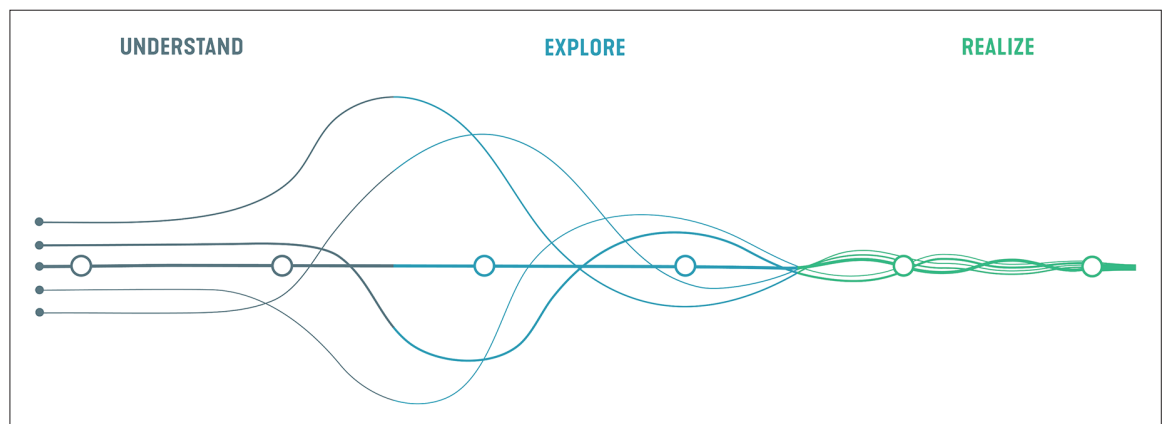


## Upgrading Climate-Control Systems in Historic Buildings: An Integrated Design Thinking Approach

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**Fig. 1.**  
*Design Process, 2020.*  
*Graphic by SmithGroup.*



There are currently more than 67,000 buildings listed on the U.S. National Register of Historic Places.<sup>1</sup> These properties are generally more than 50 years old and meet the National Register Criteria for Evaluation that examine a building's significance and integrity.<sup>2</sup> The challenges and sensitivity required to upgrade systems in historic buildings also apply to other buildings that are not listed but have architectural and historical value. Historic buildings in the United States span multiple centuries and reflect a variety of architectural styles and construction materials and methods. Approaches to heating, ventilating, and air-conditioning (HVAC) systems range from passive strategies that reflect the regional climate and technologies available when constructed to more sophisticated systems of the mid-twentieth century.

Every building-renovation project has its own set of challenges, yet design professionals naturally develop ingrained ways of approaching design challenges that can prevent them from seeing a problem in a new way. By applying an integrated design thinking approach,

design teams can embrace complexity and engage with a building's distinctive attributes to develop better solutions.

The concept of "design thinking" emerged in the 1960s, when attempts were made to apply scientific methodology to the design process, and became more broadly applied in the 1990s.<sup>3</sup> While there is neither a commonly accepted definition nor consensus on the number of phases, the approach generally has the following attributes:

- Innovation-focused
- User-oriented
- Structured and iterative
- Includes an interdisciplinary team

To examine the steps involved in designing new or upgraded climate-control systems for historic buildings, the authors walk readers through the design thinking process, comprising three main phases (Fig. 1):

- Phase 1: Understand gathers information and interprets relevant project knowledge.
- Phase 2: Explore engages a broad range of ideas and then narrows the focus.
- Phase 3: Realize refines and resolves the design direction to achieve project goals and vision.

### Phase 1: Understand

**Assemble team.** This phase is foundational to the project's success, and it requires the collective participation of a multi-disciplinary team. A typical project team includes the following core disciplines: architecture, life-safety/code consulting, mechanical/electrical/plumbing (MEP) engineering, and structural engineering. A project that involves the preservation, rehabilitation, and/or restoration of a historic building often requires the specialized expertise of a historic-preservation architect and building technologist. A historic-preservation architect enhances the team's understanding of a resource through historical research, detailed physical investigations, and analysis of historical construction and materials, along with a thorough understanding of user needs. A building technologist provides specialized services that focus exclusively on building-enclosure systems, performing hygrothermal analyses and assisting in forensic investigations. The complete team, including facility managers, code officials, and users, should be involved at the onset of the planning and design process to share diverse perspectives and evaluate issues.

**Establish goals.** The next step engages project stakeholders to understand the goals of the HVAC upgrade project. For example, is the owner seeking improved energy performance and/or operational carbon reduction? Is the existing HVAC equipment at the end of its useful life? Is the system unable to maintain environmental or thermal comfort conditions? Does the owner intend to repurpose the building for another use? Are portions of the MEP systems considered to be character-defining features? Often, there are multiple project drivers that, by virtue of the need to upgrade the system, create opportunities to improve other aspects of the system design, operation, and performance.

Commissioning helps to ensure all systems are designed, installed, tested, operated, and maintained according to the requirements of the owner. To be effective, the commissioning process should start at the earliest phase of design. The Owner's Project Requirements (OPR)

are used to communicate the owner's expectations and inform design decisions that affect construction, operation, and maintenance.

**Gather and collect.** The design team should obtain all available documentation, such as copies of original construction documents, measured drawings and/or digital files, assessment reports, etc. However, documentation of historic buildings, including subsequent upgrades and renovations, is not always available or accurate. The team may need to undertake additional means to document existing systems, such as three-dimensional laser scanning.<sup>4</sup> Digital scans can provide a high level of detail related to equipment placement, clearances, distribution routing, and structural members, which can prove helpful when planning and coordinating a system upgrade or replacement.

Even with complete and accurate documentation, the team should conduct a visual assessment to identify the general condition of systems and note key aspects of the building that may impact system design, such as the construction materials, structural system, exterior and interior finishes, and character-defining features. Depending on the nature of the observations, further system testing or forensic investigation, including selective demolition, may be required.

In particular, the mechanical engineer should document the following:

- Utilities
- System type
- Operating parameters
- Control system and strategy
- Equipment location, age, and condition
- Clearance issues
- Shafts and piping chases
- Main distribution
- Pathways for equipment removal/installation
- Air intake/exhaust openings
- Thermophysical properties of the building envelope
- Air leakage paths
- Window operability
- Water damage, mold, or surface condensation
- Operation and maintenance protocol
- Code deficiencies

**Interpret.** The data and collected documentation set the stage for exploring potential system alternatives. The design engineer synthesizes what has been learned, generating insights and framing opportunities. Unlike new construction that is purpose-built and whose systems are designed

specifically for the intended use, historic buildings are often repurposed over time to serve different uses from those initially planned. It is up to the design team to assess the suitability of the current and proposed use of the building and reconcile any conflicts between the use of the building and the preservation objectives before proceeding.

## Phase 2: Explore

In this phase, the mechanical engineer identifies and evaluates HVAC system alternatives and develops the preferred approach. It may be necessary to undertake this process separately for various portions of the building if they vary in construction materials and/or historic significance or for various programs if they differ significantly in their environmental requirements.

**Identify alternatives.** The team develops system alternatives that are suitable for the proposed use, achieve project goals, and protect character-defining features of the building from damage. Climate-control systems are categorized by the method used to produce, deliver, and control heating, air-conditioning, and ventilation. In terms of production, centralized air-handling unit (AHU) systems generate heating and/or cooling in one location for distribution to multiple locations. Centralized systems, such as a variable-air-volume (VAV) AHU with hydronic heating and cooling coils, can reduce the overall installed capacity by taking advantage of diversity and energy recovery but can be challenging to retrofit into an existing historic building due to its larger, single footprint. Decentralized systems generally comprise multiple packaged units with an integral refrigeration cycle and heating source that may also include outdoor ventilation. They are better suited to buildings with no connection to a central heating or cooling plant, with limited space to house larger pieces of equipment, with limited pathways for distribution, and/or with a desire for simplified installation or controls. Examples of decentralized equipment include self-contained floor-by-floor systems, split systems, and variable-refrigerant-flow (VRF) systems. A ground-source heat pump (GSHP) system combines packaged-units (heat pumps) with centralized piping and outdoor wells that rely on ground-source heating and heat rejection.

Climate-control systems are also categorized based on the medium used to transfer energy between the conditioned space and the plant: air, water (hydronic), and combination air and water. All-air systems rely on ductwork, whereas all-water systems rely on piping.

Combination air/water systems distribute both chilled and/or hot water, as well as conditioned air to the individual spaces. Water has both a higher density and a higher specific heat than air, making it a more efficient energy transport medium. As such, the same amount of energy can be transported in a much smaller pipe than a duct. Steam contains even more energy per pound than hot water. Since steam and other hydronic systems consume less space, they can be retrofitted into an existing building more easily. Examples include radiators, convectors, and fan-coil units (FCUs). Unless the historic building relies on natural ventilation to meet outdoor air requirements, hydronic systems are combined with a separate air system to provide mechanical ventilation. Alternatively, VRF systems comprise outdoor condensing units connected via refrigerant piping to multiple indoor units that operate as heat pumps or in heat recovery mode. There are multiple styles of indoor units including ceiling- and wall-mounted cassettes, concealed ducted units, and floor-mounted consoles, which suit a variety of conditions. Hydronic- versus air-based system decision-making should also consider the impact on shaft space, vertical openings, and life safety. A hydronic- or refrigerant-based system may reduce the requirement for shafts, combination fire-and-smoke dampers, and the spreading of smoke throughout the building.

Careful evaluation is required when using chilled water to cool and/or dehumidify at the room level in a historic building. “Sensible-only” cooling-system technologies have emerged that, when coupled with a dedicated outside air system (DOAS), provide verifiable ventilation performance, more precise humidity control, and reduce space requirements and energy costs compared to all-air systems. Sensible-only cooling systems include radiant cooling panels, active chilled beams (ACBs), and a series of fan-powered boxes with a sensible cooling coil on the plenum inlet. The DOAS unit supplies 100 percent outside air to meet the larger of the ventilation requirements or the balance of the sensible and latent cooling loads. Latent heat gain occurs when moisture is added to a space from people, equipment, infiltration, and/or moisture migration. Without detailed testing, estimating the latent heat gain due to air leakage in a historic building is difficult and complicated by the fact that these buildings likely were neither constructed with air or vapor barriers, nor were they designed to a specified air-leakage criterion. To avoid surface or coil condensation that can lead to water damage and

**Table 1. System Factors, Criteria, and Attributes**

Factors and Criteria	Attributes				
	Fan Coil Units and Dedicated Outside Air System	Variable Refrigerant Volume and Dedicated Outside Air System	Active Chilled Beams and Dedicated Outside Air System	Ground-Source Heat Pumps	Central Station Air Handling Unit
Impact on historic fabric (less is better)	Small distribution network	Small distribution network	Small distribution network	Distributed units by thermal zone	Large, centralized unit and distribution network
Visual aesthetics (preservation of appearance is better)	Vertical or horizontal unit	Range of indoor units	Air distribution device	Diffusers	Diffusers
Maintainability (easier is better)	Centralized and distributed maintenance	Centralized and distributed maintenance	Centralized maintenance; requires dewpoint control	Distributed maintenance; shorter service life	Centralized maintenance; long service life
Space demands (less is better)	Small space demand	Small space demand	Smallest overall space demand	Relies on availability of distributed closets/support space	Large, single-unit footprint; larger distribution pathways

deterioration, sensible-only cooling systems should be avoided in a historic building unless proper due diligence is applied that includes detailed testing, weatherization, and a condensation control strategy that responds to actual sensed conditions. While some sensible-only systems contain a means of condensate collection and removal, their cooling capacity may be derated when the coil is wet. Commissioning of both the building envelope and the climate-control system is recommended to verify operation under a range of conditions and to ensure proper operator training is provided.

**Differentiate alternatives.** Before evaluating system alternatives, the project team sets the stage for the decision-making process by identifying factors and their criteria. A factor is an element of a decision and one that differentiates the alternatives, while a criterion sets the standard upon which a judgment is made. If alternatives are selected because they have certain “must have” qualities with no major discernable differences, those factors are not used in the decision-making process.

**Decision-making process.** The architecture, engineering, and construction industry has widely used value-based (subjective) approaches that score and weigh factors.

The authors prefer the decision-making system called Choosing by Advantages (CBA) because it anchors decisions to relevant facts and is based on the importance of advantages.<sup>5</sup> CBA is deemed a superior decision-making method for providing transparency and building consensus.<sup>6</sup>

Table 1 summarizes several systems that may be considered in a climate-control system upgrade along with their attributes (the basis on which advantages are determined). It is not fully inclusive of all system configurations, but it aims to demonstrate the range of considerations. The beneficial difference, or advantage, of the attribute of each alternative relative to the least preferred attribute will vary depending on specific project conditions.

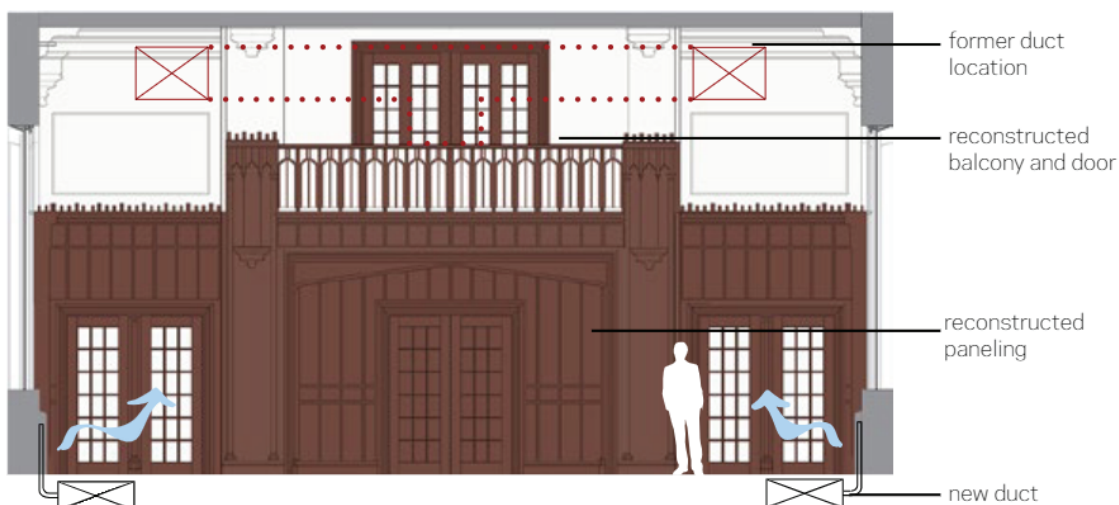
One example is Father O’Connell Hall, a 68,000 square foot historic structure prominently located on the campus of Catholic University of America in Washington, D.C. The renovation scope included restoring its 4,400 square foot Heritage Hall, a two-story banquet space with molded plaster ceilings, wood-paneled walls, and marble floor tiles. The restoration areas included the original second-floor balcony, which had been walled off

to enclose the air-handling unit serving Heritage Hall. An existing-conditions assessment revealed that the AHU was noisy, did not provide acceptable thermal comfort, and was visually intrusive because it had ceiling-hung ductwork that obscured sections of the original coffered ceiling. The team explored system alternatives and evaluated them based on the impact to the facility's historic fabric, visual aesthetics, and space demands. The preferred alternative located the new AHU in an unfinished basement below Heritage Hall, supplying air from below and discharging it through low side-wall grilles incorporated into the millwork beneath the windows (Fig. 2).

**Integrate.** The adaptive use of a historic building requires that trade-offs be made and risk analyses performed. The team must work together to make the best decisions based on their understanding of the issues. The historic-preservation architect establishes the preservation objectives for the project, informs the design team as to the degree to which interiors may be altered, and alerts them to the most significant spaces and features. The mechanical engineer identifies potential locations for equipment, ideally in secondary or tertiary spaces, such as basements or attics. Pathways for routing systems vertically include existing shafts, chimneys, closets, or storage rooms. Horizontal distribution pathways can be more challenging to integrate. Systems may be exposed, concealed, or a combination of both. While it may not always be possible to completely conceal the mechanical system, care must be taken to minimize the impact on the existing architecture.

In the U.S., building and life-safety codes are adopted at the local, regional, or state level. Additional requirements may be stipulated by government entities, insurance companies, and the client. Understanding the code requirements for the project is critical in the earliest stages of design. Often, historic buildings do not conform to current building codes, and there are situations where it might not be feasible to achieve conformance. Most jurisdictions adopt an edition of the International Building Code and International Existing Building Code. Generally, the more extensive the renovation, the greater the requirements for code compliance. These codes have a specific historic building rehabilitation chapter. Typically, the building must be listed on the National Register to use these provisions. Since they recognize the need to preserve the historic nature of buildings, these chapters are more lenient than chapters on other alterations that would require a greater level of code compliance.

Vertical openings can pose a challenge to historic building renovations. A building with unenclosed stairs or an atrium can make air distribution difficult and present a pathway for smoke and fire to travel from floor to floor, potentially compromising life safety and egress. Current codes limit vertical openings between floors except where specifically permitted, such as an atrium with a smoke-control system or a convenience stair meeting certain size limitations. Current codes require air distribution between floors to be protected in fire-rated shafts, with combination fire and smoke dampers at any duct penetrating the shaft enclosure to prevent smoke



**Fig. 2.**  
Heritage Hall, Catholic University of America, Washington, D.C. Interior elevation showing existing and proposed HVAC air-distribution concepts, 2013. Drawing by SmithGroup.

migration from floor to floor. Historic buildings may lack existing shaft spaces to distribute ductwork, and new shafts may not be feasible from an architectural, structural, historical, or building-code compliance perspective, leading to a floor-by-floor approach to HVAC equipment placement and distribution.

In buildings with low floor-to-floor heights, running a duct with an ideal aspect ratio (ratio of width to height) of 1:1 below a beam could result in a lower headroom clearance than allowed by code. Possible solutions include utilizing ductwork with a larger aspect ratio of 3:1 or less, routing ductwork to avoid primary means of egress, or using a hydronic- or refrigerant-based system to minimize the size of ductwork.

Return-air pathways can also be a challenge in buildings with low beam clearance. Installing a ceiling may not be practicable or architecturally desirable. Because the building code does not permit a corridor to be used as a return pathway, a ducted return system may be required, which will face challenges like those discussed above for a ducted supply system.

Many historic buildings are not protected throughout with automatic sprinklers. While it may not be required or desired to retrofit a historic building with automatic sprinklers, code requirements favor fully sprinklered buildings. For example, a building that is not protected throughout with automatic sprinklers could require fire-rated corridors. It should be noted that certain occupancy types, such as residential, require fire-rated corridors even if protected throughout with automatic sprinklers. Where ductwork penetrates a fire-rated corridor, a fire-rated corridor damper, a ceiling radiation damper, or a smoke damper could be required.

### Phase 3: Realize

In this final phase of the design process, the team applies a critical eye to ensure goals are met and coordinates the final details. This final coordination can take many forms, ranging from material finishes to construction methods and may involve working with local authorities having jurisdiction.

**Final coordination and details.** Retrofitting a historic building with a new HVAC system for which it was not originally designed or for which original parts are no longer available requires great care. The finished appearance should retain, reuse, or reflect the existing historical features, which may include registers, radiators,

escutcheons, radiator enclosures, etc. When original features are either no longer available or cannot meet the new or current needs of the user, the team must minimize the visual impact of the design solution by retaining character-defining features, such as decorative millwork, ornamental and vaulted ceilings, pilasters, capitals, etc. The National Park Service's *Preservation Brief 24* provides a comprehensive list of HVAC "Dos and Don'ts," which can provide a helpful checklist to the mechanical engineer.<sup>7</sup>

The new AHU for Catholic University of America's Heritage Hall was located in a previously unfinished basement, and a new return-air shaft was created in a back-of-house stair that provides roof access. The architect chose custom, decorative supply-air grilles of ¼" aluminum plate metal with a staggered pattern, which integrated into the new, furred-out millwork beneath the windows and were arranged side-by-side in a modular fashion to relate to the existing wood panels. The new system increased user comfort, improved energy performance, and was seamlessly integrated into the existing structure in a manner that brought the historic building's grand features back into view (Figs. 3-6).

Part of system design involves ensuring that adequate clearances around equipment for service and maintenance are provided. In an existing building, planning for removal of existing equipment, installation of new equipment, and future removal or replacement of system components is critical. The physical constraints of doorway, window, and/or louver openings, elevator size and capacity, and structural loading capacity impact equipment selection



**Fig. 3.** Heritage Hall, 1916. Courtesy of Catholic University of America Archives.

and specification that may require customization to meet the specific job requirements. Planning how equipment is moved in and out of a historic building and locating equipment such that it can be easily accessed for service and maintenance and thus can maintain the environment conditions within the building, is just another way to protect the building in the long term.

**Protection during construction.** Historic preservation is fundamentally about preserving, conserving, and protecting. Only by protecting a historic asset can one preserve and conserve that asset. Nevils Hall (Fig. 7) is located on the Georgetown University campus in Washington, D.C. This 69,855 square foot building complex was created in 1957 by consolidating the original Georgetown Hospital (1898) with other building units constructed between 1903 and 1912. Since 1983 the building has served as student housing and comprises four- to six-person apartments. The structure consists of wood-framed floors on steel beams and masonry bearing walls.

The climate-control system was replaced in-kind to limit the construction duration with the following notable exceptions:

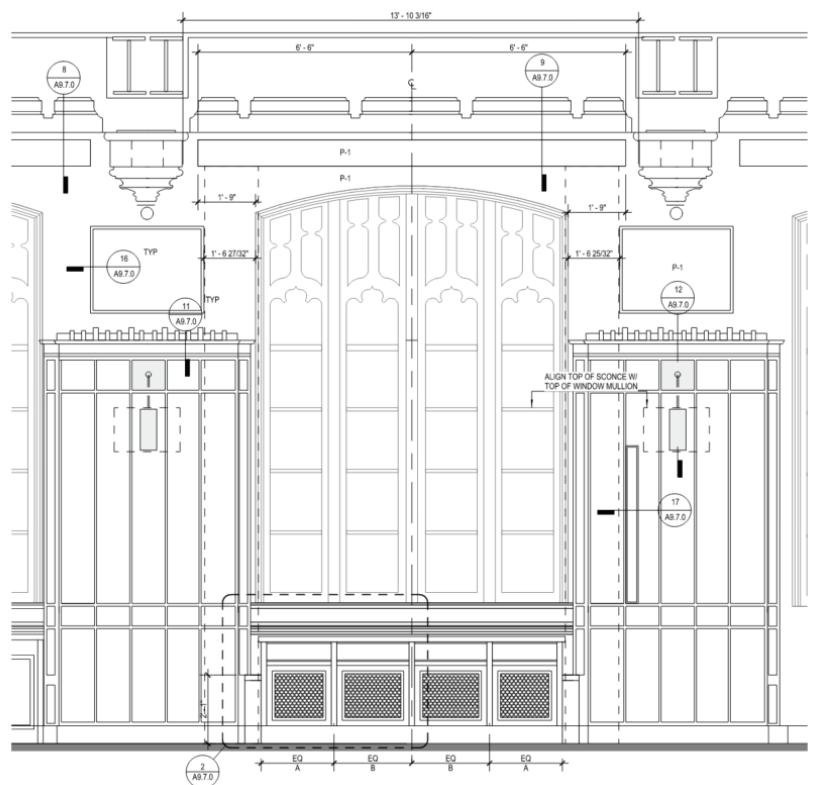
- Two-pipe console FCUs were replaced with four-pipe units to deliver heating or cooling at any given time for improved thermal comfort. Piping chases were expanded to accommodate additional piping.
- Two outside-air rooftop units totaling 4,600 cubic feet per minute with six-row coil and two-pipe seasonal changeover were replaced with three outside-air rooftop units totaling 13,300 cubic feet per minute with separate heating and cooling coils and wrap-around heat-pipe heat exchanger for better indoor temperature and relative humidity control. Outside air was supplied directly to all occupied areas of apartments in accordance with code requirements.
- Kitchen, shower, and toilet rooms were individually exhausted per code and controlled to operate continuously to remove odors, water vapor, and other contaminants. Prior to the system upgrade, shower rooms were neither directly exhausted nor directly controlled, resulting in visible mold growth on bathroom walls and ceilings. Existing cabinet-exhaust



**Fig. 4.** Heritage Hall before renovation showing enclosed mechanical balcony and exposed ductwork, 2012. Photograph by SmithGroup.



**Fig. 5.** Heritage Hall after renovation with integrated HVAC and restored historic appearance, 2015. Photograph by Alan Karchmer.



**Fig. 6.** Heritage Hall, enlarged interior elevation, 2013. Drawing by SmithGroup.

**Fig. 7.**  
Nevils Hall, Georgetown University, Washington, D.C., 2012. Photograph by SmithGroup.



fans with positively pressurized ductwork connected to a series of exhaust hoods were replaced with 22 roof-power ventilators connected to negatively pressurized exhaust ductwork to prevent moisture and contaminants from leaking into interstitial spaces.

To reduce the risk of fire during installation, the hydronic-piping specifications included flameless alternatives to soldering and welding, such as pressure-seal joints and grooved mechanical joint couplings and fittings. The time savings associated with these flameless joining methods helped enable construction to be completed over summer break.

**Coordination with local authorities.** Historic buildings often present project considerations and challenges that may not be easily characterized by prescriptive code requirements. In these cases, teams should engage the authorities having jurisdiction early in the design process. This is recommended for a performance-based design

**Fig. 8.**  
Patten Gym, Northwestern University, Evanston, Ill. Smoke and egress modeling, 2020. Graphic by SmithGroup.



approach or when requesting a code modification for a technically infeasible condition (Fig. 8). Understanding the basic principles of fire protection and life safety ensures that the safety and welfare of the public is maintained and that the building is provided with a level of safety equivalent to that required by code.

## Conclusion

The average age of commercial buildings in the United States is about 53 years.<sup>8</sup> While not all buildings over 50 years old qualify to be listed on the National Register, this statistic highlights the scale of the challenge facing the HVAC industry to upgrade climate-control systems in older buildings, some of which are historically significant. An integrated, multi-disciplinary team with specialized expertise in historic preservation, building technology, and/or life safety relies on the technical and creative capabilities of both the individual and the whole team. Following a structured and iterative design process ensures that:

- There is time for imagination, as well as for iterative development and critique to occur.
- Solutions respond to a clear formulation of the problems to be solved.
- Owners and stakeholders support the design solution.

The preservation and reuse of historic buildings protects our cultural heritage, reduces resource and material consumption, generates less landfill waste, and consumes less energy than demolishing and constructing new. Research has found that renovating existing and historic buildings compared to building new also results in lower life-cycle carbon emissions, which contribute to climate change.<sup>9</sup> Replacing outdated, energy-inefficient, and poorly functioning HVAC systems with new, energy-efficient systems that protect the historic fabric, preserve architecturally noteworthy features, improve occupant thermal comfort, and address new programmatic space needs is essential to providing historic buildings with a new lease on life.

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