental activity, undisturbed work and learning, and high sleep quality. Another goal is to ensure sufficient protection against extraordinary events, including those related to pandemic outbreaks and climate change (extreme weather events, wildfires, etc.).

Meeting the above goals will advance the design guidance for various environments and occupants, considering newly recognized threats, economic benefits of improved IEQ, and the values of going beyond requirements for minimum IEQ. Besides research for spaces occupied by people, ASHRAE should collaborate with other associations to develop guidelines and design tools for spaces designed for different goods, animals, and plants.

Technical challenges:

Many current standards dealing with IEQ provide minimum requirements, barely achieving acceptable IEQ. These environments include commercial and residential buildings, transportation, and outdoor or semi-outdoor environments where people spend a substantial amount of time, such as outdoor dining, concerts, and sports events. Complying with these current requirements may be insufficient to address and eliminate all risks related to exposure to environmental stressors caused by the thermal, acoustic, visual, and air quality conditions. Focusing on minimum requirements may additionally inhibit innovation because this does not create incentives for improvement. Furthermore, no agreed reference benchmarks or key performance indicators exist that would allow the characterization of IEQ.

Current standards prescribe requirements for an average person rather than addressing diversity in requirements and preferences. Standards and guidelines should sufficiently address all people's needs, especially vulnerable groups, and account for people's diverse preferences.

Several systems exist at present to certify IEQ. Some are part of sustainability certification schemes for buildings, and some are focused mainly on the well-being of occupants in the built environment. The systems use credits and several indicators to rate IEQ. Still, no uniform and standard system has been developed to simplify IEQ's accreditation process and reward and embrace benefits that result from improved IEQ.

The current designs, especially for buildings, do not adequately address potential risks to IEQ due to climate change, weather events, wildfires, pandemic outbreaks, and other health-related events. The technical systems for securing high IEQ are not resilient and flexible. Even though new solutions, technologies, and designs are introduced and applied to secure high IEQ, it is done without sufficient testing of their actual effects because there is not a standard methodology for examining their performance. The 2020 COVID-19 pandemic has exemplified the limitations in knowledge regarding the transmission of infectious species and incomplete preparedness of occupied environments (buildings, transportation, and outdoor spaces) and the systems used to ensure their quality in tackling the problem of transmission of infectious diseases and reducing the risk of transmission. The research must be intensified on the mechanisms of transmission of infectious diseases and the effects of technical systems and solutions (e.g., ventilation/airflow patterns, diffuser designs, updated filtration strategies, germicidal measures) that will allow proper functioning during a pandemic without a need to lock down entire communities. Such research will also bring additional benefits by reducing the risk of contracting coexisting diseases, including infectious diseases such as seasonal influenza.

IEQ control is expensive and accounts for a large portion of commercial buildings' first and subsequent operating costs; energy conservation measures introduced in buildings can reduce these costs. A cost-benefit analysis or any economic calculations must weigh IEQ control, which accounts for less than 5% of total building operating costs if the labor costs are considered. The reason is that this will secure that far greater expense can be saved by improving health and well-being of employees, reducing absence rates, and increasing performance of work and learning, and overall quality of life of staff. The savings associated with IEQ improvement are not currently a standard input for these analyses.

Although people spend 80% to 90% of their time indoors[1], they are increasingly spending more time outdoors, not only for leisure but also for work. Little is known about the benefits of spending time outdoors. Little is known about the dynamics of changing exposure, for example moving between conditioned indoor spaces and outdoors.

Finally, high IEQ is also needed for different goods, plants, and animals.

[1]BuildingGreen blog post, "We Spend 90% of Our Time Indoors. Says Who?" www.buildinggreen.com/blog/we-spend-90-our-time-indoors-says-who. December 15, 2016.

Needed Research:

1) Development of methods and systems for rating and rewarding high IEQ in buildings, transportation, and outdoor and semi-outdoor environments where people spend a substantial amount of time, both for avoiding the risks and promoting the benefits.
    a. Examining the combined effects of thermal, acoustic, visual, and air quality conditions on well-being, comfort, health, productivity, sleep, and how different IEQ factors modify different responses
    b. Development of indicators and sensing devices for rating IEQ of occupied spaces.
    c. Development of markers and systems for rating health, comfort and well-being, cognitive performance, and sleep quality.
    d. Development of simple and standard methods for collecting people's responses to different conditions defining quality of occupied environments, including comfort, health, occupants' perceptions of IEQ, etc.
    e. Identification of relevant pollutants and ventilation requirements—both under normal conditions and during extreme events—based on various criteria that consider health, comfort, cognitive performance, and sleep quality, as well as the requirements for vulnerable groups.
    f. Integration of productivity and learning attainment in the life-cycle cost assessments.
    g. IEQ requirements for different goods, plants, and animals.
    h. Education and outreach to understand decision-makers' perspectives on investments in IEQ and in design features that enhance building performance.

2) Human-centric and inclusive design and control, considering diversity.
    a. Identifying the range of human diversity and the range of physiological and psychological adaptation in the context of the quality of environments occupied by people.
    b. Development of requirements and personalized and individualized solutions for achieving high IEQ applicable to all occupants, considering variations in individual preferences and tolerances, disabilities, hypersensitivities, intolerances, medical conditions, types of activity, learning abilities, ages, compromised immune systems, etc.
    c. Development of sensing and control solutions to secure high IEQ at the environment level (building, space) and the personal level that considers preferences and behavior and allows adjustments based on occupants' continuous feedback.

3) Requirements beyond the minimum design and development of engineering solutions for substantial improvement of IEQ in spaces occupied by people, plants, or animals.
   a. Development of systems for continuous monitoring of pollutants and human responses.
   b. Monitoring the performance of current and future standards and guidelines concerning the quality of occupied environments, defined by thermal, acoustic, visual, and air quality conditions.
   c. Monitoring IEQ of sustainable designs (green and low-energy buildings, active office design, etc.) and their effects on well-being, comfort, health, productivity, and sleep.
   d. Development of engineering solutions for removing existing and new man-made and persistent pollutants (trapping at source, air cleaning, etc.).
   e. Studies on productivity, amount of illness, occupant satisfaction (comfort, noise) vs. IEQ levels/metrics, focusing on thermal, acoustic, visual, and air quality conditions.
   f. Advanced ventilation systems for measurable improvement of well-being, health, productivity, and sleep, addressing among others the impact of airflow patterns, the position of indoor sources, and ventilation effectiveness.
4) Protection against the transmission of infectious diseases and future pandemic outbreaks.
   a. Research on environmental and system design and the requirements allowing quick and effective actions to deal with the outbreaks of infectious diseases and reduce the associated risks in occupied spaces (buildings, transportation, and outdoor environments where people spend a substantial amount of time).
   b. Studies on ventilation effectiveness in relation to reducing exposure to infectious species as well as other pollutants.
   c. Developing advanced systems for improving protection against airborne transmission of infectious diseases and exposure to airborne pollutants, particularly eliminating infection risks at source (breathing zone), but also effective air cleaning technologies and the methods for their certification.
5) Maintain high quality of occupied environments independently of climate change.
   a. Methods for predicting the performance of occupied environments under changing climate, including future weather scenarios.
   b. Environmental and technical solutions for ensuring that occupied spaces, especially buildings, are resilient against changing climate.
   c. Simple retrofit solutions to adapt environments and systems to changing climate

Sustainability, Decarbonization, Energy, and Resources

Objective:

Maximizing the actual operational energy performance efficiency and resource utilization of buildings, equipment, and neighborhoods in a sustainable and more carbon-neutral fashion. To accomplish this, sharpen the understanding of the technical, economic, institutional, environmental, and human factors that contribute to the gap between predicted and actual energy/resource performance over the entire system life cycle. Develop additional tools, methods, and standards to maximize the actual energy/resource utilization of buildings, minimize their carbon footprints, and effectively communicate the benefits of these savings.

Technical Challenges:

Available data strongly suggest that the actual energy use of buildings is often higher than design energy use and/or higher than necessary to deliver required services. At the same time, indoor air quality, thermal comfort, noise, carbon footprint, and other performance attributes (e.g., infection control, food refrigeration temperatures) may not meet target levels. Measuring these energy use metrics during commissioning and ongoing maintenance of the building also present technical challenges. Many factors contribute to this, including but not limited to:

General industry and decision-making factors

1) Increasing complexity of the building enclosures and the mechanical, control, and other systems without a corresponding increase in the sophistication of tools that are easy to use and building operator knowledge and training to manage this complexity.
2) ASHRAE energy standards continue to be developed with ever increasing stringency by standing standards project committees (SSPCs). The increased stringency shas placed pressures on both the developers of the standards and designers who must comply with them. Users of the standard also are challenged by the increasing complexity of requirements and the lack of tools to help them demonstrate compliance. Additionally, these energy standards are not always coupled to standards that evaluate the actual energy use and the nonenergy performance of the building as it was constructed and is operated.
3) A significant technology challenge is that most of our equipment rating methods were developed decades ago and are beginning to show limitations in evaluating the real-world system performance (particularly variable-speed systems), and ASHRAE must think about must think about a collaborative role with

the federal government to get funding to take a fresh look at the system performance standards and their associated metrics. The current rating methods and the federal standards override the native controls of the equipment and provide no credit for innovative control schemes and do not represent actual field performance. In addition, there is not a meaningful means to compare energy use of a ground-source heat pump (COP, EER) with a split system (HSPF, SEER), much less a variable-refrigerant-flow (VRF) system.

4) The focus on first costs and low bids in the selection of design firms and contractors and in subsequent selection of design features results in a major difficulty for decision-makers to evaluate quality, value (quality/price), and life-cycle costs in design and construction, leading to an overemphasis on price in selection.
5) Moving toward net-zero energy buildings (NZEB) and decarbonized buildings, the incorporation of renewable energy resources, whether grid or point-of-use generated, will be essential to their further implementation. Buildings that incorporate renewable energy sources without energy storage present a remarkably poor load factor to the utility, further aggravating already serious generation/distribution inadequacies. The capability to analyze the interaction between renewable energy sources and thermal energy storage in the building needs more research.

Needed Research:

Sample research projects that address these technical challenges include

1) Accelerate application of building information modeling (BIM), and ensure that BIM systems are designed to meet information needs for commissioning and operations and maintenance.
2) Education and outreach to understand decision-makers' perspectives on investments in energy efficiency and design features that enhance building performance.
3) Improve building energy labeling systems. Develop and validate practical methods to model and measure building energy and nonenergy performance.
4) Develop more accurate methods to relate building energy simulation models to actual building energy use.
5) Collaborate with governments and code/regulatory bodies to develop new system energy efficiency test procedures to improve alignment between energy standards, energy models, and utility bills. Potential topics include load-based test procedures that include the impact of native controls, system performance mapping, etc. The goal would be to improve repeat ability, reproducibility, and representativeness of the system performance test procedures while also minimizing the burden of compliance.
6) Document actual energy savings and building performance improvements realized through integrated design.
7) Document actual energy savings and performance impacts for selected energy measures, and identify key design, construction, installation, and operational factors that influence savings and performance.
8) Document the impact of design alternatives on building performance metrics important to owners.
9) Expand the capabilities of dynamic simulation models to integrate modeling of building loads, mechanical systems, electrical systems, and controls.
10) Identify optimum and practical near-optimum control strategies for various systems (simulation followed by field validation).
11) Further quantify and optimize the energy savings and other benefits of commissioning and continuous com missioning for HVAC&R, enclosures, lighting, and service water heating.
12) Promulgate the use of enhanced building monitoring in order to quantify and optimize the energy savings and other benefits of proactive maintenance approaches such as prognostics and diagnostics.
13) Develop automated (and semi-automated) tools to sup port commissioning, continuous commissioning, and regular ongoing maintenance.
14) While NZEB refers to net-zero annual energy use, it neglects the benefits of thermal or electrical storage and of timing equipment usage to reduce carbon emissions, such as using energy during night or off-peak times to increase use of renewable or other clean energy sources and reduce peak transmission loading (and losses). Develop a metric other than annual NZEB that takes decarbonization objectives and source energy characteristics into account.
15) Update existing energy analysis calculation engines to model building components and systems that will be needed to meet current and future energy standards, including the ultimate NZEB goals.
16) Improve the digitalization of building systems including neighborhoods and integration of smart buildings into the power grid and other infrastructure.
17) Provide methods and standards for building energy use feedback to motivate occupants and building operators to reduce energy use. Use ASHRAE to drive social and environmental change. Extend scope of study from individual buildings to groups of buildings (neighborhoods) and develop solutions for cities to reduce environmental impact.

HVAC&R Equipment, Components, and Materials

Objective:

Historically, ASHRAE Technical Committees (TC) have proposed a robust portfolio of research projects to improve HVAC&R equipment, components, and materials. These initiatives, driven by the specialized expertise of TC members, should continue. However, there are challenges and needs in this area that span the scopes of multiple TCs, require more funding than the typical research project initiated by one or two TCs, and/or are foundational efforts that could yield high rewards but also have a significant risk of failure. This section identifies areas requiring collaboration across several TCs and/or that could attract co-funding from manufacturers, trade associations, regulatory or government agencies, and/or other research institutions.

Technical Challenge:

Many companies invest in R&D to improve their equipment; such company-funded research is proprietary. ASHRAE TCs also frequently initiate research for components and equipment. Those initiatives should continue, but much of the challenge in this area will be institutional rather than technical. The first challenge is to ensure that ASHRAE-funded research addresses precompetitive issues and goals, rather than focusing on individual companies' products. Companies often co-fund ASHRAE research projects—co-funders assist with writing the work statement and have one representative on the PES and PMS. A second challenge is to increase company involvement (and funding) for precompetitive research in HVAC&R components and equipment, both to foster industry adoption of research results and to design broader scope/more ambitious projects that will attract multiple companies' sponsorship and/or additional co-sponsorship by industry groups such as AHRI, ACCA, BOMA, USGBC, AHA, and AIA. Government agencies—especially DOE and EPA—have cooperated in ASHRAE research. Another institutional challenge is to attract government funding for larger research efforts and to enlist support from additional agencies, such as DHS, DoD, NSA (especially for cybersecurity research), and VA.

Needed Research:

1) New, low global warming potential (GWP) refrigerants. Identify and evaluate (laboratory and field tests) low-GWP refrigerants. Design equipment that can utilize these new refrigerants as well as natural refrigerants (CO_2, ammonia). Some low GWP refrigerants have increased flammability compared to traditional refrigerants: develop methods, guidance, and standards to handle and use them safely. Develop guidance and training materials for technicians and engineering company professionals on the use of new refrigerants.
2) Improved refrigerant management and reclamation. Release of refrigerants during equipment repair or replacement is a significant source of greenhouse gas emissions. ASHRAE research has contributed to development of UNEP's refrigerant management guide. However, guidelines are often not followed as contractors rush to complete a job or if the technology to capture refrigerants and/or destroy refrigerants is locally unavailable or expensive. Research is desired to develop methods to make refrigerant containment easier, less expensive, and/or mandatory. The needs and capabilities of developing countries must inform this research objective, addressing the global role of the Society.
3) Proactive maintenance based on equipment and system performance. Advances in sensor technology, wireless communications, and high-performance computing and analytics offer opportunities to monitor HVAC system and equipment performance in depth and in real time. Machine learning and artificial intelligence applied to the operating data collected can enable facility managers to detect performance trends and could identify incipient failures, enabling staff to address and repair problems before unexpected or catastrophic failures. This research area includes investigating design and placement of sensors, data collection and communication techniques, and applying data analytics to detect performance trends that indicate an a operational issue.
4) Managing local indoor environments (micro-climatization). Building occupants' comfort preferences vary significantly from person to person. While ASHRAE standard 55 provides a predicted mean vote (PMV) "comfort envelope," in practice providing mean comfort often results in some feeling uncomfortable. Systems that can tailor indoor environmental conditions—lighting and daylighting, ventilation (airflow velocity), operative temperature (mean radiant temperature [MRT]), and IAQ—to individual occupants improve both energy efficiency and occupant comfort. Design, implementation, and/or retrofit of systems and controls to match environmental conditions to individual preferences (zonal control and personal environmental conditioning within a building or other enclosed space, including mass transportation) requires research in systems, equipment, HVAC designs, low-cost sensors, secure in-building wireless communications, and control systems. Conversely, there are no easy means for individual human beings to communicate their state of indoor comfort.
5) Advanced control systems and sensors. Smart building technologies, especially for grid-interactive buildings, capable of self-analyzing and tuning building controls.
6) Infectious disease and pandemic issues. Research (by ASHRAE and others) has looked at factors affecting occupant exposure to infectious aerosols and other media. Further empirical or epidemiological-based

work is needed on the connections between indoor conditions, health outcomes, and effectiveness of controls, such as correctly applied filtration, use of outdoor air, and safer indoor air ventilation patterns to minimize exposure to pathogens. While this is an IAQ issue, its implementation involves HVAC components, including diffusers, controls, filters, and germicidal measures (such as ultraviolet light). For many designs and installations, aerosol exposure is inadequately mitigated, as the impact is largely unseen and may be perceived as non-dangerous.

7) Recyclable materials. Construct HVAC equipment out of materials that can be recycled instead of consigned to a landfill. Conversely, find opportunities to use recycled materials (e.g., replacing metal with recycled plastics, rubber, and other discarded bulk materials) to construct HVAC equipment and components. Increase use of local materials and materials with low embodied exergy. Apply additive manufacturing technology.

8) Update data and design guidance for service hot water and other potable water systems. Improved knowledge of hot-water uses and performance of fixtures, components, and appliances is necessary to design safe, sustainable, and efficient systems. The Handbook's guidance for water heater and pipe sizing in many occupancies is based on steel pipe, threaded and flanged fittings, and daily hot-water-use patterns established decades ago. Pipe friction coefficients are different for the newer materials and fittings used in today's plumbing systems. Pipe sizing is also based in part on the probability of simultaneous uses creating peak flows; these have not been revised since all devices had fixed orifices, making the flow pressure dependent. However, flow rates and flush volumes have been limited since the mid-1990s in order to conserve water. Pressure-compensating orifices are now widely available for faucets and showers, effectively making them pressure independent for about 20 psi and above. Ultralow-flow fixtures may also contribute to stagnant water conditions, leading to higher bacterial growth. Research should update ASHRAE's design guidance for pipe and water heater sizing and investigate the effects of water flow, temperature, and pH on growth of *Legionella* and other microorganisms.

Tools and Applications

Objective:

Develop user-friendly tools to help users effectively employ ASHRAE and ISO standards for design, performance analyses, and product development. Accomplishing this goal requires developing a proper understanding of users' needs for specific tools, evaluating the underlying physics and technologies to address the users' requirements, and developing appropriate user-friendly interfaces.

The purpose of such tools is to facilitate design and product development and enable practicing engineers, architects, and operators to more easily, accurately, and effectively apply the state-of-the-art knowledge and lessons-learned embodied in ASHRAE standards, design guides, and research reports. Such tools will help advance indoor environmental quality, health and well-being of occupants, energy efficiency, and resiliency of the built environment.

Technical Challenge:

The following are some technical challenges to wider development and availability of user-friendly predictive tools and digital twins:

1) Despite their availability, engineers in the HVAC&R industry are often deprived of tools and applications due to the inherent complexity and high cost of commercial software. Cost and complexity need to be reduced. User friendly interfaces, accounting for range of complexity of projects need to be accounted for.

2) Conduct a systematic survey of the work processes of design and practicing engineers at various steps of HVAC design, construction, commissioning, and operation to clearly assess needs.

3) Develop a better understanding of the underlying physics inherent in the built environment and its HVAC&R systems and ensure that this is appropriately incorporated into the development of tools.

4) Continuing improvement of ease-of-use and affordability to meet the needs of all levels ranging from small to large projects. Sometimes tools become too complex; this defeats their purpose. Also, such complex tools may become too expensive.

5) Development of interactive user interfaces.

6) Need to recognize the synergies between various aspects of building design and operation and the involvement of expertise other than just engineering to develop multi-disciplinary tools and applications.

7) The complexity of ASHRAE energy standards, in particular those that take a performance approach, places a burden on designers who must demonstrate compliance and enforcement agencies who must confirm compliance. Tools that automate compliance demonstrations are needed. These tools can also assist designers to evaluate energy conservation measures, reducing the cost of engineering high-performance buildings.

8) Many innovative designs may have significant implications for the indoor environment and require analysis of thermal comfort, visual comfort, indoor air quality, etc. Yet appropriate analytic tools may not be readily available."

9) The modeling tools that do exist are too complex to be easily used, and hence they are not used for a majority of buildings, particularly small buildings where design budgets are small.

Needed Research:

The following are examples of research and development needed for predictive tools and methodologies. Such tools can range from a simple spreadsheet to a more involved tool with an advanced graphical-user-interface and an artificial intelligence engine.

1) Conduct a systematic survey of the work processes of HVAC&R design and practicing engineers to clearly understand their needs.
2) Develop a tool to predict external wind patterns, wind pressure, and pedestrian comfort around the buildings. Such a tool could help develop appropriate strategies for wind-driven natural ventilation.
3) Develop user interfaces to allow models to be created more quickly and accurately, with the ability to import building information from design drawings (CAD and BIM).
4) Develop a predictive tool for façade and window de signs to accommodate various climate zones with current and future technologies.
5) Continuous improvement of tools for estimating building load calculation, including sensible, latent, and radiative heating and cooling loads.
6) Develop a comprehensive, easy-to-use, and afford able tool to predict spatial and temporal variations in in door airflow patterns, temperature distribution, airborne contaminant distribution, and thermal comfort of occupants and the resulting ventilation effectiveness. Such a tool should be flexible enough to accommodate a variety of advanced heating, cooling, and ventilation strategies, including passive and active chilled beams, radiation heating and cooling, and stratified air ventilation systems, including displacement ventilation and underfloor air distribution (UFAD) technologies. These tools should help not only during the early stages of the HVAC design but should become an essential tool during commissioning and monitoring.
7) Develop a tool for the selection of diffusers to meet the need of the space, thermal comfort, and indoor air quality. Currently, this need is partially being met by the vendors' catalogs. There is a need for a comprehensive vendor-neutral tool that addresses this based on the underlying physics.
8) Develop a convenient tool for building occupants to provide feedback related to their thermal comfort and indoor environmental quality on a continuous basis. Currently, there are no easy means available for occupants to communicate their discomfort with their environment. Using the latest technologies, such a tool should be linked with the building automation systems.
9) Modeling flow path and concentrations of airborne contaminants is essential to understand the spread of airborne gaseous and particulate contaminants. An easy-to-use tool should provide a high level of de sign guidance for designing HVAC airflow to optimize the flow path of airborne contaminants from an IAQ perspective.
10) Update existing energy analysis calculation engines to model building components and systems that will be needed to meet current and future energy standards, including the ultimate NZEB goals. Seek cofounding from U.S. Department of Energy (DOE).
11) Continue to develop features to automate the creation of energy models from architectural/mechanical/ electrical BIM data files.
12) Develop a standard or common information model that facilitates incorporation of Internet of Things (IoT) by recognizing that (a) buildings and HVAC&R systems will be accessing information from sources not currently envisioned, and (b) buildings and HVAC&R systems will be interconnected though information and control networks to innumerable sectors, many of which will have no clear relationship to HVAC&R systems.
13) Develop cybersecurity strategies and techniques appropriate to IoT internetworking of domains.

Education and Outreach

Objectives:

Incorporate education and outreach in every ASHRAE-funded research project. Promote communications with all stakeholders in the building industry, including designers, contractors, operators, suppliers, authorities, and users. Develop research projects that use methods that promote education of students and HVAC&R professionals. Increase the impacts of ASHRAE research on the international stage by appropriately disseminating research results.

Technical Challenges:

- New technologies and solutions require training and continuous updating of a skilled workforce.
- Research projects to improve system and equipment performance should include development of appropriate training procedures to apply the results of the research.
- There is a need for more thoroughly trained technicians proficient in refrigeration and air-conditioning equipment installation, repair, maintenance, and operations. The need is especially great at the grass-roots level in developing countries, both rural and urban areas. Vocational training institutes are not very common. Use of higher-tech online, virtual training programs and augmented reality (AR)-assisted

training could be effective for technical staff of developing countries.
- Methodologies and best practices for educating O&M personnel on sensor, equipment, and systems need to be part of continuous improvement activities.
- Determine how to appropriately make use of information technology, the cloud, connected devices, Web-based and virtual meetings, and, in general, the digital world and big data.

Strategies to Improve the Education and Outreach Components of ASHRAE Research Projects:

1. Incorporate education and outreach goals in every ASHRAE-funded research project.
    a. Encourage ASHRAE research results to be presented at the most appropriate conferences and using the best methods of dissemination (presentations, seminars, training checklists, etc.) instead of only requiring a technical paper and presentation at an ASHRAE Winter or Annual Conference. Identify appropriate international conferences and journals for dissemination of research results. If research should be presented at multiple conferences, develop a procedure to approve an increase in the project's budget to accomplish this.
    b. Develop and maintain a web-portal to make it easier for members, researchers and other stakeholders to obtain information on ASHRAE research projects especially data (including models) generated during a project.
    c. Promote the presentation of ASHRAE-funded research results at appropriate international conferences in addition to or instead of North American conferences.
2. Promote communications with all stakeholders.
    a. Establish protocols to better share ASHRAE research project results with stakeholders in the HVAC&R industry, including educational and research institutions; vendors, contractors, and manufacturers; architects; and regulators.
    b. Develop methods to obtain broader input and feedback from the industry on needed research topics and on the technical approach and/or preliminary findings of ongoing ASHRAE research projects.
    c. Deliberately engage experts to assist ASHRAE in improving communications and sharing expertise with other professional organizations.
    d. Expand use of social media or develop new tools to reach out to all stakeholders. Media could include podcasts, YouTube channels, blogs, etc.
3. Find ways to improve the quality and impact of ASHRAE research projects.
    a. Incorporate plans for education, outreach, and dissemination in every ASHRAE-funded research project.
    b. Collaborate with other trade organizations, including international organizations, to develop research project topics for the building industry.
        a. Evaluate the effectiveness of past ASHRAE research projects.
        b. Share research results more proactively with other industry leaders and authorities.
        c. Examine the procedures for periodically updating or extending ASHRAE standards, guidelines, and users' manuals to see when more timely updates are needed.
4. Increase the international impact of ASHRAE research.
    a. Invite international organizations to monitor and review research projects (e.g., by participating in the PMS).
    b. Invite principal investigators of research projects funded by international organizations other than ASHRAE to present their findings at ASHRAE conferences and publish in ASHRAE publications. Provide some financial support (travel, translation, etc.) if appropriate.
    c. Invite ASHRAE project principal investigators to present their findings to relevant international conferences and/or international organizations. Provide appropriate budgetary support as needed.
    d. Increase presentation and publication of ASHRAE research at international conferences and in international journals.
    e. Increase collaboration with international researchers on research projects.

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