ADDENDA

ANSI/ASHRAE/IBPSA Addendum f to
ANSI/ASHRAE/IBPSA Standard 209-2024

Building Performance Simulation Process

Approved by ASHRAE and the American National Standards Institute on July 31, 2026, and by the International Building Performance Simulation Association on July 21, 2026.

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 ISSN 1041-2336

International Building Performance Simulation Association

www.ansi.org

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FOREWORD

Addendum f adds a new Informative Appendix K, which clarifies the analytical intent of Cycle 6—Design Optimization and places it in context within the overall design-stage modeling cycles (Cycles 1 through 6). It provides modelers with practical guidance for applying optimization methods in high-performance building design. This informative appendix also expands upon the minimum requirements of Cycle 6 by outlining a framework for projects that choose to conduct multi-objective optimization to address multiple, and often competing, performance goals.

Informative Note: In this addendum, changes to the current standard are indicated in the text by underlining (for additions) and ~~strikethrough~~ (for deletions) unless the instructions specifically mention some other means of indicating the changes.

Addendum f to Standard 209-2024

Add new Informative Appendix K as shown on the following pages. Note to Editor: All text in this addendum is new; therefore, for readability, it has not been underlined.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX K
OPTIMIZATION METHODS FOR HIGH-PERFORMANCE BUILDING DESIGN

K1. INTRODUCTION

Building design involves evaluating multiple architectural and engineering design strategies that differ in their ability to reconcile functional requirements with environmental performance and economic objectives. The first priority is to avoid poor design choices that compromise functionality or fail to meet design objectives. After identifying options with acceptable performance, the design team continues to refine the design during design development for further performance enhancement.

The modeling cycles prescribed in this standard provide a structured process that supports the design teams in the progressive refinement of the design as it develops. Completing the Load Reduction Cycle together with one additional modeling cycle fulfills the standard’s minimum requirements; however, some projects may elect to exceed the minimum requirements. Projects pursuing high-performance, net-zero energy or carbon-neutral goals, or aiming for green building certification, benefit from applying multiple iterative modeling cycles during the design stage.

This informative appendix explains how this expanded analysis supports holistic design strategies that balance energy efficiency, sustainability, occupant well-being, and cost-effectiveness. It begins with an overview of how the analytical intent of design-stage modeling cycles can be met, then elaborates on the optimization methods modelers can apply to support high-performance design.

K2. SIMULATION-ASSISTED DESIGN REFINEMENT

As the design matures, the model should reflect increased resolution and accuracy. With the application of Cycles 1 through 5, the recommended methods transition from simplified conceptual analyses to detailed dynamic simulations that capture system interactions, equipment performance, control behavior, and time-dependent effects.

In concept design, the goal is to identify dominant design drivers and sensitivities, not to predict energy use. Cycles 1 and 2 use simplified geometry and represent building envelope elements using equivalent surfaces with averaged properties. Abstracted HVAC representations with a limited number of thermal zones are used to run comparative and parametric analysis, testing variables the architects can change early in concept design.

As the schematic design starts to develop, Cycle 3 is introduced with more accurate representation of the building geometry and envelope reflecting decisions made during previous design phases. During these early cycles, comparative and parametric analysis are generally sufficient to quantify the impact of load-reduction measures and inform early architectural and passive design decisions. These analysis methods test sensitivity of one or more fundamental performance metrics relative to one or more design variables.

Before the start of the design development phase, Cycle 4 is introduced to help the project decide on what HVAC design concept to adopt. This expected consequential outcome from the model requires it to incorporate enough HVAC system details to support design decision making. Unlike the models used in earlier cycles, the model is expected to explicitly represent HVAC equipment efficiencies, system configuration, and control schemes.

When Cycle 5 is applied to refine the details during design development, the model is expected to reflect detailed geometry and building systems details. The simulation methods used can target one fundamental objective such as consumption or peak demand reduction and test incremental changes to one or more HVAC or envelope design variables at a time, for example, energy recovery effectiveness or dimensions of shading devices.

K3. THE NEED FOR OPTIMIZATION IN HIGH-PERFORMANCE BUILDING DESIGN

The modeling cycles described in Section K2 are adequate for many projects and can effectively support the refinement of design strategies using parametric analysis and commonly available project resources. However, for projects with more ambitious performance goals, higher complexity, and more constraints, it may be beneficial to implement Cycle 6—Design Optimization, or even to exceed its minimum requirements for more comprehensive analysis.

In a parametric analysis workflow, model inputs are treated as predefined parameter values rather than decision variables, and simulations are executed for a fixed set of parameter combinations decided prior to execution. Objectives and constraints, where identified, are not used to influence the selection of subsequent simulations and are applied only in post-processing to compare or screen results.

While achieving incremental performance improvements can be challenging in itself, identifying the truly optimal design is even more difficult. Reaching a high level of design refinement requires a systematic optimization process that determines the most effective configuration of design parameters given the project's constraints. In building design, optimization aims to enhance overall performance across multiple criteria, including energy efficiency, indoor environmental quality, and cost-effectiveness. Ultimately, design teams must integrate multiple parameters, balancing competing objectives to achieve the best possible overall performance.

K4. TYPES OF OPTIMIZATION ANALYSIS

Optimization problems may be classified by the number of variables and objectives involved. The analysis might adjust a single variable or multiple variables and could address one or more performance objectives. When it expands beyond one objective, the process is called "multi-objective optimization."

- In a single-variable, single-objective analysis, the model varies one parameter while keeping all others constant. For example, the modeler could adjust the window-to-wall ratio or insulation thickness to either minimize or maximize a specific performance indicator, such as annual energy use.
- A multi-variable, single-objective analysis, which is a requirement of Cycle 6, varies several parameters at once to understand their combined effect on one performance goal. For instance, a study might change multiple envelope properties and HVAC efficiency values simultaneously to see how they together impact energy use.
- When building design needs to meet multiple performance goals at the same time, the analysis is treated as a multi-variable, multi-objective optimization problem. This method recognizes the trade-offs among objectives, such as energy efficiency, cost, and occupant comfort. While not required under Cycle 6, it may be optionally specified in applications where it can deliver notable benefits as described in Sections K6.2 and K9.2.

K5. DEFINITION OF THE OPTIMIZATION PROBLEM: OBJECTIVES, VARIABLES, AND CONSTRAINTS

The optimization process begins with defining clear performance objectives, identifying essential design variables, and establishing relevant constraints. The design team then moves on to select an optimization method capable of addressing the desired outcomes.

a. **Define Design Objectives.** Identify and prioritize measurable design objectives that correspond to performance goals. Examples include minimizing energy consumption, peak loads, life-cycle cost, or capital cost. Other design objectives may focus on environmental performance, such as minimizing carbon emissions or reducing embodied carbon of construction material. Design objectives could also address indoor environmental quality (IEQ) such as improving thermal comfort, spatial daylight autonomy, or indoor air quality metrics.

b. **Select Key Design Variables**. Decide which design parameters can be varied to significantly improve the objectives. These should be variables that the design team can influence. Examples include thermal insulation, window-to-wall ratio, glazing type, shading device geometry (overhang depth, fin spacing), roof reflectance, HVAC equipment efficiency and sizes, temperature set points, etc.

   If unsure which variables matter most, perform a preliminary sensitivity analysis. For example, if thermal insulation beyond a certain point yields negligible benefit, that variable might be fixed at a standard value to focus efforts elsewhere. Early exclusion of variables with low impact helps simplify the optimization problem.

c. **Define Constraints.** Establish practical limits for the chosen variables and objectives to keep the search within feasible bounds and avoid impractical or noncompliant results. Constructibility constraints could imply a maximum limit for insulation thickness, available glazing performance might be limited by local product offerings, or capital cost can be capped based on allocated budget.

K6. CHOOSING THE SUITABLE OPTIMIZATION METHOD

Once the design team has clearly identified the design objectives, which parameters can be adjusted, and the applicable constraints, the next step is to determine how the optimization will be performed. The choice of the optimization method and the level of analytical rigor must correspond to the complexity of the performance objectives, maturity of the design, available simulation tools, and analytical expertise.

K6.1 When to Apply Single-Objective Optimization. Use single-objective optimization when one performance criterion dominates decision making and other requirements can be enforced as constraints. This approach is typical in early design stages or when analytical resources and expertise are limited. This approach is most effective under the following conditions:

- Clear primary goal: A single metric is the key performance indicator (KPI). For example, the owner's project requirements define the project's top priority as minimizing annual energy use, peak demand, or carbon emissions.
- No major trade-offs: Other requirements like comfort and illumination levels can be enforced by code as fixed constraints rather than competing secondary objectives subject to trade-off.
- Predictable behavior: The KPI responds predictably to changes in design variables. For instance, improving the chiller plant efficiency consistently reduces the annual energy use.
- Limited time or resources: Early design phases when project schedules, team capacity, or access to specialized optimization tools and expertise are limited. In such cases, focusing the analysis on the primary objective provides quick directional insight without overcomplicating the analysis.

K6.2 When to Apply Multi-Objective Optimization. Use multi-objective optimization when multiple performance metrics, such as energy use, cost, comfort, and carbon emissions, must be evaluated simultaneously and where trade-offs between them are significant. Project teams could find this approach most valuable for large or complex projects committed to high-energy performance targets, seeking multiple sustainability objectives or subject to strict economic criteria. Such applications warrant the more extensive time and effort involved in the utilization of the more advanced methods and tools this method entails.

In building design, sometimes improvements in one aspect degrade another; for example, maximizing daylight might increase cooling loads or impair comfort. Unlike traditional design approaches that optimize one performance aspect at a time, multi-objective optimization explores the influence of multiple design variables on several performance criteria and reveals trade-offs between them.

Multi-objective optimization addresses conflicting objectives inherent in high-performance building design such as balancing energy use reduction with comfort improvement and cost-effectiveness. The following examples of conflicting objectives illustrate the need for applying multi-objective optimization:

a. IEQ and Energy. IEQ enhancement measures can inadvertently increase HVAC loads and energy consumption. Examples include the following:
   - Daylighting versus energy efficiency: Larger windows enhance daylight but increase heat gain and cooling demand. Conversely, using high-performance glazing or shading to reduce heat gain can diminish daylight quantity or quality.
   - Thermal comfort versus energy efficiency: More strict requirements for unmet load hours or humidity control may increase cooling and heating loads.
   - Indoor air quality versus energy efficiency: Increasing outdoor air ventilation rates enhances indoor air quality but may increase cooling and heating loads.

b. Cooling and Heating. Strategies that reduce cooling loads may lower summer energy use but also restrict passive heating, increasing winter consumption. Examples include the following:
   - Increasing roof solar reflectance reduces the cooling load in summer but may increase the heating load in winter.
   - Lower glazing SHGC reduces heat gain and cooling loads in the summer but may increase winter heating loads by limiting passive solar heat gains.

c. Energy and Water. Measures that save water, such as air-cooled condensers, can increase energy use, while energy-efficient evaporative equipment raises water consumption.

K7. OVERVIEW OF OPTIMIZATION METHODS AND ALGORITHMS

When many variables and constraints are involved, the number of possible design combinations can be very large. Optimization methods efficiently explore the solution space, prioritizing promising regions based on prior results and avoiding unnecessary evaluations of poor-performing configurations. This guided search enables the identification of high-performing solutions within reasonable time and computational effort.[K1]

In building design practice, design optimization is performed using a workflow in which an optimization tool implements an optimization algorithm, controls the process, and repeatedly calls a building energy simulation engine. The optimization tool modifies selected input parameters, triggers the simulation engine to run performance calculations, reads the resulting outputs, and then uses the optimization algorithm to determine the next set of design variables to evaluate. This automated, iterative process continues until a set of optimal or near-optimal solutions is identified.[K2]

While there are many methods used in solving optimization problems in general, common use of optimization methods in building design practice could be concentrated in a few accessible methodologies. Studies analyzing trends and optimization algorithms across hundreds of publications over the past two decades show that practical applications tend to rely on a limited number of algorithm families that can work effectively with complex building simulation models.[K2] Evolutionary algorithms, particularly genetic algorithms (GAs) and the Non-Dominated Sorting Genetic Algorithm II (NSGA-II), are the most prevalent algorithmic families in published case studies and advanced practice, credited for their ability to handle nonlinear, multimodal design problems common in building design.[K2,K3] Single-objective solvers (often GA-based) and multi-objective frameworks (often using NSGA-II) are used to navigate performance trade-offs. For detailed engineering problems, gradient-free direct search methods (e.g., pattern search) are commonly used for simulation model calibration.[K4]

The application of evolutionary algorithms, for example, begins by creating a population of possible design solutions and then evaluating them against specified performance criteria. Building simulations are run sequentially in batches with incremental improvements. The optimizer selects the fittest solutions, which then undergo processes such as alteration, combination, or removal to generate a new population for retesting. Mimicking evolution by natural selection, this cycle repeats over many generations. In single-objective optimization, the process converges toward one or more high-performing solutions that best meet a single goal. In multi-objective optimization, such as with the widely used NSGA-II algorithm, the result is a set of Pareto-optimal solutions representing the best trade-offs between competing design objectives.[K3]

K8. PRESENTATION OF OPTIMIZATION RESULTS AND PARETO-OPTIMAL SOLUTIONS

In optimization problems involving multiple, often conflicting objectives, the results are often not a single best solution but a set of Pareto-optimal solutions. These solutions represent the best achievable trade-offs among competing objectives. Because of these trade-offs, no single solution in this set dominates the others by being better in all objectives at the same time. In other words, Pareto-optimal solutions are nondominated solutions, meaning that an improvement in one objective causes a deterioration in at least one other objective.[K1] For example, increasing daylight availability may sacrifice thermal comfort or increase energy use intensity. The full collection of these nondominated solutions forms the Pareto Front, which presents in graphical format the range of optimal compromises available to decision makers to choose from.

K9. HOW TO APPLY OPTIMIZATION IN HIGH-PERFORMANCE BUILDING DESIGN

Project teams can use the guidance in this informative appendix to:

- Define the project's performance metrics
- Establish clear objectives, variables, and constraints for performance simulation
- Specify the optimization method suitable for the project
- Integrate design optimization activities within the design schedule and deliverables.

K9.1 Applying Single-Objective Optimization. This standard includes the optional Cycle 6—Design Optimization, which allows design teams to conduct optimization studies as part of the performance simulation aided design process. The minimum requirements of Cycle 6 can be satisfied by conducting multivariant, single-objective optimization. This is often sufficient to meet the requirements of many projects by addressing the most critical objectives within reasonable effort and utilizing resources commonly available to project teams.

K9.2 Applying Multi-Objective Optimization. For complex or high-performance projects involving multiple and conflicting objectives, such as energy efficiency, comfort, cost, and carbon performance, this informative appendix may be used to define an advanced optimization scope that extends beyond Cycle 6 requirements. Projects pursuing multi-objective optimization may reference the Purpose, Analysis, and Reporting provisions outlined herein, in conjunction with the requirements in Cycle 6 of this standard.

K9.2.1 Purpose. Use performance simulation to identify design alternatives that optimally meet multiple, and potentially competing, design objectives. Use multi-objective optimization methods to explore the impact of complex interactions between multiple variables on two or more objectives. Evaluate the trade-offs and synergies between design alternatives and their impact on design objectives. Identify the alternative or set of alternatives that achieve the best overall performance across several objectives. The outcome might be optimal alternatives that concurrently optimize two or more objectives, or Pareto-optimal range of alternatives, each optimally meeting a primary objective while maintaining secondary objectives within acceptable limits.

K9.2.2 Analysis

- The energy modeler shall identify two or more optimization objectives for the analysis that relate to the energy performance goals as identified in Section 5.6.
- The energy modeler shall identify the multi-objective design optimization method used.
- Conduct an optimization analysis using the defined multi-objective optimization objectives, design variables, and design constraints.

K9.2.3 Reporting. Results from multi-objective optimization modeling shall be presented in a structured format that communicates the relationships and trade-offs among competing objectives. The presentation should enable the interpretation of the results quantitatively and visually, including the following:

- Summary table listing key design variables and corresponding performance metrics for all Pareto-optimal solutions.
- Pareto Front Plots highlighting nondominated (Pareto-optimal) solutions
- Sensitivity analysis charts showing the relative influence of design variables on objectives.

K10. APPENDIX K REFERENCES

K1. Li, R., Y. Zhang, X. Wang, and J. Chen. 2025. A Review on Multi-Objective Optimization of Building Performance: Insights from Bibliometric Analysis. *Heliyon* 11(2):e33269.

K2. Machairas, V., A. Tsangrassoulis, and K. Axarli. 2014. Algorithms for Optimization of Building Design: A Review. *Renewable and Sustainable Energy Reviews* 31:101–12.

K3. Evins, R. 2013. A Review of Computational Optimisation Methods Applied to Sustainable Building Design. *Renewable and Sustainable Energy Reviews* 22:230–45.

K4. Welle, B., J. Haymaker, and Z. Rogers. 2011. ThermalOpt: A Methodology for Automated BIM-Based Multidisciplinary Thermal Simulation for Use in Optimization Environments. *Proceedings of the 2011 Building Simulation Conference*, 1396–1403. Wakefield, MA: International Building Performance Simulation Association.

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